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FOREWORD

It is my great pleasure to welcome delegates of the Sustainable Building and Construction Conference at Coventry University (SB13@Coventry). As part of the triennial SB conference series, SB13@Coventry is intended to provide a focal forum for an interactive dialogue and learning between industry practitioners and academia. This is manifested within the conference programme, which in addition to presentations from international delegates from 11 countries, the programme covers a range of activities including presentations of and site visits to “state of the art” sustainable buildings, keynote and feature presentations from leading experts and facilitated workshops to synthesise future challenges, current cutting edge knowledge and pathways for meeting these challenges. I do hope that the delegates will bring home benefits from the activities.

The proceedings comprise papers from variety of sources and topics, and they have been grouped under different themes, which reflect the current issues of sustainability in building and construction. Given the current financial climate, they represent a positive contribution to advancing the knowledge in this area. All papers have undergone a review process which, I hope, has provided a useful feedback to the authors. I am most grateful to members of Organising and Scientific Committees who have helped with their reviews despite competing demand on their time. The authors should be applauded for their effort to improve the papers based on the reviewers’ feedback. To recognise excellent work, there are five paper prizes to be awarded, funded by the Chartered Institute of Building, VINCI Construction UK Ltd and ICON. ICON also provides a prize for delegate with most contribution to the workshops.

The conference would not take place without the great help and support from numerous individuals and organisations. I wish to thank them all!! It is impossible to mention every single individual and organisation here. Nevertheless, I wish to acknowledge the special contributions from VINCI Construction UK Ltd, the Chartered Institute of Building, Action Programme for Responsible Sourcing and ICON for sponsoring the conference. My thank also goes to individuals from Manufacturing Technology Centre, Severn Trent PLC, Coventry Sports and Leisure Centre and Engineering and Computing Building, who have provided an excellent opportunity to visit the buildings and learn from their experience in the design, construction and maintenance of sustainable buildings. Particularly thanks to Joe Catalin Visan and Graeme Elliot for looking after the logistics and administration of the conference with immense dedication and hard work. I am really grateful for the support from members of Organising Committee and Loughborough University who has allowed me to work on the preparation of the conference.

I do hope that this edition of the SB conference series will bring benefits to individual delegates and positive impact on the advancement of knowledge in sustainable building and construction.

Dr Robby Soetanto, Loughborough University
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DEVELOPING AND TESTING A GLOBAL COMMON CARBON METRIC APPROACH FOR MEASURING ENERGY USE AND GREENHOUSE GAS EMISSIONS FROM BUILDING OPERATIONS

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Abstract. *This paper describes the development, application and pilot-testing of a common carbon metric (CCM) approach and tool formulated by the Sustainable Buildings and Climate Initiative of the United Nations Environment Program (UNEP-SBCI). The CCM approach allows measurement of energy use and reporting on greenhouse gas emissions from buildings' operation in a consistent, reportable and verifiable manner, for buildings around the world. This work is intended to support policy-makers, cities, and owners of building portfolios in establishing baselines for the performance of their building stock. The CCM tool is a simple and transparent Excel spreadsheet that can be filled by participants with estimated or measured energy data (annual or monthly). It can be used for two types of measurement approaches: (1) Top-down (or building-stock) wherein the users inputs data for a stock of buildings (which can be a city/community stock, or a portfolio of buildings for instance) and (2) Bottom-up (or single-building) wherein the users separately input data for each of the buildings being assessed. This approach is aimed at verifying the results of the building-stock approach, by conducting a measurement for a representative sample. The feedback from the first pilot testing of CCM conducted from May through July 2010 helped to refine scope of building area, type, and occupancy, and inclusion of globally-recognized references for emission factors and climate zones. Phase 2 Pilot testing was undertaken from July to October 2011 focusing on further evaluating the 'building-stock' approach to measurement and reporting. Participant feedback and results us being used by the authors to make further refinements to CCM prior to its dissemination for use in the international community. Ultimately it is hoped that CCM will inform international climate change policy-making and potential development of appropriate mechanisms to finance energy reductions in the buildings sector, especially in developing countries.*

Keywords: *carbon metric, energy efficiency, greenhouse gas emissions, operational energy*

1 INTRODUCTION

Globally buildings are responsible for 40% of the annual energy consumption and up to 30% of all energy-related greenhouse gas (GHG) emissions (UNEP-SBCI 2013). As most global cities are projected to grow in population through increased urbanisation and birth-rate, this energy use and resultant GHG emissions will increase. The Intergovernmental Panel on Climate Change's 4th Assessment Report (IPCC AR-4) confirmed that the building sector has more potential to deliver quick, deep and cost effective GHG mitigation than any other sector (Pachauri and Reisinger 2007). Significantly increased building energy efficiency can be achieved in the short-term. Energy consumption in both new and existing buildings could be cut by an estimated 30-50% by 2020 through readily available technologies, design, equipment, management systems, and alternative generation solutions. This can be funded through investments that quickly payback and result in significant environmental, social, and economic benefits.

However there is a lack a common approach to measuring GHG emissions and a common approach for reporting on the building sector's progress or contribution to achieving emissions reduction targets. Without a common language, and a common approach to accounting for emissions, the building sector is unable to participate cost effectively in the global carbon market. Developing common metrics for use in gathering consistent data and reporting the climate performance of existing buildings is essential in:

- Supporting policy-making to reduce GHG emissions from buildings, especially in developing countries;
- Providing a framework for how to measure emission reduction in buildings so as to support formulation of Nationally Approved Mitigation Action (NAMA) plans, flexible mechanisms, carbon crediting; and other emission reduction mechanisms and plans; and
- Establishing a system of measurable, reportable, and verifiable (MRV) indicators for the follow-up of policy implementation, resulting emission reduction and reporting on building-related GHG emissions.

To address this gap, the Sustainable Buildings and Climate Initiative of the United Nations Environment Program (UNEP-SBCI) has developed a set of methodologies for measuring and reporting the energy and GHG emissions performance of portfolios of buildings. These methodologies are called the Common Carbon Metric (CCM) Protocol and Reporting Template (Excel-based tool). Both the authors have been involved in development and pilot testing of the CCM protocol and tool. While the Common Carbon Metric is not a building rating tool, it is consistent with methods for assessing the environmental performance buildings used globally. UNEP-SBCI's intent in developing the CCM is to provide the industry with a globally consistent methodology by which to measure and report energy use and report corresponding emissions from building operations. UNEP-SBCI released the first draft of the CCM at the 15th Conference of the Parties (COP15) in Copenhagen in December 2009 and followed with the launch of implementation through two pilot phases to test the CCM methodologies. It is hoped that CCM provides the foundation for accurate performance baselines to be drawn, national targets set, and carbon traded on a level playing field.

This paper describes the development, application and pilot-testing of a common carbon metric (CCM) approach and tool formulated by UNEP-SBCI. The CCM approach allows measurement of energy use and reporting on greenhouse gas emissions from buildings' operation in a consistent, reportable and verifiable manner, for buildings around the world.

2 DEVELOPMENT OF THE COMMON CARBON METRIC (CCM) PROTOCOL AND TOOL

While all stages of a building's life-cycle (including construction and demolition) produce carbon emissions, the buildings operational phase accounts for 80-90% of emissions resulting from energy use mainly for heating, cooling, ventilation, lighting and appliances. Therefore, this is the stage of the building's life-cycle that is the focus of the Common Carbon Metric & Protocol.

The CCM protocol specifically defines the two major approaches to collecting data on buildings: the bottom-up approach benchmarks and the top-down approach baselines. Monitoring carbon mitigation measures on a regional or national scale requires a top-down approach, while assessing individual building projects requires a bottom-up approach. It also articulates the most relevant metrics that facilitate the comparison of building performance overtime and against benchmarks, including an energy intensity metric and carbon intensity metric. For greater context on these performance metrics, the CCM tool was enhanced after the phase 1 pilot so that a building(s)' GHG inventory can be correlated with a climate region by the number of heating and cooling degree days of its location.

UNEP-SBCI's goal in developing the CCM is to assist cities and major portfolio owners to establish baselines for the energy and emissions performance of their building stock (termed the 'Whole' in the CCM). The Whole may represent a city, in which case the boundary of the Whole is the physical boundary at the city's limits, or it may be a large portfolio of buildings, in which case the Whole is the total area of that portfolio's stock.

The two methods which can be used to assess performance in the CCM are explained below:

2.1 A "top-down" approach

Here, the performance of the Whole is characterized at a coarse level using estimated data on the fuel and electricity consumption of the Whole. The methodology requires that consumption data are first provided for the Whole itself and then allocated amongst different building types on a percentage basis. At a minimum, the consumption data must be allocated amongst two broad types of buildings: residential and non-residential buildings. If more specific data are available, then the data may be further disaggregated by specific types of buildings (e.g., hotels, offices, single-family homes, etc.). The Whole does not include industrial building types to avoid double counting of emissions related to the industrial sector.
Data requirements:

- Area of the Whole (m^2).
- Total occupancy of the whole (number of occupants, or number of residents where information on occupancy is limited).
- Information on the percentage of the Whole's occupants and building area attributable to different categories of building stocks (%). At a minimum, the occupancy and area data must be allocated amongst two broad categories of buildings: residential and non-residential buildings. If more specific data are available, then the data may be further disaggregated by the specific building categories listed in Table 5.
- Information on the total amount of electricity consumed by the Whole and on the amounts of different types of fuels used (various measurement units will be accepted by the CCM).
- Information on the percentage of the Whole's electricity and fuel use that is attributable to

different categories of building stocks (%). Again, energy use data must be allocated amongst two broad categories of buildings: residential and non-residential buildings. If more specific data are available, then the data may be further disaggregated by the specific building categories.

- Custom emission factors may optionally be provided in place of the default emission factors for electricity and fuel use.

2.2 A "bottom-up" approach

Here, the performance of individual building(s) is characterized at a fine level using measured electricity and fuel consumption data specific to those buildings. The bottom-up approach is intended to help assess the accuracy of the performance metrics computed through the top-down approach. Ideally, the buildings for which data are entered through the bottom-up approach represent a statistically valid sample set from which to validate the performance of the Whole.

Data requirements: The following must be supplied for each building:

- Descriptive information, including building name, building category, year of construction and year of last major retrofit, and address.
- Occupancy (number of occupants) and area (m^2).
- Data on the total amount of purchased and metered electricity (in kWh).
- Data on the total amount of different fuels consumed (various measurement units).
- Custom emission factors may optionally be provided in place of the default emission factors for electricity and fuel use.
- Users may optionally report the amount of purchased green power or the amount of renewable energy that has been generated on-site and returned to the grid.

2.3 Occupancy

The ratio of people-to-building-area differs greatly depending on building type, function, and country. Some countries have developed standard occupancy defaults for specific building types. In addition, there are a variety of ways to calculate and estimate building occupancy, such as annual hours of building operation.

Consequently, consistent measurements of occupancy are crucial. The CCM does not provide a single definition for occupancy estimations at this stage, nor does it provide any country or building-type defaults. However, users are provided with the following general rules-of-thumb:

- Occupancy of residential buildings can be determined using the number of persons sleeping within the defined area.
- Occupancy of non-residential buildings for the bottom-up approach may be determined using the "full-time equivalent" (FTE) concept, which requires users to estimate how many people occupy a given building for approximately eight hours. Visitors and part-time staff can be totaled up and divided by eight hours and added to the total as FTEs. Any occupancy data must reflect the number of actual occupants, as opposed to the number of intended occupants.

Data on occupancy at the level of the Whole are especially likely to be limiting. In cases where such data are limiting, users may enter data on the number of residents, as opposed to the number of occupants. This proxy is mainly suitable for residential building stocks, because the long-distance commuting of workers will affect the number of occupants of non-residential buildings.

2.4 Performance metrics

The data provided under either approach are then used to develop performance metrics for both energy consumption (in kWh) and GHG emissions (in kg $CO_{2\text{-equivalent}}$ [CO_{2e}.]), on a per area basis and a per occupant basis if occupancy is known.

- **Energy consumption in kWh.** The CCM converts fuel consumption into energy consumption data using information from the Intergovernmental Panel on Climate Change (IPCC); specifically, default values for the lower heating value of different fuels. The lower heating value is a measure of the quantity of heat liberated by the complete combustion of a given amount of fuel.
- **GHG emissions in kg $CO_{2\text{-equivalent}}$ [CO_{2e}.],** Because different GHGs differ in the severity to which they can affect the climate system, it is necessary to convert the emissions of different GHGs onto a common basis, so that the aggregate climate impact of buildings can be determined. CO_2-equivalency provides this common currency by expressing the emissions of a given GHG in terms of the amount of CO_2 emissions that would realize an equivalent impact on the climate.

The four metrics prioritized by the CCM are:

kWh/m^2/year	kgCO_2e/m^2/year	kWh/occupant/year	kgCO_{2e}/occupant /year

The working of the CCM tool was tested using two successive pilot tests run in 2010-11 and 2011-2012, so as to underpin the data collection effort necessary to establish global, national, regional, and corporate baselines for the sector that contributes one third of the global energy related emissions. The tool will allow policy-makers and owners to understand the relevant performance of their building stock, which is critical to setting targets and choosing appropriate incentives, strategies, and/or policies to improve performance. Feedback collected from the participants of the pilots has helped in the development of the CCM tool.

3 PILOT-TESTING CCM: PHASE 1

UNEP-SBCI released the first draft of the CCM at the 15th Conference of the Parties (COP15) in Copenhagen in December 2009 and followed with the launch of a pilot phase, in Paris, France, at UNEP-SBCI's Symposium on Sustainable Buildings on 19 May, 2010. The Pilot included a coordinated stakeholder review of Phase 1 of the CCM, with a view to uncover practical issues surrounding the implementation of the CCM, to develop consensus methodologies for unresolved aspects of assessing building performance and to prioritize areas for further research.

In total, 19 different organizations and individuals provided feedback, and seven Pilot Participants road tested the Excel-based platform. Across all Pilot Participants, building performance was assessed for a total of 46 individual buildings (total building area: 1.44 km^2) and for five larger stocks (total building area: 176.60 km^2).

The application of the CCM tool in phase 1 can be demonstrated through City A which provided data on a geographically defined Whole (total area: 176 km^2) with an occupancy of 3,700,000 and a total energy use of 63,152 TJ. City A was able to generate performance baselines for its residential and non-residential building stocks at the level of the Whole. City A also provided data on 10 non-residential buildings through the bottom-up approach, allowing it to compare the average performance of these buildings with that of the Whole's non-residential stock. The reconciliation of top-down and bottom-up approaches is useful in checking for accuracy. The results for both approaches are shown in table 1. Red cells indicate that the average performance of a set of buildings of a given building type, as measured through the bottom-up approach, is less than the performance of the Whole's non-residential building stock. Green cells indicate better performance compared to the Whole's non-residential building stock.

Building category	kWh / m^2	kg CO_2e / m^2	kWh / occupant	kg CO_2e / occupant
Average performance baselines for specific building types, measured through the bottom-up approach				
Office	222.8	151.9	8,387.9	5,568.1
Retail	221.5	147.0	7,859.0	5,217.0
Hotel	302.8	142.8	14,305.3	6,745.3
Other	156.0	103.6	2,736.1	1,816.3
Performance baselines for the Whole, measured through the top-down approach				
Non-residential	282.4	182.8	5,831.7	3,774.6
Residential	51.5	32.8	3,733.7	2,376.5

Table 1: Reconciliation of top-down and bottom-up results for case-study A in the Phase 1 pilot.

4 PILOT-TESTING CCM: PHASE 2

The Phase 1 pilot revealed some feedback which prompted the following changes in the Phase 2 CCM tool to enhance functionality, relevance and ease-of-use:

- The ability to distinguish regions of similar climates but different emission factors.
- Incorporate a weather normalization using a degree-days approach (figure 2).
- Allow reporters to note how much on-site renewable energy was returned to the grid.

Figure 1: Degree day information (from degreedays.net) was included in CCM Phase II

Major renovation of old inefficient buildings is a vital link in reducing energy consumption in the current and future building stock. The process of renovation has a major impact on the performance standards of the building. Statistics on renovation will help policy makers, housing associations/ owners understand the quality of building stock as well the impact of country level policy on renovation standards. Phase II CCM incorporates a column for the year of renovation in addition to the year of construction (table 2).

Building name	Building ID	Year of Construction	Year of last major retrofit
Building A		1918	2008
Building B		2008	

Table 2: Year of last major Renovation included in phase 2, bottom up approach

Phase 2 of the pilot study was conducted between July and October 2011. CCM Pilot Phase 2 concentrated efforts on a building-stock (top-down) approach to measurement and reporting. Participants were able to establish baselines for the energy and climate performance of their building stock (termed the 'Whole' in the CCM) as seen in figure 3 and 4. The pilot participants were located in different climate zones, and in both developed and developing countries. Though data input for this phase was focused on the building-stock approach. The building-level (bottom-up) approach is used as verification through representative sampling. Organizations were encouraged to use measured data instead of estimated data.

The CCM Phase 2 implementation was based on an Excel platform. Participants were invited to provide their views on the functionality of the platform and recommendations for improvement or other means of input and use of information generated. As the data and reporting from the application of the CCM were intended to assist in the establishment of baselines and support actions to improve the environmental performance of their building stocks, users were encouraged to consider how best to retain and effectively utilize the information generated through the CCM testing process.

In total, eight pilot participants road tested the Excel-based platform, allowing performance metrics to be computed for a total of 131 individual buildings (total building area: 7.4 km^2) and for three larger stocks (or Wholes) (total building area: 177 km^2).

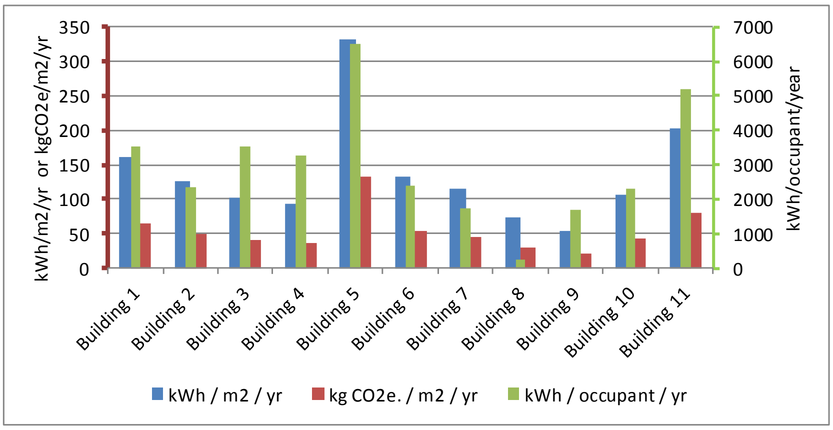

Figure 3: Sample outputs from phase II pilots: Energy consumption of individual buildings indicated by different performance metrics highlights that although some buildings (e.g. Office D) consume more energy per square meter, their overall efficiency in terms of energy consumed per occupant is lower than average.

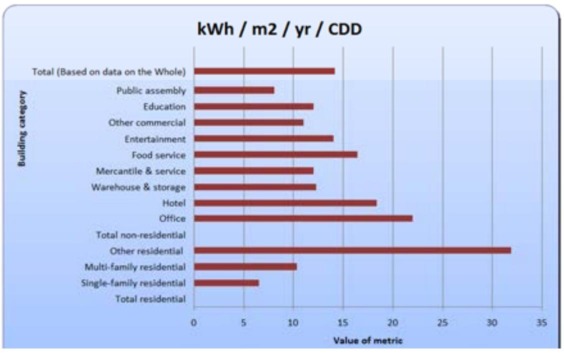

Figure 4: Sample outputs from phase II pilots showing top-down energy summary in relation to local climate.

5 DISCUSSION AND KEY FINDINGS FROM PILOT-TESTING

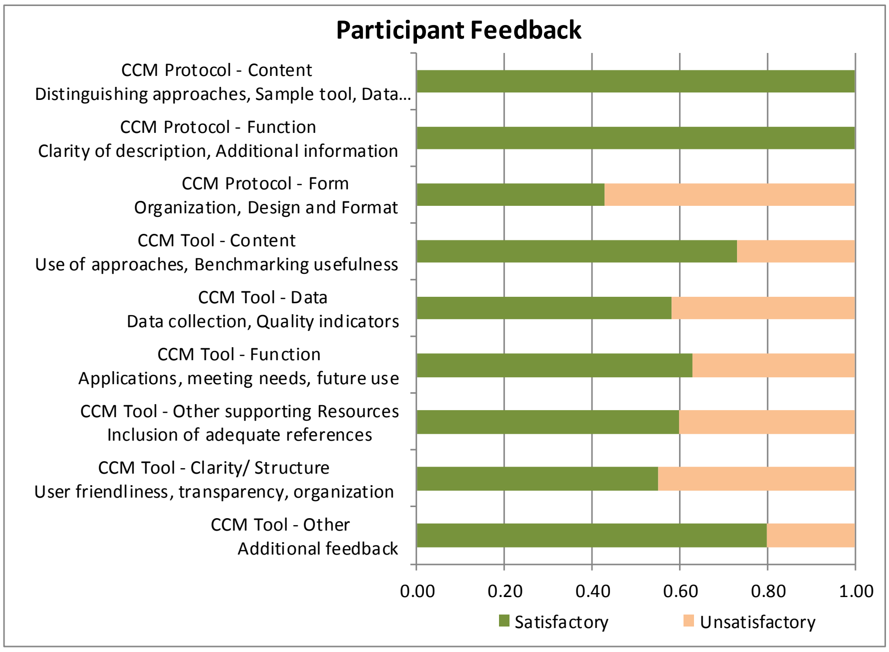

Figure 5: Estimating overall participant satisfaction in key areas. Satisfaction Ratings (S.R.) were calculated for each question, based on feedback comments, S.R is a value between 1 or 0 for polar questions and between 0 and 4 for qualitative comments where 0 is most unsatisfactory and 4 is extremely satisfied. Average values of S.R were combined to give a satisfaction factor between 0 and 1, where 1 indicated high satisfaction.

5.1 Key findings and outcomes

The key outcomes and findings of the Phase 1 review revealed the need for robust definitions, normalization and sample worksheets which were addressed through the Phase 2 pilot. The user feedback and participant submissions from Phase 2 are as follows:

- The strongest feedback was the need for a clearer guide about weather normalization and choosing a suitable base temperature. The participant must understand the use and relevance of the additional metrics (e.g. kWh/m^2/year/CDD) for establishing benchmarks which can be compared across different climates.
- Emission factors need to be explained with clarity, focusing on the ability and method of using different emission factors for the same building. Ambiguity about which emission

factors to be used for systems such as district heating/ cooling, steam etc. need to be removed. Most participants felt that the range of fuels provided was adequate.

- A simple step by step manual with explicit instructions for each key in field, including information such as basic understanding, resources for further information, relevance in bench marking and example would be useful.
- Improving the bottom up summary to generate a more graphical output and including navigation buttons between the top down and bottom up summaries would be beneficial.
- Increased information on how to interpret results, with comments on performance benchmarks would be highly valuable to the inexperienced user. Comparing the performance of the company portfolio with average benchmarks within the sector and region would be a useful addition, adding perspective to the results.
- Country specific guidelines for approximating data such as age of building and renovation could be included since such data has proved to be difficult to obtain.
- The text size within the tool varies markedly, making it difficult to use. Uniform font sizes throughout the tool would be useful.
- An increase in the quality and variations of output results would increase the long term usability of the tool by many organizations.
- Importantly, the pilot organisations used both top-down and bottom-up approaches indicating that CCM should remain committed to developing and testing both approaches in the future.

5.2 Improved platform for CCM

Quantifying the GHG and energy performance of buildings is a data-intensive process, particularly where large numbers of buildings are concerned. Moreover, the methodologies for quantifying emissions are complex and not well suited to implementation in an Excel environment. A primary recommendation for future work is the development of dedicated software, an open access, web-based platform for pilot and demonstration purposes. The review process identified the following features that were too cumbersome to implement in Excel, but that should be included in the new platform:

- Ability to track the performance of the same building sets over time.
- Capability to create inventories for building sets stretching across different cities/regions, including inventories at the national level.
- Methodologies to measure and report fugitive emissions from air-conditioning systems and the emissions from combined heat and power (CHP) systems.
- Ability to input data by an organization's financial year and by calendar year.
- Ability to input more granular data on fuel consumption. In particular, it would be beneficial to be able to supply data on a monthly basis through the bottom up approach because: (1) monthly data reveal use patterns according to climate condition, and (2) monthly data reveal fluctuations in the type of power used (e.g., hydro power). Phase 2 pilot of the CCM has begun to allow users to disaggregate electricity consumption data by month for the top-down and bottom-up approaches.

6 WIDER APPLICATION OF CCM

The Bali Action Plan, calls for measurable, reportable and verifiable National Appropriate Mitigation Actions (NAMAs) on a country level. The NAMAs for the building sector can assist developing countries in recognizing the significant mitigation potential of the building sector that can be integrated in broader national and regional strategies. To facilitate NAMAs, a globally consistent MRV methodology is essential to measure and track energy use and energy reductions from buildings. CCM could meet the MRV requirements in future. CCM is able to support the establishment of baselines from the sector or sub-sector (residential, commercial, etc.), thus allowing measurement over time of increased efficiency and GHG reductions from a particular building stock.

Also CCM is currently being developed into an ISO standard on carbon metric of buildings (ISO/TC59/SC17). This standard will provide a framework for how to measure emission reduction in buildings so as to support formulation of holistic approaches including carbon crediting as well as various emission reduction mechanisms. It is hoped that the standard will also help to establish a system of measurable, reportable, and verifiable indicators for the follow-up of policy implementation and reporting on building-related GHG emissions

7 CONCLUSION AND FURTHER WORK

The Phase 2 pilot of CCM has revealed some interesting findings, which provide an insight into the next steps in the development and testing of CCM, to become the universal MRV approach for measuring and reporting energy use and emissions from building operations. Some of the steps for further work are as follows:

- Although the Excel-based platform of CCM is regarded as being transparent by majority of the pilot participants, the Excel tool is also found to be brittle and incompatible especially when different versions of MS Office are used by different participants. This needs to be addressed possibly by developing a web-based version of CCM.
- In the Phase 2 pilot, only one inventory out of nine inventories submitted used estimated data of energy use, while the rest focussed on measured data. This is a major step forward in the right direction given the widening gap between estimated and measured energy performance of buildings.
- Although the intention of CCM Phase 2 pilot was to focus on the top-down approach, only three out of the nine inventories submitted, used the top-down approach while the remaining six used the bottom-up approach focussing on individual buildings. This shows that CCM should remain committed to developing and testing both top-down and bottom-up approaches in the future.
- Finally, although the current focus of CCM is on measuring and reporting energy use and greenhouse gas emissions from building operations, the same framework could be used for other environmental and social indicators such as water, materials, social impact or biodiversity.

REFERENCES

R.Gupta, *Final report on the results of Phase 2 Pilot of Common Carbon Metric,* Internal report submitted to UNEP-SBCI, France (2012).

R.K.Pachauri and A.Reisinger, *Climate Change 2007: Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, Switzerland, pp 104 (2007).

UNEP-SBCI, *Why buildings?* [online] available at http://www.unep.org/sbci/AboutSBCI/Background.asp (accessed on 27/02/2013).

UNEP-SBCI and WRI, *Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations: Towards a Common Carbon Metric* (2010).

World Resources Institute , *Final report on the results of Phase 1 Pilot of Common Carbon Metric*, Internal report to UNEP-SBCI, France (2010).

Sustainable Building Conference 2013

A HYPOTHETICAL DYNAMIC MODEL OF CONSTRUCTION ENERGY CONSUMPTION AND CO_2 EMISSIONS

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Abstract. *Energy consumption and CO_2 emissions (ECCEs) are some of the sustainability issues threatening human life around the globe today. The built environment has been argued to be one of the contributors to this menace because throughout its construction, operation and maintenance, and deconstruction, it contributes nearly 50% of all CO_2 emissions, 33% of landfill waste, and consumes 13% of raw materials and 50% of water. This paper carries out an analysis of ECCEs of construction activities in a typical construction site. System dynamics (SD) is used as both the methodology and modelling tool to capture and predict construction energy use and CO_2 emission. The results reveal that SD has the capability of predicting construction projects' energy use and CO_2 emission by comparing the dual for each construction plan thereby selecting optimum energy-efficient construction plan. The paper concludes that the approach is hope to provide energy-efficient project management method and comprehensive evidence of CO_2 emission to the client and the projects approving authorities when seeking approval once the model is validated through case studies.*

1 INTRODUCTION

Since the World Commission on Environment and Development rose from the world summit on Environment in 1987, sustainable development as a concept has emerged and become the mainstream of 21st century. Sustainability in all areas of human endeavours is hence a topical issue around the globe and the built environment is not an exception. Interestingly, it has been argued that the construction industry is a major contributor to human development and the overall quality of life through the provision of the most important life's essentials: shelter, water supply and sanitation, roads and railway networks, etc. Undoubtedly, however, the construction industry is one of the largest sectors in the world and indeed a significant industry. This is because its output worth more than £100bn a year, providing work for about 3 million people, and generating nearly 10% of gross domestic product (HM 2008; Willetts *et al.* 2010). Throughout its construction, operation and maintenance, the built environment contributes nearly 50% of all carbon emissions, 33% of landfill waste, and consumes 13% of raw materials and 50% of water (HM 2008; Willetts *et al.* 2010). Without mincing words, these figures demonstrate the positive impact the 'end-products' of construction industry can have on humanity and clearly show why the industry needs to be a leader in embracing sustainability in order to minimise its detrimental impact and mitigate negative impacts on future generations (Shen, Wu, and Wang 2002; Presley and Meade 2010).

The processes involved in construction are many, energy consuming and prone to CO_2 emissions. For example, prior to on-site construction, the process of gathering materials for construction involves ECCEs. Likewise, equipment manufacturing consumes energy and releases CO_2 into the atmosphere. These can then be termed as the ECCEs during the production process of the materials and equipment *i.e.* production-related ECCEs. During the actual construction, however, ECCEs do occur as well in the form of materials and equipment transportation, workers transportation, on-site assembly of structural members, and the likes. When the project is completed, there comes the operation stage of the facility and again, a lot of energy is used up here and a great deal of CO_2 is released into the atmosphere, while at the same time the deconstruction activities of this facility also witness ECCEs. By implication ECCEs occur throughout the life cycle of any construction project.

Literature indicates that construction industry always comprises many influencing variables which make construction projects highly complex (Saparauskas 2007; Motawa 2008) and therefore difficult to understand, predict and keep under control (Nguyen and Ogunlana 2005). The issue of ECCEs in construction has further compounded the problem of this complexity because ECCEs themselves are complex systems and based on this fact, it is evident that there are many variables (both qualitative and quantitative) in play that are with multiple interdependent elements, interconnected, highly dynamic, chaotic in nature and with many feedback loops. Considering all these characteristics, it is problematic in estimating ECCEs for construction activities.

To this end, appropriately estimating ECCEs of construction activities on a specific construction project has been a subject of problem mainly because the linear and deterministic tools that focus on one part of the system at a time cannot be effectively used to do this kind of complex system for it cannot adequately capture the behaviour of such a system. Hence, the need for a more robust tool that is non-linear and non-deterministic in nature that will be able to capture all the interconnectivities, interdependencies, dynamism, and chaotic nature of the variables involved while estimating ECCEs of construction activities. It is against this backdrop that the research intends to use the SD approach as both the methodology and tool for the analysis and estimation of ECCEs of construction activities with a view to providing a robust tool to track energy consumption and carbon footprints of construction projects during the pre-construction stage.

2 METHODOLOGY

System dynamics (SD) is used as both the methodology and tool for this research. It is a modelling platform that has the capability of analyzing the behavior of complex systems like ECCEs of construction activities. The approach uses a cause-effect relationship with the attendant feedback loops [causal loop diagram (CLD)] in understanding the system as a precursor to the stock and flow diagram in readiness for simulation. The major steps involved in SD methodology are depicted in Figure 1. A detailed description of the SD methodology has been reported somewhere else (Oladokun *et al.* 2012a and 2012b). In this paper, CLD is not included, but the basic principles regarding the stock and flow diagram is hence discussed.

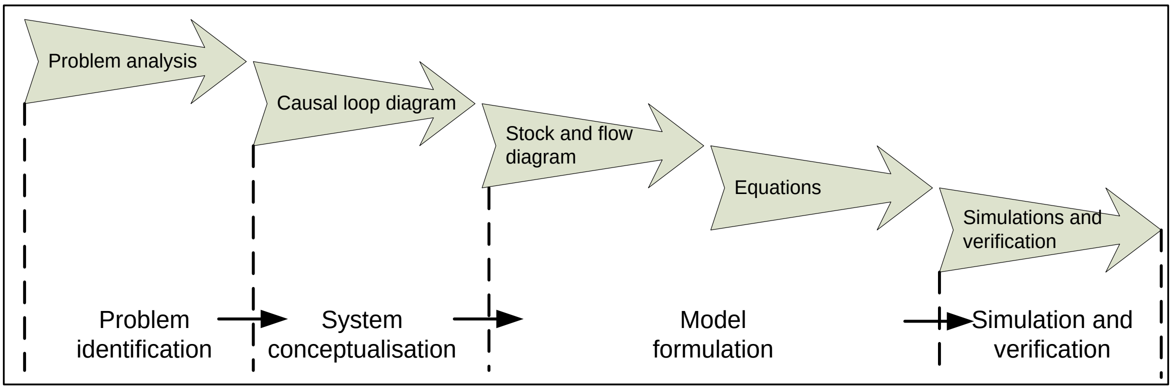

Figure 1: Basic steps of SD approach (Adapted from Lê and Law, 2009)

2.1 Stock and Flow Diagram

Stock and flow, according to Ranganath and Rodrigues (2008), is the "pictorial representation of the behavior of the system in the form of accumulation (stock or level) and flow (rate)". Stocks are represented by rectangles (suggesting a container holding the contents of the stock), for example, Stocks A and B in Figures 2 and 3; whereas inflows are represented by a pipe (arrow) pointing into (adding to) the stock (Figures 2 and 3). It is possible to have outflows as well and these are represented by pipes pointing out of (subtracting from) the stock. Valves serve as the control for the flows. In this research, Stock 'A' represents energy source and this is regulated by energy use for production of materials/equipment; for transportation of materials, equipment, and workers; and for on-site construction. Energy use in this case is regarded as the flow and the rate of energy use will accumulate Stock 'B', which is CO_2 emission (Figure 2). In terms of SD representation, Figure 2 is then transformed into Figure 3. The stock and flow diagram is discussed more in section 4 of the paper in order to conceptualise the problem.

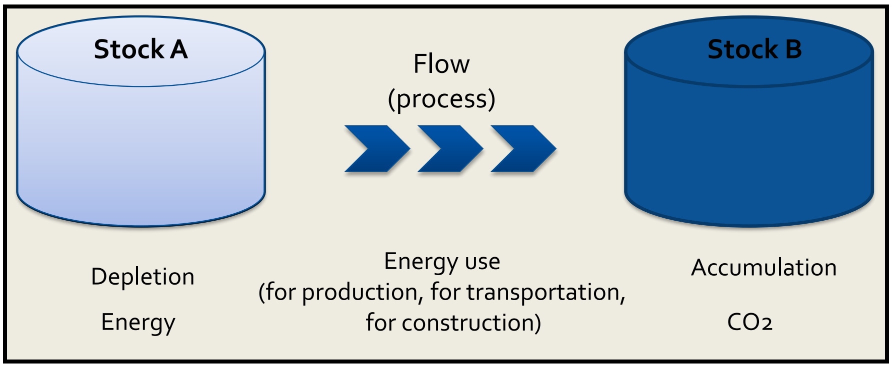

Figure 2: Basic representation of stock and flow diagram

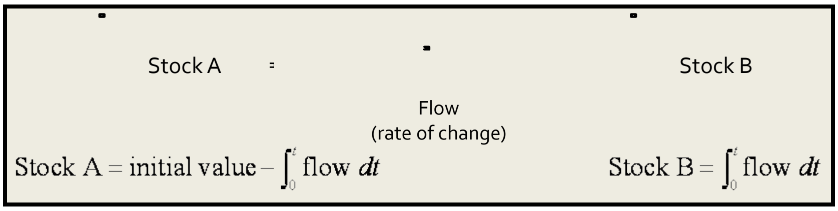

Figure 3: SD representation of stock and flow

2.2 Model Boundary

In order to show a complete picture of energy consumption and CO_2 emissions of different construction activities, it is necessary to give a description of what is included in the model, hence the need for a model boundary. Figure 4 shows the model boundary for the research. It has been asserted by Yan (2010) that majority of CO_2 emissions in the construction industry is as a result of fuel consumption in the form of diesel and petrol to power different construction equipment and also from the use of electricity to run some tools and site offices. As such, the research focusses on energy consumption related to transportation of construction materials, equipment and workers as well as energy consumption during the on-site assembly (Figure 4). CO_2 emissions relating to those construction processes are then covered by this research.

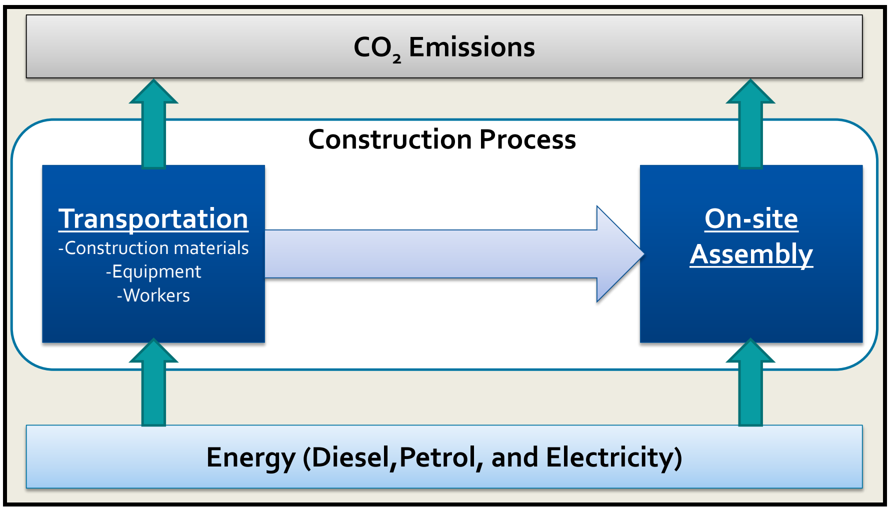

Figure 4: Model boundary for the research

3 ENERGY CONSUMPTION AND CO_2 EMISSIONS ESTIMATION

As indicated in the preceding section, the model boundary is formed in order to state the scope of the study. The study only concerns with the issues of ECCEs related to transportation on construction projects. This is being investigated from the point of view of the ones required for moving equipment, materials and workers as well as on-site equipment use. Energy is used in the form of electricity, diesel and/or petrol. CO_2 is emitted in one way or the other. The model then looks at a web of variables interacting together in order to estimate ECCEs as a result of the consumption. This is then estimated based on the output of the system dynamics model (see Figure 5 for the stock and flow diagram).

It needs to emphasise that the amount of CO_2 emissions as a result of energy consumption depends on the characteristics of the construction projects. This has to do with the site location, method of construction, the type of structural member assemblage, material of construction, *etc.* Site location, for example, has effects on both transportation and construction plan (Figure 5). The construction plan affects the work quantity which in turn affects the work load and the rate of transporting materials from factory. All these present a kind of complex system that are interrelated and inter-dependent on one another as shown in Figure 5.

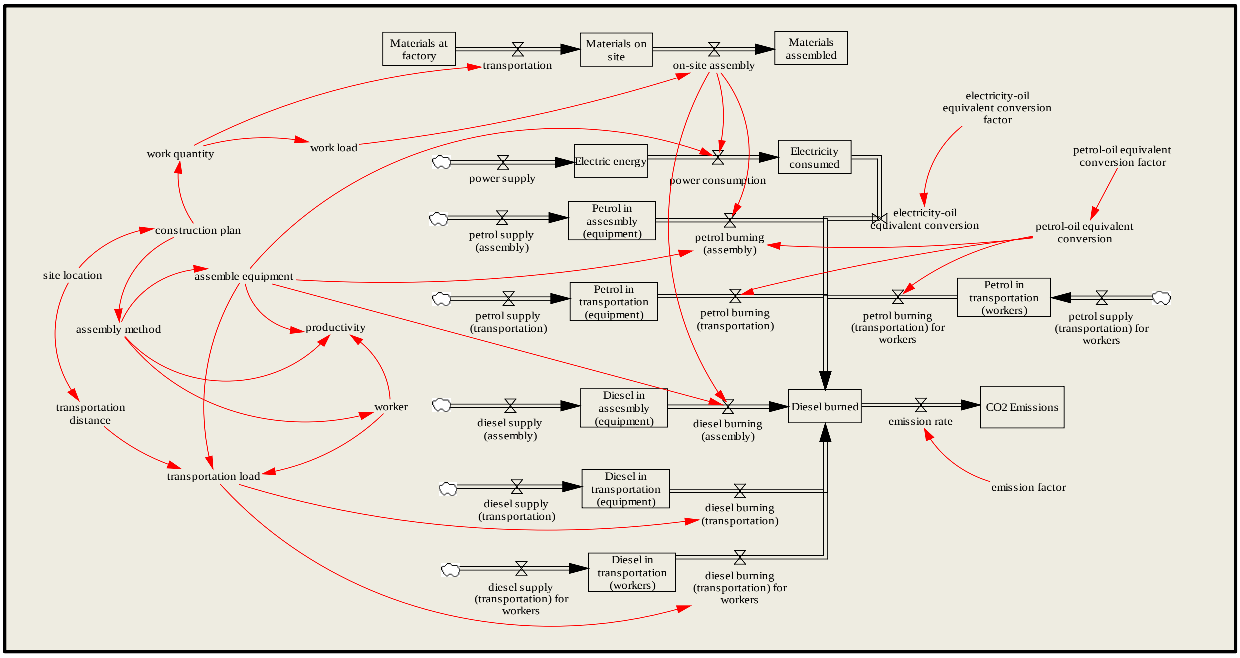

Figure 5: Stock and flow model

The model in Figure 5 has the capability of estimating CO_2 emissions based on the on-site use of equipment ($E_{on\text{-}site}$), transportation of equipment (E_{te}), transportation of materials (E_{tm}), and transportation of workers E_{tw}). This model, however, did not account for CO_2 emissions due to materials production. A total CO_2 emission (E_{tot}) is then calculated to be the summation of all the above mentioned emissions. Mathematically, this is represented thus:

$$E_{tot} = E_{on\text{-}site} + E_{te} + E_{tm} + E_{tw}$$

From the above equation, CO_2 emissions of different activities can then be estimated on specific construction projects thereby providing a basis for monitoring emissions relating to each activity on site and mapped into the construction plan as shown in Figure 6. CO_2 emissions profile can then be produced from the construction plan for the entire project duration which in turn will reveal the CO_2 emissions at any point in time.

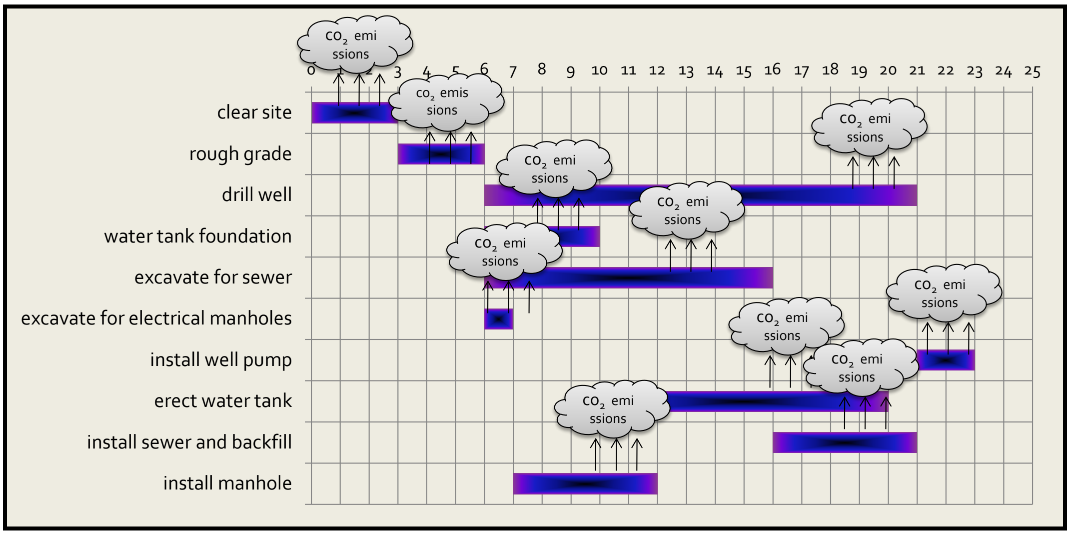

Figure 6: An example of the model application

4 CONCLUSIONS AND FURTHER WORK

This research was conducted mainly to propose a methodology for capturing ECCEs related to on-site construction activities. The research identified two types of ECCEs as production-related and project-related ones. The research focused on project-related ECCEs that are due to transportation of equipment, materials and workers as well as on-site equipment use. The paper has, therefore, demonstrated the efficacy of innovative SD approach in analyzing and estimating ECCEs of construction activities thereby providing the basis for monitoring carbon emissions related to construction projects. This has the capability of providing energy-efficient project management and aid in choosing energy-efficient construction plan for construction projects. It is hope that the model will provide a comprehensive evidence of CO_2 emission to the client and the projects approving authorities when seeking approval once the model is validated. The next stage of the research is to subject the model to empirical data that will be collected through case studies and validate the model accordingly.

REFERENCES

HM Government, *Strategy for sustainable construction*, London (2008).

M.A.T. Lê and K.H Law, “System dynamic approach for simulation of experience transfer in the AEC industry”, *Journal of Management in Engineering*, **25** (4), 195–203 (2009).

I.A. Motawa, “System dynamics for controlling sustainable projects”, *In Proceedings of CIB Joint International Symposium: Transformation Through Construction*, 15-17 November, Dubai (2008).

L.D. Nguyen and S.O. Ogunlana, “Modelling the dynamics of an infrastructure project”, *Computer-Aided Civil and Infrastructure Engineering*, **20**, 265-279 (2005).

M.G. Oladokun, I.A. Motawa and P.F.G. Banfill, "Modelling techniques for capturing the socio-technical aspects of sustainability in post-occupancy stage of buildings", *In: Proceedings of Retrofit 2012 Academic Conference*, University of Salford, Greater Manchester, United Kingdom, 24th – 26th January (2012a).

M.G. Oladokun, I.A. Motawa and P.F.G. Banfill, "Understanding and improving household energy consumption and carbon emissions policies – A system dynamics approach", *In: Proceedings of International Conference for Enhanced Building Operations*, University of Salford, Manchester, United Kingdom, 23rd – 26th October (2012b).

A. Presley and L. Meade, "Benchmarking for sustainability: an application to the construction industry", *Benchmarking: An International Journal*, **17**(3), 435-451 (2010).

B.J. Ranganath and L.L.R. Rodrigues, *System dynamics: Theory and case studies*, I.K. International Publishing House Pvt Limited, New Delhi (2008).

J. Saparauskas, "The main aspects of sustainability evaluation in construction", *In: 9th International Conference on Modern Building Materials, Structures and Techniques*, Vilnius, Lithuania (2007).

L.Y. Shen, M. Wu and J.Y. Wang, "A model for assessing the feasibility of construction project in contributing to the attainment of sustainable development", *Journal of Construction Research*, **3**(2), 255-269 (2002).

R. Willetts, J. Burdon, J. Glass and M. Frost, "Fostering sustainability in infrastructure development schemes", *Proceedings of the Institution of Civil Engineers: Engineering Sustainability 163,* September Issue **ES3**, 159–166 (2010).

H. Yan, "Greenhouse gas emissions in building construction: A case study of one Peking in Hong Kong", *Building and Environment*, **45**(4), 949-55 (2010).

Sustainable Building Conference 2013

POST OCCUPANCY EVALUATION (POE) OF MULTI-UNIT RESIDENTIAL BUILDINGS AND THE CONTRIBUTION OF RESIDENTS TO ACTUAL ENERGY CONSUMPTION

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Abstract. *Occupants of two LEED certified, high-rise condominium towers were given an occupancy questionnaire that explored both their satisfaction levels and their behavioural patterns. Suite-level energy consumption data was also collected, but not used in the current study. After analysis of 72 responses it was found that the major successes of the buildings were in the areas of control over heating and cooling, overall design, and certain air quality parameters. The buildings were found to underperform primarily in the areas of lighting and noise, which is consistent with other studies of green buildings. A surprising finding was that despite expressing a high degree of control over heating and cooling, 24.8% expressed dissatisfaction with the usability of their HVAC system. Moreover, 47.6% either underused or never used their sophisticated in-suite energy recovery ventilation system. The reasons for this are varied but appear to be caused by lack of information and specific barriers to use.*

Keywords: *post-occupancy evaluation, occupant behaviour, usability studies, low carbon housing, multi-unit residential buildings, energy efficiency*

1 INTRODUCTION

In 2012, the Canadian Green Building Council certified 346 buildings with the LEED designation (CaGBC, 2012). Though formal evaluation, verification and measurement (EV&M) is becoming more commonplace, it is safe to say that only a fraction of these buildings have had the various aspects of their projected performance verified during their occupancy phases. It is also safe to say that only a fraction have undertaken the measurement of occupant satisfaction that many researchers insist upon (Abbaszadeh et al., 2006; Baird, 2010; Combe et al., 2011; Newsham et al., 2012; Stevenson & Leaman, 2010). As a result, it is often unknown whether or not these buildings are meeting their technical aspirations, and also whether or not this technical performance comes at the expense of occupant satisfaction.

Researchers also insist that post-occupancy evaluations (POE) collect data about how occupants experience, use, and control their buildings, as this at least partially determines energy efficiency (Birt & Newsham, 2009; Dietz, Gerald, Gilligan, Stern, & Vandenbergh, 2009; Gill, Tierney, Pegg, & Allan, 2010). For example, Gill et al. (2010) found that "energy-efficiency behaviours account for 51%, 37%, and 11% of the variance in heat, electricity, and water consumption, respectively, between dwellings.” These types of studies are scarce, as they require both enhanced questionnaire techniques, as well as access to dwelling-level energy consumption data. This is echoed by Stevenson & Leaman (2010): “more sophisticated evaluation strategies that interrelate human factors directly with the physical performance of housing also need to be developed.”

The call for post-occupancy evaluations to explore occupant behaviour in buildings is only slowly being met by a proportional rise in the complexity of questionnaire tools deployed in such assessments (e.g., Gill et al., 2010). This project builds on past research by using a questionnaire tool to explore issues of usability, control, and knowledge and how these interact with occupant satisfaction and energy consumption. For example, this project implicitly explores what Brown et al. (2009) call a philosophical divide “between those who believe occupants should be kept comfortable with minimal engagement, and those who believe that only through active engagement of occupants can we approach the limits of energy efficiency.” By exploring the energy use of residents within a building that provides a high-degree of control opportunities, we can begin to explore this divide – and other important usability issues – in an understudied building type.

This project addressed these concerns by delivering an occupant questionnaire to residents of two high-rise LEED-Gold condominium towers in Toronto, Canada. The results below point to POE as a powerful methodology and also suggest that occupancy of green buildings is an important research area.

2 RESEARCH METHODS

2.1 Building typology

The majority of Canadian post-occupancy evaluations have been carried out in commercial and institutional buildings (e.g., Baird, 2010; Birt & Newsham, 2009; EcoSmart Foundation, 2006; Newsham et al., 2012). This is problematic because the various design and management innovations in multi-unit residential buildings (MURBs) need to be evaluated in order to determine if they are meeting both designer and occupant expectations. This project uses a questionnaire to collect information from occupants which can then be compared to individual energy consumption data.

The sites for this research are a matching pair of LEED-certified (gold) high-rise condo towers in Toronto, Ontario, Canada.[1] These buildings were completed in 2010 and have been occupied for over 2 years at the time of data collection. These buildings have many features which make them attractive research sites. One feature which is explicitly explored in the questionnaire is the provision of an in-suite ventilation system that is entirely controlled by the occupant. In traditional high-rise condo towers (100+ units), centralized ventilation delivers treated air to pressurized corridors, forcing air under the unit’s doors and into suites. In the study buildings, suite entry doors are entirely weather-stripped and fresh air is brought into the suite either using the energy-recovery ventilation (ERV), which exchanges heat from exhaust air into incoming outdoor air; or by using operable windows, which during the winter is thought to be an undesirable and profligate adaptive behaviour. Additionally, each suite has at least one thermostat which controls a fan-coil system that delivers either heating or cooling,

[1] At the time of submission, data has only been collected for one of the towers. By the time of final submission we will have collected and analyzed data for the second tower, which will be included in the final draft.

giving the occupants ample ability to control thermal conditions in their suites. A final advantage of the test buildings is that each suite has three energy meters which collect data about - and charges residents for - hot water, electricity, and thermal energy.[2] Unit numbers were used to link this energy data to responses from the occupant questionnaire.

2.2 Condo evaluation questionnaire

For this project we delivered a modified paper version of the BUS Methodology Domestic Questionnaire. Core questions of this questionnaire have been used in a variety of buildings, mostly in the UK. The main modifications made to the questionnaire were to elaborate on questions surrounding control and usability. For example, the personal control section was expanded to include questions about the usability and usage patterns of the various HVAC systems in the individual suites. The majority of the questions use a 7 point likert scale. IT should be noted that in-depth interviews are scheduled to compliment results from the questionnaire, but these will not take place until late summer, 2013.

A novel aspect of this methodology is that it enables comparisons between responses from the questionnaire and suite level energy consumption. Though this work is still underway and will not be included in the current paper, it will eventually lead to a quantification of the relationship between, for example, understanding one’s thermostat and using it optimally. In order to access suite-level energy consumption data, a consent form was used which asked occupants to release their energy use data by providing their unit number. This unit number was then submitted to the energy management company and the data was provided in spreadsheet form.

3 RESULTS

A paper version of the questionnaire was delivered directly to all 420 suite doors of the two test buildings. Occupants were given 2 weeks to complete the questionnaire and return it to the concierge. A response rate of 17.1% (n=71) was achieved, all of which were from unique suites.

3.1 Building comparisons

For general results it is useful to compare results from this building to relevant residential buildings from the BUS Methodology database. This process compares results from the test building to benchmarks generated from the most recent and relevant buildings in the database.[3] For example, mean scores from a 7 point likert scale asking about satisfaction with overall design in the study building were 5.8, which was found to be higher than the database mean of 5.13; putting this building in the 66th percentile. Similarly, occupants were found to be more satisfied than most with both air quality and temperature in both winter and summer, scoring slightly higher than most buildings in the database.

An aspect of indoor comfort that occupants were less satisfied with was the stability of both winter and summer temperatures, with mean scores in the 24th and 36th percentile

[2] The suites use a 2-pipe fan-coil system to deliver heating or cooling. Sensors on the incoming pipe collect flow rate and temperature change data in order to determine how much heating or cooling energy is being used in the suite.
[3] To conserve space, results from the BUS Database will only be reported for the first of the two towers. The second tower scored very similarly on all reported factors.

respectively. This instability is likely to be influenced by a number of factors, for example, East vs. West orientation, number of occupants, hours at home, and the like. Notwithstanding its causes – which will be teased apart in future work with this dataset – this finding suggests that occupants lack either the opportunity or the knowledge to control their suites effectively. This is an important point to keep in mind for the following discussion.

3.2 Control and usability

When discussing usability and control in the current context it is important to remember that occupants of the study building have a high degree of control opportunities in their suites, with operable windows, in-suite ventilation, and at least one thermostat. This was confirmed by a comparison to the BUS database which found that control over heating and cooling were in the 71^{st} and 91^{st} percentiles respectively (see Figures 1 and 2).

However, in two questions that were exclusive to this study (and therefore not compared to the BUS Methodology database) occupants were asked to indicate how easy or difficult it was to make changes to indoor environmental conditions and also to rate the usability of their HVAC systems. 17.5% of respondents reported having trouble adjusting their indoor environment, while 24.8% were dissatisfied with usability of their HVAC systems. On the one hand these findings are surprising given that the building scored so well on access to heating and cooling controls, on the other hand it seems to suggest that there is a difference between opportunities for control and proper use of controls to achieve ideal indoor environmental conditions.

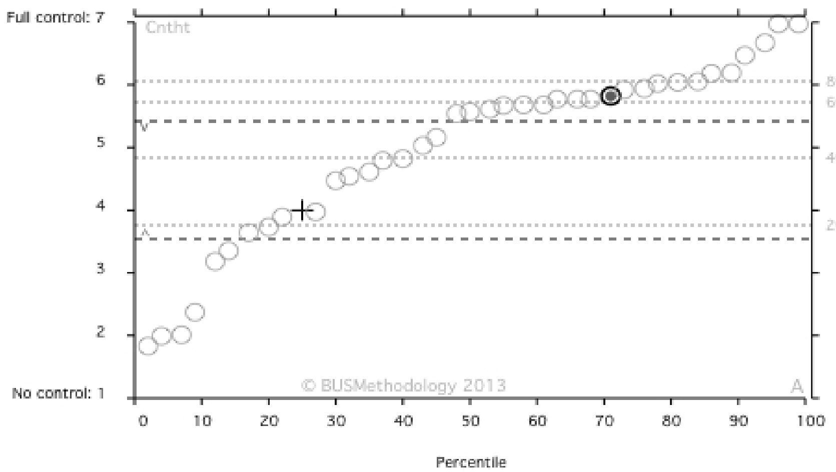

Figure 1: Scores for control over heating (study building solid circle)

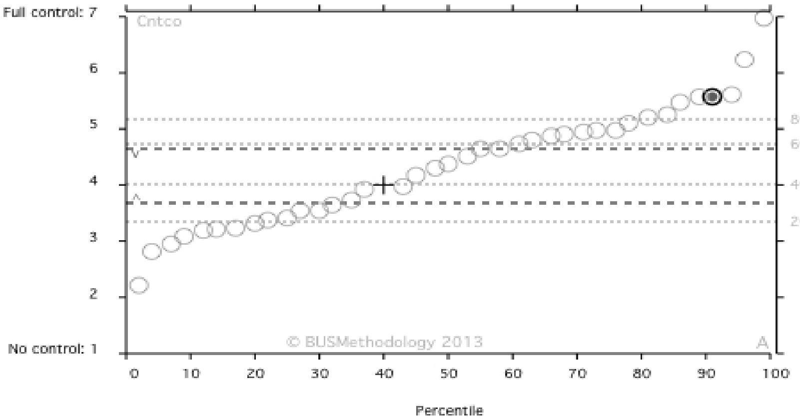

Figure 2: Scores for control over cooling (study building solid circle)

3.3 Energy recovery ventilator (ERV)

Despite favourable control opportunities, 24.8% of occupants were dissatisfied with the usability of the HVAC controls within their suite. This number makes sense when one considers that ventilation – which is a major factor in indoor environmental conditions – was found to be very poorly understood and underused by occupants of the study building. Only 47.2% of respondents reported using their ERV system daily in the winter. Incidentally, this rate of usage is consistent with the number of occupants who have read the instruction manual that came with their unit (42.5%) and suggests that those who do not know about the ERV do not use it; thus pointing towards re-education as a means of increasing use (and therefore energy efficiency).

However, there is more going on here than simple lack of information. First, occupants are made aware of the ERV system from building management in the form of a twice yearly email about owner performed ERV filter maintenance. This implies that most occupants know about the ERV system but suggests that either it is either too hard to understand and operate on a conceptual level, or that the means by which it is controlled are too complicated.

To speak to the former concern we can look to responses from a questionnaire item which asked occupants to identify the function of the only air vent in their master bedroom. Only 14% of respondents could correctly identify that this vent delivered pre-heated, filtered, fresh air via the ERV system. This finding suggests that occupants do not completely understand the function (nor perhaps even the benefits) of their ERV system, and that perhaps this is a source for its underuse. However, a curious finding undermines this point as 46.3% of people who reported using their ERV daily could not properly identify the function of their master bedroom air vent. This suggests that detailed knowledge about vents, for example, may not be essential in determining whether or not an occupant will use their ERV.

There is another finding which suggests that the control surfaces of the ERV (Figure 3) are not a major barrier to use; something which is confirmed by a lack of negative comments about controls surfaces (see Figure 5). Of the people that used the ERV, 75.6% of people found it easy to operate, suggesting that the controls are not a major barrier to ERV use.[4]

[4] Further work will use the usability matrix employed by Stevenson et al., (2013) to confirm this.

Figure 3: Primary control surface for ERV system

Figure 4 displays negative comments about the ERV system which give clues as to why it is underused. One finding echoes Stevenson et al., (2013), who found that "there was no demonstration of how to get into [ERV] unit for cleaning the heat exchanger filter." Comments 3 - 7 (Figure 4) clearly show that occupants are either unaware or unduly challenged by the task of cleaning the ERV filter, which could lead to outright abandonment of its operation (i.e., comment 5). The rest of the comments clearly show that occupants are either unaware or disappointed with the ERV system. It is important to note that 38% of occupants appear to have no knowledge of the ERV system, these occupants only account for comments 1 - 3 in Figure 4. It is also interesting to note that there was no difference between renters and owners in the study building, both had similar use patterns of their ERV system.

HVAC Control Comments	1. "Do not know anything about ERV" 2. "Do not know how to use ERV" 3. "Not sure about ventilator - I believe building changes and operates" 4. "Instructions for cleaning ERV need to be clearer" 5. "Tried to clean, way too difficult, did not bother" 6. "Very difficult to clean ERV, located too high" 7. "ERV system - marginal benefit, hard to clean" 8. "ERV - sometimes wonder if it works at all; no effect when it is on/off" 9. "HVAC too noisy" 10. "HVAC fans make loud noise" 11. "The ventilation is really loud" 12. "Noisy fan, have to adjust TV when it comes on in winter" 13. "Need better thermostats. Fans are too loud all year long while running" 14. "Constantly have to adjust thermostat depending on which room I am in"

Figure 4: Occupant comments about HVAC system

Notwithstanding the precise cause, the lack of ERV use has implications for the amount of fresh air in the suites, as well as their energy efficiency. After all, if occupants are opening windows during winter instead of using the ERV, we would expect to see a rise in the heating consumption for suites which do not correctly acquire fresh air via the ERV system.[5] Given that people were found to be significantly satisfied with the level of indoor air quality found in their suites, and that the ERV is only sometimes used for fresh air, there is likely a relationship here.

3.4 Noise

No discussion of a POE of a green building would be complete without a brief discussion about noise; which is a popular plague in this new building type (e.g., Abbaszadeh et al., 2006). Though not immediately related to energy efficiency, noise is nonetheless an important aspect of the occupant experience in green buildings. The study building was found to score below the BUS Methodology benchmarks on control over noise, noise from other people, and noise from outside. There is another very important source of noise in the suites: the noise generate by the functioning of the fan coil and ERV systems. Figure 4 clearly shows that the noise generated by the ERV system presents a possible barrier to its use, and therefore that noise can negatively impact energy efficiency.

4 CONCLUSION

Though there is much more work to do with this dataset, the preliminary findings point to this building type as generally successful, but not without usability challenges. This should not come as a surprise, as Brown & Cole (2009) point out: “the successful design of environmentally sustainable, adaptive buildings requires a heightened level of intelligence both in terms of building form, system integration, operation and management, as well as in terms of building occupants themselves.” In other words, LEED certified condo towers provide new opportunities for control, but how are occupants reacting to and using these opportunities?

The current work has demonstrated that usability challenges are complicated, but through creative use of occupancy questionnaires and energy data, researchers can begin to understand, and even remedy, these challenges.

REFERENCES

S. Abbaszadeh, L. Zagreus, D. Lehrer and C. Huizenga, “Occupant satisfaction with indoor environmental quality in green buildings”, *Proceedings of Healthy Buildings*, Lisbon, Vol. III, 365-370 (2006).

G. Baird, *Sustainable buildings in practice: what the users think*, Routledge, New York (2010).

B. Birt and G. Newsham, *Post-occupancy evaluation of energy and indoor environment quality in green buildings: a review*, National Research Council of Canada (2009). Retrieved from http://archive.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc51211.pdf on February 15, 2013.

Z. Brown and R. Cole, “Influence of occupants’ knowledge on comfort expectations and behaviour”, *Building Research & Information*, **37**(3), 227-245 (2009).

Z. Brown, H. Dowlatabadi, and R. Cole, “Feedback and adaptive behaviour in green buildings”. *Intelligent Buildings International*, 1, 296–315. (2009).

[5] This is another pending research question that will be answered with deeper exploration of this dataset.

CaGBC, *LEED Projects in Canada* (spreadsheet) (2012). URL: http://www.cagbc.org/Content/NavigationMenu/Programs/LEED/ProjectProfilesandStats/default.htm (last visited 2013-02-15).

R.J. Cole, J. Robinson, Z. Brown and M. O'Shea, "Re-contextualizing the notion of comfort", *Building Research & Information*, **36**(4), 323–336. (2008).

N. Combe, D. Harrison, H. Dong, S. Craig and Z. Gill, "Assessing the number of users who are excluded by domestic heating controls", *International Journal of Sustainable Engineering*, **4**(1), 84-92 (2011).

T. Dietz, G. Gerald, J. Gilligan, P. Stern and M. Vandenbergh, "Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions", *Proceedings of the National Academy of Sciences*, **106**(44), 18452-18456 (2009).

EcoSmart Foundation, *Building Performance Evaluation (BPE): Project Evaluation Report for Building "A"* (2006). Retrieved from http://maquinamole.net/EcoSmart.ca/?p=1020 on February 16, 2013.

Z. Gill, M. Tierney, I. Pegg and N. Allan, "Low-energy dwellings: the contribution of behaviours to actual performance", *Building Research & Information*, **38**(5), 491-508 (2010).

G. Newsham, B. Birt, C. Arsenault, L. Thompson, J. Veitch, S. Mancini, A. Galasiu, B. Gover, I. Macdonald and G. Burns, *Do green buildings outperform conventional buildings? Indoor environment and energy performance in North American offices.* Research Report RR-329: National Research Council Canada (2012).

F. Stevenson, I. Carmona-Andreu and M. Hancock, "The usability of control interfaces in low-carbon housing", *Architectural Science Review*, iFirst, 1-13 (2013).

F. Stevenson and A. Leaman, "Evaluating housing performance in relation to human behaviour: New challenges", *Building Research & Information*, **38**(5), 437-441. (2010).

Sustainable Building Conference 2013

KNOWLEDGE TRANSFER IN PROJECT TEAMS DELIVERING OFFICE BUILDINGS TO SUSTAINABLE BUILDING STANDARDS

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Abstract. *Sustainability is fundamentally transforming construction industries worldwide. The nature of product demanded by tenants, constructed by developers, required by governments and favoured by capital providers is changing and becoming more complex. Seamless transfer of knowledge between the more divergent set of actors involved in these projects is required to deal with this complexity. The gap between the performance of green buildings as designed and as built could be interpreted as an indication that this transfer is not flawless. Nowadays almost every actor involved in the construction process claims to strive for sustainability. However, the way they perceive and translate it into practice varies widely between different construction project participants. Therefore a better understanding of how knowledge on sustainable construction is transferred and adopted is needed. A subsequent enhancement of this process could offer a solution to secure a certain standard of sustainable building quality. These issues are explored in an on-going research project comparing knowledge transfer practices in construction teams delivering office buildings to sustainable building standards in Germany and the UK, by using social network analysis. The paper sets out by providing a brief background of the context of the study. This is followed by the conceptual framework on knowledge transfer and the methodological approach. Thereafter selected initial findings and preliminary conclusions are discussed.*

Keywords: *sustainable office buildings, sustainable construction, knowledge transfer, social network analysis*

1 INTRODUCTION

Sustainable development as a concept has been gaining increasing attention across various sectors (e.g. Pitt et al. 2009) since the Brundtland Commission Report in 1987. Many new policies, legislation and initiatives that are related to environmental performance and sustainability have emerged around the world (Dixon et al. 2008). Such developments mainly followed the Rio de Janeiro Summit in 1992 and the South African summit in 2002 (Ugwu 2005). They resulted in an increasing need for all industries to respond to this new agenda. With its high impact on the environment, construction industry is no exception.

One of its responses is the development of rating methodologies for assessing the sustainable performance of buildings (Atkinson, Yates and Wyatt, 2009) against a wide range of criteria, and awarding certificates such as BREEAM in the UK and DGNB in Germany. Research on how to achieve these standards and reach governmental targets is abundant. It has two main short-comings. First, it oversees the reasons behind the recently acknowledged gap between the design performance and as-built performance of a facility. Second, it largely focuses on residential buildings. As such commercial buildings, and its largest sub-sector of offices, which emit similar amounts of CO2 do not receive the necessary attention (WBCSD, 2009).

The aim of this research is to address these issues by developing a better understanding of how knowledge on sustainable construction is transferred and adopted within project teams delivering new office buildings to sustainable building standards in Germany and the UK. The objectives are to use social network analysis in order to explore the connection between network density and types of transferred knowledge. In addition network centrality supports the identification of experts, consumers and brokers of knowledge on sustainable construction. Furthermore methods to transfer this special knowledge are identified. The background section illustrates the gap in the literature. The conceptual framework on knowledge transfer is then presented, followed by the methodological approach. Selected initial findings and preliminary conclusions are discussed in the final section.

2 BACKGROUND

Most sustainability assessment methods rely more on the evaluation of the design stage, even if some environmental impacts are better measured by actual performance (Nelson 2012). There have been several studies comparing the actual performance of sustainable buildings with their intended one, revealing differing results (Robinson 2008). For instance, a New Buildings Institute study in 2008 compared intended energy efficiency with actual energy performance of LEED certified projects, and revealed that the results differed widely from the intentions, with some green buildings using even more energy than their conventional counterparts. This proves a need for linking design intent to operational performance (Robinson 2008).

Identifying the main barriers preventing construction industry from delivering a high-quality sustainable standard is a starting point. Economic barriers include the length of payback period, initial investment costs and lack of supply (e. g. Dixon et al. 2009). In addition still only a small number of professionals in the industry possess the specialised knowledge and experience to design and operate sustainable buildings successfully (Nelson 2007; WBCSD 2009; Kurul et al. 2011). There also seem to be difficulties in the process of putting this new knowledge into practice (Ugwu 2005). Previous research has shown that for professionals the main barriers to adopt sustainable building techniques are personal know-how and commitment (WBCSD 2009). This finding reflects not only a lack of training and education in relevant techniques (Dixon et al. 2008), but also personal commitment and a supportive environment and business acceptance.

Although all project team members have to constantly absorb new technology and techniques in order to remain competitive (Fong 2003), sustainability engagement is higher for senior staff, and generally in larger organisations (Dixon et al. 2008). Delivering truly sustainable buildings requires engagement of staff at all levels through the translation of strategic policy initiatives to concrete design guidelines and actions at the micro level (Ugwu 2005). Current practices in designing for sustainability (Bierkeland 2002 in Ugwu 2005), and the way construction companies connect, deploy and manage this sustainability knowledge in order to deliver the design, need to be analysed in order to develop effective means of this translation (Ugwu 2005). This evaluation will result in a better understanding of the divergent ways in which different actor groups perceive and translate sustainability into practice (Rohrbacher 2001; Williams and Dair 2006).

In addition to the translation issues, the level of complexity in projects, where the ultimate goal is to deliver a ‘green building’, is higher than in standard ones (Myers 2008). This is due to the increased number of people involved, but also because of the nature of technical knowledge required. Furthermore some sustainable buildings require high-tech components, which are supplied by specialized companies, e.g. renewable energy solutions. Hence the supply-chains are more distributed and intricate than before (Williams and Dair 2006). Thus various sorts of new services and consultancies become more important, as a high level of expertise is required for solving the complex problems of ecological optimization (Rohrbacher 2001; Williams and Dair 2006).

The increasing importance of sustainability has important consequences not only on the technological practice of construction industry, but also on its structure and its communication channels (Rohrbacher 2001). As a result, better co-operation and integration of various stakeholders is required through enhanced knowledge sharing from inception to completion (Rohrbacher 2001; Williams and Dair 2006). However, characteristics such as professional silos with their own knowledge and language render knowledge transfer in project teams even more difficult (Bresnen et al. 2003). This fragmentation has vital implications for attempts to develop shared perspectives on innovation, knowledge and learning (Bresnen et al. 2003). Additionally it has to be acknowledged that the various actor groups on a construction project use different tools for transferring their knowledge. For instance architects transfer knowledge differently than bricklayers.

Fernie et al. (2003) indicate that knowledge is personal, and therefore knowledge sharing takes place through the interaction of individuals. Hence social community plays a vital role in enhancing or inhibiting knowledge transfer (Bresnen et al. 2003). As knowledge is a set of shared beliefs constructed through social interactions and embedded within the social contexts, Fong (2003) declares that social networks are the most important vehicle for knowledge exchange, with team members deeply reliant upon colleagues, friends and ex-colleagues as resources for generating knowledge. Within a project environment the personal knowledge of whom to contact in order to receive the required knowledge, appears to be most important (Bresnen et al. 2003). Hence success depends rather on interpersonal connections, than technological mechanisms (ibid). Even so, further research combining the concepts of social networks, knowledge content and knowledge transfer is needed, to fully understand the interrelations and dependencies (see for example Hansen 2002; Inkpen and Tsang 2005). This research aims to close this gap in the area of sustainable construction.

3 CONCEPTUAL FRAMEWORK ON KNOWLEDGE TRANSFER

The conceptual framework is based on literature of the knowledge transfer process and its influencing factors, as well as influencing social network characteristics. It is divided into three main parts: knowledge input, knowledge transfer process and possible output.

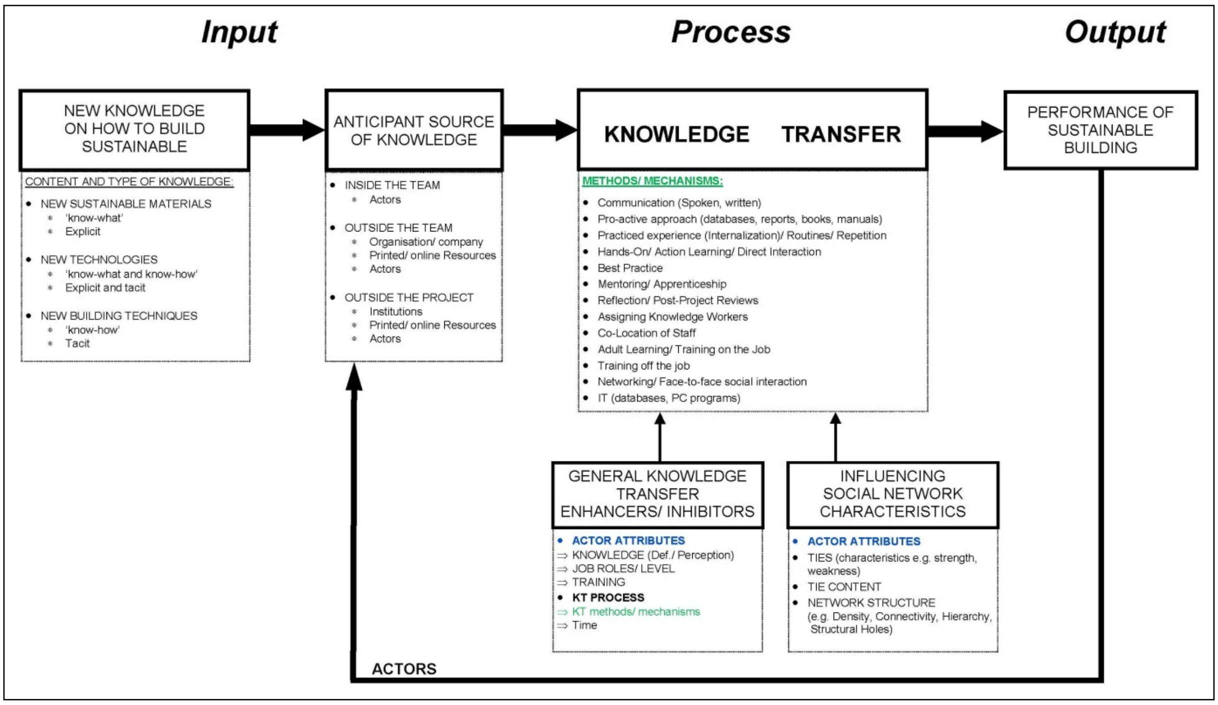

Figure 1: Conceptual framework for knowledge transfer

The input section first describes what kind of knowledge we are actually looking at, when it comes to sustainable construction, and secondly the anticipant source of the required knowledge. Three different content areas of this so-called 'new knowledge' on how to build sustainably were identified as materials, e.g. triple-glazed windows, technologies, such as rain water harvesting systems, and techniques, i.e. 'know-how', on how to put sustainable design into a good quality built result. These three areas include different types of knowledge, such as tacit or explicit. This sub-division facilitates a better examination of the knowledge flow in construction project environments dealing with sustainability issues, and thus reveals whether certain knowledge is required more by actors performing certain roles.

Such knowledge can reside inside and outside of the immediate work team, i.e. the employees of one of the participating companies to one particular construction project. Individuals are called actors in accordance with the social network analysis literature. Printed or online repositories, e.g. data available from manufacturers and suppliers of new materials and technologies, are other sources, but of explicit knowledge only.

The knowledge transfer process is often treated in literature more or less as a black box (Berends 2005). In this conceptual framework the 'black box' reveals several methods for transferring knowledge, in particular tacit knowledge. As explicit knowledge is easier to store and transfer, e.g. in reports, the focus lies on the more complex transfer of tacit knowledge.

Additionally general knowledge transfer influencing factors and social network characteristics, which influence the knowledge transfer process, were also identified in literature. For instance the network density influences the type of knowledge that is transferred through it (e.g. Reagans and McEvily 2003; Nahapiet and Ghosal 1998). The density value indicates a mean strength of all possible ties (Hannemann and Riddle 2005). Hence the maximum value would be 1.0, i.e. 100% of all possible ties being present.

Moreover centrality measures are important in order to investigate which actor is more central i.e. cross-linked than others regarding the relationship under examination (Pryke 2008), in this case knowledge transfer on sustainable construction. The degree centrality measures are divided into in-degree and out-degree. The in-degree of a node, i.e. an actor, is the total number of other nodes which have ties towards it, while the out-degree is the total number of other nodes to which it directs ties (Scott 2003). In this study the in-degree represents the number of people who ask an actor for advice. Hence the out-degree value represents, if someone is asking questions on sustainable construction. Furthermore social network literature (e.g. Müller-Prothmann 2007) divides actors into experts and knowledge consumers. The in-degree centrality value identifies experts, i.e. knowledgeable people in the area of sustainable construction. Knowledge consumers do not possess any in-degree centrality, but a high out-degree value. This indicates that they only ask others for advice, but are never asked themselves, i.e. they 'consume' the knowledge without transferring it onwards, but also that they are perceived by the other network actors to not possess any expert knowledge on the subject, thus are never asked. Nevertheless, the combination of a high in- and out-degree value implies the actor to be a knowledge broker i.e. receives knowledge and forwards it, or an expert in some areas and a consumer in others.

A possible output, hence the result of an enhanced knowledge transfer on sustainable construction could offer a solution to secure a certain standard of sustainable building quality.

4 THE METHODOLOGICAL APPROACH

The research project seeks to compare the different perceptions of knowledge flows and ways to manage knowledge within sustainable office construction projects in the UK and Germany. Case studies were adopted as research strategy, with one construction project resembling one case study. In total two case studies in the UK and three in Germany were conducted. The data collection tools were mainly questionnaires with a combination of quantitative data on actor attributes, such as awareness, social network data, including the subject discussed in each knowledge transfer that took place, and the knowledge transfer methods chosen for it, and some qualitative data on perceptions of the sustainable construction process and its knowledge transfer. These were backed-up with a small set of participant observation data.

This paper presents initial findings from the first case study in the UK. The data collection was conducted in December 2011. The construction project was located in central London and was a speculative development carried out by a main contractor. It was a mixed use scheme of prime office, combined with a small residential and retail part with a total gross area of approximately 80,000 square meters. The project aimed to achieve an excellent BREEAM office 2006 certificate. A total of 39 questionnaires were completed.

The knowledge network of this case study was drawn using the social network data in UCINET (Borgatti et al. 2002) and is displayed in Figure 2. Each square symbolizes one actor, i.e. one construction project participant. The colours indicate the job level, e.g. professionals. This grouping was considered appropriate as knowledge transfer in construction projects is widely assumed to be top-down according to hierarchy levels (e.g. Ugwu 2005). The letter codes denote the company each actor works for, e.g. CM1-9 are all working for the construction management company. The weight of the links between the actors represents the frequency of the knowledge transfer between two nodes. The more often they have exchanged knowledge on sustainable construction the thicker the line, i.e. the stronger the tie (Hannemann and Riddle 2005). The link direction is from the recipient to the knowledge source.

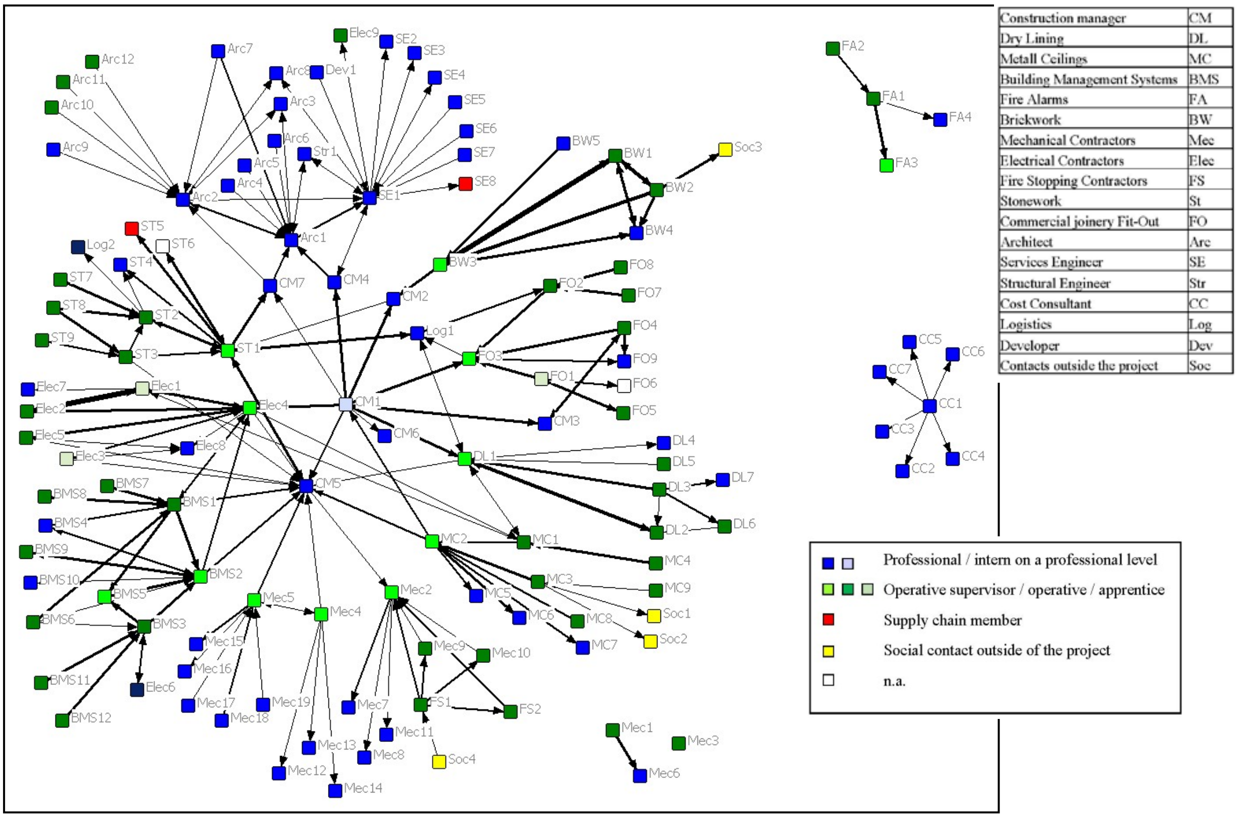

Figure 2: Social Network Case Study UK1 - frequency of knowledge transfer

5 PRELIMINARY FINDINGS ON SOCIAL NETWORK CHARACTERISTICS AND TIE CONTENTS

The size of this network is 125 nodes, made up of 39 research participants and 86 other project participants named by them.

The network density, as described in section 3, is 0.0320 with a standard deviation of 0.3480, i.e. 3% of all possible ties are present in this network. 3% is a very low value, implying that this network is rather sparse than cohesive. As Hannemann and Riddle (2005) stated, the larger the network the smaller the density, hence this result is normal. The standard deviation is larger than the mean, which indicates a great variation in the strength of the ties, i.e. frequency of knowledge transfer.

According to the literature, explicit knowledge should be effectively communicated in this sparse network made up of weak ties and structural holes (e.g. Reagans and McEvily 2003; Nahapiet and Ghosal 1998). Fernie et al. (2003) support this view by stating that weak ties seem to limit the exchange of tacit knowledge. Further exploration of the tie contents shows that in the main explicit knowledge is transferred within this network.

Table 1 gives an overview of the frequencies of the various tie contents.

Tie Content	Frequency Count	Valid Percentage
Materials	45	21.6%
All: Materials, Technologies and Techniques	45	21.6%
Materials and Techniques	34	16.3%
Techniques	20	9.6%
No data on tie content	19	9.1%
Materials and Technologies	19	9.1%
Techniques and Technologies	16	7.7%
Technologies	10	4.8%

Table 1: Tie contents

It is clear that the two most mentioned subjects are materials (21.6%), and all three subjects combined (21.6%). These are followed by materials and techniques (16.3%). In the main, this knowledge is explicit. Nevertheless this finding also shows that many questions evolve around new materials and technologies and the techniques required for their installation. This new knowledge on techniques was previously defined as tacit and was part of in total 55.2% of all knowledge transfers. However, as argued by literature (Reagans and McEvily 2003; Nahapiet and Ghosal 1998) it is easier to transfer explicit knowledge through such sparse networks. Therefore the rather large amount of transferred tacit knowledge is an interesting finding and will be further investigated in the other case studies.

Table 2 displays the degree centrality measures, as described in section 3, conducted with UCINET (Borgatti et al. 2002) for the 10 most central actors in this case study.

Actor	In Degree	Actor	Out Degree
Elec4	26	ST1	30
BMS2	24	CM1	29
CM5	24	BW1	20
BW3	22	BW2	20
BMS1	21	BMS1	18

Table 2: Centrality measures

A significant result shows when linking the in- and out-degree values with the actor attribute job level, as shown below.

Perceived experts:

- Elec4, supervisor of the electrical contractors
- BMS2, supervisor of the building management systems company
- CM5, construction project manager in charge
- BW3, supervisor of the brickwork company
- BMS1, operative of the building management systems company

Knowledge consumers or brokers:

- ST1, operatives' supervisor of the stonework company
- CM1, intern/ professional of the construction management company
- BW1, operative of the brickwork company
- BW2, operative of the brickwork company
- BMS1, operative of the building management systems company

The knowledge consumers are mostly operatives and one intern. This result is as expected. BMS1 is an exception as he/ she has a high in- and out-degree centrality, hence can be seen as a knowledge broker. However, only one out of the perceived experts is on a professional level, CM5, three are supervisors and one is an operative. This might indicate a need for more divergent knowledge in sustainable construction projects. Alternatively, when looking at the network structure, this could also be due to the supervisors' role as interface between professionals and operatives. This approach is also reflected in the used methods to transfer knowledge on sustainable construction, as displayed in Figure 3.

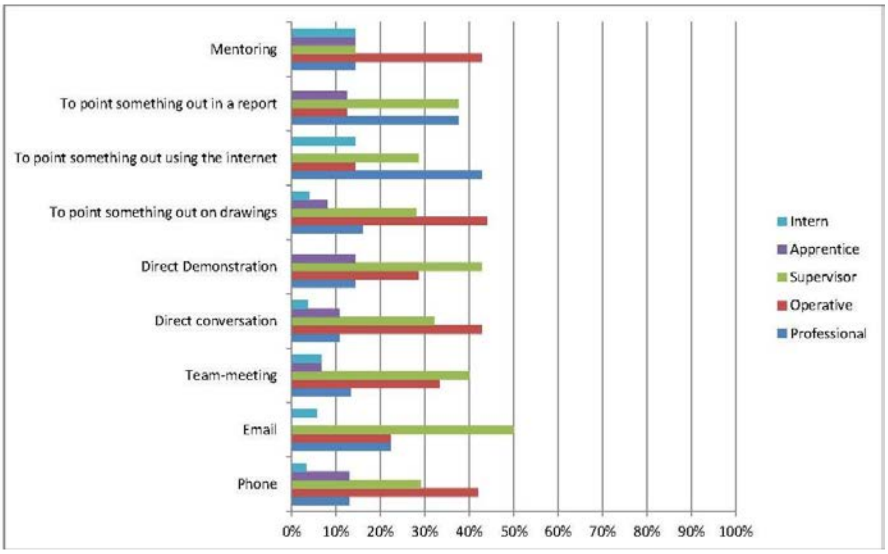

Figure 3: Knowledge transfer methods linked to job levels

As shown in Figure 3, there seems to be a difference in the use of methods to transfer knowledge between the various construction workforce members depending on their job level. Operatives and their apprentices prefer more direct methods, such as mentoring, direct demonstration, conversation, pointing something out on drawings, team meetings and phone, whereas professionals use more computer based methods, such as internet, reports and emails. A remarkable result is that operatives' supervisors use nearly all methods. This might be due to them acting as an interface between professionals and operatives.

Previously the following five actors were identified as the ones with the highest in-degree centrality, hence the most central actors and perceived experts on sustainable construction. When looking at the methods they used to transfer knowledge, one can see that this was according to their job level and did not differ due to their actor centrality.

- Elec4, supervisor — phone, email, direct conversation, team meeting
- BMS2, supervisor — direct conversation, phone, email, drawings, report, book, mentoring
- CM5, professional — no data
- BW3, supervisor — direct conversation, phone, email, team meeting, demonstration, drawings, report, routines
- BMS1, operative — direct conversation, phone, drawings

This finding leads to the assumption that the link between knowledge transfer methods and job level seems to be stronger than the one with actor centrality. This will be further explored in the other case studies.

6 CONCLUSION

There is an increasing perceived value and thus need of sustainable commercial buildings worldwide. However, one of the main barriers towards delivering sustainable construction can be found in the transfer of knowledge on how to build sustainably. This paper suggests that enhancing this special knowledge transfer between all project participants could help in the long run to secure a certain standard of green building quality. An on-going research project comparing knowledge transfer practices of construction project teams delivering office buildings to sustainable building standards (BREEAM and DGNB) in Germany and the UK forms the basis of this paper. It sets out by providing a brief background of the context of the study. This is followed by the conceptual framework on knowledge transfer and the methodological approach. Social network analysis is used to explore the extent to which social network characteristic influence this special knowledge transfer. Results show that, although the network density is rather sparse, both tacit and explicit knowledge were transferred through it. By exploring the tie contents, the findings show that the two most discussed subjects on sustainable construction were materials and a combination of all three subjects (materials, technologies and techniques). The most central actors regarding this knowledge transfer, thus perceived by the others as experts on sustainable construction were mostly supervisors. This paper concludes by presenting that the methods used to transfer knowledge on sustainable construction depend rather on the job level of an actor, not on the centrality.

REFERENCES

C. Atkinson, A. Yates and M. Wyatt, *Sustainability in the built environment. An introduction to its definition and measurement*, BRE (2009).

H. Berends, “Exploring knowledge sharing: moves, problem solving and justification”, *Knowledge Management Research & Practice*, **3,** 97-105 (2005).

E. Bresnen, Newell, Scarbrough, Swan, “Social practices and the management of knowledge in project environments”, *International Journal of Project Management,* **21**, 157-166 (2003).

S. Borgatti, M. Everett, L. Freeman, *UCINET, Analytic Technologies: software for social network analysis*, Harvard, MA (2002).

T. Dixon, A. Colantonio, D. Siers, R. Reed, S. Wilkinson and P. Gallimore, “A green profession? A global survey of RICS members and their engagement with sustainability agenda”, *Journal of Property Investment & Finance,* **26**(6), 460-481 (2008).

T. Dixon, Ennis-Reynolds and S. Roberts, “Is there a demand for sustainable office? An analysis of UK business occupier moves (2006-2008)”, *Journal of Property Research,* **26**(1), 61-85 (2009).

S. Fernie, Green, Weller and Newcombe, “Knowledge sharing: context, confusion and controversy”, *International Journal of Project Management,* **21,** 177-187 (2003).

P. S. W. Fong, “Knowledge creation in multidisciplinary project teams: an empirical study of the processes and their dynamic interrelationships”, *International Journal of Project Management*, **21**, 479–486 (2003).

R. A. Hanneman and M. Riddle, *Introduction to social network methods,* Riverside, University of California (2005).

M. T. Hansen, “Knowledge Networks: Explaining Effective Knowledge Sharing in Multiunit Companies”, *Organization Science,* **13**(3), 232-248 (2002).

A. Inkpen and E. Tsang, “Social Capital, Networks, and Knowledge Transfer”, *Academy of Management Review,* **30**(1),146-165 (2005).

E. Kurul, J. Tah and F. Cheung, “Does the UK built environment sector have the institutional capacity to deliver sustainability?” *Architectural Engineering and Design Management* **8**(1), 42-54 (2011).

T. Müller-Prothmann, *Social Network Analysis: A Practical Method to Improve Knowledge Sharing. Hands-On Knowledge Co-Creation and Sharing; Practical Methods and Techniques.* A. S. Kazi, Wohlfahrt, L., Wolf, P., (ed.) Stuttgart, Knowledge Board: 219-233 (2007).

D. Myers, *Construction Economics - a new approach.* Taylor & Francis, London and New York (2008).

J. Nahapiet, S. Ghoshal, "Social capital, intellectual capital, and the organizational advantage." *Academy of Management Review* **23**(2), 242-266 (1998).

A. Nelson, *The Greening of U.S. Investment Real Estate – Market Fundamentals, Prospects and Opportunities*, RREEF Research (2007).

A. Nelson, *Building Labels vs. Environmental Performance Metrics: Measuring what's Important about Building Sustainability*, RREEF Research (2012).

M. Pitt, M. Tucker, M. Riley and J. Longden, "Towards sustainable construction: promotion and best practices", *Construction Innovation* **9**(2), 201-224 (2009).

S. Pryke, *Social Network Analysis.* Advanced Research Methods in the Built Environment. A. Knight, L. Ruddock (ed.), Wiley-Blackwell (2008).

R. Reagans and B. McEvily, "Network Structure and Knowledge Transfer: The Effects of Cohesion and Range", *Administrative Science Quarterly* **48**(2), 240-267 (2003).

M. A. Robinson, *Breaking the "Vicious Circle of Blame".* Prime Property Award, Union Investment: 76-79 (2008).

H. Rohrbacher, "Managing the Technological Transition to Sustainable Construction of Buildings: A Socio-Technical Perspective", *Technology Analysis & Strategic Management,* **13**(1), 137-150 (2001).

J. Scott, *Social Network Analysis - a handbook* (2007).

O. Ugwu, "A service-oriented framework for sustainability appraisal and knowledge management", *ITcon* **10**: 245-263 (2005).

WBCSD, *Energy Efficiency in Buildings. Transforming the Market*, World Business Council for Sustainable Development: 72 (2009).

K. Williams and C. Dair, *What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments*, Sustainable Development (2006). DOI: 10.1002/sd.308

SUSTAINABLE CONSTRUCTION IN NIGERIA: UNDERSTANDING FIRM LEVEL PERSPECTIVES

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Abstract. *The quest for sustainable development has called for far reaching changes in the way construction is carried out. The built environment accounts for a large quota of material and energy consumption, biodiversity loss, pollution and waste generation. As developing countries pursue improvements in infrastructure and buildings, there are concerns over the manner in which these developments would occur especially considering the weak institutional forces at play in such countries. Literature suggests sustainable construction as a source of competitive advantage and identifies several strategies and action plans in the pursuit of sustainable development in the broader context. However, there is a dearth of literature relating to sustainable construction in developing countries. It also remains to be demonstrated what the current direction and capabilities of the construction firms are. As such, this research studies firm-level engagements with the sustainability agenda in the Nigerian construction sector with a view to understanding how the firms make sense of the sustainability agenda, the current thinking, practices and motivations of these firms. Traditional competitive literature identifies valuable, rare, inimitable and non-substitutable resources (the resource based view) as sources of competitive advantage. However, more recently, the dynamic capabilities view calls for constantly renewing resources to match dynamic environments. This paper discusses Firm-level considerations of Sustainability, and the proposed methodology for studying how these play out in the Nigerian Construction sector. A multi-case study research design was adopted and three Nigerian construction firms of different sizes have been selected in a bid to understand the firm reconfigurations, if any, with respect to the sustainability agenda. Due to the weak institutional forces within Nigeria the findings of this research are expected to help inform and guide future sustainability interventions within the sector.*

1 INTRODUCTION

Sustainability in the construction sector has been a key theme globally for close to two decades now. The sector has responded in different ways, in line with ‘meeting developmental needs today, while considering the effect on future generations’ (World Commission on Environment and Development., 1987). This is against the backdrop of the general consensus among scholars and stakeholders that the construction sector is culpable in some of the most serious environmental damage and equally adverse social and economic impacts on humanity (CIOB, 2004). However, developing countries are often faced with challenges and priorities that are different from those of more advanced countries. These include, but are not limited to huge infrastructure and housing deficit, weak institutions of Government, rapidly rising population, skills shortage, social inequity and relative unstable political climate (Ofori, 1998, du Plessis, 2007). As a consequence, they have not been able to replicate most of the progress made towards sustainable construction globally.

However, some of these underdevelopment especially in the built asset is viewed by some researchers (du Plessis, 2007) as providing the opportunity to avoid the mistakes of more developed countries. This presents such countries with a number of advantages, such as avoiding issues of technology lock-in for example. This paper first of all discusses the concept of sustainability with respect to the construction sector. It then looks at considerations of the concept as a source of competitive strategy using the lens of the Dynamic Capabilities View. Lastly, it explains the proposed research design and the methodological considerations for this study of construction firms operating in the Nigerian Construction sector.

2 SUSTAINABLE CONSTRUCTION

2.1 The growth of Sustainable Construction

The concept of sustainable construction covers a broad range of concerns and is usually operationalized under the themes of environment, society and economy. Concerns about the devastating effects of man's production capacity and the inequity in distribution of the World's wealth, especially after the post second world war period, initially surfaced in the early sixties. These were particularly highlighted in the publications of '*Silent Spring*' (Carson, 1962), and '*Limits to Growth*' (Meadows et al., 1972). Other milestones in this pursuit was the publication of 'Our Common Future' (World Commission on Environment and Development., 1987) and 'Agenda 21' (United Nations Division for Sustainable Development., 1992).

In-between the publication of these documents, several panels, committees and conferences were set up and enlightenment of this challenge grew. In recognition of the resource intensive nature of construction, and its strategic position to bring about far reaching changes, 'Agenda 21 for Sustainable Construction' (CIB, 1999) was promoted as an international blueprint to guide National Governments and produce action plans at more local levels. However, this document was criticized as not having taken into consideration the peculiarities of developing nations (du Plessis, 2001, du Plessis, 2007, Ofori, 2007). This led to the 'Agenda 21 for sustainable construction in developing countries'. Despite these action plans, there is little evidence in these developing countries, particularly in Africa that the sustainability agenda has moved forward.

2.2 Sustainable Construction in Practice

The term sustainable construction has sparked numerous interpretations, debates and approaches in academic circles. According Hill and Bowen (1997), the term described the responsibility of the construction sector in attaining 'sustainability'. This is through reduction in energy, material and water usage, reduction of wastes, careful consideration of land use, air quality and indoor environment (Pearce et al., 2012). To pursue sustainable construction, the industry is expected to evolve its processes of creating the built environment. It requires continuous innovations, interventions and interdependency at various levels of society.

On the downside, the concept of sustainable construction has been beset by problems concerning a cohesive definition and understanding. The differences in interpretation have resulted in challenges to its implementation. Table 1 chronicles different interpretations ascribed to sustainable construction from different and diverse sources (Murray and Cotgrave, 2007, du Plessis, 2007, Pearce et al., 2012). This is of severe consequence especially in a country (Nigeria) where understanding and awareness of sustainability issues amongst practicing professionals was found to be deficient (Dania et al., 2007).

Source	Interpretation of sustainable construction
Academic Charles Kibbert, University of Florida (Kibbert, 2004)	"The creation in a responsible manner of a healthy built environment based on resource efficient and ecological principles"
Construction Industry improvement body Construction Best Practice Programme CBPP (2002)	"The contribution of the construction process, built environment and construction industry to sustainable development"
UK Government DTI (2001)	"The construction industry: being more profitable and competitive; delivering greater satisfaction, wellbeing and value; respecting/treating stakeholders more fairly; enhancing/protecting natural environment; minimising resource consumption"
Overseas Government The Netherlands CIB (1999, p.45)	"A way of building which aims at reducing (negative) health and environmental impacts caused by the construction process or by buildings, or by the built-up environment"
African Academic Du Plessis (2007)	"An integrative and holistic process of construction which aims to restore harmony between the natural and the built environment"

Table 1: Different Interpretations of Sustainable Construction

2.3 Developing countries and the sustainability agenda

Construction in developing countries exemplifies a paradox. While it improves the much needed infrastructure base required for the socio-economic development they desperately needs, it also has damaging consequences. Lessons from their more developed counterparts indicate that better consideration of the environment, societies and financial resources can be made in line with the tenets of sustainable development.

In most developing countries and particularly in Africa, historical legacies have resulted in unstable socio-economic conditions which have produced inadequate institutions and personnel to nurture a construction sector resisting change. Common challenges are rapid rates of urbanization, deep poverty, social inequity, low skills levels, institutional incapacity, weak governance, uncertain economic environment and environmental degradation which makes development very challenging (Ofori, 1998, du Plessis, 2007) in addition to a poor infrastructure base.

Considering their recent rapid rate of urbanization and the acceleration of infrastructure development, it is imperative for the developing world to prevent avoidable negative impacts of construction by latching on to the sustainability agenda (du Plessis, 2007). Despite all the drivers of, and sustainability becoming an important focal point from a global construction perspective (Thorpe and Ryan, 2007), evidence in literature of any serious progress in this regard in developing countries are very little. In Nigeria, the Government indicated its commitment by convening several awareness campaigns and conferences (Federal Ministry of

Environment Housing and Urban Development., 2008). Recently, the Green Building Council of Nigeria was conceived and Professional bodies allied to the sector are taking keen interest (Akindoyeni, 2012), but the effects of these efforts remains to be established.

The Agenda 21 SCDC document suggests a strategic framework and a stakeholder's plan of action (du Plessis et al., 2002). This framework captures a broad strategy for wholesome adoption of sustainability. However, the implementation of these suggestions provides a bigger challenge. Du Plessis (2007) expressed that a 'responsive, capable and viable' local construction sector is key to embarking on a path of sustainable construction in her proposed strategic framework. As construction firms are amongst the key stakeholders (CIB, 1999), they have been the focus of several researchers in driving the agenda (Dyllick and Hockerts, 2002, Salzmann et al., 2005, Pinkse and Dommisse, 2009).

The suggestions of du Plessis have come under criticism as being normative and reductionist, neither reflecting the capabilities, nor indicating the responsibilities of individual stakeholders. This study focused on the construction firm as the unit of analysis in understanding how this strategic framework could be useful.

3 THE NIGERIAN CONSTRUCTION SECTOR

In Nigeria, the Construction sector is crucial to development as it accounts for millions of jobs while providing the infrastructure required for growth. The sector has posted impressive growth rates of over ten per cent in the last few years (Federal Republic of Nigeria, 2010, Central Bank of Nigeria, 2011). Rapid population growth, high rural-urban migration, an expanding middle class and sustained macroeconomic expansion has resulted in a housing shortfall estimated at about 16million units (Adebayo, 2002, Oxford Business Group, 2011). A similar shortfall is equally replicated in public and commercial buildings as well as infrastructure. This reflects plenty of future potential that the construction industry possesses.

The Nigerian construction industry is characterized by construction firms ranging from the Small and Medium Enterprises, to the big, technically competent multinational construction firms. Government accounts for being the largest client of the industry, though recent years have recorded increased patronage from private sector clients (Oxford Business Group, 2011).

The clamour by stakeholders for sustainable development in Nigeria is only relatively recent. Prior to 1989, when a national environmental policy was enacted, policies governing the environment were fragmented and scattered in different Government agencies documents (Ajayi and Ikporukpo, 2005). This policy has been revised once and regulations on the environment are only being formulated recently (NESREA, 2007). Put simply, Nigeria is lagging behind world developments associated with sustainability within the construction sector and beyond.

In du Plessis' framework, she posits that there should 1) exist a capable and viable construction sector; 2) the sector should be able to respond to demands of sustainable construction; 3) be cooperation from different stakeholders and; 4) development of three interdependent and multi-dimensional enablers: technological, institutional and value system enablers (Table 2). The capabilities (technical or dynamic) of Nigerian construction firms have not been studied before. This research uses the dynamic capabilities lens to study construction firms with a view to determining if the conditions hold true in the Nigerian context. This is in an attempt to understand the landscape in which construction firms operate.

Time	Technological	Institutional	Values
Immediate	Benchmarking and Assessment	Clarified roles and responsibilities	Mapping the route to change
	Knowledge systems & data-capturing	Education	Understanding the drivers
		Advocacy & awareness	Re-evaluating heritage
		Cooperation and partnership	
Medium	Technologies to mitigate impact	Linking research to implementation	Develop a new way of measuring value and reward
		Develop regulatory mechanism	Develop codes of conduct
Long term	Technologies for the future	Strengthening implementing mechanisms	Corporate social responsibility reporting
	Changing the construction process	Using institutions as drivers	
		Regional centres of excellence	

Table 2: Enablers for sustainable construction in developing countries' agenda (Source: du Plessis, 2007, p.70)

4 STRATEGIC MANAGEMENT AND DYNAMIC CAPABILITIES

The dynamic capabilities view (DCV) of the firm is embedded in the strategic management and evolutionary economics fields. The strategic management field is a robust body of knowledge which has evolved since the 1940's. 'Strategic management involves leadership, creativity, passion and analysis, building an organization that generates and responds to change, ………. and ensuring necessary resources are developed and allocated to worthwhile opportunities' (FitzRoy et al., 2012 pg 12).

"As markets become more globally integrated and new forms of technology and competition arise, companies have to adapt and exploit these changes in their business environment through technological, organizational or strategic innovation" (Helfat, 2007 pg 1). The strategic management perspectives dominating the firm based approach are the resource-based perspective (RBV) and the DCV perspective. The RBV focuses on strategies for exploiting existing endogenous firm-specific assets (Wernerfelt, 1984, Barney, 1991) that are valuable, rare, inimitable and non-substitutable (VRIN). This has been criticized as being too 'static' (Eisenhardt and Martin, 2000). The DCV encompasses skill acquisition, learning and accumulation of organizational and intangible assets in which lies great potential for contribution to strategy and maintaining market competitiveness.

The DCV approach addressed two key issues not previously the focus of attention of previous strategy perspectives: renewing competences in response to innovations and the key role of strategic management in reconfiguring to match the changing environment. It distinguishes the 'difficult-to-replicate', ordinary, zero level (technical) capabilities of firms from those higher level capabilities that are required to respond to fast moving business environments 'open to global competition and characterised by dispersion' marked by costumer relevance and competitive considerations (Winter, 2003, Teece, 2009).

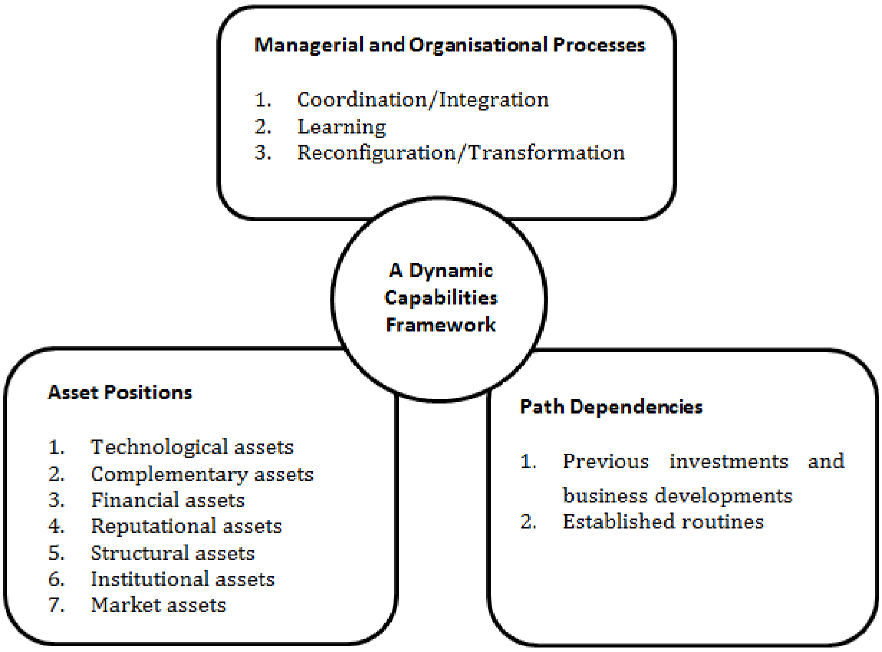

Figure 1: Dynamic capabilities framework based on Teece et al. (1997)

The construction landscape in Nigeria recently depicts a very dynamic environment of technological and social innovations. To survive the changing operating conditions, 'firms must develop "dynamic capabilities" to create, extend or modify ways in which they make their living'(Helfat, 2007pg 1) . Dynamic capabilities (DC) could entail internal growth, acquisitions and strategic alliances or creation of new products and production processes or better still the management's ability to lead profitable firm change and growth.

DC can be seen as a potentially integrative approach to understanding newer sources of competitive advantage (Teece et al., 1997). Its proponents argue that market leaders could have very sound technical capabilities but failure to strategize and respond to changing market conditions could be hazardous to its long term survival (Teece, 2009). The DC concept has also come under some criticism for its supposed weakness. It is purported to have inconsistent labels (Zahra et al., 2006), tautological definitions (Zollo and Winter, 2002), lack of theoretical foundation and incompleteness (Arend and Bromiley, 2009). However, Green et al (2008, pg 76) attributes some of these criticisms to the fact 'that the literature on DC is still emerging and the various competing perspectives are reflective of the schisms that fragment the broader strategic management literature'.

Some other critique of the DC is the insufficient concern for competition (Williamson, 1999) and its purported post hoc identification of successfully dynamic firms in empirical works (Zahra et al., 2006). This study addresses these concerns by selecting firms on a basis of market position and its strategies with respect to sustainability in order to gain competitive advantage therein. This in itself does not address the empirical challenges of dynamic capabilities. However, Wang and Ahmed (2007) propose a research model of DC which is adopted for this study. The model tries to identify the relationships between the organizational variables of '*market dynamism*', '*firm strategy*', '*capability development*' and '*firm performance*'.

5 RESEARCH DESIGN

The study is an exploratory research which adopts a qualitative multi-case study methodology (Eisenhardt, 1989) in order to gain insight into how the construction firms of different sizes evolve their capabilities in response to the sustainability agenda (or otherwise). Three Construction firms, one large multinational, one medium indigenous and one small firm were selected for this purpose. A multi-case study was required to investigate potential differences in firms based on classifications of size and technical capabilities. The suitability of a case-study research design is that it investigates social life within the parameters of openness, communicativity, naturalism and interpretivity (Sarantakos, 2005).

5.1 Selection of the construction firms

The choices of the firms were based on carefully selected criteria. The selected firms have strong presence in the capital city of Abuja, which is the fastest growing city in the country and has the highest rate of procurement of public buildings. A justification of this choice lies in the fact that Government still remains the largest client of the building construction industry and these projects also have the most formal contractual arrangements in the Nigerian context. They also have a track record of participation in Public projects for as long as practicable. However, the most important criterion is access (Creswell, 2009) to the firms to carry out the research. For this purpose, the following companies referred to by the following names were selected:

i. Mainstreet Nigeria PLC: one of the top multinational firms in Nigeria and has been in active participation in the Nigerian construction sector since 1965.

ii. Keystone Construction Ltd: ranks as one of the largest and most successful indigenous construction firms in Nigeria.

iii. Enterprise Dimension Ltd: incorporated in 1996, it is also an indigenous but dynamic, fast growing small scale construction firm.

5.2 Data collection and analysis

Data Collection

The case studies of the construction organizations are on-going and were designed to document firm level strategies for addressing sustainability concerns. This includes training of personnel, various technologies adopted, drivers, influences, choice of materials and methods, techniques for mitigation of adverse construction effects, and responses to statutory provision from the inception of construction to the provisions made at the conclusion of the project. The basis of the protocol for the case studies across the three firms are provided from the list of requirements generated from literature. The methods of data collection employed thus far are structured interviews with appropriate management personnel and analyses of archival records of the firms.

Analysis

The data to be collected is qualitative in nature. Each interview would be transcribed in full and coded with the use of a computer-assisted qualitative data analysis software, NVivo (Sarantakos, 2005, Bryman, 2008). The research model by Wang and Ahmed (2007) would be used as a guiding template for the analysis of the transcribed data.

5 CONCLUDING REMARKS

Due to this research being at the early stages of data collection and transcription, no conclusive findings can be offered. However, the research intends to gather robust data on the activities of the selected construction firms that can help understand the current terrain in which they operate, and the suitability of dynamic capabilities framework to explain this. It would also help in shaping the questions for future researches that can help influence construction sector specific innovations of sustainable development/construction.

REFERENCES

A.A. Adebayo, *Sustainable construction in Africa: agenda 21 for sustainable construction in developing countries*, Africa Position Paper *(*2002).

D. Ajayi and C. Ikporukpo, "An analysis of Nigeria's environmental vision 2010", *Journal of environmental policy & planning,* 7**,** 341-365 (2005).

A. Akindoyeni, "Transformation agenda and building production in Nigeria", *42nd National conference and annual general meeting of the Nigerian Institute of Building,* Enugu (2012).

R. J. Arend and P. Bromiley, "Assessing the dynamic capabilities view: spare change, everyone?", *Strategic Organization,* 7**,** 75-90 (2009).

J. Barney, "Firm resources and sustained competitive advantage", *Journal of Management,* 17**,** 99-120 (1991).

A. Bryman, *Social research methods*, Oxford University Press, Oxford (2008).

R. Carson, *Silent spring,* MA, Houghton Mifflin, Boston (1962).

Central Bank of Nigeria, *Annual report 2011*. Central Bank of Nigeria, Abuja (2011).

CIB, *Agenda 21 on sustainable construction*, CIB, Rotterdam (1999).

CIOB, *Sustainability and Construction*, Chartered Institute of Building, Ascot (2004).

J.W. Creswell, *Research design : qualitative, quantitative, and mixed methods approaches,* London, Sage, Los Angeles (2009).

A.A. Dania, J.O. Kehinde and K. Bala, "A study of construction material waste management practices by construction firms in Nigeria", *The Proceedings of the Third Scottish Conference for Postgraduate Researchers of the Built and Natural Environment (PRoBE07).* Glasgow Caledonian University, Glasgow, Scotland (2007).

C. Du Plessis, "Sustainability and sustainable construction: the African context", *Building Research & Information,* 29**,** 374-380 (2001).

C. Du Plessis, "A strategic framework for sustainable construction in developing countries", *Construction Management and Economics,* 25**,** 67-76 (2007).

C. Du Plessis, CIB & UNEP-IETC, *Agenda 21 for sustainable construction in developing countries,* CSIR Report BOU/E020, CSIR, CIB & UNEP-IETC, Pretoria (2002).

T. Dyllick and K. Hockerts, "Beyond the business case for corporate sustainability", *Business Strategy and the Environment,* 11**,** 130-141 (2002).

K.M. Eisenhardt, "Building theories from case study research", *The academy of management Review,* 14**,** 532-550 (1989).

K. M. Eisenhardt and J. A. Martin, "Dynamic capabilities: what are they?", *Strategic Management Journal,* 21**,** 1105-1121 (2000).

Federal Ministry of Environment Housing and Urban Development, *Managing the Nigerian environment for sustainable development: challenges and opportunities,* Abuja (2008).

Federal Republic of Nigeria, " 2009 Annual collaborative survey of socio-economic activities in Nigeria: main atatistical report" *National bureau of statistics central bank of Nigeria and national communications commission, ed.* , Abuja (2010).

P.T. Fitzroy, J.M. Hulbert and A. Ghobadian, *Strategic management : the challenge of creating value,* Routledge, London (2012).

S.D. Green, G.D. Larsen and C.C. Kao, "Competitive strategy revisited: contested concepts and dynamic capabilities", *Construction management and economics*, 26**,** 63-78 (2008).

C.E. Helfat, *Dynamic capabilities : understanding strategic change in organizations,* Malden, Mass and Blackwell, Oxford (2007).

R.C. Hill and P.A. Bowen, "Sustainable construction: principles and a framework for attainment", *Construction Management and Economics,* 15**,** 223-239 (1997).

D.H. Meadows, D.L. Meadows, J. Randers, and W.W. Behrens, *The Limits to growth : a report for the Club of Rome's project on the predicament of mankind ,* Earth Island Ltd (1972).

P.E. Murray and A.J. Cotgrave, "Sustainability literacy: the future paradigm for construction education?", *Structural Survey*, 25**,** 7-23 (2007).

NESREA, *Report of the first national stakeholder's forum on the new mechanism for environmental protection and sustainable development in Nigeria*, National Environmental Standards and Regulations Enforcement Agency, Abuja (2007).

G. Ofori, "Sustainable construction: principles and a framework for attainment – comment", *Construction Management and Economics,* 16**,** 141-145 (1998).

G. Ofori, "Construction in Developing Countries", *Construction management and economics,* 25**,** 1 – 6 (2007).

Oxford Business Group, "Real estate and construction", *The Report: Nigeria 201,* Oxford Business Group ed. (2011).

A.R. Pearce, Y.H. Ahn and Hanmiglobal, *Sustainable Buildings and Infrastructure: Paths to the Future,* Routledge, Oxon, Abingdon, Oxon (2012).

J. Pinkse and M. Dommisse, "Overcoming barriers to sustainability: an explanation of residential builders' reluctance to adopt clean technologies", *Business Strategy and the Environment,* 18**,** 515-527 (2009).

O. Salzmann, A. Ionescu-Somers and U. Steger, "The business case for corporate sustainability: literature review and research options", *European Management Journal,* 23**,** 27-36 (2005).

S. Sarantakos, *Social research,* Palgrave Macmillan, Basingstoke (2005).

D.J. Teece, *Dynamic capabilities and strategic management : organizing for innovation and growth,* Oxford University Press, Oxford (2009).

D.J. Teece, G. Pisano and A. Shuen, "Dynamic capabilities and strategic management", *Strategic Management Journal*, 18**,** 509-533 (1997).

D. Thorpe and N. Ryan, "Responding to global issues: sustainability and innovation in the Australian SME residential building construction sector", *ICCPM/ICCEM 2007: 5th International conference on construction project management, 2nd international conference on construction engineering and management,* Building and Construction Authority, Nanyang Technological University, Korea institute of Construction Engineering and Management, Singapore (2007).

United Nations Division for Sustainable Development, "Agenda 21", *United Nations Conference on Environment & Development*, 3 - 14 June, Rio de Janerio (1992).

C.L. Wang and P.K. Ahmed, “Dynamic capabilities: A review and research agenda”, *International Journal of Management Reviews,* 9**,** 31-51 (2007).

B.Wernerfelt, “A resource-based view of the firm”, *Strategic Management Journal,* 5**,** 171-180 (1984).

O.E. Williamson, “Strategy research: governance and competence perspectives”, *Strategic Management Journal*, 20**,** 1087-1108 (1999).

S.G. Winter, “Understanding dynamic capabilities”, *Strategic Management Journal*, 24**,** 991-995 (2003).

World Commission on Environment and Development, *Our common future,* Oxford University Press, Oxford (1987).

S.A. Zahra, H.J. Sapienza and P. Davidsson, “Entrepreneurship and dynamic capabilities: a review, model and research agenda”, *Journal of Management Studies,* 43**,** 917-955 (2006).

M. Zollo and S.G. Winter, *Deliberate learning and the evolution of dynamic capabilities*, 13**,** 339-351 (2002).

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BEYOND SUSTAINABLE BUILDINGS: ECO-EFFICIENCY TO ECO-EFFECTIVENESS THROUGH CRADLE-TO-CRADLE DESIGN

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Abstract. *Sustainable building development focuses on achieving buildings that meet performance and functionality requirements with minimum adverse impact on the environment. Such eco-efficiency strategies are however not feasible for achieving long-term economic and environmental objectives as they only result in damage reduction without addressing design flaws of contemporary industry. The cradle-to-cradle (C2C) design philosophy which has been described as a paradigm changing innovative platform for achieving ecologically intelligent and environmentally restorative buildings appears to offer an alternative vision which, if embraced, could lead to eco-effectiveness and the achievement of long-term environmental objectives. Adoption of C2C principles in the built environment has however been hindered by several factors especially in a sector where change has always been a very slow process. From a review of extant literature, it is argued that the promotion of current sustainable and/or green building strategies - which in themselves are not coherent enough due to their pluralistic meanings and sometimes differing solutions - are a major barrier to the promotion of C2C principles in the built environment. To overcome this barrier to C2C implementation, it is recommended that research should focus on developing clearly defined and measurable C2C targets that can be incorporated into project briefs from the inception of development projects. These targets could enable control, monitoring and comparison of C2C design outcomes with eco-efficient measures as well as serve as a guide for project stakeholders to achieve eco-effective "nutrient" management from the project conceptualization phase to the end of life of the building.*

Keywords: *barriers, cradle-to-cradle, eco-efficiency, eco-effectiveness, sustainable buildings*

1 INTRODUCTION

The achievement of sustainable development in the built environment has been receiving growing attention in the last decade (Williams and Dair, 2007). This has led to widespread research on how to achieve "zero carbon", "zero waste" or "zero emissions" targets in buildings (Xing et al., 2011). Most of these strategies are however embedded in an eco-efficient paradigm where there seems to be a priori stance that development projects are bound to impact negatively on the environment. This stance has given rise to a proliferation of reductionist strategies that seek to minimize any such negative environmental impacts of buildings. McDonough et al. (2003) have argued that applying sustainability principles to systems that are fundamentally flawed from a design perspective can only be successful in reducing resource consumption and pollution in the short term. It just amounts to limiting the negative impacts of poor designs by having to send less material to landfill or use less energy to heat “energy-efficient” buildings (McDonough and Braungart, 2003). It is considered that such marginal reductions in carbon emissions accruing from the implementation of conventional sustainability principles are likely to be undone by the burgeoning global population and ever increasing resource demands. Thus in the long term, achieving eco-efficiency would have little value unless the underlying flaws associated with the design of human systems are addressed (McDonough and Braungart, 2003).

Unlike conventional sustainability philosophy, the cradle-to-cradle (C2C) philosophy articulates a conceptual shift beyond the achievement of eco-efficiency towards eco-effectiveness - which has emerged as a metaphor that represents a vision of designing to create a positive footprint on the environment (McDonough and Braungart, 1998; McDonough et al., 2003). Rather than design systems that seek to minimize any negative environmental impacts, the C2C philosophy seeks to promote intelligent designs that have a positive synergetic relationship with the environment (Braungart et al., 2007). C2C has therefore been described as a paradigm changing innovative platform (Mulhall and Braungart, 2010) that requires new thinking if it is not just going to end as a fad in the built environment context.

The aim of this paper is to interrogate the C2C design philosophy as a strategy for achieving eco-effectiveness in the built environment and to argue a case for its wider adoption as the principal philosophy to drive planning, design and implementation of development projects. To achieve this, the concepts of eco-efficiency and eco-effectiveness are contrasted based on a review of extant literature to establish the gaps in environmental and economic performance that must be bridged. The case for C2C as the missing link is then presented. Subsequently, the C2C implementation processes as well as potential barriers to the achievement of eco-effectiveness in the built environment through C2C designs are discussed. The potential implications of these barriers to C2C implementation are further discussed before conclusions are drawn.

2 ECO-EFFICIENCY VERSUS ECO-EFFECTIVENESS

Sustainable development strategies over the years have focused on reducing the negative impact of human activities whilst ensuring that economic and social benefits are not compromised (Williams and Dair, 2007). Such strategies therefore strive for eco-efficiency – doing more with less – by targeting a reduction in resource and energy consumption. The Oxford English Dictionary defines being efficient as the quest to achieve maximum productivity with minimum wasted effort or expense, and more specifically preventing the wasteful use of a particular resource (Dictionary, 2006). Eco-efficient strategies are therefore underpinned by concepts of dematerialization, reduced toxicity, increased recycling (Braungart et al., 2007) and extended product lifespan (Stahel, 1982). Setting a zero target and working towards this target presents a scenario whereby waste reduction from the construction process by 90% for instance or reduction in negative emissions from a production process by 80% is considered a considerable achievement. McDonough and Braungart (1998) argued that such reductions usually appear outwardly admirable because of the double barrelled economic and environmental benefits that accrue from cutting down waste as well as natural reduction in resource consumption, energy use and emissions. It also eases the feeling of guilt since corporations and individual households are being “less bad” (McDonough and Braungart, 1998).

The UK Government for instance, has set an ambitious target to achieve zero carbon homes in the UK by 2016 (Osmani and O'Reilly, 2009b). Different legislation and EU directives are also being promoted to reduce waste to landfill in UK and across the EU. Releasing fewer toxic emissions, generating lesser amounts of waste and using lesser energy are however short term measures that only "slow down" the negative consequences of human activities on the environment. Harm is still being caused, only at a much slower pace. Even the much popular 3R's strategy of reduce, reuse and recycle (Kibert, 2001) which has often being promoted as a strategy for achieving sustainability in the built environment has not resulted in the creation of a true circular/spiral loop of material flows. Although well intended, Braungart et al. (2007) have described this form of recycling being practiced as "downcycling" as products are not designed from the very onset to facilitate true material recycling. Recycled building materials are often downgraded in quality that they have to be used for lesser quality purposes until they ultimately end up in landfills. Design considerations are not made to support accumulation of intelligence that can contribute to preserving or enhancing the integrity and value of materials over time – upcycling. Arguably, these zero carbon and zero waste efforts which have become necessary as "stop gap" measures to address global climate change challenges and which have been promoted in study streams such as circular economy (Zhijun and Nailing, 2007), industrial ecology (Erkman, 1997) and sustainable building (Williams and Dair, 2007; Häkkinen and Belloni, 2011) have not been entirely successful in altering the linear end-of-pipe (cradle-to-grave) material flow systems where materials eventually end up in landfill sites.

The generation of waste is a human phenomenon (Anastas and Zimmerman, 2003) as natural eco-systems do not generate any waste. The persistent problems of waste and toxicity therefore raise questions regarding the embeddedness of the eco-efficiency paradigm in the reduction of resource consumption, carbon emissions and waste as shown in Table 1. Braungart et al. (2007) for instance have described the quest to achieve eco-efficiency as a reactionary approach that: (1) does not address the need for a fundamental redesign of industrial material flows, (2) does not support long-term economic growth and innovation, and (3) does not effectively address the issue of toxicity. Perhaps eco-efficiency strategies concentrate much more on reducing the negative impacts of flawed designs thus strangling opportunities for promoting a rethink on how to design systems that actually have a positive rather than zero or fewer negative impacts on the environment.

The eco-effectiveness vision in contrast to the eco-efficiency vision aims to inspire designs underpinned with the intention to create a positive rather than reduced negative or zero effects on the environment. Effectiveness is defined in the Oxford dictionary as successfully producing intended results (Dictionary, 2006). McDonough and Braungart (2002) therefore proposed the concept of eco-effectiveness where unlike reduction and dematerialization, a truly supportive relationship between ecological, social and environmental systems is created through the establishment of cradle-to-cradle (cyclical) material flow metabolisms. Thus, eco-effectiveness focuses on promoting a positive ecological footprint and positive emissions by designing with the intention of creating gains. It is a proactive rather than reactive approach where toxic materials are replaced with air cleansing and self-purifying material alternatives (Mulhall and Braungart, 2010), and designs are conceived with the intention of facilitating true recycling or even upcycling and where a truly regenerative, closed and continuous loop system is realised. As McDonough and Braungart (2003) put it, "imagine buildings that make oxygen, sequester carbon, fix nitrogen, distil water, provide habitat for thousands of species, accrue solar energy as fuel, build soil, create a micro climate, change with the season and are beautiful". This would then mean that the higher the number of such buildings, the better it would be for the environment and for human health due to the positive effects.

The above arguments for the adoption of an eco-effectiveness vision in the built environment do not however render eco-efficient strategies useless. The combined implementation of eco-effective and eco-efficient strategies as complimentary approaches has been acknowledged in literature (see Braungart et. al., 2007). Such a two-pronged strategy promises enormous benefits for the environment in the long-term.

	Eco-efficiency paradigm	Eco-effectiveness paradigm
Vision	• To achieve "zero waste" and "zero carbon" emissions	• To achieve positive ecological footprints/emissions
Focus	• Reactionary approach that focuses on damage management and waste management	• Proactive approach that focuses on damage avoidance and the creation of gains
Strategies	• Energy efficiency, reduced consumption, extended product lifespan and design for durability	• Cradle-to-cradle designs, intelligent material pooling
Approach to material usage	• Minimization in the use of materials • Design for durability • Recycling which gradually ends up as downcycling	• Celebrates creative and extravagant use of materials • Allows for shorter life span of products • True recycling by designing to facilitate maintenance of material flows in a closed system
Approach to toxicity	• Reduction in use of toxic substances	• Replacement of known toxic substances or maintaining these in a closed continuous loop if replacements are unavailable
Study streams	• Circular economy, industrial ecology, sustainable building	• Cradle-to-Cradle

Table 1: Eco-efficiency versus the eco-effectiveness design paradigms

3 ECO-EFFECTIVENESS THROUGH CRADLE-TO-CRADLE DESIGN IN THE BUILT ENVIRONMENT

As argued above, a long term strategy for the built environment would be to create a truly positive synergy between ecological, social and economic targets – eco-effectiveness. This concept of eco-effectiveness has been described as the major strength of the C2C body of thought (Debacker et al., 2011). With inspiration from natural flow systems where the sun is the primary source of energy and where so called wastes from biogeochemical processes undergo metabolism to generate food for other biological processes, McDonough and Braungart (2002) proposed three C2C principles for achieving eco-effectiveness as:

- Waste is equal to food: waste either serves as a technical or biological nutrient
- Use of current solar income: dependence on solar sources of energy
- Celebrate diversity: promoting biodiversity, cultural and conceptual diversity.

Achieving these three principles in the built environment begins with a C2C design where buildings and other infrastructure are designed such that anything that would otherwise have resulted in waste is conceived as a nutrient for other technical or biological processes. Thus, buildings should be designed to facilitate disassembly and true recycling or upcycling of technical and biological nutrients (Mulhall and Braungart, 2010). Such design considerations could be for example preserving the value of steel by separating the different grades and specifying where they have been used in the design so as to avoid the loss of value that could accrue from mixing different grades of steel in the recycling process. Design considerations should also be made to facilitate the deployment of an intelligent material pooling (IMP) process throughout the service life of the building and after decommissioning. This can be in the form of specifying use periods for different components of the building, providing dis-assembly instructions and specifying details of where the different components can be sent back to at the end of their service life. The IMP process can also be facilitated by the establishment of IMP communities that are supported by common material banks (Braungart et al., 2007). These common material banks would operate as support hubs for upcycling and recirculation of technical nutrients across the IMP community. A building materials database that features the eco-toxicological profile of different materials can also be established to guide materials specifications at the design stage. Thus toxic materials should be avoided entirely and where non-toxic replacements for materials are unavailable, design considerations can be made to ensure that toxic materials fit into a closed continuous technical material loops (Braungart et al., 2007). Features such as bio-digesters and wastewater treatment ponds (Mulhall and Braungart, 2010) could also be integrated into the development to treat and recycle the biological nutrients in wastewater. Self-cleansing and self-purification façades (Hüsken et al., 2009) can also be incorporated into the designs to clean and purify the surrounding air.

With energy, the aim is a total dependence on solar income or other renewable forms of energy that are still primarily driven by the sun’s radiation – wind, geothermal and hydro and biogas. However, it is acknowledged that renewable energy technologies such as solar photo voltaic (PV) and solar thermal can at present only be relied upon for the provision of intermediate-load electricity whereas base-load electricity is still provided by conventional energy sources: coal, nuclear and fossil fuels (Goffman, 2008). Irrespective of these technical difficulties, McDonough and Braungart (2002) still emphasise the dependence on solar income as a long-term aspiration of the C2C vision where renewable energy can gradually substitute for the use of conventional energy sources in the future as well as even feed off excess solar energy to the national grid. This way, buildings and other infrastructure could serve as energy production hubs rather energy consuming facilities (Mulhall and Braungart, 2010). Features are also integrated into designs to support biodiversity as well as cultural and conceptual diversity i.e. providing habitat for other flora and fauna, designing to fit the local area and designing flexible structures that can support mixed uses respectively. Biodiversity for instance could be promoted in the designs by integrating features such as aquaponics, roof gardens or even fish ponds.

By establishing closed and continuous energy, water and material loops, a positive synergy between buildings, infrastructure and the environment can be realised. Waste would no longer be an issue as materials would be truly recycled through the IMP process. Implementing C2C in the built environment context is however a slow process that can be hindered by various industry specific barriers which are briefly explored in the next section.

4 BARRIERS TO C2C ADOPTION IN THE BUILT ENVIRONMENT

The construction sector has been described as very conservative sector that is dominated by a high number of small to medium sized firms, making innovation and the change adoption a very slow process (Debacker et al., 2011). Though the implementation of C2C principles in the built environment promises to be an innovative strategy towards the positive re-coupling of the relationship between buildings, infrastructure and the environment, there are several implementation barriers. Braungart et al. (2007) have acknowledged that establishing eco-effective material flow systems rests on establishing a coherent network of information flows. Diffusion of appropriate knowledge across the construction supply chain is therefore undisputedly fundamental to the implementation of C2C in the built environment and any barrier(s) to the accumulation, management, diffusion and sharing of such knowledge is likely to be the 'Achilles heel' to C2C implementation in the built environment. However, a major barrier to the diffusion of C2C knowledge in the built environment could arguably stem from the already pluralistic meanings of "sustainable buildings" and its related terminologies. Stenberg and Raisanen (2006) revealed that the plurality of meanings of "green buildings" as a terminology promotes competing ideas. Similarly, Guy and Moore (2007) have echoed that the remarkably diverse proliferation of ideas about the term "sustainable architecture" inhibits a coherent classification of what it stands for. These pluralistic meanings of different sustainability strategies which are arguably more embedded in the eco-efficiency paradigm are likely to inhibit the promotion of a complimentary strategy such as the achievement of eco-effectiveness through C2C designs.

Apart from these knowledge sharing and transfer barriers, the inability to achieve a high level of collaboration amongst development stakeholders that is required for implementing C2C principles on projects is likely to constitute a barrier to C2C implementation in the built environment. There is also the tendency for a short-term rather than a long-term focus amongst development stakeholders where even in the case of green buildings, Chalifoux (2006) revealed that construction professionals tend to eliminate green building features without taking life cycle cost assessments into consideration even though this raises the operational cost of buildings. The reluctance of developers and other built environment professionals to buy into new and emerging technologies that are unproven is also likely to pose a barrier to C2C adoption. The mere fact that the C2C concept is being propagated as a platform that can facilitate innovation towards the achievement of a closed loop material metabolism cycle suggests that project development stakeholders should be prepared to adopt new and innovative technologies that may not have been tried and tested. In a study undertaken by Osmani and O'Reilly (2009a), it was also revealed that there was a general lack of confidence in emerging green technologies amongst housing developers in England and Wales. Developers for instance are therefore less likely to implement new technologies due to the unknown inherent risks. All these factors could constitute socio-cultural barriers to C2C implementation in the built environment.

There are also technological barriers to C2C implementation as the level of technology available in the built environment can still not meet C2C objectives in its entirety. Debacker et al. (2011) found from their case studies of C2C inspired developments that the lack of comprehensive material selection options were a major barrier for adopting the C2C principles in building projects. There is therefore the need for development of new C2C oriented products for use in the construction sector given that the most easily accessible products on the market do not meet C2C criteria and even when they do, are not available in volumes and varieties that can meet project requirements.

There could also be some economic barriers to the implementation of C2C in the built environment as even in the sustainable building literature, existing economic models have been criticised for being unable to concretely demonstrate to client stakeholders that operational costs would offset any initial investment costs (Häkkinen and Belloni, 2011). For example, there is even a lack of agreement on the estimated energy performance of PV panels and the length of time that it would take for such installations to payoff installation costs in the long term (Cousins, 2011). Indeed, this lack of comprehensive economic models could be as a result of the lack of adequate knowledge on the long-term costs and risks associated with new technologies. There is therefore the need for comprehensive economic models that can demonstrate economic benefits of C2C adoption. Again, rather than assuming the commercial attractiveness of C2C developments which could lead to economic benefits of such developments, it is imperative that such commercial benefits are demonstrated in reality to inspire C2C adoption in the built environment.

C2C barriers	Examples of barriers
1. Socio-cultural barriers	• Knowledge sharing/transfer barriers arising from plurality of meanings of existing eco-efficient strategies • Lack of collaboration amongst development stakeholders • Preferability of conventional technologies and products that have been tried and tested as against new products and technologies • Affinity for short-term rather than longer-term operational benefits amongst development stakeholders
2. Technological barriers	• Lack of comprehensive building material database that meet C2C criteria • Lack of renewable energy technologies that can provide the bulk of energy demands • Lack of extensive knowledge and expertise for adoption and proper installation of C2C oriented technologies amongst professionals • Extensive proliferation of eco-efficiency as the target of technological innovations
3. Economic barriers	• Lack of extensive demand for C2C products and designs • Lack of a proven economic model to demonstrate to client stakeholders that C2C implementation provides long-term economic value • Lack of proven examples to demonstrate commercial attractiveness of C2C developments
4. Legal and regulatory barriers	• Lack of flexibility in existing building regulations • Legal difficulties in establishing take-back lease agreements • Embeddedness of existing legislation in the eco-efficiency vision

Table 2: Potential barriers to the implementation of C2C in the built environment

There are also legal and regulatory barriers to C2C implementation in the built environment. Debacker et al. (2011) revealed that inflexible laws and regulations were a major barrier to C2C implementation as this was usually cited by stakeholders as a major hindrance. Hoffman and Henn (2008) have also revealed that many regional building codes do not permit the integration of certain features such as composting toilet or greywater systems into building designs. Current legislation on waste and energy are arguably more likely to favour the achievement of eco-efficient rather than eco-effective targets given the continued focus of EU directives and legislation on “waste reduction” and cutting down of carbon emissions. In addition to these regulatory barriers, the “product of service” concept which has being advocated by Braungart et al. (2007) as an ideal strategy for the transition from eco-efficiency to eco-effectiveness is likely to require a corresponding legal framework in the built environment context. This concept is premised on the arrangement that various components of a building for example, are leased to the property owners for a defined period and are taken back after their service life. Although this concept releases the property owner from the task of disposing of these components or products at the end of their service life and facilitates the IMP process, such an arrangement would have to be supported by an appropriate legal framework which at the moment is non-existent. These legal barriers have to be overcome to facilitate C2C implementation in the built environment. The potential barriers to C2C adoption in the built environment context are summarized in Table 2.

5 POTENTIAL IMPLICATIONS AND DIRECTIONS FOR FUTURE RESEARCH

The implementation of C2C principles in the built environment could serve as a platform to promote developments that truly create a positive synergetic relationship with the environment. This can only be possible if potential barriers to C2C implementation in the built environment context are overcome. The various barriers discussed in the previous section could also serve as C2C drivers in the built environment if steps are taken in the right direction. Government initiatives are required to drive C2C implementation in the built environment either through the provision of fiscal incentives such as tax rebates for incorporating C2C features in developments. Again, the introduction of C2C oriented legislation or policies as well as flexibility of existing regulations to accommodate C2C innovations is likely to drive the adoption of C2C as a design and development model for the built environment. Such legislation for instance could advocate for provisions to be made in development proposals to ensure that any form of by-products generated as a result of the development fits into a pre-specified technical or biological material metabolism pathway. There is also the need for more research on solar and other renewable energy technologies as well as research that can result in a wide variety of materials and products that meet C2C criteria. If C2C is to be promoted successfully in the built environment, there is also the need for a more coherent C2C framework that is supported by practitioner manuals to guide built environment professionals on how C2C principles can be tangibly realised in building and infrastructural designs and how these can be properly articulated in design briefs. Clearly defined and measurable C2C targets that can be incorporated into project briefs from project inception could enable control, monitoring and comparison of C2C design outcomes with other eco-efficient measures as well as serve as a guide for project stakeholders to achieve eco-effective “nutrient” management from the project conceptualization phase to the end of life of the building.

The arguments presented in this paper are only based on a synthesis of extant literature and there is the need for further empirical research to evaluate the efficacy of achieving eco-effectiveness in the built environment through C2C designs as well as barriers to C2C implementation amongst development stakeholders.

6 CONCLUSIONS

The conceptual and operational differences between the eco-efficiency and the eco-effectiveness paradigms have been discussed. It has been argued that eco-efficient strategies are likely to be of no value in the long-term due the burgeoning global population and the associated increase in demand for material, energy and water resources. Based on these discussions, it has emerged that there is the need for a vision that goes beyond the achievement of eco-efficiency in the built environment. The eco-effectiveness vision has been heralded as a complimentary strategy for creating a positive footprint on the environment in the long-term. Strategies for the achievement of eco-effectiveness in the built environment through C2C design have also been discussed. However, there are several barriers to the implementation of C2C principles in the built environment. These barriers have being categorised as socio-cultural, technological, economic as well as legal and regulatory barriers. Central to most of these barriers is the current proliferation of eco-efficiency measures as a development model in the built environment as well as the pluralistic meanings of terminologies such as "green building", "sustainable buildings" and "sustainable architecture". These pluralistic meanings of the presently dominant eco-efficiency strategies are therefore likely to present knowledge diffusion and transfer barriers in the usually conservative built environment sector.

These barriers could however become drivers to C2C implementation in the built environment if necessary steps are taken to promote C2C oriented technological innovation, promote the necessary legal and regulatory support framework as well as a coherent C2C framework accompanied by guides and manuals that support the tangible realisation of C2C in designs. Given that the arguments presented in this paper are only based on a synthesis of extant literature, it has also been suggested that further empirical research be conducted to evaluate the efficacy of achieving eco-effectiveness in the built environment through C2C designs as well as the barriers to C2C implementation amongst development stakeholders.

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REFERENCES

P.T. Anastas and J.B. Zimmerman, "Peer reviewed: design through the 12 principles of green engineering", *Environmental science & technology*, 37(5), 94-101 (2003).

M. Braungart, W. McDonough and A. Bollinger, "Cradle-to-cradle design: creating healthy emissions–a strategy for eco-effective product and system design", *Journal of Cleaner Production*, 15(13), 1337-1348 (2007).

A. Chalifoux, "Using life cycle costing and sensitivity analysis to "sell" green building features", *Journal of green building*, 1(2), 39-48 (2006).

S. Cousins, "Taking the green gremlins in hand", *Construction manager*, September issue, 16-20 (2011).

W. Debacker, T. Geerken, P. Stouthuysen, V.M. Holm, K. Vrancken and S. Willems, *Sustainable building, material use and cradle to cradle: A survey of current project*

practices, OVAM, Mechelem, Belgium (2011).
C. Soanes and A. Stevenson (ed.), *Concise Oxford English Dictionary*, Oxford University Press, Oxford (2006).
S. Erkman, "Industrial ecology: an historical view", *Journal of Cleaner Production*, 5(1), 1-10 (1997).
E. Goffman, *Why not the sun? Advantages of and problems with solar energy*, ProQuest discovery guides (2008).
S. Guy and S.A. Moore, "Sustainable architecture and the pluralist imagination", *Journal of architectural education*, 60(4), 15-23 (2007).
T. Häkkinen and K. Belloni, "Barriers and drivers for sustainable building", *Building Research and Information*, 39(3), 239-255 (2011).
A.J. Hoffman and R. Henn, "Overcoming the social and psychological barriers to green building", *Organization & Environment*, 21(4), 390-419 (2008).
G. Hüsken, M. Hunger and H. Brouwers, "Experimental study of photocatalytic concrete products for air purification", *Building and Environment*, 44(12), 2463-2474 (2009).
C.J. Kibert, "Policy instruments for sustainable built environment", *J. Land Use & Envtl. L.*, 17, 379 (2001).
W. McDonough and M. Braungart, "The next industrial revolution", *The atlantic monthly*, 282(4) (1998).
W. McDonough and M. Braungart, Cradle *to cradle: Remaking the way we make things.* North point press, New York (2002).
W. McDonough and M. Braungart, "Towards a sustaining architecture for the 21st century: the promise of cradle-to-cradle design", *Industry and environment*, 26(2), 13-16 (2003).
W.McDonough, M. Braungart, P.T. Anastas and J.B. Zimmerman, "Applying the principles of green engineering to cradle-to-cradle design", *Environmental Science & Technology*, 37(23), 434-441 (2003).
D. Mulhall and M. Braungart, *Cradle to cradle criteria for the built environment*, Duurzaam Gebouwd, Netherlands (2010).
M. Osmani and A. O'Reilly, "Challenges facing housing developers to deliver zero carbon homes in England", *World academy of science, engineering and technology*, 53, 604-612 (2009).
M. Osmani and A. O'Reilly, "Feasibility of zero carbon homes in England by 2016: A house builder's perspective", *Building and Environment*, 44(9), 1917-1924 (2009).
W.R. Stahel, *The product life factor. An Inquiry into the Nature of Sustainable Societies: The Role of the Private Sector*, Series: 1982 Mitchell Prize Papers, NARC (1982).
A.C. Stenberg and C. Raisanen, "The Interpretative" Green" in the Building: Diachronic and Synchronic", *International Studies of Management and Organization*, 36(2), 31-53 (2006).
K. Williams and C. Dair, "What is stopping sustainable building in England? barriers experienced by stakeholders in delivering sustainable developments", *Sustainable development*, 15(3), 135-147 (2007).
Y. Xing, N. Hewitt, and P. Griffiths, "Zero carbon buildings refurbishment—A Hierarchical pathway", *Renewable and sustainable energy reviews*, 15(6), 3229-3236 (2011).
F. Zhijun and Y. Nailing, "Putting a circular economy into practice in China", *Sustainability Science*, 2(1), 95-101 (2007).

THE ASSOCIATION BETWEEN CLIMATE CHANGE SCENARIOS AND RISKS ON THE BUILDING SECTOR

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Abstract. *It is perceived that climate change will have a significant impact on a variety of complex human decisions that will affect both our social systems and human-made assets. Understanding how and when climate change risk related information is formed, disseminated and consumed is key to insure the optimal timing and design of policies, systems and procedures, which affect all aspects of the built environment. Thus, this paper will review the scientific evidence regarding climate change risks and its impact on building assets. The paper will report and discuss the findings from the literature regarding the physical, social and economic risks from the impact of climate change. It will classify these findings into risk categories and sub-categories for further analysis and quantitative investigation. This paper will also present the association between the emerging climate change and buildings; and by understanding these risks, it will assist in the development of mitigation and adaptation strategies.*

1 INTRODUCTION

Many design, construction and operational variables have affected and will continue to affect the performance of building assets. Among these variables are the emerging risks from climate change and their impacts, which have been considered to be the main challenges facing the environment and human society (De Wilde and Coley, 2012 and Rickaby *et al.*,2009) for the next few decades (Rosanne *et al.*, 2000). Climate change is not a new phenomenon; but started before humans inhabited the planet (Woodward, 2008). Contemporary changes in the global climate are caused by both natural factors such as the Earth's orbit and volcanic eruptions (Hulme *et al.*, 2002 and EPA, 2009); and human activities (Lemmet, 2009). Policy makers first directed their attention towards climate change during the 20th century, due to the large numbers of scientists who emphasised that the main reason for this phenomenon was the accumulation of carbon dioxide (CO2) in the atmosphere (O'Neill *et al.*, 2001). A discussion of the causes associated with global warming leads to the investigation of additional climate change patterns that are seen to increase the severity of the changing temperature, flood, drought and extreme weather (IPCC, 2007).

Climate change scenarios will have a significant impact on all aspects of human life, including our buildings (Roaf *et al.*, 2009 and De Wilde and Coley, 2012). The impact of climate change scenarios on the building sector can be classified as **physical** (Garvin *et al*, 1998 and McCarthy *et al*, 2001); **social** (Environmental Justice Foundation, 2012 and Midgley *et al.*, 2005); and **economic** (Mark, 2008, Environmental Justice Foundation, 2012 and De Wilde and Coley, 2012). This paper will review the risks emerging as a consequence of climate change and will examine their impact on building assets. The identified risks are then clustered according to their classification as physical, social or economic dimensions; this will provide a valuable way of creating synergies, risks and adaptation and mitigation strategies.

2 THE RELATIONSHIP BETWEEN CLIMATE CHANGE AND BUILDINGS

Buildings contribute towards greenhouse gas (GHG) emissions, representing about 30% of the average global emissions (Lemmet, 2009). This contribution will increase the severity of climate change and will contribute to a wide range of risks. Climate change impacts heavily on buildings themselves, due to events, such as higher temperatures, storms and rainfall (Steenbergen *et al.*, 2012). The most notable challenges facing buildings arise from the increasing average temperatures and changing precipitation patterns (Capon and Oakley, 2012). However, commonly, building performance measurement depends on the exposure to the climate (De Wilde and Coley, 2012). The majority of buildings are designed to last for several decades or longer (typically the age of buildings varies between 50 and 100 years or more), and thus it is crucial to consider the risks and impact of climate change as it will occur over time, in order to ensure the longevity and performance of buildings (Hacker *et al.*, 2005). The obsolescence of the climatic data, which is used in the building sector results in exacerbating the risks and impacts of climate change scenarios on new buildings (Pretlove and Oreszczyn, 1998). In addition, awareness of the potential impact of climate change scenarios can help in the assessment of the emerging risks and provide appropriate policies to avoid or cope with such risks (Alkhaled *et al.*, 2007).

3 CLASSIFICATION OF CLIMATE CHANGE SCENARIO RISKS ON BUILDINGS

Climate change scenarios affect all aspects of human activities including the environment, social life and the economy (Roaf *et al.*, 2009). According to Midgley *et al.*, (2005), the projected climate change risks have serious implications for the competing interests of environmental integrity and socio-economic development.

Figure 1: Classification of CCR on buildings

In addition, many studies and reports have reported physical, social and economic risks as being emerging challenges when facing climate changes (Environmental Justice Foundation, 2012). Thus, this paper classifies climate change risks to buildings based on these three clusters, as shown in Figure. 1. The context of these risks is described and analysed in the subsequent sections.

4 PHYSICAL RISKS OF CLIMATE CHANGE SCENARIOS ON BUILDINGS

According to Horváth and Pálvölgyi (2011), climate change poses varying risks to buildings, which can be taken into consideration during their design, construction, and maintenance. The fabric and structure of buildings is affected by environmental conditions such as flooding, storms and high wind speeds; all these alter the ground conditions, i.e. wetting and drying. Furthermore, changes in the temperature also affect the performance of buildings, in terms of internal overheating or cooling, and also increase the risk of fire, particularly during the summer (Capon and Oakley, 2012). The CIBSE (2005) has grouped the potential risks from climate change scenarios on buildings into two groups, as :Direct impacts (including the following impacts on buildings; impacts on the structure which include, wind pressure, flooding and landslides; and impacts on their construction such as rain penetration, fabric damage); and indirect impacts (referring to the influence on the indoor climate such as temperature, humidity and growth of mould).

4.1 Physical risks on buildings from increase average temperature

The changes in temperature will affect buildings both internally and externally. The internal effects take the form of either changing the climate or demanding more energy for cooling or heating and can increase the risk of fire. The external effects include damage to the fabric of the buildings and construction. In addition, this will also lead to more contractions in the materials that comprise the buildings, which may cause breaks. According to Wilby (2007) and Ross *et al*., (2007), the key risks from higher temperatures within the building sector are an intensified urban heat island, increased energy consumption,,increasing temperatures, reduced service life of materials, and increased risk of cracking.

Under the effects of climate change, a building's components, are expected to have respond quickly to the risks of climate change (Capon and Oakley, 2012). Additionally, changing the average temperature and the level of humidity affects the timber causing timber corrosion and rotting in the structure, which leads to a reduction in the performance overall (Garvin *et al.*, 1998). According to Snow and Prasad (2011), increased humidity in buildings leads to the growth of mould and reduces their overall thermal performance. Meanwhile, the possibility of a higher risk of fire manifests due to the decreased level of humidity.

4.2 Physical risks on buildings from Flooding

Currently, flooding is considered to be one of the most critical risks for buildings, and this will continue into the 2020s. It is expected that, by 2050 flooding will represent one of the most significant threats to buildings, as a direct result of climate change (HR Wallingford, 2012 and Garvin *et al*., 1998). Floodwaters are polluted, and usually contain silt or sewage, which causes additional damage to buildings; this impacts on the ground and basement level of buildings, which are exposed to the threat of flooding. The amount of damage from flooding depends on the water level inside the buildings (Ross *et al*., 2007). According to BRE (1996), flooding occurs when there is a large surplus of precipitation, which dilutes the concentrations of sea water or sewage, as well as the silt; such water becomes more dangerous in the context of housing and populations as it contains contaminants. Furthermore, water damage from the flooding affects the contents of buildings, such as the walls and flooring, as well as undermining the foundations and spreading diseases that are present in sewage, soil and mud (Snow and Prasad, 2011). According to Wingfield *et al*., (2005), the DTLR (2002) stated that the most important factors surrounding the risks from flooding on buildings was the flood depth. The table below illustrates various risks on buildings, based on the flooding level**.** The risks from flooding on buildings can affect their most important features from the perspective of inhabitants, such as their foundations, and their fabric and finishing materials. These effects may in turn lead to the removal of the buildings, or the reduction in their longevity.

Depth of Flood	Damage to Building	Damage to Services and Fittings	Damage to Personal Possessions
Below ground Floor	o Damage to building components o Entry of water to basements and floor voids o Foundations erosion o Deformation foundations components and Concrete	o Damage to electrical sockets and services in basements and cellars o Damage to floor coverings in basements and cellars	o Damaged to personal belongings and furniture in basements and cellars
Up to half a metre above ground floor	o internal damages such as wall finishes and plaster linings o Floors and walls becomes saturated by water and sewage o Chipboard flooring likely to require replacement o Damage to internal and external doors and skirting	o Damage to downstairs electricity meter and consumer unit o Damage to gas meters, boilers and telephone services o Damages to carpets and floor coverings o Disruption white goods	o Damage to furniture and electrical goods o Damage to small personal belongings o Contaminated food in low cupboards
More than half a metre above ground floor	o Increased damage to walls and possible structural damage o Cracking and damages to windows	o Damage to higher units, electrical services and appliances o Disable services inside the building	o Damage to most of personal possessions o Damages to most of the furniture

Table 1: Flood risks on buildings; modified from (Wingfield et al., 2005)

4.3 Physical risks on buildings from extreme weather events

Extreme weather events include unusual precipitation, strong storms, and high speed winds (Cowie, 2007). Increased wind speed and strong storms increase the risks of building damage, such as that to roofs, and can cause damage and crucial structural failure, increasing water penetration from rain through the walls and around the windows (Garvin *et al*., 1998). Moreover, disturbances in climate change events affect the severity of storms and wind speed, leading to increased risks and damage to buildings. The increase in wind speed can be seen to be as much as 25%. Importantly, the proportion of damage to buildings from such an increase will be approximately 650% (Australia Government Department of Climate Change-AGDCC, 2009).

According to Ross et al. (2007), the main effect of storms can be seen on the roofs of buildings; and this depends on the speed of the winds and the extent of the rain. Increased rainfall and high temperatures directly affect the cladding of buildings and weakening their resistance to different climatic conditions, there is therefore an increased possibility of failure affecting the cladding system (Garvin et al., 1998). Thus, a succession of these effects further weakens the building's elements and increases the probability of wind and storm damage. Moreover, condensation and water penetration, cause the corrosion of metallic items, such as brackets, fixings, and frames, all of which weaken buildings and reduce their lifetime and performance (Vivian et al., 2005). The following (Table. 2) summarises some of the emerging physical risks from climate change scenarios for buildings.

Building Elements	Emerging Physical Risks	References
Foundations and Sub-structure	Movement of the ground	Capon and Oakley (2012)
	Crash the foundation	
	Expansion and contraction of the concrete	BRE (1996)
	Carbonate and cracking	Garvin *et al* (1998)
	Increasing subsidence and heave	Vivian *et al* (2005)
	Peak structural loads	De Wiled and Coley (2012)
	Concrete expand and shrink	BRE (1996)
Materials	Corrosion of building metallic	Capon and Oakley (2012)
	Burst pipes	Garvin *et al* (1998)
	Reduced durability of materials	Ross *et al* (2007)
	Swells and distort of the timber due to wetting	BRE (1996)
	Damage to internal and external doors and skirting	Wingfield *et al* (2005)
	Growth of mould	Capon and Oakley (2012)
	Rot wood	
Roofs	Erosion	Vivian *et al* (2005)
	Decreased durability of roofs	
	Increase the load into the drainage system	
	Fall and failure of roofs due to wall deflections	Wingfield et al (2005)
	Reduce ability of roof to get rid the water and snow	Ross *et al* (2007)
Facades	Cracks, fissures and malformation	Vivian *et al* (2005)
	Damages to building facades due to soils instabilities	
	Exposure to severe storms and increase facades damages	
	Breakthroughs water with sewage, soil and mud	Snow and Prasad (2011)
	Rain and dust penetration	Garvin *et al* (1998)
	Broken due to the pressure of storms water and debris	Scottish Executive (2004)
	Exposure to hurricanes and storms	Capon and Oakley (2012)
	Increased coastal erosion	Vivian *et al* (2005)
Walls, finishes and interior	Cracking walls	Ross *et al* (2007)
	Mould growth	
	Increase risks of fire	Snow and Prasad (2011)
	Increased interior wetting of walls, materials and finishes	BRE (1996)
	Increases the duration of dryer to be ready to repair or replace	
	Inundation for cellars, basement and ground floor	Wingfield et al (2005)
	Contamination the building components by sewage and the sediments	Scottish Executive (2004)
	Absorb large quantities of water and distort	
	Dirty and permanently stained due to sewage-contaminated water	
Operation condition	Reduction in use of buildings and facilities	Australia Government Department of Climate Change (2009)
	System go out of range	(De Wiled and Coley, 2012)
	More energy consumption for heating and cooling	

Table 2: The identified physical risks from climate change scenarios on buildings

5 EMERGING SOCIAL RISKS FROM CLIMATE CHANGE SCENARIOS

The risks in the building sector may be diverse, and have both health and economic effects for society (Garvin *et al*., 1998). Moreover, social impacts are expected to be significant and vary based on the places, environment, community and social groups which are affected (Vanclay, 2002). In general, based on the work undertaken by the International Association for Impact Assessment (IAIA, 2003), social risks refer to any impacts on humans which affect their lives both directly or indirectly in terms of health, culture, economics and biophysical factors, as well as on their lives in general. Based on the work of Vanclay (1999) and Armour (1990) and Vanclay (2002) the risks may affect social groups include the method and style of people's lives, risks to their community, people’s culture, risks to property and personal rights, impacts on health, concerns and aspirations of people, and the political system. The social impacts affect social groups in many different ways. One of these is the risk of climate change scenarios on buildings. With reference to Chalmers *et al*. (2009), social risks from climate change scenarios can be divided into three categories: Impacts on health and wellbeing, impacts on access to services, and poverty and social inclusion. Therefore, in general, it seems that the social risks from climate change relate to the risks to buildings and this is the case across all social groups. The following are classifications of social risks from climate change scenarios that relate to the building sector.

5.1 Social risks from increase in the average temperature

Overheating occurs when the temperature is high inside a building, during which time occupants can feel uncomfortable and anxious. The risk from high temperatures starts with feelings of discomfort, which subsequently affect productivity and performance at work, and may result in illness and death as a result of overheating (Capon and Oakley, 2012). Furthermore, changes in temperature - especially a rise in temperature - affects public health and causes greater exposure to skin cancer, and may then lead to death due to heat (HR Wallingford, 2012). According to Wilby (2007), increases in temperature will lead to a reduction in the air quality of buildings, which can cause diseases, especially asthma, and may increase mortality rates due to thermal pressure. Furthermore, rising temperatures threaten the health of the heart, increase the rate of sudden death, and increase the risk of heart disease and heart attacks.

Based on an Australian study, which was undertaken on a group of people during the period 1996 - 2004, an increase in the sudden death rate were experienced by approximately 34% in the hotter summer months when compared to the winter months (Alarabiya, 2012). Chalmers *et al*., (2009) demonstrated, through reference to other research (Tapsell *et al*., 1999; Hajat *et al*., 2003 and Few *et al*., 2004), a loss of personal belongings and possessions, damage to property and a disruption of life due to changing climate conditions, as well as causing tension and anxiety, and panic associated with the risks of climate change.
According to Capon and Oakley (2012), based on Thomas (1998), the internal temperature of a building is extremely important to its occupants, and can affect health and productivity at work. For instance, high temperatures in the bedroom lead to discomfort and anxiety during sleep, leading to poorer performance at work; and this situation worsens if the work environment is warmer.

From a social perspective, the risks of the temperature increasing inside buildings has an effect on its occupants in the form of physical harm, such as disease and the threat of death, or psychological harm, such as through heat discomfort. All of this negatively affects performance at work and behaviour with other members of society whether at work or home. In addition, there are other effects, such as the breakdown of devices due to greater heat, and cooling system failures; all of which exacerbate problems.

5.2 Social risks from floods

According to Wingfield *et al*. (2005), based on Johnson (2005), flooding has direct risks for people in terms of both their physical and mental health, which has become clear and notable due to flooding experiences of affected communities. In addition, Twigger-Ross and Orr (2012) have listed the most critical social risks of flooding on the building sector, as Economic impacts, loss of personal belongings, impacts on physical and psychological health hassle and stress caused by instability,changes in the society in terms of the population, the disruption of services, and the deterioration of the neighbourhood environment.

Increases in the frequency of flooding will increase the risks to people, through higher rates of mortality and injuries, as well as problems with mental health issues and rising levels of stress due to flooding (HR Wallingford, 2012). Moreover, the Intergovernmental Panel for Climate Change (IPCC) predicts that, in the 21st Century, the sea level rise will be between 18cm and 20cm, with approximately one-third of coastal countries finding more than 10% of their land area within five metres from the sea level. This will lead to a significant migration and movement of people (Vidal, 2009). According to Wilby (2007), based on LCCP (2002), the rise in the sea level will affect those residing in low level areas. For instance, the second national report undertaken in the Kingdom of Bahrain for the United Nations Framework Convention on Climate Change, which discloses the results of immersion analyses for the years 2050 to 2100, reveals that more than 11% of the total area of Bahrain will be lost by 2050 due to an increase in the sea level of approximately 0.3 metres (Alwasatnews, 2012). Moreover, the Environmental Justice Foundation (EJF) warns that the risks of climate change will lead to the displacement of approximately 150 million people around the world. In 2008, around 20 million people were displaced due to the risk of climate change. This included 800,000 people as a result of cyclone Nargis in Asia; and approximately 80,000 others due to floods and heavy rainstorms in Brazil (Vidal, 2009).

Furthermore, according to Hajat *et al*., (2005) the negative effect on humans from of flooding can be divided into two g roups: Physical risks (occur during the occurrence of floods or afterwards, and during the damage repair process; these impacts include death and various injuries, the destruction of property, displacement, and the deprivation and loss of personal items) and psychological risks (occur immediately following the exposure to flooding accidents, and include trauma, fear, and the fear of disaster).
and lack of public services, as well as psychological impacts, such as fear and depression.

5.3 Social risks from extreme weather events

Drought is one of the extreme climate change patterns (WMO, 2009); which has widespread risks for people. These can include direct risks affecting daily life, or indirect risks to the surrounding environment. Drought reduces water availability, which leads to increased demand for water to irrigate green areas; thereby reducing the presence of green spaces around buildings. These green areas help to cool the air and provide buildings with shade (Capon and Oakley, 2012).

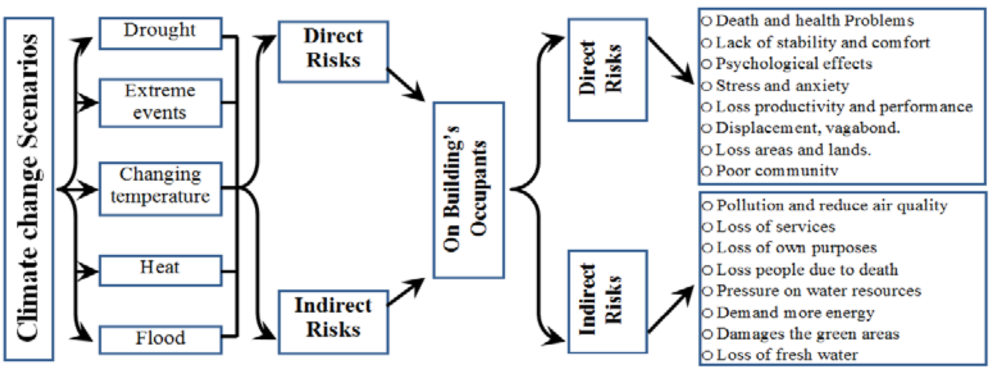

Figure 2: The social risks from climate change on building's occupants

Furthermore, the more extreme manifestations of climate change, such as storms and strong winds, lead to a loss of opportunities for relaxation and pleasure due to increased damage to the natural and cultural amenities, such as green and play areas, and heritage and attractions (Chalmers *et al*., 2009). Basically, all aspects of communities are affected by climate change patterns, although most of these impacts impact people who live in poorer societies with low quality buildings and housing (Midgley *et al*., 2005). Accordingly, the social risk of climate change scenarios may lead to influence on the behaviour and reactions of building occupants whether in public or private buildings. From a social perspective the climate changes risks on buildings and their occupants can be divided into ways direct and indirect risks as illustrated in Figure. 2.

6 ECONOMIC RISKS OF CLIMATE CHANGE SCENARIOS ON BUILDINGS

Previously, the impacts of climate change scenarios on the building sector have been reviewed in terms of their physical and social risks. Moreover, these risks have included the costs from an economic perspective regarding both individuals and groups, which include the public sector, such as the government, and the private sector, such as insurance companies. According to the Deccan Chronicle (2012), global economic growth will reduce by around 3.2% of gross domestic product (GDP) by the end of 2030 due to risks of climate change.
According to HR Wallingford (2012), climate change scenarios constitute a threat to the economy as businesses deal with patterns of climate change on a daily basis, and these are considered to be a key challenge.

6.1 Economic risks from increase in the average temperature

Heat waves, particularly in the work place, lead to greater risks on businesses, especially with regards to their profitability; by affecting employees' productivity and the increased consumption of energy use (CCRA, 2012). Heat waves have a negative impact on the performance of employers resulting in losses. Thus in July 2006, organisations operating within the UK lost almost £840 million per week because of the weakness of employee productivity due to the effects of increased temperature during that period (Roberts, 2008). Moreover, according to Capon and Oakley (2012), the Centre for Economics and Business Research study (CEBR, 2003) states that the thermal comfort in the work environment is very important as it affects productivity, which in turn impacts upon an increase in financial loss. Productivity declines by about 8% when the temperature is 26°C, and the losses amount to approximately £35 million; whereas increases in this percentage may reach 29% when a temperature is estimated at 32°C; and this will lead to losses of approximately £126 million. Employees lose more than half of their production at 38°C, which is estimated to result in approximately 62%, and the financial losses will be around £270 million. In addition, by the year 2050 - as a consequence of high temperatures - the use of energy, especially for air cooling, will increase by around 10 - 16%, thus leading to increases in the economic pressure on countries (Glynn and SN, 2005).

6.2 Economic risks from flooding and extreme weather events

According to Garvin *et al*., (1998), the impacts of extreme weather has much potential in terms of damaging the economy. The economic impacts on the building sector can be viewed as: delays and disruption, damages the use of materials, day lost due to the frequency of climate change, and disruption to the use of the plants. Such risks result in the disruption of work progress, especially in businesses, and a reduction in its growth; which leads to significant financial loss. Moreover, extreme weather events incur huge cost losses in the economics of many countries. For example, in Australia, between 1967 and 1999, financial losses due to floods, hurricanes and strong storms were around $28.6 billion, which accounted for approximately 75% of the total financial losses due to natural disasters during this period (DCC, 2009). Moreover, sudden changes in climatic patterns, crashes and breakdown outdoor works, such as in construction, result in an increased duration of projects, as well as increased delays in delivery. This also leads to increases in associated costs, thus meaning additional financial losses (Graves and Phillipson, 2000).

Moreover, because of extreme weather events, especially in terms of increased precipitation and strong storms, which lead to increased risks to buildings; such risks cause increases to annual insurance payments. As result insurance becomes more difficult to acquire, and insurance companies more difficult to find as a result of such increased costs (CCRA, 2012; and Wagner, 2012). The economic risks from climate change are increasingly dramatic as illustrated in Figure. 3 below with the expected loses during 2010 - 2060 due to extreme weather events (Repetto, 2012).

Year	2010	2020	2030	2040	2050	2060
Expected Annual Loss	1.75	5.3	14.8	39.1	99.6	247

Figure 3: Expected Annual Losses from extreme climate events by $ billions, (Repetto, 2012).

Increases in the strength of climate change scenarios will lead to the destruction of infrastructure, such as roads and public buildings, airports, public services, power and water supply systems and networks; and these will lead to higher costs of repair and renewal, resulting in negative effects on the economy of these countries (EPA, 2010). Furthermore, as can be seen from the above analysis, it can be stated that the essential economic risks on buildings resulting from climate change scenarios may be divided into three groups, as illustrated in Figure. 4. There is overlapping effect between these three groups in terms of the economic risk impacts from climate change. For instance, if companies are affected by these risks, they will be forced to increase their project costs and insurance and will increase the economic risks at both the individual and public level.

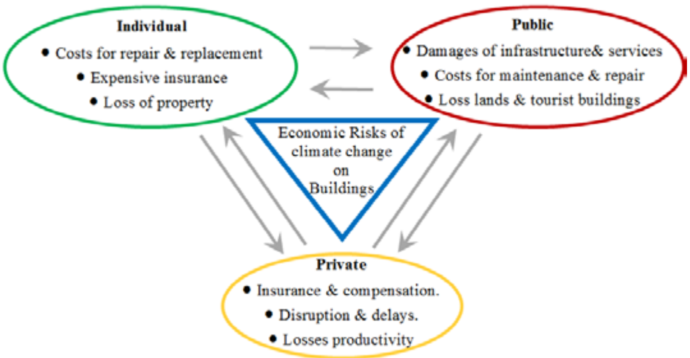

Figure 4: The significant economic risks of climate change on buildings

7 CONCLUSION

There is consensus among the majority of policy and decision makers that the emerging risks from climate change have become a global problem. This problem calls for additional efforts to understand the nature and impacts of these emerging risks. The effects of climate change scenarios on buildings have been classified in terms of their physical, social and economic aspects. These risks interact with each other to create further risks and challenges for policy makers. Further work will strengthen the list of emerging risks and will quantify their likelihood of occurrence over time; as well as providing data on the significance of their impact.

REFERENCES

Alarabiya, *Rising temperatures threaten heart health* (2012). Available from http://www.alarabiya.net/articles/2012/09/20/239181.html, [accessed on 21st September 2012].

A.A. Alkhaled, A.M. Michalak and J.W. Bulkley, "Applications of risk assessment in the development of climate change adaptation policy" , *World Environmental and Water Resources Congress 2007*: *Restoring Our Natural Habitat* (2007).

Alwasatnews, *Predicted adverse effects on sectors and systems and ways of life in Bahrain due to climate changes* (2012). Available from http://www.alwasatnews.com/3490/news/read/646262/1.html [accessed on 26th September 2012].

Australia Government Department of Climate Change, *Climate change risks to Australia's coast, a first pass national assessment*, Department of Climate Change, Australia (2009).

Building Research Establishment Scottish Laboratory (BRE), *Design guidance on flooding damage to dwellings*, The Scottish Office Development Department (1996).

R. Capon and G.Oakley, *Climate change risk assessment for the built environment sector*, Department for Environment Food and Rural Affairs, London (2012).

H. Chalmers, M. Anderson, T. Houghton, T. Maiden, S. Parham and A. Pilling, *Differential Social Impacts of Climate Change in the UK*, SNIFFER report UKCC22 , pp. 1-53 (2009). Available from: http://www.sniffer.org.uk/Resources/UKCC22/Layout_ClimateChange/12.aspx [accessed on 5th July 2012].

Chartered Institution of Building Services Engineers (CIBSE), *Climate change and the indoor environment: impacts and adaptation*, CIBSE TM36 (2005).

Climate Change Risk Assessment (CCRA), *Summary of the key findings from the UK climate change risk assessment*, Department for Environment Food and Rural Affairs, London (2012).

J. Cowie, Climate *change: biological and human aspects*, Cambridge University Press (2007).

P. de Wilde and D. Coley, "The implications of a changing climate for buildings", *Building and Environment*, 55, 1-7 (2012).

DECCAN Chronicle, "100 million will die by 2030 if world fails to act on climate", *DECCAN Chronicle*, 7th October (2012). Available from http://www.deccanchronicle.com/channels/sci-tech/climate/100-million-will-die-2030-if-world-fails-act-climate-report-572 [Accessed on 24th September 2012].

Department of Climate Change (DCC), *Climate change risks to Australia's coast*, Commonwealth of Australia, Australia (2009).
Environmental Justice Foundation (EJF), *Climate change and human rights* (2012). Available from: http://ejfoundation.org/climate/human-rights [accessed on 24th September 2012].
S.L. Garvin, M.C. Phillipson, C.H. Sanders, C.S. Hayles and G.T. Dow, *Impact of climate change on building*, Construction research communications, Garston (1998).
S. Glynn, *Climate change in the Northwest and its impacts: a summary document*, The Northwest Climate Group (Sustainability Northwest), UK (2005).
S. Glynn and S.N. (Sustainability Northwest) , *Climate change in the northwest and its impacts: a summary document*, The Northwest Climate Group (2005).
H. M. Graves and M. C. Phillipson, *Potential implications of climate change in the built environment*, Foundation for the built environment report 2, CRC, London (2000).
J. Hacker, M. Holmes, S. Belcher and G. Davies, "Climate change and the indoor environment: impacts and adaptation", *The Chartered Institution of Building Services Engineers CIBSE*, ISBN 1903287502, pp. 1-55, February (2005).
S. Hajat, K.L. Ebi, R.S. Kovats, B. Menne, S. Edwards and A. Haines, "The human health consequences of flooding in Europe", *A review extreme weather events and public health responses*, W. Kirch, R. Bertollini and B. Menne (eds), Springer Berlin Heidelberg, pp. 185-196 (2005).
S.E. Horváth and T. Pálvölgyi, "Buildings and climate change: impacts on roofs and vulnerability to wind storms", *Materials Technology, Anyagtechnologia*, 3–4, pp.62-66 (2011).
HR Wallingford, *The UK climate change risk assessment 2012 evidence report*, Department for Environment Food and Rural Affairs, London (2012).
M. Hulme, J. Turnpenny and G. Jenkins, *Climate change scenarios for the United Kingdom: the UKCIP02 briefing report*, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich (2002).
Intergovernmental Panel on Climate Change (IPCC), *Climate change 2007: impacts, adaptation and vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson (eds.), Cambridge University Press, Cambridge UK (2007).
International Association for Impact Assessment (IAIA), *Social impact assessment, International Principles*, Special Publication Series No. 2 (2003).
S. Lemmet, "Building and climate change", *United Nations Environment Programme (UNEP)*, 1-56 (2009).
E.K. Mark, "Building human resilience: The role of public health preparedness and response as an adaptation to climate change", *Elsevier Inc. on behalf of American Journal of Preventive Medicine*, 35(5), 508-516 (2008).
J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds.), *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press (2001).
G.F. Midgley, R.A. Chapman, B. Hewitson, P. Johnston, M. de Wit, G. Ziervogel, P. Mukheibir, L. van Niekerk, M. Tadross, B.W. van Wilgen, B. Kgope, P.D. Morant, A. Theron, R.J. Scholes and G.G. Forsyth, *A status quo, vulnerability and adaptation*

assessment of the physical and socio-economic effects of climate change in the Western Cape, Report to the Western Cape Government, CSIR Report No. ENV-S-C 2005-073, Stellenbosch, Cape Town, South Africa (2005).

B.C. O'Neill, F.L. Mackellar and W.Lutz, *Population and climate change*, Cambridge University Press, Cambridge (2001).

S.E.C. Pretlove, and T. Oreszczyn, "Climate change: The impact on the environmental design of buildings", *Building Service Engineering Research and Technology*, 19(1), 55 – 5 8 (1998).

R. Repetto, "Massachusetts' rising economic risk from climate change", *State Based Climate Change Series*, Better Future Project (2012).

P. Rickaby, B. Cartmel, L. Warren, J. Willoughby and R. Wilson, *Climate change toolkit: 01 climate change briefing*, The Royal Institute of British Architects (RIBA), UK (2009).

S. Roaf, D. Crichton and F. Nicol, *Adapting buildings and cities for climate change A 21st century survival guide (2nd ed.)*, Elsevier Ltd., UK (2009).

S. Roberts, "Effects of climate change on the built environment", *Energy Policy*, 36, 4552–4557 (2008).

W. Rosanne, F. J. Lee, J. R. Corney, S. Romanello, J. Bonnell, B. Luthy, C. Figuerido and N. Ntsiko, "Public understanding of climate change: certainty and willingness to act", *Environmental Education Research*, 6(2), 127-141 (2000).

K. Ross, G. Saunders and O. Novakovic, *Climate change and innovation in house building: designing out risk*, IHS BRE Press on behalf of NHBC Foundation (2007).

Scottish Executive, *Planning advice note PAN 69 - planning and building standards advice on flooding*, TSO, London (2004).

M. Snowand and D. Prasad, *Climate change adaptation for building designers: An introduction. environment design guide (EDG)*, EDG 66 MSa, pp. 1-11, February (2011).

R.D.J.M. Steenbergen, T.Koster and C.P.W. Geurts, "The effect of climate change and natural variability on wind loading values for buildings", *Building and Environment*, 55(0), 178-186 (2012).

The World Meteorological Organization (WMO), *Progress report on the implementation of the global observing system for climate in support of the UNFCCC 2004-2008*, August 2009, GCOS-129 World Meteorological Station-TD/No. 1489, GOOS-173, GTOS-70 (2009).

C. Twigger-ross and P. Orr, *The UK climate change risk assessment evidence report annex B: social vulnerability to climate change impacts*, Department for Environment Food and Rural Affairs, London (2012).

F. Vanclay, "Conceptualising social impacts", *Environmental Impact Assessment Review*, 22, 183– 211 (2002).

J. Vidal, "Global warming could create 150 million 'climate refugees' by 2050", *The Guardian*, Tuesday 3 November (2009). Available from http://www.guardian.co.uk/environment/2009/nov/03/global-warming-climate-refugees?INTCMP=SRCH [accessed on 26th September 2012].

S. Vivian , N. Williams and W. Rogers, *Climate change risks in building – an introduction*, CIRIA, C638 (2005).

G. Wagner, "An optimist's case for climate policy", *Strategy+ business*, 10th September (2012). Available from: http://www.strategy-business.com/article/00133?gko=ee1fd&cid=TL20121018&utm_campaign=TL20121018 [accessed on 18th September 2012].

R.L. Wilby, "A review of climate change impacts on the built environment", *Built Environment*, 33(1), 31-45 (2007).

J. Wingfield, B. Malcolm and P. Bowker, *Improving the flood resilience of buildings through improved materials, methods and details: Review of existing information and experience (Final Report)*, report number WP2c (2005).

J. Woodward, *Climate change*, Dorling Kindersley Limited, New York (2008).

INVESTIGATION OF A SUB-WET BULB TEMPERATURE EVAPORATIVE COOLER FOR BUILDINGS

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Abstract. The paper presents a computer model and experimental results of an indirect evaporative cooling system for air conditioning in hot and dry climate regions. The system uses porous/fired clay materials as wet media for water evaporation. The supply air and working air flows were staged in separate ducts and in counter flow direction. Modelling results were conducted for ambient air dry bulb temperature ranging from 30^o C to 45^o C and relative humidity lower than 65%, showing that supply air would be cooled to below wet bulb temperature. In addition, it was estimated that the indirect evaporative cooler would achieve cooling capacity of approximately 27 W/m^2 of exposed ceramic material wet area and with overall wet bulb effectiveness greater than unity. This performance would make the system a potential alternative to conventional mechanical air conditioning systems in buildings.

1 INTRODUCTION

Energy consumption in buildings is stands at between 30–40% of the total primary energy use globally (Dodoo et al., 2011). A major part of this is used to provide comfortable indoor climatic conditions for occupants. For example, in regions with cold climates such as northern Europe, energy for space heating and hot water accounts for over 60% of the total energy used in buildings, whereas in hot climate region a similar proportion of energy consumption is for air cooling in buildings (Proctor, 2010). The growth in air conditioning systems in the world is mainly driven by an increase in living standards, affordability, population increase and cheap electrical energy in some regions such Middle East. This has led many countries to build new power generation plants and extend grid infrastructure to meet peak electricity loads, which in turn impacts negatively on the environment by emitting more greenhouse gases.

Current air conditioning market is dominated by mechanical vapour compression systems, which are energy intensive systems and suffer from low thermal performance in hot climate conditions. Hence, in hot dry climate region, application of low carbon cooling technologies is once more the focus of many researchers including methods of integration into modern buildings and materials that are more durable.

2 EVAPORATIVE COOLING TECHNOLOGY

The use of evaporative cooling for thermal comfort in buildings is not new. The earliest use of evaporative cooling was by ancient Egypt and the Roman Empire using for example wet mats (cooling pads) over doors and windows to cool the indoor air when wind blew through the mats (Vissers, 2011). Evaporative cooling is widely found in Middle East and Persian architecture often integrated into the windcatchers. Evaporative cooling is a low carbon and economically feasible method for cooling buildings in hot and dry climates.

2.1 Direct evaporative cooling systems

Direct evaporative cooling is the process of evaporating liquid water to the surrounding air and causing its temperature to decease. A typical direct evaporative cooler, as shown in Figure 1, uses a fan to draw in outside air through a pad wetting media and circulates the cool air through the building.

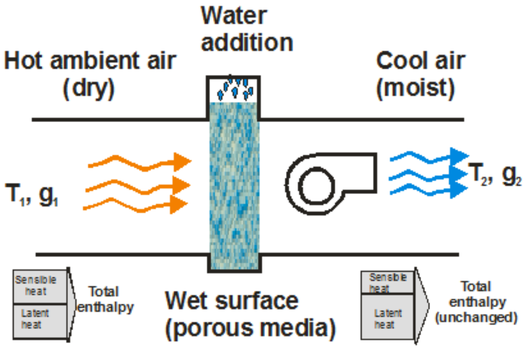

Figure 1: Schematic of a direct evaporative cooling system

The energy required for evaporation of water is provided by the air, though at the expense of increasing its moisture content and decreasing its temperature. Since the process is adiabatic, the sensible heat loss by the air is balanced out by latent heat gain, which appears as moisture content increase. The heat and mass transfer between the warm dry air and water can be expressed as follows (Jones, 2001).

$$(\dot{m}_a h_1 + \dot{m}_{v1} h_{v1}) - \dot{m}_{wv} h_{fg} = (\dot{m}_a h_2 + \dot{m}_{v2} h_{v2}) \tag{1}$$

where m_a, h_1 and h_2 are air mass flow rate, inlet and outlet enthalpy respectively. m_{v1} , h_{v1} , m_{v2} and h_{v2} are the water vapour inlet mass flow rate, enthalpy, outlet mass flow rate and enthalpy respectively. m_{wv} and h_{fg} are the water evaporation rate and latent heat of evaporation repectively. The amount of water required can be computed as:

$$\dot{m}_{wv} = \dot{m}_{da}(g_2 - g_1) \tag{2}$$

where m_{da} is dry air mass flow rate, g_1 and g_2 are the inlet and outlet air moisture content respectively.

The effectiveness of direct evaporative coolers is primarily influenced by the air wet bulb temperature and in a well-designed system the air could be cooled to within 2 to 3^{o}C of the wet bulb temperature which presents a severe thermodynamic limitation.

2.2 Indirect Evaporative cooling and sub wet bulb temperature

This has led several researchers to develop and modify the thermal process of direct evaporative cooling system to achieving sub-wet bulb temperature, referred to as Dew point or Sub-wet bulb temperature evaporative cooling (Maisotsenko, 2003). In this coolers arrangement, the air streams are separated into dry channel for supply air and wet channel for rejecting spent working air. The supply air in the dry channel is cooled indirectly by transferring its heat to the working air in the wet channel through a thin non-permeable channel wall. To achieve sub-wet bulb temperature, part of the cool air in the dry channel is diverted to accomplish the evaporation process in the wet channel, as shown in Figure 2.

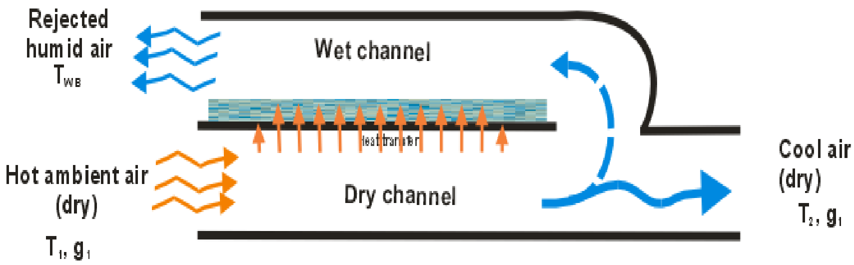

Figure 2: A simple schematic of a sub wet bulb temperature indirect evaporative cooler

The advantage of this arrangement is that the moisture content of the cooled air remains unchanged. Hsu et al. (1989) carried out a theoretical and experimental study on two configurations of closed-loop wet surface heat exchangers to achieve sub-wet bulb temperature cooling through counter flow and cross flow air stream arrangements. Boxem et al. (2007) presented a model for a compact counter flow Indirect Evaporative Cooler with finned exchanger. The performance of a 400 m^3/h air flow rate cooler was analysed and showed that for inlet air temperatures higher than 24 C the model results accuracy were within 10%. Zhao et al. (2008) presented a numerical study of a counter flow Indirect Evaporative Cooler for sub-wet bulb temperature cooling. The authors suggested a range of design conditions to maximize the cooler performance including air velocity range, height of air passage, and length to height ratio of air flow rates. It was shown that even under UK summer conditions the cooler can yield wet bulb effectiveness of up to 1.3. Riangvilaikul et al. (2010) presented experimental results for a sensible evaporative cooling system at different inlet air conditions (temperature, humidity and velocity) covering dry, temperate and humid climates. The results show that wet bulb effectiveness ranged between 92 and 114%. A continuous operation of the system during a typical day of summer season in a hot and humid climate showed that wet bulb effectiveness was almost constant at about 102%. Hasan (2010) also presented a theoretical model of four different configurations of indirect and sub wet bulb temperature coolers: two-stage counter flow cooler, two-stage parallel flow cooler, single-stage counter flow regenerative cooler and combined parallel-regenerative cooler. The author concluded that with higher number of staged coolers, the ultimate temperature to be reached is the dew point of ambient air.

2.3 Wet media materials

The wet media used in evaporative coolers is an essential component of an evaporative cooler. It is usually made of a porous material with large surface area and capacity to hold liquid water. According to Wanphen and Nagano (2009),the selection of wet media materials is based on their effectiveness, availability, cost, safety, and environment factors. Zhao et al. (2009) investigated various types of porous materials such as metal and plastic foams, zeolite and carbon fibres to be used as wet media for heat and mass transfer in evaporative cooling systems. Musa (2008) also investigated the use of more common aspen pads materials for indirect evaporative cooling system. Riffat and Zhu (2004) employed ceramic materials for indirect evaporative cooling systems. Figure 3 shows some common wet media materials that can be found in evaporative cooling systems.

a) b) c) d)

Figure 3: Wet media materials a) metal foams b) organic impregnated materials (Aspen) c) PVC padding d) Celdek paper

3 DESIGN OF A POROUS CERAMIC SUB-WET BULB TEMPERATURE EVAPORATIVE COOLER

3.1 Description

In this project, porous ceramic materials in the form of hollow flat shells were used as wet media in a sub-wet bulb temperature evaporative cooler. Porous ceramic materials were selected for their stable structural, non-corrosion properties and easily moulded into desired shape. Figure 4 shows the configuration of the sub-wet bulb temperature evaporative cooler using the porous ceramic material for water evaporation.

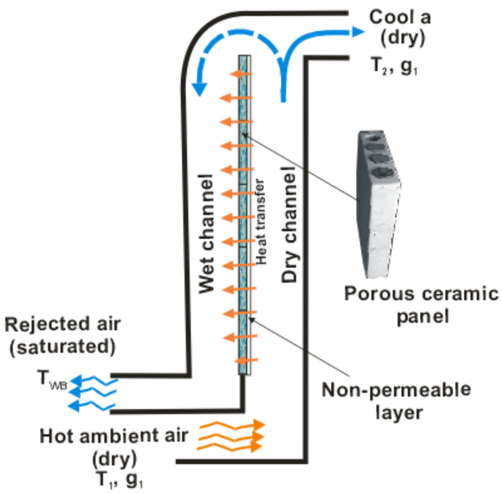

Figure 4: A schematic of the sub-wet bulb temperature porous ceramic evaporative cooler

The porous ceramic panels were placed between the dry and wet air ducts to form small and narrow ducts with air flowing at low velocity. The dry channel side of the porous ceramic panel is sealed with a thin non-permeable membrane while the wet channel side allows water to sip through its micro-pores onto its surface forming a thin water film. This allows direct contact with the airflow and hence causing water evaporation. The air streams in the dry and wet channel flow in counter flow arrangement and the supply air exchanges sensible heat with the water in the porous ceramic panels that in turn are cooled through water evaporation on the wet channel side. This results in a drop in temperature of the air in the dry channel without changing its moisture content while the air in the wet channel is rejected at saturation state.

3.2 Mathematical model

The sub-wet bulb temperature evaporative cooler was modelled using common energy and mass conservation laws. In the model the dry and wet channel were divided into small elements (finite volumes) to which the energy and mass transfer equations were applied.

Energy conservation in the dry channel

Air is cooled in the dry channel by transferring its sensible heat to the wet channel through the non-permeable layer and the porous ceramic panels. This can be expressed as follows:

$$\frac{\dot{m}_d \partial h_d}{\partial A} = -U(T_d - T_{fw}) \tag{3}$$

where m_d, h_d,T_d , A and U are the air flow mass rate, enthalpy, temperature, heat transfer coefficient and area of the dry channel. T_{fw} is the temperature of the water film on the wet channel side.

Energy conservation in the wet channel

The heat transfer mechanism in the wet channel is more complicated than in the dry channels, as sensible and latent heat is exchanged between the airflow and the water film on the surface of the porous ceramics. This is expressed as (Halasz, 1998):

$$\frac{\dot{m}_w \partial h_w}{\partial A} = \kappa(T_{fw} - T_w) + \sigma(g_{fw} - g_w)h_{fg} \tag{4}$$

where m_w, h_w,T_w, g_w, and κ are the air mass flow rate, enthalpy, temperature, moisture content and convective heat transfer coefficient in the wet channel. T_{fw}, g_{fw}, and σ are the water film temperature, saturated air moisture content, and mass transfer coefficient. It is assumed that air flow regime in both dry and wet channel are laminar and the mass transfer coefficient, σ obeys the following Lewis number correlation(Hasan 2010, Halasz, 1998):

$$Le = \frac{\kappa}{\sigma c_p} \tag{5}$$

where Lewis number, Le, value ranges from to 0.9 to 1.15 and to simplify the analysis it is often taken to be 1, c_p is specific heat of humid air.

Mass conservation in the wet channel

Water evaporation from the ceramic panel surface appears as an increase of the air moisture content along the length of the wet channel. The mass balance for the water vapour in the wet channel can be written as:

$$\frac{\dot{m}_w}{} \frac{\partial g_w}{\partial A} = \sigma(g_{fw} - g_w) \quad (6)$$

Overall energy balance

The overall energy and mass balance at the water film interface between the air flow in the dry channel, the water film on the ceramic surface and the air flow in the wet channel can be expressed as:

$$\frac{\dot{m}_{fw} C_{pfw} \partial T_{fw}}{\partial A} = U(T_d - T_{fw}) - \sigma(g_{fw} - g_w) h_{fg} - \alpha(T_{fw} - T_w) \quad (7)$$

where C_{pfw} is specific heat of water.

The computer modelling was performed using Matlab© software. The governing differential equations were discretised and applied to each finite volume element along the dry and wet channel length. It was assumed that the air properties, heat and mass transfer coefficients are constant in each finite control volume, the water film and the non-permeable membrane thermal resistances are assumed to be negligible.

The initial conditions used in this model include known air properties (temperature and moisture content) for the dry channel and air moisture content for the wet channel. The main design parameters of the system are given in Table 1.

Air channel Length	0.5 m
Air channel Width	0.5 m
Air channel Height	0.005 m
Mass low rate in the dry channel	0.0266 (kg/s)
Mass flow rate in the wet channel	0.01 (kg/s)
Air flow regime	Laminar

Table 1: design and modelling parameters

Computation of the operating parameters of airflow along the air ducts length was performed iteratively until converging conditions were satisfied giving a temperature difference between two consecutive iterations less than 0.01°C.

4 Experimental test rig

A laboratory test rig was built to test the porous ceramic sub-wet bulb temperature evaporative cooler is shown in Figure 5. The porous ceramic panels were filled with water through and overhead tank while a fan was used to draw air at controlled temperature and relative humidity from an environmental chamber and circulate it through the evaporative cooler dry and wet channels. The rig was fully instrumented to measure the air temperature, moisture content and flow rates along the dry and wet channels.

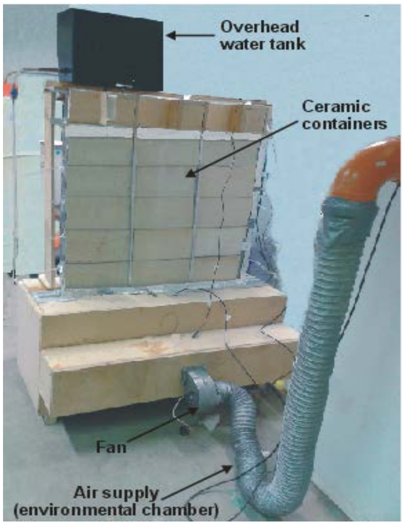

Figure 5: A laboratory experiment rig of the ceramic evaporative cooler

5 RESULTS AND DISCUSSION

The thermal performance of the porous ceramic evaporative cooler design was evaluated using computer modelling and laboratory testing. Figure 6 shows the computer and experimental results of the air temperature profile in the dry and wet channel. For initial inlet air (atmospheric air) dry bulb temperature, T_{dbi}, of 30°C and relative humidity of 35% (i.e., wet bulb temperature, $T_{wbi,}$ of 18.8°C and dew point of 12.5°C), the computer model predicts that the dry bulb temperature of the air in the dry channel would be cooled to 16.9° C which is 1.9°C below the web bulb temperature. The airflow along the wet channel, on the other hand, increased from 16.9° C to 19.8° C, as the energy balance between sensible heat loss and latent heat gain is positive. The experimental measurements however show the air temperature at the outlet of the dry channel is about 22.8°C and that of the wet channel is 22°C. The discrepancy between the experimental and computer model results could be explained by the difficulties in obtaining a uniform air distribution in the dry and wet channel.

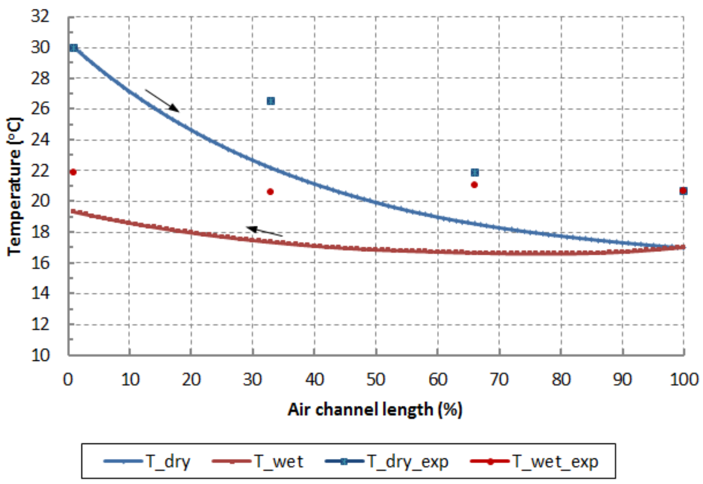

Figure 6: Temperature profile along the dry and wet channel (air inlet from left to right) air mass flow rate m_d=80m^3/h

The representation of the state of the air in the dry and wet channels on a psychrometric chart is shown in Figure 7. It can be seen that the air temperature at the dry channel outlet, T_{do}, is lower than air wet bulb temperature, T_{wb}, at the inlet with the ultimate air supply temperature equals to dew point temperature, T_{dp}.

Further evaluation of the performance of the evaporative cooler was carried out by calculating its cooling potential at various dry bulb and relative humidity conditions as shown in Figure 8. It can be seen that the cooling capacity is strongly influenced by the dry bulb temperature and relative humidity of air. The cooling capacity at 40°C and 35% relative humidity is around 27W/m^2 of the wet porous ceramic area.

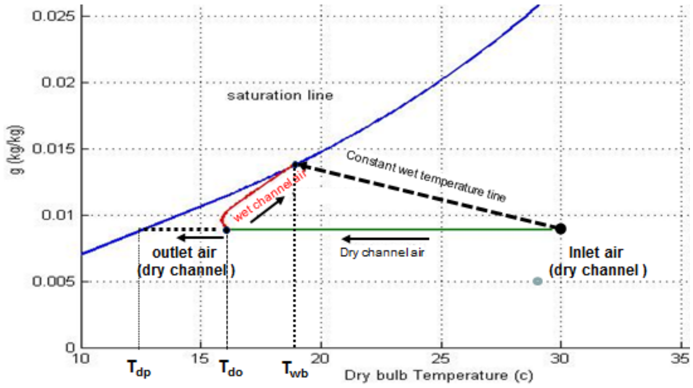

Figure 7: Air operating states on psychrometric chart

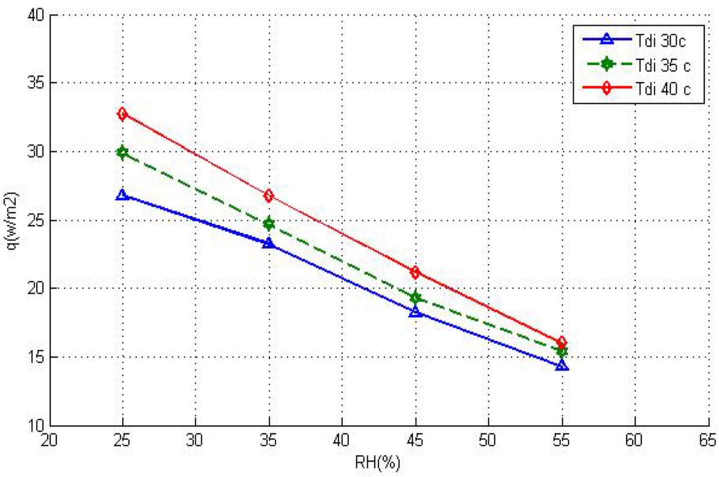

Figure 8: Cooling capacity (Mass flow rate 80m^3/h)

Finally, the effectiveness of the evaporative cooler was also evaluated, which can be determined using two different methods: the wet bulb and dew point effectiveness. The wet bulb effectiveness is the ratio of the difference between inlet and outlet air temperature to the difference between inlet air temperature and its wet bulb temperature (Riangvilaikul and Kumar, 2010). The mathematic expression of the wet bulb effectiveness is given by:

$$\varepsilon_{wb} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{wb,in}} \quad (7)$$

The dew point effectiveness, on the other hand, is the ratio of the difference between inlet air temperature to the difference between inlet air temperature and its dew point temperature (Frank, 2011). The mathematic expression of the dew point effectiveness is expressed as:

$$\varepsilon_{\mathrm{db}} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{dp}} \tag{8}$$

For the design inlet air conditions of 30°C and 35% relative humidity the web bulb effectiveness is $\varepsilon_{\mathrm{wb}}$=1.23 and dew point effectiveness is $\varepsilon_{\mathrm{db}}$= 0.779 . This shows that the sub wet bulb temperature evaporator cooler has wet bulb effectiveness higher than unity, a thermal performance that can compare favourably with more mechanical vapour compression systems and can contribute to reducing overall energy consumption for air condition in buildings.

5 CONCLUSION

A computer model and experimental results of a sub-wet bulb temperature evaporative cooler using porous ceramic materials were presented. It was shown that the evaporative cooler can achieve high thermal performance in terms of low air supply temperatures and effectiveness. The structural stability and manufacturing controllability of ceramic materials lend them well to integration into buildings and performing the function of air conditioning in regions with hot and dry climatic conditions.

ACKNOWLEDGEMENT

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REFERENCES

S. Anisimov, V. Vasiljev and D. Mochov, “Heat and mass transfer in plastic indirect evaporative air cooler under combined flow conditions”, *Proceedings of Healthy Buildings Conference*, Espoo, Finland, vol. 2, pp.655-660 (2000).

G. Boxem, S. Boink and W. Zeiler, “Performance model for small scale indirect evaporative cooler”, *Proceedings of Clima WellBeing Indoors,* REHVA World Congress, Helsinki, Finland, No.1676 (2007).

D.R. Crum., J. W. Mitchell and W.A. Beckman, “Indirect evaporative cooler performance”, *ASHRAE Transactions*, 93, pp.1261-1275 (1987).

B. Frank, “On-site experimental testing of a novel dew point evaporative cooler”, *Energy and Buildings,* 43**,** 3475-3483 (2011).

B. Halasz, *A general mathematical model of evaporative cooling devices,* Elsevier, Paris, pp. 245-255 (1998).

A. Hasan, “Indirect evaporative cooling of air to a sub-wet bulb temperature”, *Applied Thermal Engineering,* 2460-2468 (2010).

S.T. Hsu, Z. Lavan and W.M. Worek, “Optimization of wet-surface heat exchangers”, *Energy* 14, 757-770 (1989).

W.P. Jones, *Air Conditioning Engineering,* 5th Edition, Butterworth Heinemann (2001).

V. G. L Maisotsenko., T.L. Heaton and A.D. Gillan, *Method and plate appartus for dew point evaporative cooler*, United State patent application (2003).

M. Musa, *Novel evaporative cooling systems for building applicatio,* PhD thesis, University of Nottingham Library (2008).

A. Odoo, L. Gustavsson and R. Sathre, “Building energy-efficiency standards in a life cycle primary energy perspective”, *Energy and Buildings*, 43**,** 1589-1597 (2011).

Proctor, High EER at 46ºC Kingdom of Saudi Arabia air conditioner project. In: *Amad for techincal consultation and laboratries and proctor engineering group*, l. (ed.). Ministry of Water and Electricity in Saudi Arabia (2010).

B. Riangvilaikul and S. Kumar, “An experimental study of a novel dew point evaporative cooling system”, *Energy and Buildings*, 42, 637-644 (2010).

B. Riangvilaikul and S. Kumar, “ Numerical study of a novel dew point evaporative cooling system” *Energy and Buildings,* 42**,** 2241-2250 (2010).

S.B. Riffat and J. Zhu, “Mathematical model of indirect evaporative cooler using porous ceramic and heat pipe”, *Applied Thermal Engineering*, 24 457–470 (2004).

D.R.Vissers, *Study on building integrated evaporative cooling of glass-covered spaces*, Building Physics and Systems, Eindhoven University of Technology, (2011).

S. Wanphen and K. Nagano, “Experimental study of the performance of porous materials to moderate the roof surface temperature by its evaporative cooling effect”, *Building and Environment*, 44**,** 338-351 (2009).

X. Zhao, J.M. Li and S.B. Riffat, “Numerical study of a novel counter-flow heat and mass exchanger for dew point evaporative cooling”, *Applied Thermal Engineering*, 28, 1942-195 (2008).

X. Zhao, Z. Duan, C. Zhan and S.B. Riffat, “Dynamic performance of a novel dew point air conditioning for the UK buildings”, *International Journal of Low Carbon Technologies,* 4, 27-35 (2009).

EXPERIMENTAL AND NUMERICAL STUDY OF APPLICATION OF HEMP IN BUILDING ENVELOPES WITH SPECIAL REFERENCE TO ITS HYGROTHERMAL PROPERTIES

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Abstract. *This research focuses on the experimental determination of key hygrothermal properties of fibrous hemp insulation and applying the data as inputs for numerical simulation tool to determine the hygrothermal behaviour of the material in timber frame thermal envelopes. Simulations have been run for envelopes with and without vapour barrier. The findings are then compared with the findings for stone wool insulation for similar exposures. This shows how hemp performs compared to conventional mineral wool insulation during service conditions. It was found that hemp performed as well as stone wool as an insulation material. However there is more risk of interstitial condensation in stone wool integrated thermal envelope at certain periods than in a hemp integrated thermal envelop.*

1 INTRODUCTION

The climate change act 2008 makes it legally binding that the net UK carbon account for the year 2050 will be at least 80% lower than the 1990 baseline (Great Britain, 2008). About 27% of the total CO2 emission from UK is down to the domestic buildings (Boardman, 2007) and about 17% is down to non-domestic buildings (Retrofit for non-domestic buildings, 2012). Within the domestic sector, highest amount of energy is being used in space heating. BRE (Building Research Establishment) stated that cost effective measures could save 25% of this energy and 65% of the savings could be attributed to improved insulation standards (Halliday, 2008). Consequently, to reduce 80% carbon emission, the older housing stock needs to be thermally refurbished and newer housing stock needs to be adequately insulated.

For the insulation market, it implies that the demand and supply of thermal insulations will steadily increase. Currently, due to the introduction of the Code for Sustainable Homes and other energy saving initiatives, there is a growing tendency in the construction industry of using materials with green credentials. An appropriate green material should have lower embodied energy and should be obtained from renewable sources. As far as thermal insulation is concerned, although the market is heavily dominated by mineral and synthetic thermal insulation materials, a number of bio-based insulation materials are gradually penetrating the market. Lack of reliable data about the hygrothermal performance of these new insulation materials is a market barrier. Therefore there is a need for assessing the performance potential of these newer products.

2 BIO-BASED INSULATIONS AND HEMP

The principal bio-based insulations that are available in the UK market are fibrous hemp, flax, wood fibre and sheep wool insulations. Among these insulations, hemp has a robust production potential in the UK as only 0.064% of arable land is required to produce enough hemp fibre to meet the existing demand for loft insulation (Murphy and Norton, 2008). Hemp comes from renewable source, hemp is biodegradable, and hemp plants require very little amount of fertilizer (Roulac and Hemptech, 1997).

The key hygrothermal properties of insulations are their moisture dependent thermal conductivity and moisture management capacity. While there are certain data available about the embodied energy and life cycle analysis of hemp insulations, not much data are available about their hygrothermal properties. Once a range of values of these performance potentials are successfully determined for hemp insulations, these data can be used further in the simulation tools to evaluate their performance in building envelopes.

3 HYGROTHERMAL PROPERTIES OF HEMP INSULATION

Experiments were carried out to determine the key hygrothermal properties of hemp insulation. A brief description of the determination of these properties is provided in the following subsections.

3.1 Sorption isotherm

Sorption isotherms of hemp and stone wool were determined following BS EN ISO12571 (2000), as shown in Figure 1 (Latif *et al*., 2011). The moisture content U (kg/kg) was calculated in the following way:

$$U = (m-mo)/mo \tag{1}$$

Where, mo = mass at dry condition, m = mass at equilibrium moisture content (EMC) to any relative humidity.

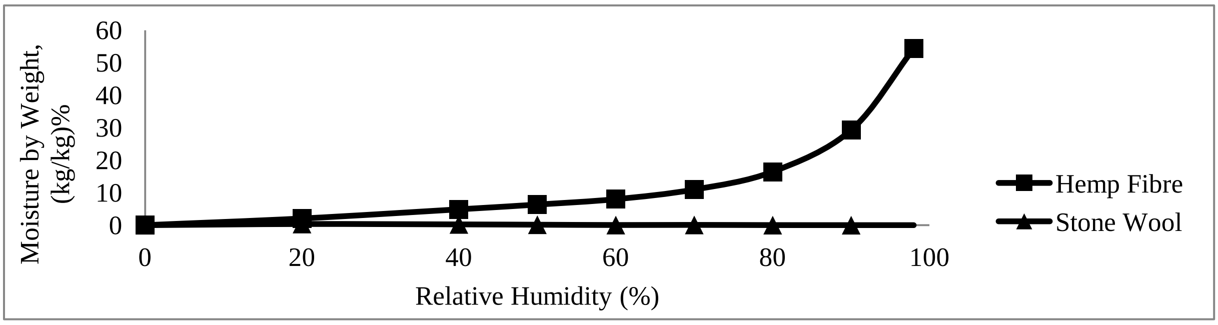

Figure 1: Sorption isotherm of hemp and stone wool at constant temperature of 23°C.

3.2 Vapour diffusion resistance factor

Water vapour diffusion resistance factor was determined by dividing water vapour permeability of air by water vapour permeability of the material. It was determined by following BS EN 12086 (1997). The result of vapour diffusion resistance factor in wet cup method is shown in the Table 1. The vapour diffusion resistance factor of hemp insulation in dry cup test was 1.64.

Material	W, Water Vapour Permeance (mg/m^{2}h.Pa)	Z, Water Vapour Resistance (1/W)	δ, Water Vapour Permeability (mg/mhPa)	μ, Water Vapour Diffusion Resistance Factor (-)	S_d, Water Vapour Equivalent Air Layer Thickness (m)
Hemp	9.93	0.102	0.558	1.29	0.072
Stone Wool	6.51	0.154	0.455	1.54	0.108

Table 1 : Vapour transmission properties of hemp and stone wool.

3.3 Water absorption coefficient

Water absorption coefficient or ‘A’ value (kg/(m^2√s) is the expression of the mass of water absorbed by a test specimen at unit surface area at unit square root of time. ‘A’ value is determined according to the BS EN ISO 15148 (2002). Water absorption Δm (Kg/m^2) in root of time (√s) of the samples of the similar hemp insulations is shown in the figure 3.

As plotting Δm against square root of the time did not give a straight line (figure 2), the following equation for ‘A’ value was applied:

$$A_{w,24} = (\Delta m_{tf})/(\sqrt{86400}) \quad (2)$$

Where Δm_{tf} (kg/m^2) is the value of Δm at tf time, tf is 24 hours expressed in seconds. Average ‘A’ value og hemp insulation was determined as 0.04 kg/(m^2√s).

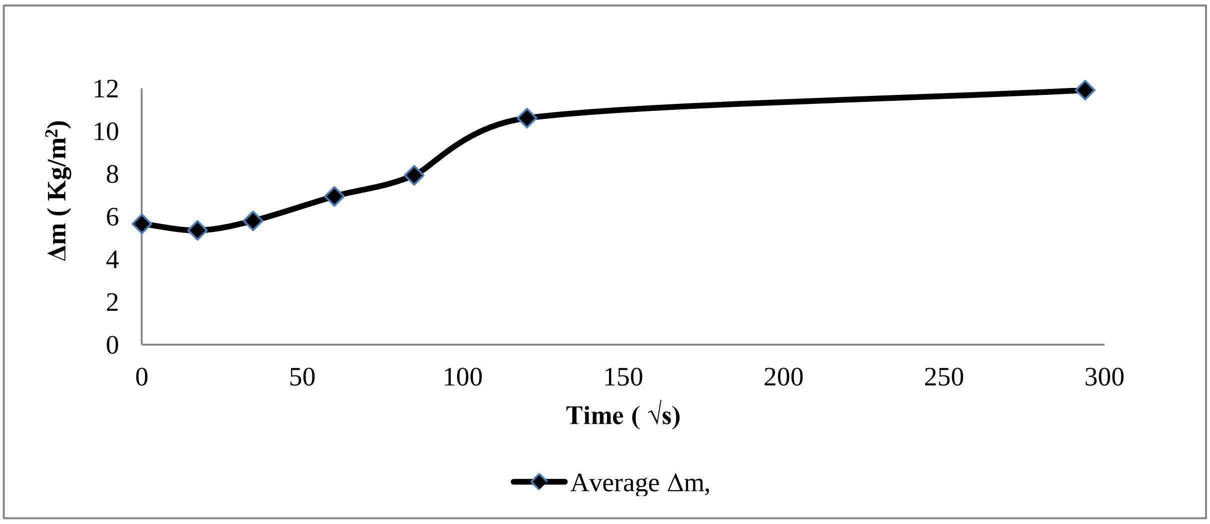

Figure 2: Water absorption of hemp insulation against square root of time.

3.4 Thermal conductivity

Thermal conductivity values of insulations are determined by the following equation:

$$q = -\lambda\ (\partial T/\partial X) \tag{3}$$

where, q = heat flux density (W/m^2), λ = thermal conductivity in dry condition (W/m-K), ∂T= temperature difference between the warm side and cold side (°C), ∂X = thickness of the sample (m). In case of moisture dependent thermal conductivity and equivalent thermal conductivity, λ can be replaced by λ* and λequi, respectively.

The declared thermal conductivity of dry hemp insulation used in this experiment is 0.039 W/m-K. For measuring moisture dependent conductivity, hemp insulation was conditioned in the climate chamber to reach required equilibrium moisture content (EMC). After the insulation samples attained EMC, the samples were wrapped with cling film and were placed in the hotbox. The results are shown in Figure 3, Figure 4 and Table 2.

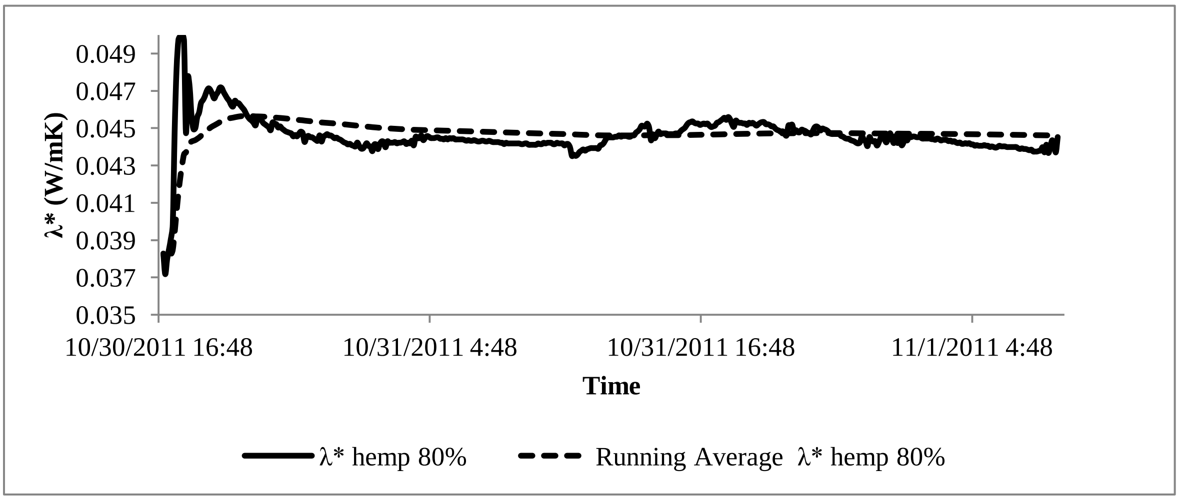

Figure 3: Thermal conductivity of hemp, EMC at 80% relative humidity.

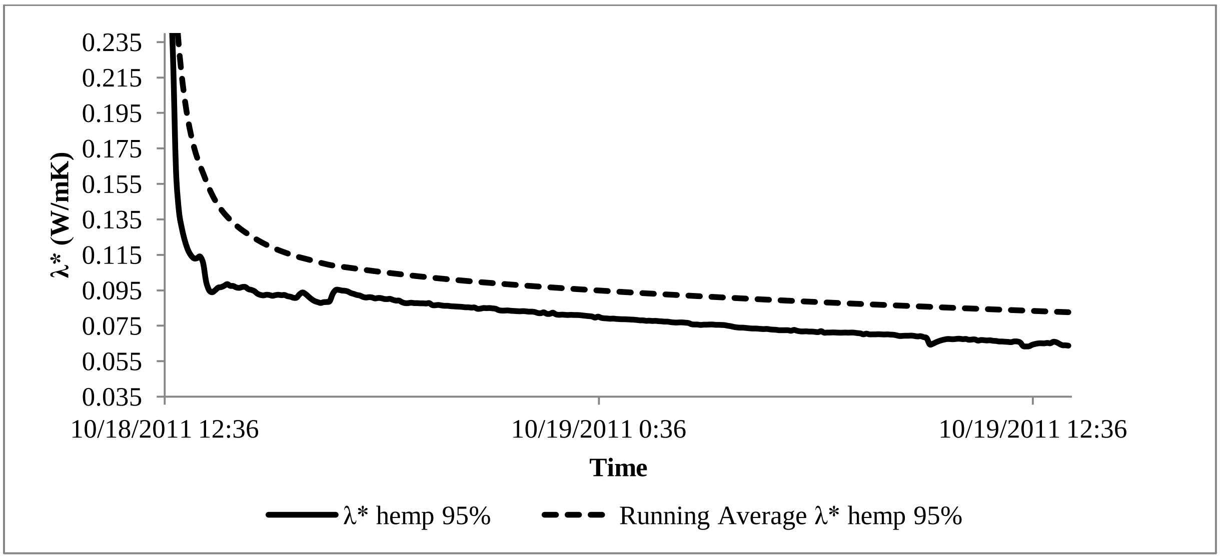

Figure 4: Thermal conductivity of hemp, EMC at 95% relative humidity.

	Thermal conductivity at 80% relative humidity (W/mK)	Thermal conductivity at 95% relative humidity (W/mK)
Hemp	0.044	0.064

Table 2: Thermal conductivity of hemp, EMC at 80% and 95% relative humidity.

4 NUMERICAL SIMULATION

4.1 The software

The WUFI software (Kunzel, 1995) is was used for the numerical simulation of long-term hygrothermal behaviour of insulation materials in real weather condition. The following subsections provide brief description of the governing equations, the method, the wall assemblies and the findings.

4.2 The governing equations

The WUFI software a numerical computational tool to predict hygrothermal performance of building envelope WUFI uses the following coupled heat and moisture balance equations respectively and the solutions are obtained by finite volume method:

$$dH/d\vartheta \;\; \partial\vartheta/\partial t = \nabla.(\lambda \nabla\vartheta) + h_v \nabla.(\delta p \nabla(\varphi\rho sat)) \tag{6}$$

$$dw/d\varphi \;\; \partial\varphi/\partial t = \nabla.(D\varphi \nabla\varphi + \delta p \nabla(\varphi\rho sat)) \tag{7}$$

Where
$dH/d\vartheta$ = Heat storage capacity of moist building material (J/m3K)
$dW/d\varphi$ = Moisture storage capacity of building material (Kg/m3)
λ= Thermal conductivity of the material (W/mK)
$D\varphi$ = Liquid conduction coefficient of building material (kg/ms)
δp = Water vapour permeability of building material (Kg/msPa)
hv = Evaporation enthalpy of water (J/kg)
ρsat = Saturation vapour pressure (Pa)
ϑ = Temperature (°C)
φ = Relative humidity (-)

Data obtained experimentally has been used as inputs to the modelling such that an indicative performance has been obtained of bio-insulation products under a range of hygrothermal conditions.

4.3 Method

The hygrothermal performance of hemp and stone wool insulation was determined for timber frame walls with and without vapour barrier. Numerical simulations were run for the weather of Birmingham. The method applied is as follows:

- Experimental data were used for assigning hemp and stone wool material properties.
- Weather data was taken obtained from Meteonorm, a global meteorological database.
- High internal moisture load was selected in the WUFI software.
- Each of the simulations was run for three years.

- Results were analysed in spread sheet.

4.4 Timber frame wall assemblies

One very common detail for timber frame wall from inside to outside is: gypsum plaster board, insulation, oriented strand board (OSB), breather membrane, air layer and rain screen. This assembly is tested without and with vapour membrane (figures 5 and 6) using hemp and stone wool insulations separately.

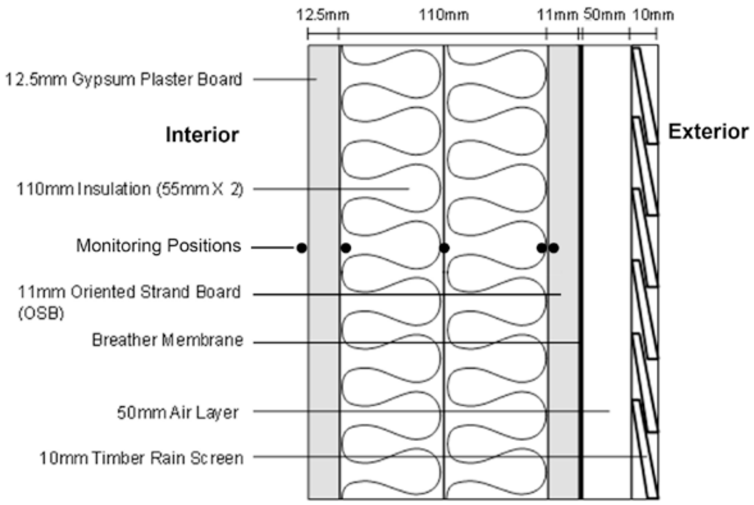

Figure 5: Timber frame wall without vapour barrier.

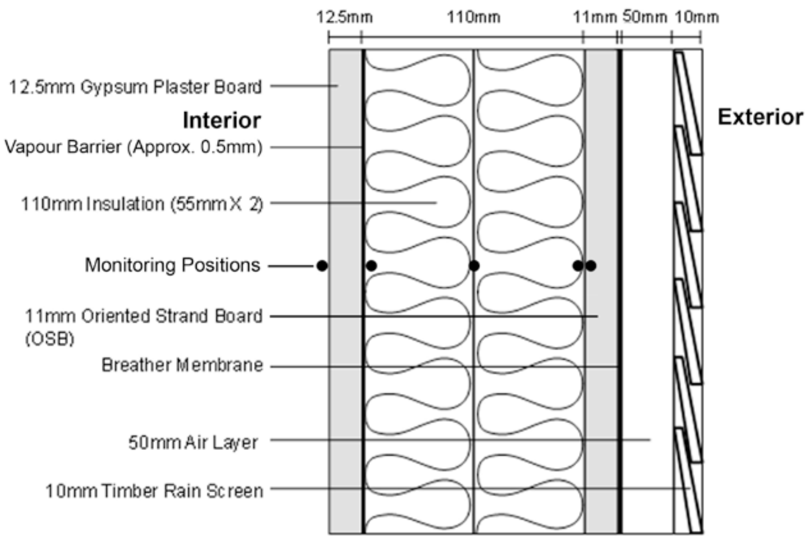

Figure 6: Timber frame wall with vapour barrier.

4.5 Results and discussion of numerical simulations

4.5.1 Timber frame wall without vapour barrier in Birmingham

Figure 7 shows the relative humidity in the hemp-OSB and the stone wool-OSB interfaces in a vapour open wall during the second year of the simulation run. One critical difference between hemp and stone wool can be observed during January. It can be observed that relative humidity in stone wool remained more than 85% for about 15 days and in hemp for about 7 days. The more an insulation is exposed to critical relative humidity the more it is vulnerable to mould growth. Therefore in this case there is a higher chance of mould growth in stone wool in terms of providing favourable environmental condition. Apart from these few days, relative humidity is less than 80% in the insulation-OSB interfaces of both insulations most of the time. Therefore the critical interface of the wall assembly does not seem to be vulnerable to either condensation or mould growth.

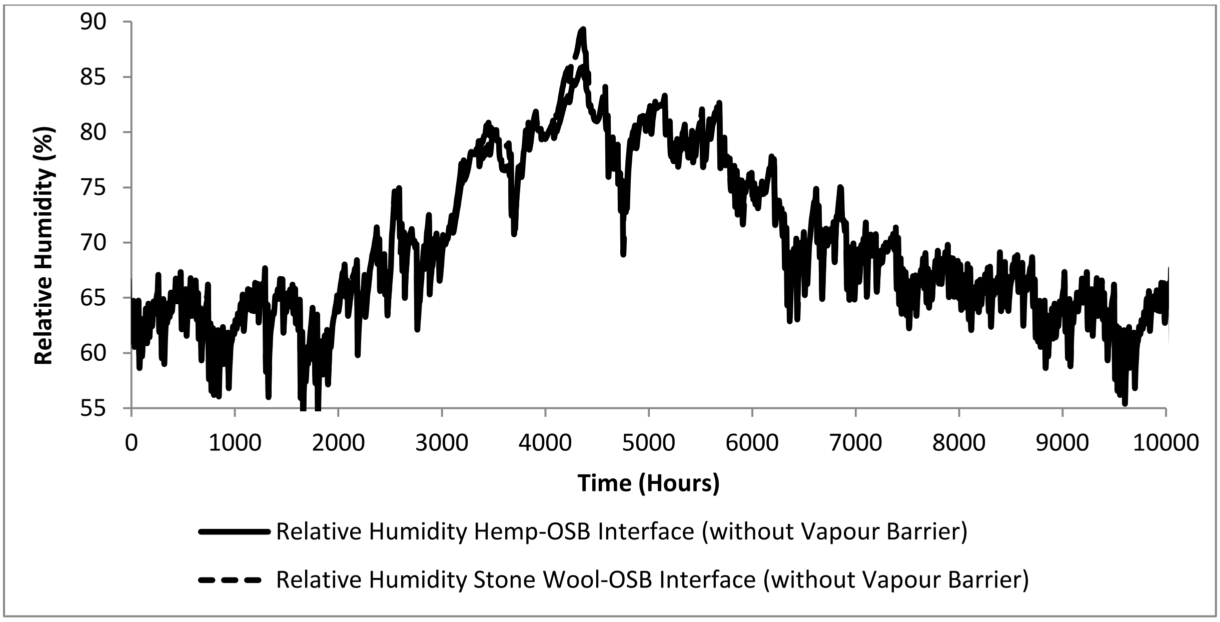

Figure 7: Relative humidity in the timber frame wall without vapour barrier in Birmingham.

It can be noticed in figure 8 that average moisture content is higher in hemp-OSB interface than in stone wool-OSB interface. This is due to the moisture adsorption capacity of hemp. Despite the higher amount of adsorbed moisture content in hemp insulation, the moisture content is always far below the hygroscopic saturation limit of hemp insulation except between 9 January to 16 January, 1993. On the other hand the moisture content in stone wool insulation is far higher than its saturation hygroscopic capacity, which means that condensation occurred in the stone wool-OSB interface all the time. It implies that hemp can better manage moisture and reduce the frequency of condensation compared to stone wool insulation in the tmber frame wall without vapour barrier.

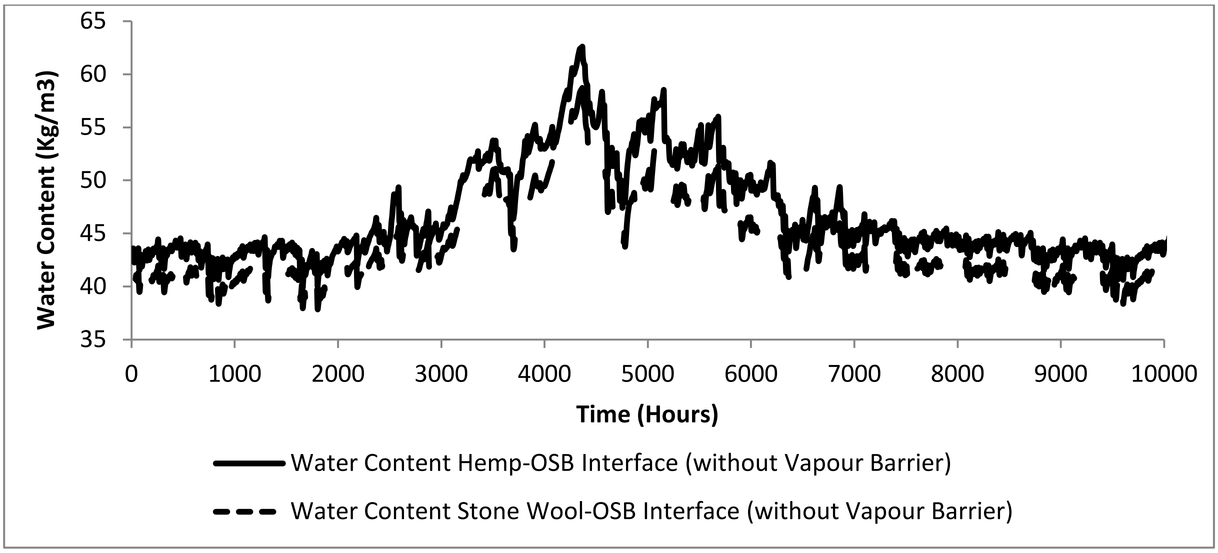

Figure 8: Water content in the timber frame wall without vapour barrier in Birmingham.

4.5.2 Timber frame wall with vapour barrier in Birmingham

The analysis of the result of the numerical simulations for timber frame wall with vapour barrier shows that relative humidity in the insulation-OSB interface is not critical most of the times for both hemp and stone wool insulation (Figure 9). The average relative humidity in stone wool-OSB interface is 3% higher than that in hemp-OSB interface. The reason seems to be the moisture adsorption capacity of the hemp insulation.

Water content in hemp-OSB interface is within its hygroscopic capacity while water content in total stone wool insulation is far higher than its hygroscopic capacity (Figure 10). Therefore there is higher likelihood of interstitial condensation in the stone wool than in hemp insulation.

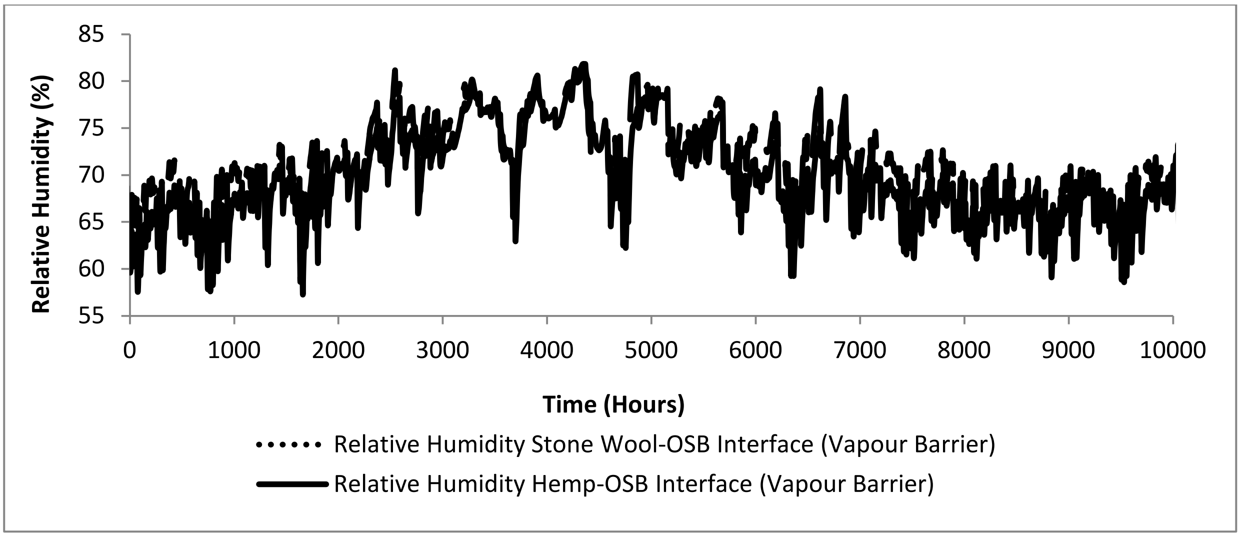

Figure 9: Timber frame wall with vapour barrier in Birmingham.

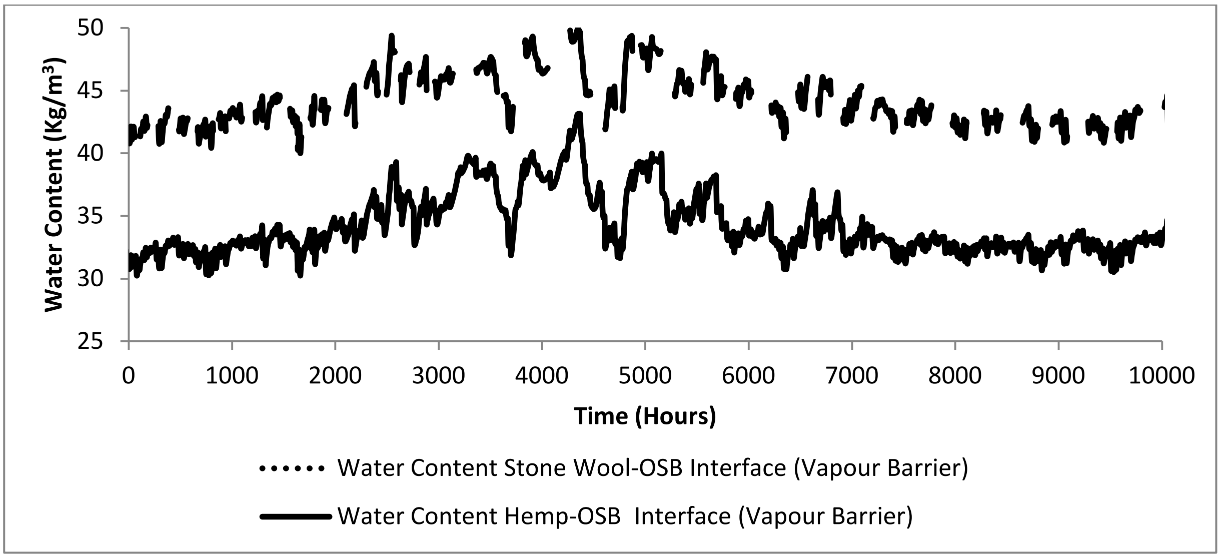

Figure 10: Timber frame wall with vapour barrier in Birmingham.

4.5.3 Summary of the numerical simulation

Birmingham represents moderate UK climatic condition. From the context of Birmingham and on the basis of the WUFI simulation, it can be concluded that vapour open timber frame wall assemblies with hemp insulation will be able to operate appropriately without initiating any severe risk of mould growth or interstitial condensation in many parts of the UK. For climates with various extremes, like higher rainfall or colder temperature, separate simulations have to be carried out. In case of timber frame assembly with or without vapour barrier, relative-humidity was lower in hemp-OSB interface than in stone wool-OSB interface and water content was within the hygroscopic range for hemp insulation. Hence in terms of moisture management hemp is likely to perform better than stone wool insulation.

5 Conclusion

Various hygrothermal properties of the insulation materials were determined following British Standards and through experiments in hotbox. Experimental results show that conductivity of hemp insulation does not change significantly until it is exposed to very high humidity conditions. Experimental material data has been used as inputs for hygrothermal simulation programme. It has been shown through the numerical hygrothermal simulations that, in timber frame wall assembly, fibrous hemp insulation perform better than stone wool insulation in terms of managing relative humidity and hygroscopic moisture content in the insulation-OSB interfaces. Future work will focus on the integration of hemp insulation in solid wall assemblies.

REFERENCES

B. Boardman, *Home truths: a low-carbon strategy to reduce UK housing emissions by 80% by 2050*, (2007) [online]. Available at: http://www.foe.co.uk/resource/reports/home_truths.pdf (Accessed: 12 June 2009).

British Standards Institute, *BS EN ISO 12086: Thermal insulating products for building applications -Determination of water vapour transmission properties*. British Standards Institute, (1997).

British Standards Institute, BS EN ISO12571: *Hygrothermal performance of building materials and products-Determination of hygroscopic sorption properties*, British Standards Institute, (2000).

British Standards Institute, *BS EN ISO 15148: Hygrothermal performance of building materials and products - Determination of water absorption coefficient by partial immersion*, British Standards Institute, (2002).

Great Britain, *Climate Change Act 2008*, Chapter 27, The Stationery Office, (2008).

S. Halliday, *Sustainable Construction*, Butterworth- Heineman, (2008).

E. Latif, S. Tucker, and D. C. Wijeyesekera, *Fibrous hemp insulation: An initial study of its thermal and hygric properties*, International Sustainable Development Research Society (ISDRS): 17th Annual Conference, New York 08-10 May. New York: Columbia University, (2011).

R. J. Murphy and A. Norton, *Life Cycle Assessment of Natural Fibre Insulation Materials:Final Report*, NNFCC, (2008).

Retrofit for non-domestic buildings (2012) Availale at: http://www.ukgbc.org/content/retrofit-non-domestic-buildings (accessed: 10 April 2012).

J. Roulac and Hemptech (Firm), *Hemp horizons : the comeback of the world's most promising plant*, Chelsea Green Publication, (1997).

M. H. Kunzel, *Simultaneous heat and moisture transport in building components: one and two dimensional calculation using simple parameters*, PhD thesis, Fraunhofer Institute of Building Physics, (1995).

DESIGNING CONCRETE WITH RECYCLED ECOLOGICAL AGGREGATES

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Abstract. *As sustainability is becoming a fundamental requirement for all modern industrial processes, modern environmental policies should also deal with enhancing the efficiency in the use of raw materials and reducing* CO_2 *emissions. Alternative sources for cementitious materials and natural aggregates for concrete production are recently emerging and gaining the interest of concrete industry. At the COPPE-UFRJ a research line is under development with the main aim to develop "ecological concrete" solutions, characterised by a significant replacement of traditional cement and by replacing natural aggregates with recycled aggregates from demolition waste. In this paper, the preliminary results of this research line are reported. The possible impact of alternative processing procedures to produce recycled aggregates from construction demolition waste are discussed. The particle size distribution as well as the associated water absorption capacities are evaluated and considered in the mix design. A series of experiments are conducted on different concrete samples, at both fresh and hardened states. Test results are discussed and compared to the results of a reference mixture. The activities presented in this paper are framed within the EU-funded network on the topic of "Environmentally-friendly solutions for Concrete with Recycled and natural components" (www.encore-fp7.unisa.it).*

1 INTRODUCTION

As widely known from scientific literature, Recycled-Concrete Aggregates (RCA) are particularly characterised by significantly higher water absorption capacity and lower mechanical properties with respect to the "natural" gravel and sand employed to produce ordinary concretes (Xiao et al. 2004, Evangelista and de Brito 2007, Etxeberria et al. 2007, Yong and Teo 2009, Corinaldesi 2010, Malešev et al. 2010, Kwan et al. 2011). The reason for such a behaviour could be the higher porosity that is characterising the outer layers of crushed concrete particles or debris. Since this outer structure of RCA is clearly affecting the relevant physical and mechanical properties of RAC, a certain attention is usually paid to monitor these effects, possibly by means of their additionally induced water content, in terms of workability at the fresh state and strength of the hardened material (Ogawa and Nawa 2012).

The research work reported in this paper is mainly focussing on understanding the feasibility and effectiveness of those processes that have to be performed on crushed particles such that the properties of RCAs can be controlled accurately. Particularly, the effect of the *homogenisation* of demolished concrete rubbles, their *grinding and sieving* to obtain particles in the size ranges needed for concrete production and, finally, the possible *autogenous cleaning* procedure are considered herein. Such processes are fully detailed in Section 3, which reports both the practical aspects and the effects it will induce on the relevant physical properties of the processed material particles.

To investigate the potential of such processing procedures on the final properties of concrete, three batches of class C30 concrete samples characterised by a 50% coarse aggregates replacement ratio (in equivalent volume) were produced. The mixtures were designed by taking into account the main properties of both natural and recycled components, such as grain-size distribution, water absorption capacity and specific mass. Then, an experimental programme was performed to analyse the rheological behaviour and the time evolution of the relevant mechanical properties of concrete made with recycled aggregates (with and without autogenous cleaning) and the results are compared with ordinary concretes.

The experimental activities described in this work were carried out at the Laboratório de Estruturas e Materiais (LabEST) which is part of the Programa de Ingenharia Civil (PEC/COPPE) of the Universidade Federal do Rio de Janeiro (UFRJ), within the framework of the European EnCoRe project on Environmentally-friendly solutions for Concrete with Recycled and natural components (www.encore-fp7.unisa.it).

2 MATERIALS

The key components of the materials used for the production of the concrete samples are described in the following subsections

2.1 Cement

All mixtures considered in this study were produced by using high initial strength cement, denominated by CP V ARI RS according to the NBR 5733 (NBR = National Brazilian Standard) and characterised by a specific mass of 3100 kg/m^3. In terms of mechanical properties, a characteristic value of 25 MPa is foreseen for compressive strength after 3 days, with an expected rise to 55 MPa after 60 days. The grain size distribution analysis of Portland cement used in this study leads to the observation that it is a fine cement chracterised by 95% of its particles smaller than 50 μm and that the diameter corresponding to 50% of the passing particles is 15 μm.

2.2 Natural components

Natural aggregates, made of common crushed limestone, were divided in three size classes according to the local practice:

- *Brita 1*, with a nominal diameter ranging from 19 mm to 9.5 mm;
- *Brita 0*, with a nominal diameter ranging from 9.5 mm to 4.75 mm;
- *Sand*, with a nominal diameter smaller than 4.75 mm.

Moreover, in order to characterise the natural aggregates, both their water absorption and specific weight were evaluated according to the standard procedure proposed by NBR

NM 52 (2003), for fine aggregates (i.e., sand) and NBR NM 53 (2003) for coarse aggregates (i.e., Brita 0 and Brita 1). Table 1 reports the results of the above experimental tests.

Aggregates	***Size***	***Specific mass***	***Water absorption***
	[mm]	***[kg/m^3]***	***[%]***
Sand	d < 4.75	2668	1.40
Brita 0	4.75 < d < 9.5	2688	3.39
Brita 1	19 < d < 9.5	2634	1.28

Table 1: Water absorption after 24 hours and specific weight for natural aggregates

2.3 Recycled concrete aggregates

The recycled concrete aggregates employed in this study were obtained from the demolition remainings of the hospital Clementino Fraga Filho (Rio de Janeiro – BR), whose implosion process is depicted in Figure 1. Materials from the demolition process were selected and analysed by LabEst (COPPE – UFRJ Rio de Janeiro) and the main results of these analyses are reported in Section 3.

Figure 1: Demolition of hospital Clementino Fraga Filho (Rio de Janeiro - BR)

2.4 Superplasticizer

A polycarboxilate superplasticizer, named Glenium 51, was used to control the workability. It is characterised by a specific mass of 1.07 kg/l and a solid concentration of 30%.

3 RECYCLED AGGREGATES PROCESSING AND ANALYSIS

The recycled aggregates received from the demolished hospital were processed in the following steps:

- *particle homogenisation*, with the objective to select homogeneous samples from the demolition debris;
- *grinding and sieving*, aimed at transforming the demolition debris in aggregates of appropriate size classes;
- *autogenous cleaning*, intended at removing the outer cement paste layers residing on the aggregate surfaces.

The first two processes are generally performed on demolition waste to produce RCAs. In addition, the third one was specifically carried out to possibly enhance the quality of RCAs and, with this, the mechanical properties of Recycled Aggregate Concrete (RAC). Thus, several experimental tests were performed on RAC samples to determine their key physical and mechanical properties and possibly compare the results with the corresponding samples made with ordinary natural aggregates, characterised by water absorption, specific mass, grain size distribution and image analysis using photographs.

3.1 Recycled aggregates processing

The first stage of the processing procedure carried out on the crushed concrete particles was based upon collecting and selecting such particles and debris by considering their predominant colour. Therefore, at the demolition site the debris were selected and subdivided in the following two fractions:

- the “gray” fraction, consisting of particles mainly made of structural concrete (and, in a minor portion, mortar) debris;
- the “red” fraction, made of clay brick and other ceramic-based (i.e. tiles) materials .

In this study the focus is mainly on the possible application of the “gray” fraction. Particularly, the homogenisation process was carried out by means of the so-called “cells process” (homogenising cells process), in which the raw material (Figure 2a) is distributed on a plastic sheet in different homogeneous layers throughout the whole length of the sheet (Figure 2b).Thus, the distribution of the raw concrete particles is homogenous over the sheet length and, starting from the middle section, the layers of raw materials are subdivided in several sections called cells (Figure 2c) characterized by a homogenous size distribution of particles.

Figure 2: Homogenisation process

The homogenised material was grinded through a crusher shown Figure 3a. The machine was filled with raw material from the top. During grinding the material was separated in two classes, namely fine (Figure 3c) and coarse aggregates (Figure 3b). For each sample of the homogenised material, about 40% was obtained as coarse aggregates (nominal diameter bigger than 4.75 mm in Figure 3b) and the rest was defined as fine aggregates (sand Figure 3c).

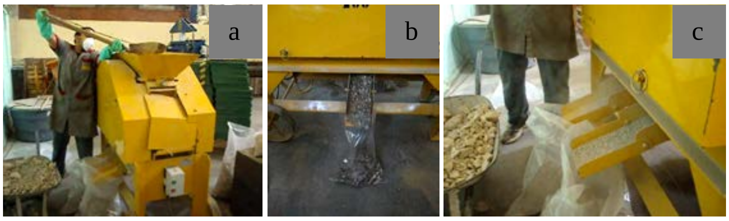

Figure 3: Grinding process with crusher.

After grinding, the recycled aggregates were sieved to divide the material in the three size classes already defined in Subsection 2.2. With the aim of reducing the amount of fine materials (mainly debris from cement paste and mortar) attached to the surface of recycled aggregates, an *autogenous cleaning* process was conceived and performed. This process led the particles rotating in a mill drum and colliding against each other. Consequently, cleaning their surface was realized successfully as part of the attached impurities were removed. The mill drum, 30 cm in diameter and 50 cm in height (Figure 4b), was filled up to the 33% with raw recycled aggregates and the rotation rate was imposed to be 60 rotations/minute (Figure 4c).

Figure 4: Autogenous cleaning

The efficiency of this autogenous cleaning process was analysed by investigating how it actually modified the key physical properties of the particles after different durations of the cleaning process (ranging from 2 to 15 minutes). To have a preliminary understanding of the possible efficiency of this process, some preliminary autogenous cleaning trials were performed on raw concrete particles (i.e., not homogenised). The effect of such trial procedures was "measured" by determining the water absorption capacity of the same particles after different "cleaning" durations. Figure 5 reports the average values of the water absorption capacity measured from tests performed on recycled concrete particles which were preliminarily classified as Brita 0 and Brita 1 (see Subsection 2.2). The graph proposed in Figure 5 demonstrates the significant decrease in terms of water absorption capacity observed from the recycled concrete particles when cleaning for a duration ranging from 2 to 10 or 15 minutes. These preliminary findings also determined the choice for the autogenous cleaning duration of the homogenised particles to the two cases of 10 and 15 minutes.

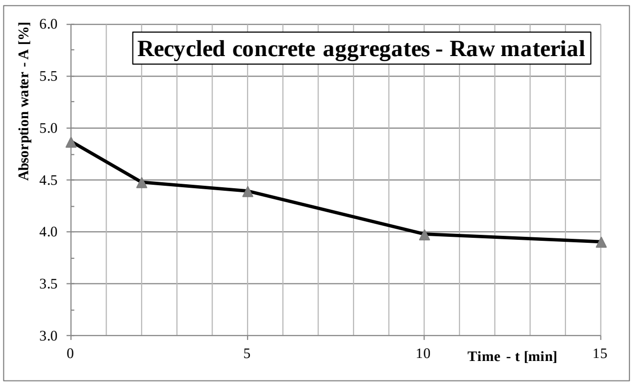

Figure 5: Autogenous cleaning results on raw material

3.2 Analysis on RCA

The first tests performed to “measure” the efficiency of the autogenous cleaning process on the concrete particles were carried out to determine water absorption and specific mass, performed according to NBR NM 53 (2003) for coarse aggregates (i.e., Brita 0 and Brita 1). Figure 6 reports the results of the water absorption tests. It can be seen from the figure that the implemented cleaning process led to a significant decrease in water absorption capacity, as a result of the removal of outer cement paste layers and fine mortar attached at the outer surface of raw concrete particles, and the consequent reduction of the voids percentage. In fact, the results highlight that after the autogenous cleaning procedure, the amount of absorbed water was reduced by 50% and 20% for Brita 0 and Brita 1, respectively.

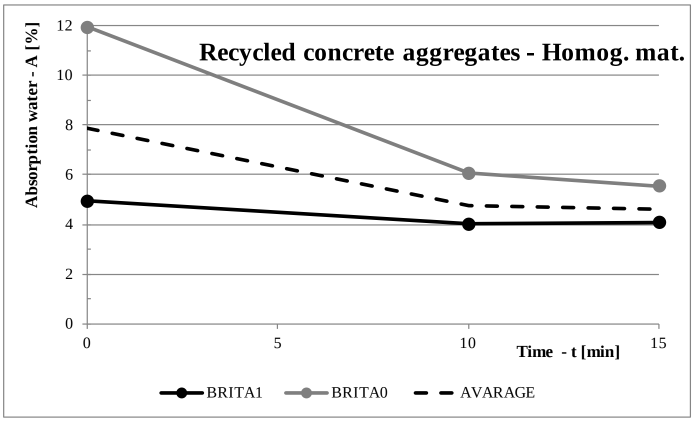

Figure 6: Water absorption (%) at 24 hours weight of recycled aggregates

Moreover, the above observations were also confirmed by the measurements of the specific mass on the processed particle samples. Table 2 provides an overview of the potential of the autogenous cleaning procedure considered in this study to transform crushed concrete particles into cleaned recycled concrete aggregates.

Aggregates	Size[mm]	Autogenous cleaning [min]	Specific mass [kg/m^3]	Water absorption [%]
Brita 0	4.75 < d < 9.5	0	2535	11.94
		10	2566	6.06
		15	2586	5.56
Brita 1	9.5< d < 19	0	2268	4.94
		10	2358	4.01
		15	2328	4.09

Table 2: Water absorption (%) at 24 hours and specific weight of recycled aggregates

Another interesting evidence of the autogenous cleaning efficiency was obtained from the grain size distribution, throughout the sieving analysis realised according to the NBR NM 248 (2003). Figure 7 shows that the cleaning process leads to an increase of the amount of fine particles. Thus, it confirms the results of the previous tests and point out that a significant part of the outer layers of the crushed concrete particles were actually removed and transformed into very small particles, which could possibly be employed to improve the aggregate particle packing of concrete mixtures with recycled aggregate replacements.

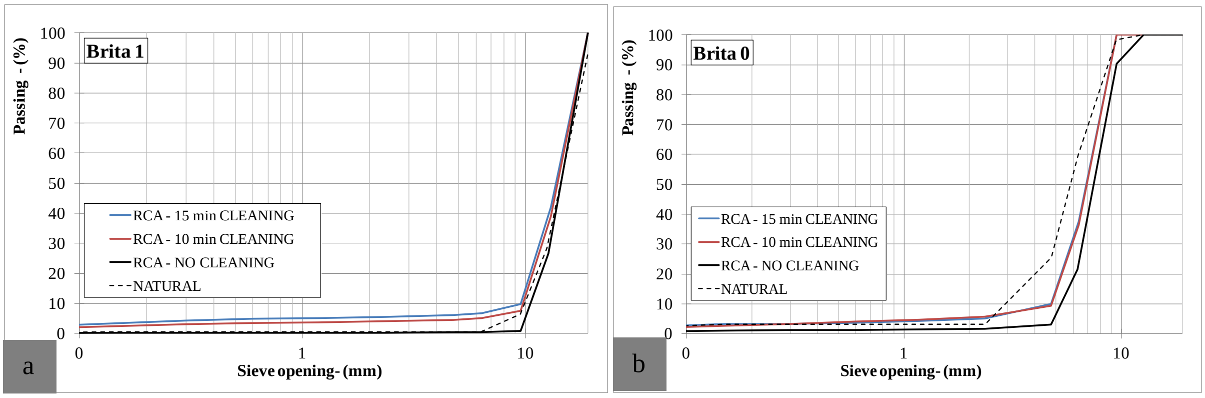

Figure 7: Grain size distribution comparison for natural and recycled aggregates.

A final assessment of the actual effectiveness of the autogenous cleaning procedure can be obtained through a comparative visual analysis. Pictures of concrete particles are taken after the three different durations of cleaning and are reported in Figure 8. The pictures show that the autogenous cleaning process not only removes the cement paste residuals possibly attached at the aggregate surface, but also modifies the final shape of recycled aggregates. Particularly, Figure 8 shows that the particle surface colour, roughness and shape evolved as a result of the autogenous cleaning procedure, with a clear modification of these characteristics after 15 minutes.

Figure 8: Image analysis using photographs

4 MIX DESIGN AND EXPERIMENTAL PORGRAMME

4.1 Mix design and casting procedure

Based on results obtained so far from the crushed concrete particles processed to recycled aggregates, three mixes were designed to analyse the different behaviour of concrete made with recycled aggregates with different amounts of replacement. Particularly, a reference mixture, named MIX0, was made with all natural components. Moreover, two mixtures, denoted as RAC50NC and RAC50C, were designed by replacing 50%, of natural coarse aggregates with recycled ones without cleaning and with 15 minutes of autogenous cleaning, respectively.

All batches were produced by using 300 kg/m^3 of cement and 160 litres of free water with the aim of keeping the free water constant at a w/c ratio of 0.53. To compensate for the water absorption of both the dried recycled and natural aggregates, additional water was poured during the mixing process in the mixes taking into account the values of water absorption test reported in the previous sections. Table ~~3~~ shows the compositions of the concrete mixtures considered in the following experimental activities. The different mixtures were produced according to the following procedure. In the first step, sand, fine and coarse aggregates were added to the mixer and mixed for 90 seconds; then, the cement was added and mixed for further 90 seconds. In the following step, 70% of the total water amount was added to the aggregate blend before adding it to the mixture, and then this blend was mixed for one minute; then, the superplaticizer and the rest of water was added, and mixing proceeded further for another 10 minutes. Finally, a slump test was performed and the concrete was cast in steel cylinders. After one day the specimens were demoulded and the concrete placed in a water cured room (21°C) up to perform the compressive strength test.

MIX	**Cement** [kg/m^3]	**Water** [kg/m^3]	**Added Water** [kg/m^3]	**w/c**	**Superplast.** [kg/m^3]	**Natural Components**			**RCA without cleaning**		**RCA with cleaning**	
						Sand [kg/m^3]	**Brita 0** [kg/m^3]	**Brita 1** [kg/m^3]	**Brita 0** [kg/m^3]	**Brita 1** [kg/m^3]	**Brita 0** [kg/m^3]	**Brita 1** [kg/m^3]
0	300	160	31.4	0.53	4.02	952.6	439.9	470.2	-	-	-	-
RAC50NC			71.8			950.4	-	-	346.6	404.0	-	-
RAC50C			49.9			951.3	-	-	-	-	403.1	415.1

Table 3: Mix design

5 MECHANICAL AND RHEOLOGICAL BEHAVIOUR

5.1 Properties of concrete on fresh state

The properties of fresh concrete were investigated through a slump test. Slump tests were performed on samples for the various mixes under consideration, according NBR NM 67. The slump test results are reported in Figure 9 and clearly highlight the effect of the autogenous cleaning process. First of all it is worth to mention that a higher slump value was observed for the mix with unprocessed recycled aggregates (Mix RAC50NC) with respect to the corresponding reference mix (MIX0). This largely depends on the fact that the same amount of superplasticizer was added to all mixtures, whereas the absorption compensation water was added while based on the water absorption tests carried out on aggregates after 24 h of absorption time. As a matter of fact, the recycled aggregates in the concrete mix cannot absorb such an amount of water in a short period time. Since the mixing process is much shorter than the absorption time, the remaining part of the water just modifies (increases) the water content (and the w/c ratios) and leads to an increase in workability (and a decrease in compressive strength). Thus, such a higher amount of free water available in Mix RAC50NC, led to slump values significantly higher than those corresponding to the reference mix. Further investigations are needed to better understand the role of added water in RACs and, possibly, to achieve a sound definition of such a key parameter. The same effect is observed for the mix with processed (cleaned) aggregates (MIX RAC50C), whose lower water absorption capacity required a lower amount of added compensation water and, led to lower slump values.

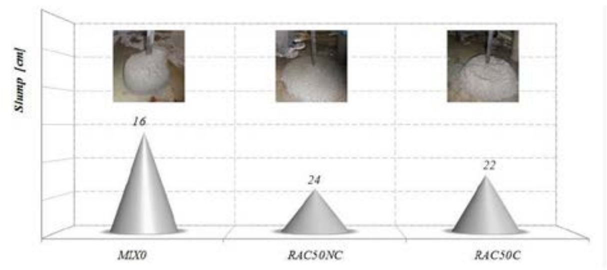

Figure 9: Slump test results

5.2 Properties of concrete on hardened state

The compressive strength of concrete mixtures was determined at the age of 2, 7, 14, 28 and 60 days according to the NBR 5739 on cylindrical specimens with a nominal diameter of 100 mm and a height of 200 mm. Figure 10 reports the results of the compression tests. The samples of MIX0 present a compressive strength after 28 days of 33.02 MPa and, with ongoing evolution of the hydration process a compressive strength 37 MPa was reached at an age of 60 days.

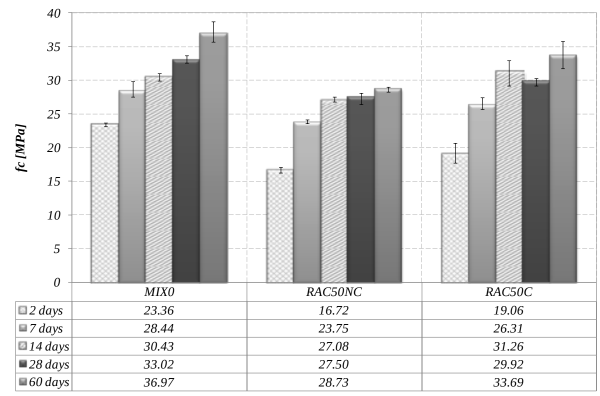

Figure 10: Compressive strength test results

A significant reduction in compressive strength (around 20%) was measured for of Mix RAC50NC. This is probably due to both a weaker quality of coarse aggregates used in the mix, but also due to a higher amount of absorption compensation water that increased the effective value of the w/c ratio, which was already observed before in terms of workability and rheological properties. However, the beneficial effect of the autogenous cleaning process clearly emerges by analysing the compressive strength results obtained for MixRAC50C, where a significantly smaller reduction was measured.

6 CONCLUSIONS

The experimental results reported in this paper point out the key (and often underrated) influence induced by the processing procedures on the physical and mechanical properties of RACs.

Particularly, the following considerations can be remarked:

− the autogenous cleaning process implemented at the laboratory scale led to interesting results in terms of enhancement of the properties of crushed concrete particles, especially in terms of water absorption capacity;
− the refined absorption tests carried out on the processed aggregates and the characterisation in terms of rheological parameters of the resulting fresh concrete paste emphasized the actual influence of absorption water on the physical and mechanical properties of RACs;
− the results obtained in terms of uni-axial compressive strength showed a positive effect of the autogenous cleaning process on the RAC samples as tested in this experimental programme.

Finally, it is worth mentioning that scaling up the amount of particles and the dimensions of the mill drum can have a significant effect on the actual effectiveness of the processing procedures investigated in this work. The experimental results reported herein pointed out the potential of the autogenous cleaning process: a pilot application at industrial scale should be conducted to confirm same effects.

REFERENCES

Corinaldesi V. (2010), *Mechanical and elastic behaviour of concretes made of recycled concrete coarse aggregates*, Construction and Building Materials, Vol.24(9), 1616–1620, September 2010.

Etxeberria M., Vázquez E., Marí A., Barra M. (2007), *Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete,* Cement and Concrete Research 37 (2007) 735–742

Evangelista L., de Brito J. (2007), *Mechanical behaviour of concrete made with fine recycled concrete aggregates*, Cement and Concrete Composites, Vol.29(5), 397-401, May 2007.

Kwan W.H., Ramli M., Kam K.J., Sulieman M. Z. (2011), *Influence of the amount of recycled coarse aggregate in concrete design and durability properties,* Construction and Building Materials, Vol.26(1), 565–573, January 2012.

Malešev M., Radonjanin V., Marinković S. (2010), *Recycled Concrete as Aggregate for Structural Concrete Production,* Sustainabilty-open acces journal, April 2010.

Xiao J., Li J., Zhang C., (2005) *Mechanical properties of recycled aggregate concrete under uniaxial loading* , Cement and Concrete Research, Vol.35(6),1187-1194, June 2005.

Yong P.C., Teo D.C.L. (2009), *Utilisation of Recycled Aggregate as Coarse Aggregate in Concrete,* UNIMAS E-Journal of Civil Engineering, AUGUST 2009, Vol.1(1). March 2009.

NBR NM 52: *Agregado miúdo - Determinação da massa específica e massa específica aparente*.

NBR NM 53: *Agregado graúdo - Determinação de massa específica, massa específica aparente e absorção de água*.

NBR NM 67: *Concreto - Determinação da consistência pelo abatimento do tronco de cone*.

NBR NM 248: *Agregados - Determinação da composição granulométrica*.

NBR 5739: *Concreto - Ensaio de compressão de corpos-de-prova cilíndricos*.

Ogawa H. and Nawa T. (2012), *Improving the quality of recycled fine aggregates by selective removal of brittle defects,* Journal of advanced concrete technology vol.10, 395-410, December 2012.

SUSTAINABLE CONSTRUCTION: RELIABLE FORECASTING FOR BUILDING CONSTRUCTION PRICES

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Abstract: *A reliable forecasting for future construction costs or prices would help to ensure the budget of a construction project can be well planned and limited resources can be allocated more appropriately in construction firms. Although many studies have been focused on the construction price modelling and forecasting, few researchers have considered the impacts of the global economic events and seasonality in price modelling and forecasting. In this study, an advanced multivariate modelling technique, namely the vector correction (VEC) model with dummy variables was employed and the impacts of the global economic event and seasonality were factored into the forecasting model for the building construction price in the Australian construction market. Research findings suggest that a long-run equilibrium relationship exists among the price, levels of supply and demand in the construction market. The reliability of forecasting models was examined by mean absolute percentage error (MAPE) and The Theil's inequality coefficient U tests. The results of MAPE and U tests suggest that the conventional VEC model and the VEC model with dummy variable are both acceptable for forecasting building construction prices, while the VEC model that considered external impacts achieves higher prediction accuracy than the conventional VEC model does.*

1 INTRODUCTION

Modelling and forecasting prices in the construction market are essential for relating construction statistics in resource usage, cost management and analysis, as the variation of the construction price could affect the decisions of construction developers, clients, property investors and financial institutions. More importantly, the ability to forecast construction price trends can result in more accurate bids and can avoid under- or over-estimation in the construction projects. The fluctuation of construction prices is mainly caused by the changes of market conditions in terms of the demand and supply of construction works (Wong and NG 2010). Changes in construction prices are not only affected by the variation of market conditions, but also affected by other factors such as government policies and special global events. Global events such as the 1997 Asian financial crisis and the SARS outbreak influenced demand and price for construction significantly in Hong Kong and Singapore (Hua 2005; Fan et al. 2010). Fluctuations in the construction market may be due to changes in local economic conditions, and future price for construction may be not hard to predict as it follows a slight upward movement. However, the combined effect of the market cycle and global economic events on the price for the construction market is indeed more difficult to forecast. A dramatic change in the global economic environment such as the recent global financial tsunami would further increase the uncertainty. Therefore, a more reliable forecast of building construction price would help construction developers, contractors and investors to make appropriate decisions that could ensure budget, limited resources and financial commitments can be well planned during this global recession and help to develop the construction industry in a more sustainable manner.

Many techniques have been developed to model and forecast price in the construction market, such as Box-Jekins technique, one of most commonly used univariate method, was applied by Hua and Pin (2000) to forecast construction demand, price and productivity and Wong et al. (2007) in construction labour demand. Akintoye and Skitmore (1993) modeled construction price by a linear multi-regression model with the market demand and supply equilibrium. However, very little research, yet, has been done to analyse the effects of the recent global financial crisis on the price of the construction market. Whether disturbances by crises should be involved in the modelling of construction price or not has never been discussed. The recent global financial crisis happened in the late 2000s and is considered by many economists to be the worst financial crisis since the Great Depression of the 1930s (Jiang and Liu 2011). The Australian economic was injured deeply in the crisis. The recent global financial tsunami also triggered unexpected shock waves to the Australian construction market. The Australian construction approvals shrank by almost one-third in March 2009 as compared to its peak in March 2008, while construction prices and house prices declined by 3% and 6% respectively between March 2008 and March 2009. Except the effects of special economic events, the construction price also may be affected by seasonal effects. The seasonal changes of construction demand caused seasonality in the construction price has been approved and the increased demand in autumn can lead rise in price level also was observed in Canada (Skitmore et al. 2006). Consequently, the effects of seasonality on the construction price will be estimated in the price modelling and forecasting.

The negative effects of the recent financial crisis on the construction market have been well recognized. Hence, analysing the dynamic effects of the recent crisis on the construction market and forecasting the movement of building construction price after the crisis are very important. In this study, the external impacts from the recent financial crisis and seasonality on the construction market were considered in the price modelling. An advanced multivariate regression modelling technique, the vector error correction model with dummy variables, was adopted to predict price in the building construction market and the long-run relationship between price-levels and market conditions was estimated. The reliability of the VEC model with dummy variables was verified against various validation tests and prediction accuracy tests, and then compared with conventional VEC model for identifying a more reliable forecasting technique for the construction price.

2 THE MODEL DEVELOPMENT

The structure of the construction market and the nature of the process leads the level of price more to market-oriented than cost based (Skitmore et al. 2006). When the construction market at a high price, a lower level of construction will be demanded than at lower price and vice versa, while the higher the price in construction the greater level of supply will be offered and vice versa. In a competitive market, the construction prices are determined by the demand

and supply and the model of construction price is derived from the construction demand and supply interaction (Akintoye and Skitmore 1993). The interaction can be expressed as follows:

where is the construction price at time *t*, and are the levels of demand and supply in the construction market at time *t*.

2.1 The conventional vector error correction model

The vector error correction model is a combination of the vector autoregressive model and co-integration restrictions. Cointegration, an econometric property of time series variables, is generally used to estimate the long-run relationships between non-stationary variables. If the level of time series data is not stationary but a linear combination of variables is stationary after an initial difference, then the series can be said to be co-integrated to the order one or (1). They will tend to come back to the trend in the long run, even though they deviate from each other in the short run. A prior condition for the cointegration test is that all the variables should be integrated in the same order or contain a deterministic trend (Engle and Granger 1991; Luo et al. 2007; Jiang et al. 2011). A unit root test is conducted for each variable by using the Augmented Dickey-Fuller (ADF) unit root test and the Phillips-Perron (PP) unit root test which were introduced by Dickey and Fuller (1979) and Phillips and Perron (1988) respectively.

The conventional vector error correction (VEC^c) model employed by Jiang and Liu (2011) is represented in Equation (2).

where are the independent (1) variables being integrated to an (0) vector, C is the intercept, is the matrix which reflects that the short-run dynamic relationship between the elements of , and is residual. = ( ), is the lag operator, *k* is the number of lags, while is the matrix containing long-run equilibrium information. If the elements of are (1) variables and co-integrated with rank ($= r < p$, then the rank of can be rewritten as , is the error correction term and is stationary. This implies that there exist $r < p$ stationary linear combinations of . is a vector of cointegration relationships and is a loading matrix defining the adjustment speed of the variables in *Y* to the long-run equilibria defined by the co-integrating relationships.

The Johansen cointegration test was introduced by Johansen and Juselius (1990) who conducted the multivariate maximum likelihood approach in order to reveal the number or cointegration equations without using arbitrary normalisation rules. The lag length of the VEC model is selected for a time series in VAR modelling on the basis of the sequential modified likelihood ratio test (LR) statistic, final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SC) and Hannan-Quinn information criterion (HQ). The test results of the lag length selection are then inputted into the Johansen cointegration test to construct the VEC models with different combinations between construction demand

and each economic indicator. Once all variables are proved to be stationary and co-integrated, a vector error correction model can be formulated.

2.2 The VEC model with dummy variables

The VEC model containing exogenous variables was earlier used by Ramey (1993) for analyzing the effect of seasonality and monetary-policy disturbance on the money market. Based on Equation (2), the VEC model with dummy variables (VEC^d) can be represented in Eq. (3).

where is dummy variable *j* at time *t*, *N* is the number of endogenous variables, *n* is the number of dummy variables, are vectors. In this study, the interventions of the recent global financial crisis and seasonality have been considered, hence $n = 2$. The one-off event dummy is an exogenous variable which indicates the presence or absence of the intervention in the variation of construction price. The intervention remains at 1 for the duration of the presence of the event otherwise the intervention is 0 during the period of the absence of event. The first sign of deterioration in Australia's construction market was in the second half of 2008 when the construction price and approvals for construction declined over 3% and 29% respectively during these six months. At the same time, the government announced it would guarantee all bank deposits, and an economic stimulus package worth AUD 10.4 billion was announced. In this package, AUD 1.5 billion was allocated to support housing construction. This announcement could be considered as an ideal indicator that denoted when the financial crisis started to affect the Australian economy. Though a series of effective boost strategies, the approvals of Australian construction industry reach the same level in the September quarter of 2009 as the beginning of the global financial crisis. The price-levels in the construction market started to goes up steadily from the September quarter of 2009 while Australian Government was able to announce that the economy of Australia had recovered from the late 2000s global financial crisis (Henry 2009). Indeed, the period of the late 2000s global financial crisis that affected the Australian economy can be defined as starting in September 2008 and finishing in September 2009.

2.3 Techniques for evaluating prediction accuracy

After constructing the two prediction models, serial correlation Lagrange multiplier tests (LM), White's heteroskedasticity test (White), and Jarque-Bera normality test (Jarque-Bera) were conducted to verify the standard assumptions on, residual correlation, heteroskedasticity, and normality respectively. Then, the out-of-sample testing was carried out to test the prediction reliability for the conventional VEC model and the VEC model with dummy variables. The prediction accuracy was estimated by comparing the predicted values with the actual values. The two testing techniques mainly used for estimating forecasting reliability were conducted; the mean absolute percentage error and the Theil's inequality coefficient *U*. The characteristics of these measures have been elaborated in other studies such as (Jiang and Liu 2011). Generally, any result of the MAPE test smaller than 10% is considered as acceptable, while the closer the Theil's inequality coefficient *U* value is to 0 the better the prediction results achieved.

3 DATA COLLECTION

All the quarterly data series contained in this study was adapted from the Australian Bureau of Statistics (ABS) in the period of September 1996 to March 2011. The data series from September 1996 to June 2009 were used to develop forecasting models. The last seven data points, seven quarters, were retained to evaluate the accuracy of the forecasting models. Furthermore, the data series from September 2008 to June 2009 were used to undertake an intervention analysis to analysis the impact of the recent global financial crisis on the construction market in Australia. The construction price is an economic data which can be surveyed and measured in many ways. The producer price index (PPI) of the construction industry is one of them and is commonly applied as a measure of construction price. The output building construction producer price index was adopted as the building construction price for the Australian construction market. The output building construction producer price index, a significant element helping to reflect price movement for the construction industry, measures changes in prices of the outputs to the construction industry which is the builder selling price (Australian Bureau of Statistics 2011).

The value of construction approvals has been used to represent the demand in the construction market because it is an indicator of changes in the level of construction demand (Hua 2005). In this study, the value of building construction approvals was adopted to represent the level of demand in building construction because it can be explained as the total monetary cost of the construction work that clients are able and will be able to purchase in a given period. The value of building construction completion was abstracted to represent the level of supply in construction because it is the total money amount of products in the construction market that suppliers can provide in a given period. Value of construction completion has been adopted in the study of Malpezzi and Maclennan (2001) to represent the level of supply in the construction market. The construction producer price index, value of construction approvals and completions from September 1996 to March 2011 is shown in Figure. 1, which shows a clear V-shape both in the construction producer price index and the value of construction approvals in the building construction industry during the recent financial tsunami.

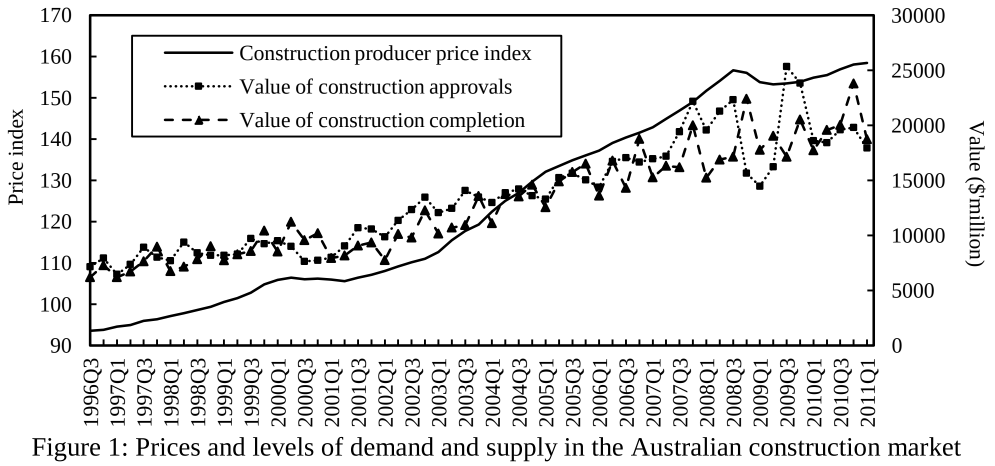

Figure 1: Prices and levels of demand and supply in the Australian construction market

4 EMPIRICAL RESULTS

4.1 Long-run relationship estimation

Following the model development approach, the ADF and PP unit root tests were conducted to determine the integrated order of the series. The results were summarized in Table 1 and suggest that all the variables were stationary after the first difference at the 0.01 and 0.05 significance levels. Thus, the construction producer price index, value of building construction approvals and completions are integrated of order one, i.e. *I(1)*. Based on the VAR lag length selection system, the smallest values of the LR FPE, AIC, SC and HQ tests indicate that the lag length for the VEC models was three.

Variables	ADF unit root test				PP unit root test			
	Level		First difference		Level		First difference	
	T-Stat	P-value	T-Stat	P-value	T-Stat	P-value	T-Stat	P-value
CP	-1.85	0.67	-3.27	0.02*	-1.66	0.75	-3.27	0.02*
CD	-1.50	0.53	-8.91	0.00**	-1.31	0.62	-10.93	0.00**
CS	-0.97	0.76	-10.96	0.00**	-1.82	0.37	-32.57	0.00**

** denotes rejection of null hypothesis of unit root based on their P-value at the 0.05 significance level*
*** denotes rejection of null hypothesis of unit root based on their P-value at the 0.01 significance level.*

Table 1: Results of unit root tests

After that, Johansen cointegration test was carried out to test long-run relationships among variables in the VEC system and the results are summarised in Table 2. The results of the trace statistics indicate that each variable in has a linear trend with an intercept but the construction price has no trend in the co-integrating relation, while there is no more than one cointegrating relationship. It reveals that the value of building construction approvals and completions have a strong influence on the building construction price index in the long-run and the cointegration equation can be written in Equation (4).

Indeed, the deterministic trend in model three and one cointegration relationship were identified and implemented into the VEC models. The coefficient estimates in the equilibrium relation confirm that the increases in demand will pull the construction price rise and the price fall when the supply increases in the long-run.

Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	5% critical value	P-value
None *	0.42	46.99	35.19	0.00
At most 1	0.24	19.02	20.26	0.07
At most 2	0.09	4.79	9.16	0.31

*The asterisks * denote rejection of the hypothesis at the 0.05 level.*

Table 2 Johansen cointegration tests among construction prices, demand and supply

4.2 Model estimation and validation

Cointegration tests have identified a long-run relationship among the construction price, the levels of supply and demand in construction, while the conventional VEC model and the VEC model with global event and seasonal dummy variables were constructed based on Equations (2) and (3) respectively. The estimates of the conventional VEC model and the VEC model with dummy variables for the construction price were reported in Table 3. The specifications of two VEC models show that the construction price is affected by the levels of supply and demand in the long-run. In addition, the lagged price and level of demand in construction play significant roles to explain the price variation, while the lagged level of supply cannot affect the movement of the construction price in the short-term. The conventional VEC model and the VEC model with the global event and seasonal dummy variables were examined for their model fit based on the values of R-squared, Sum square residue, S.E equation and Log likelihood. The VEC model with dummy variables has a higher R-square value with 0.65 than the conventional VEC model with 0.60. This suggests that approximately 65% of the variations in the Australian construction price could be captured by the VEC model with dummy variables.

The global financial crisis dummy variable performs a negative coefficient in the model with -0.1, which confirms that building construction price in Australia received a negative impact from the recent global financial crisis. Furthermore, a positive significant seasonal impact was found in the Australian construction market on the price level in the third quarter each year with coefficient 0.04. Contractors and property investors are suggested to have a strategic placement of contracts or portfolio on the market to avoid the seasonal price peak in Australia.

Models	VEC[c]			VEC[d]		
Variables						
	1			1		
	1.65 (3.57)***			1.67 (2.82)***		
	-2.47 (-5.25)***			-2.48 (-4.44)***		
C	0.05 (0.86)			0.04 (1.06)		
CointEq1	0.01 (0.25)			0.01 (0.21)		
	2.64			2.60		
				-0.10 (-2.20)**		
				0.04 (1.71)**		
Error correction	*t*-1	*t*-2	*t*-3	*t*-1	*t*-2	*t*-3
	-0.55 (3.33)***	-0.06 (-0.34)	0.30 (1.68)*	0.48 (2.91)***	-0.18 (-0.98)	0.33 (1.85)**
	0.04 (2.86)***	0.02 (1.54)*	0.03 (2.45)**	0.02 (2.08)**	0.01 (1.12)	0.03 (2.72)***
	-0.01 (-1.13)	0.00 (0.12)	0.00 (1.06)	-0.00 (-0.78)	0.01 (1.00)	0.01(0.73)
R-squared	0.60			0.65		
Sum sq. residue	0.01			0.01		
S.E. equation	0.00			0.01		
Log likelihood	186.59			193.76		

** denotes t-statistics significant at 0.1 level;** denotes t-statistics significant at 0.05 level; *** denotes t-statistics significant at 0.01 level.*

Table 3 Estimation results via the VEC model and the VEC model with dummy variables

Validation tests include serial correlation Lagrange multiplier tests, White's test heteroskedasticity, and Jarque-Bera normality test were carried out to verify the assumptions of statistical soundness for the conventional VEC model and VEC model with dummy variables. The results of model validation were summarized in Table 4, which indicates that the two VEC models passed all validation tests at the 5% significant level. Therefore, there is no significant departure from the standard assumptions for two VEC models.

Modelling technique	VEC^c	VEC^d
LM(4)	15.13 (0.88)	14.43 (0.11)
LM(8)	8.61 (0.47)	12.21 (0.20)
LM(12)	7.95 (0.54)	9.16 (0.42)
White	131.22 (0.23)	136.01 (0.39)
Jarque-Bera	5.99 (0.42)	9.93 (0.13)

Note: LM(p) is the Lagrange multiplier test for residual serial correlation with p lag length; White is White's test for heteroskedasticity; Jarque-Bera is the Jarque Bera test for normality of the residuals; figures in parentheses denote probability values.

Table 4 Model validation

The MAPE and Theil's inequality coefficient *U* were employed to evaluate the predictive ability of the two models. The predictive adequacy of the two forecasting models was further evaluated by comparing them with the actual building construction price index over the forecasting period as shown in Table 5. The values of the MAPE test of the two models are both less than 10% absolute percentage error and the coefficients *U* are all close to 0, which indicates that the conventional VEC model and the VEC model with dummy variables both perform excellent in for predicting the construction price. Furthermore, the results of the evaluation of prediction accuracy suggest that the VEC model with event and seasonal dummies gives a slight better prediction result in construction price forecasting compared with the conventional VEC model by achieving a lower MAPE and Theil's inequality coefficient *U* statistics i.e. 0.61% and 0.0036 respectively.

Period	Actual price index	Predicted price index			
		VEC^c	Percentage error	VEC^d	Percentage error
2009Q3	153.50	151.78	-1.12%	151.81	-1.10%
2009Q4	153.90	155.80	1.23%	154.23	0.22%
2010Q1	154.90	155.36	0.30%	154.68	-0.14%
2010Q2	155.50	156.59	0.70%	157.04	1.00%
2010Q3	156.90	154.73	-1.38%	155.48	-0.91%
2010Q4	158.10	156.23	-1.18%	156.82	-0.81%
2011Q1	158.50	159.13	0.40%	158.66	0.09%
		MAPE =	0.90%	MAPE =	0.61%
		U =	0.0049	*U* =	0.0036

Table 5 Evaluation of the construction price forecasts generated by the conventional VEC model and the VEC model with dummy variables

5 CONCLUSIONS

In this study, the long-run relationship among building construction prices and levels of supply and demand was involved in the proposed models. Furthermore, the impact of the late 2000s global financial crisis and seasonality were developed as dummy variables which were factored in the forecasting model to evaluate the dynamic effects of the recent crisis and seasonality on the variation of the building construction price. The assessments of the predictive performance of two forecasting models were conducted by the out of sample forecasts during the September quarter 2009 and the March quarter 2011. The findings of this study can be summarized as follow:

1) The result of long-run estimation confirmed a long-run relationship among construction prices and levels of supply and demand, which indicated that although the construction price, supply and demand may move divergingly in the short-run; it will come back and reach equilibrium in the long-run.
2) The estimation results of the event dummy variable revealed that the effect of the late 2000s global financial crisis on the price for construction was negative and statistically significant. Seasonal effects also have been confirmed according to the estimates of the forecasting models.
3) The reliabilities of both the conventional VEC model and VEC model with dummy variables have been proved in the building construction price prediction, while a better prediction performance can be achieved by inserting dummy variables into the conventional VEC model to involve the dynamic impact of special global events and seasonality in the forecasting model. With increasing energy and waste costs, tougher economic environment and increased stakeholder expectations, delivering building and construction projects in a more resource efficient and sustainable way has become the top priority for the construction industry. A reliable forecasting for the future prices of construction would assist to achieve this goal.

REFERENCES

Australian Bureau of Statistics. *Producer Price Indexes: Australia cat. no. 6427.0*, Australian Bureau of Statistics, Canberra, (2011).

A. Akintoye, and M. Skitmore, “Macro models of UK construction prices”, *Civil Engineering Systems*, **10**, 279-299 (1993).

D. A. Dickey, and W. A. Fuller, “Distribution of the Estimators for Autoregressive Time Series With a Unit Root”, *Journal of the American Statistical Association*, **74**, 427-431 (1979).

G. B. Hua, “The dynamic effects of the Asian financial crisis on construction demand and tender price levels in Singapore”. *Building and Environment*, **40**, 267-276 (2005).

G. B. Hua, and T. H. Pin, “Forecasting construction industry demand, price and productivity in Singapore: the Box-Jenkins approach”, *Construction Management and Economics*, **18**, 607-618 (2000).

H. Jiang, and C. Liu, “Forecasting construction demand: A vector error correction model with dummy variables”, *Construction Management and Economics*, **22**, 969-979 (2011).

H. Jiang, Y. Song, and C. Liu, “House Price Bubble Estimations in Australia's Capital Cities with Market Fundamentals”, *Pacific Rim Property Research Journal*, **17**, 132-156 (2011).

J. M. W. Wong, A. P. C. Chan, and Y. H. Chiang, “Forecasting construction manpower demand: A vector error correction model”, *Building and Environment*, **42**, 3030-3041 (2007).

J. M. W. Wong, and S. T. NG, “Forecasting construction tender price index in Hong Kong using vector error correct model”, *Construction management and Economics*, **28**, 1255-1268 (2010).

K. Henry, *The Global Financial Crisis and the Road to Recovery*, The Treasury of Australian Government, Canberra, (2009).

M. Skitmore, G. Runeson, and X. Chang, “Construction price formation: full-cost pricing or neoclassical microeconomic theory?”, *Construction Management and Economics*, **24**, 773-783 (2006).

P. C. B. Phillips, and P. Perron, “Testing for a unit root in time series regression”, *Biometrika*, **75**, 335-346 (1988).

R. F. Engle, and C. W. J. Granger, *Long-run Economic Relationships: Readings in Cointegration*, OXford University Press, New York, (1991).

R. Y. C. Fan, S. T. Ng, and J. M. W. Wong, “Reliability of the Box-Jenkins model for forecasting construction demand covering times of economic austerity”, *Construction Management and Economics*, **28**, 241-254 (2010).

S. Johansen, and K. Juselius, “Maximum likelihood estimation and inference on cointegration -- with applications to the demand for money”, *Oxford Bulletin of Economics and Statistics*, **52**, 169-210 (1990).

S. Malpezzi, and D. Maclennan, “The long-run price elasticity of supply of new residential construction in the United States and the United Kingdom”, *Journal of Housing Economics*, **10**, 278-306 (2001).

V. Ramey, “How important is the credit channel in the transmission of monetary policy?”, *Carnegie-Rochester Conference Series on Public Policy*, **39**, 1-45 (1993).

Z. Luo, C. Liu, and D. Picken, “Granger causality among house price and macroeconomic variables in Victoria”, *Pacific Rim Property Research Journal*, **13**, 234-256 (2007).

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ENVISIONING THE FUTURE PATHWAYS FOR RESPONSIBLE SOURCING IN THE UK CONSTRUCTION INDUSTRY

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Abstract. *The management of sustainability objectives through the supply-chain of construction products and materials is termed as responsible sourcing (RS). In the UK, since 2008, RS standards have been established and now many products and materials suppliers are able to offer certified 'responsibly-sourced' products. Such an initiative is seen as evidence of organizational responsibility in the construction industry and has gained high levels of legitimacy among certain leader businesses and sectors, but broader uptake has remained somewhat elusive. Since 2010, the APRES network project (http://apres.lboro.ac.uk) has been investigating this space, for example, benefits of RS, training needs of SMEs, relationships with other certification routes and RS legitimation strategies. The culmination of the APRES project will be the publication of a visioning report which maps the future pathways towards greater engagement in RS across the broader UK construction sector. The initial underpinning data for the report was obtained during a joint industry-academic workshop held in November 2012. This was undertaken using Open Space Technology (OST) and involved 25 participants from a range of organisations, including client, contractors, product manufacturers and selected academic experts. This paper explains the background to RS, describes the workshop process and presents the key findings. It concludes that the four factors that are most likely to influence institutionalization of RS in the future are regulation, standardization, involvement of the upstream value chain and procurement practices. These factors are to be investigated further prior to publication of the visioning report later in 2013.*

1 INTRODUCTION

The management of sustainability objectives through the supply-chain of construction products and materials is termed as responsible sourcing (RS). In the UK, since 2008, RS standards have been established and now many products and materials suppliers are able to offer certified 'responsibly-sourced' products. Such an initiative is seen as evidence of organizational responsibility in the construction industry and has gained high levels of legitimacy among certain leader businesses and sectors, but broader uptake has remained somewhat elusive. As part of the Action Programme for Responsible Sourcing project, funded by EPSRC, a collaborative visioning workshop was held in 2012, using the Open Space Technology method, to identify the key influencing factors that may determine the future success of RS and hence characterize the pathways for its broader adoption in the industry. This paper explains the background to RS, describes the workshop process and presents the key findings. It concludes that four factors that are most likely to influence institutionalization of RS in the future are regulation, standardization, involvement of the upstream value chain and procurement practices.

2 RESPONSIBLE SOURCING IN THE UK CONSTRUCTION INDUSTRY

The construction industry plays a major role in sustainable development, i.e. through sustainable planning, design and construction of buildings and infrastructure, to address a ‘triple bottom line’ of environmental, economic and social objectives. In the UK, recent national targets on sustainable construction (e.g. on waste, water and energy) included one which required that 25% of all construction products should be procured via approved responsible sourcing (RS) schemes by 2012 (HM Government, 2008), as a means of ensuring that products are sourced from manufacturers that can demonstrate sustainability within their supply chains. Given that the construction sector accounts for around 8% of GDP per annum, this was a significant development, but one which was quasi-voluntary, essentially market-driven and lacked a common definition (Glass, 2011a, Glass 2012). Use of the term RS varies; responsible sourcing, ethical sourcing, sustainable procurement and sustainable supply-chain management are used interchangeably in the literature (Glass et al, 2012a). In a bid to clarify this, the UK standards BS8902 (British Standards Institution, 2009) and BES6001 (Building Research Establishment, 2009) suggest that RS should focus on the management of sustainability objectives throughout the life-cycle of a product, notably including key environmental, social and economic objectives, together with effective auditing of the supply-chain of any constituent materials (Glass, 2011a), which importantly includes ethical concerns and traceability. Livesey and Hughes (2013) note that ‘*traceability is becoming the new benchmark for measuring a product’s ethical performance… potential risks to reputation lurk(ing) in the multifaceted layers of global supply chains…*’. So, RS is complex; no one party is responsible, rather it requires the involvement of manufacturers, clients, contractors and designers (Glass et al, 2012b) to be demonstrated and assessed effectively.

RS is enacted in sustainable construction through the action of specifiers and buyers. At present, project teams can gain credits for using RS products within commonly used sustainability assessment methods for buildings (e.g. BREEAM and the Code For Sustainable Homes), affording them a potential market advantage when specifiers are selecting materials for a project. For example, over 90% of all UK concrete production is available with an RS certificate, and more than 80 responsible sourcing certificates have been awarded to about 40 UK material producers (including plasterboard, brick etc), yet some common building products are not certified (e.g. glass, aluminium). There is also a problem of scope – currently plant, personal protective equipment and other goods are not covered. Upstill-Goddard et al (2012) explain that any engineered to order products are also notably absent from the list of certified products and Appleby (2011:324) notes that “*there are no credits associated with the responsible sourcing of building services*”. While many UK practitioners have heard of responsible sourcing, there is a lack of awareness of products and their credits in building sustainability assessment tools. There is also an imbalance (participation asymmetry), with larger manufacturers and major contractors being well-informed and pro-active, but very few SMEs engaging at all (Glass et al, 2012a). Based on a survey of UK contractors and manufacturers, Glass et al., (2012b) identified the major drivers for RS as:

1. Client/customer requirements
2. Keeping up with competitors
3. Legislation/regulation
4. Market advantage
5. Brand

In terms of major barriers:

1. Cost of certification
2. Lack of interest from clients/customers
3. Lack of knowledge/understanding

All this suggests that RS is still at the early stages of adoption. While many, mostly large companies are now actively participating in seeking certification as an ongoing part of their sustainability/management standards auditing cycles, there remain some substantive gaps in coverage and participation. The APRES project (Action Programme for Responsible Sourcing, see http://apres.lboro.ac.uk) is a network of over 150 industry and academic organizations with a shared goal of furthering RS in the UK construction industry and beyond. Following two major conferences on RS in 2011 and 2012 organised by the network, the project aimed to co-create a contribution to knowledge by identifying a future vision for RS in the form of pathways to greater engagement. To some extent the broad trajectory of such a vision is set out by Livesey and Hughes (2013), who suggest that heightened public awareness, public sector procurement, product differentiation and BREEAM ratings will encourage greater engagement in RS, but this is not yet substantiated through research.

So, as a first phase of creating this vision and gathering early empirical data on the subject, a workshop was organized to coincide with the 2012 industry conference on RS. The aim of the workshop was to identify the key influencing factors that would determine the future success of RS and hence characterize the pathways outlined above. This event was convened and designed in collaboration with a core group of APRES members which included contractors, materials suppliers, specifiers and academic experts. The next section explains the approach used to identify the influencing factors.

3 RESEARCH METHOD - OPEN SPACE WORKSHOP

Open Space Technology (OST) was selected as the underpinning approach for the first phase of the visioning process (www.openspaceworld.org) (Owen, 2008). The technique emerged from Harrison Owen in the 1980s who developed it as a way of holding more effective business conferences (he felt that the most important outcomes emerged in the coffee breaks rather than the formal timetabled sessions and wanted to capitalise on this). The method is not patented and has proved very popular – many thousands of events have used this format, mainly in the business realm, but also for research purposes.

OST was chosen here because of its suitability to provide a structured method for framing the scope, content and direction of pathways for RS engagement in the UK construction industry, without restricting the topics, emphasis or content that might emerge (i.e. there is no set agenda); and its open, consensus-building approach. In this way one could describe OST as an unstructured and rather risky approach to data collection, because it relies wholly upon the participants present to be able, and willing, to offer suggestions and insights. For this reason, responses from them absolutely must be provoked, so it requires a well-defined opening question or problem statement to initiate the process as well as a group of participants that are capable of responding to the question/statement.

In this case, an independent, experienced facilitator was appointed to convene an OST Workshop (called the APRES Collaborative Visioning Workshop) which was attended by a multi--disciplinary group of 25 participants. The group comprised six representatives from large construction companies, eight staff from construction products manufacturing organisations, four independent consultancies, six academic specialists and one client representative. The group was effectively self-selecting, based on the workshop being offered to them as an optional half-day session, as part of a national conference on RS. Registration was monitored to ensure that an appropriate range of stakeholders attended; a target of 20-40 participants was deemed manageable in a half-day event. The delegates can be characterized as middle managers to director level staff, with sustainability and/or procurement expertise. Most had a self-expressed job role or professional interest that involved RS and more than half had responsibility for either supplying or purchasing of construction products; six of the delegates were from SMEs, which was particularly welcome, given the problems with SME participation in RS as noted earlier. While there could be said to be some subject-expertise or positivist bias in the group, the expertise of this elite sample was required and necessary to be able to achieve the planned outcome.

In line with the research problem outlined in the previous section, the opening question was: "*Responsible and ethical sourcing for construction is routine for all major companies in the UK… so how do we get there?*". This question had been formulated and refined in an iterative process, prior to the workshop, in consultation with 10 industry informants (an expert group of contractors, manufacturers, specifiers and consultants with extensive RS experience). The word 'ethical' was inserted to reflect specifiers' reported interests in social and human factors; 'major' was inserted to provoke debate around the role of company size, and the tense of the question was future-focused to encourage forward-looking debate (and hence insights for the development of RS pathways). The facilitator explained that the vision/s should embrace both clients and suppliers (i.e. the whole value chain) and asked that the participants explore how theory could be turned into routine practice in the future.

The rules and process of OST were explained to the participants, who first individually offered suggestions for discussion, i.e. possible answers or points of discussion to the question posed above. They were asked to explain these from the middle of the plenary circle. Seven initial suggestions were forthcoming:

- *What do we actually want to change?*
- *Should we have more transparency about the bad news?*
- *Is there a role for tax relief/financial instruments?*
- *How do we know what 'responsible' looks like?*
- *If we were starting again, with what we know now, what would we do?*
- *How do/should we 'buy' projects?*
- *Do we need different schemes for different supply chains?*

Delegates then moved freely between seven designated flipcharts for about 1.5 hours; they wrote down key points as the discussions developed, morphed and refined. In accordance with the principles of OST, there was a clearly observable ebb and flow of people between the topics, without any intervention from the facilitator, with large groups gathering and evolving, then breaking down naturally as people moved in and out of conversations at their own pace. The initial seven proposers were then asked to summarise the key points from their flipchart sheets in a plenary session and a final phase involved small groups working on goals, the end point and next steps (not reported here).

After the workshop, all the flipcharts were transcribed and the facilitator, project lead and a researcher checked the content, then used a clustering approach to identify the factors which were most likely to influence future institutionalization of RS, i.e. regulation, standardization, involvement of the upstream value chain and procurement practices, as described in the following section. Informal feedback from the participants was very positive; they had enjoyed the OST approach and felt it was highly appropriate for the problem in hand. Several expressed interest in applying the technique themselves.

4 KEY FACTORS INFLUENCING RS PATHWAYS

The OST approach could be seen as risky from the facilitator’s point of view, but in this instance, with a clear question to respond to, it was very successful in extracting several very fruitful topics for discussion from the delegates. The workshop question was clear and yet simultaneously sufficiently challenging and provocative to create debate. Moreover, the participants understood and worked effectively within the overall format of the event (despite most not having any experience of the OST approach).

This section provides a narrative account of the main workshop outcomes, presented under the overarching headings of the four key factors listed above.

4.1 Regulation

There was a clear indication from the participants that regulation could be part of the response to the current situation, but there was no overall consensus that it was definitely a good idea to drive RS forward. Some believed that a voluntary and consensus-driven ‘*code of practice*’ would be more appropriate, than say including RS within Building Regulations. That said, while they argued that RS should become mandatory in public procurement, they nevertheless questioned which body or government department should take the lead for implementing the necessary infrastructure and policing it. Given the broad scope of RS, it was not immediately clear whether overall responsibility would lie with DEFRA, the Environment Agency, the Cabinet Office (where the government procurement function now resides) or another body. The group argued that incentives were needed as well as penalties; it was suggested that incentivisation could be deployed, for example through tax or tax relief for RS products, but it was thought that this should only be used as a temporary mechanism, principally to broaden industry engagement with RS. The manufacturers noted that certified RS goods did not attract a price premium in the market and were not being sold as a premium product, so price-based differentiation would be neither relevant nor helpful in this situation.

4.2 Standardization

The landscape of standards for RS was debated extensively and lengthily (standardization here should not be taken to mean standardization of products). There were criticisms about the ability of the current standards to reflect the needs of SMEs and complex, multi-component based construction products (such as M&E and othr engineered to order products). Hence, the value of the standards in the context of sustainability assessment frameworks such as BREEAM was questioned. Participants suggested however that there was a paradox; on the one hand, smaller companies might require simpler and/or specific versions of the standards to ‘*get going*’, whereas companies that had already achieved certification were seeking greater differentiation through standards; for example, by making the credits in BES 6001:2009 (tougher to achieve or extending their scope (suggestions here including re-orienting the standard around key risks, thus better reflecting different supply-chains, having additional credits for good practices and mandating 100% traceability of constituent materials).

There was also a discussion about how standards could be utilized to engage material sectors that currently do not have any RS certificates in place and/or '*unethical'* suppliers, as this was seen to be a major impediment to progress. At present, it is not possible to deliver a whole building using only RS-certified products. Yet there appeared to be some appetite, at least on the part of the contractors, to investigate a means to reward RS practices in other areas of their activity, such as PPE, plant and equipment (certification bodies have reported enquiries to do so, although this is not covered under current RS standards), which they felt was somewhat exposed to scrutiny.

4.3 Involvement of the upstream value chain

Despite calling for all companies (not just major companies) to be involved in the future of RS in construction, client awareness and education was a particular cause for concern among the delegates. It was noted that clients were crucial in providing the leverage to change embedded practices in the industry, but beyond a few informed clients, there were thought to be relatively low levels of awareness about RS. Some noted that clients '*did not know how to ask for a sustainable building*'. They also discussed the problem of specifiers and how there was a clash of cultures, interpretations and understandings about RS in the upstream part of the supply-chain; architects and engineers were described as '*the missing members of the supply chain*' and the delegates explored how this might be addressed through the use of different language or development of new decision-making tools. There was a valuable discussion around the construction industry's general reluctance to detect and communicate its failings and participants argued that companies should strive to be more transparent. There was however some fear that this might compromise market reputation and negatively impact on clients' perceptions, even thought it could be seen by some as '*a good thing*'.

4.4 Procurement practices

There was complete and unquestioned agreement that, collaboration was essential now and in the future, to ensure that the ethos of RS was embedded in project procurement practices. Delegates suggested that '*the power of procurement could be used for positive change'*. Yet the breadth of the subject and its relative immaturity appear to conspire to create a fragile buying environment for RS. A specific frustration emerged regarding the '*policing'* of RS practices from initial enquiry to point of purchase. Participants from construction materials suppliers reported that there was a '*specification gap'*, in which senior procurement staff in contractors would specify a named product (because of its RS credentials), but at the point of purchase or for a specific site, the buyer would opt for a non-RS, performance-equivalent product, primarily on the basis of cost (but it was also acknowledged that buyers may not be aware of RS). This was seen as counter-productive and undermined trust in the supply-chain; suppliers reported that this made them question the value of certification in the marketplace and hence their investment in seeking and paying for certification audits.

Perhaps as a result, the participants called for a standard set of questions on RS to be developed, such that pre-qualification questionnaires from contractors were consistent. There was thought to be too much variation and time was wasted in answering different question sets. The contractors and suppliers suggested that they would feel more motivated if clients actually sought feedback on the RS successes on a project, following completion. That said, they did not rule out the role of competition in the marketplace as a stimulus for progress; reporting of successes was thought to have been a major factor to date in driving broader uptake of RS among peers.

5 CONCLUSIONS

Based on the outcomes from the collaborative visioning workshop on RS, there are some quite clearly-defined problem areas that are currently affecting its broader adoption in construction. Returning to the question: "*Responsible and ethical sourcing for construction is routine for all major companies in the UK… so how do we get there?*", it is now possible to discern a few significant conclusions that can help define and characterize the pathways to greater engagement in RS.

First, there is a need for constancy and consistency of RS in the project procurement process. It was clear that a lack of awareness on the part of the upstream value chain, a fragile buying environment and the specification gap, are problems for RS all along the project procurement process. RS needs to be clear and visible throughout, to all project stakeholders, much in the same way that health and safety has now become embedded. There needs to be a closer proximity between RS and everyday decision-making.

Secondly, there is a need for a well-publicized and verified case for RS, based on both ethical and financial grounds (whether incentivized or not). This can be a lever to encourage clients to engage with the subject and if it is coupled with a consensus-built code of practice, in line with the first point, then there may be no need for a regulatory approach. Importantly, without a more explicit account of the possible 'savings' to be gained from RS, the extent of engagement across the broader construction sector will necessarily be restricted only to those organizations with a greater reverence for CSR and ethical principles. Specifiers were thought to require some type of balanced assessment tool for construction materials.

Thirdly, there is a need for RS-related standards to evolve urgently to better reflect industry's needs, e.g. the differentiation in levels of achievement that have created a greater maturity in the market, albeit for only about 40 companies and the needs of smaller businesses. Much of the content of BES 6001:2009 is now over five years old and the expected update in late 2013 seems rather overdue. It will be interesting to see how the next version of the standard responds to these points.

Finally, there is a need to maintain the momentum and positive, pro-active attitude displayed by the workshop participants and extend this to more companies, but this will be challenging in times of economic recession. That said, the client representative reported strong market commitment to sustainable construction and evidence of convergence between sustainability, responsible sourcing and property values, which is very promising. Anecdotal reports that BREEAM Excellent is now the de facto performance standard for commercial properties in London is particularly encouraging.

It should be noted that it was not an aim of the OST workshop to identify or quantify these factors as impelling and impeding forces (i.e. through force-field analysis), but this may be a useful follow-up exercise now the four main areas of concern have been articulated to a greater extent. Certainly, the next phase of the research will develop an industry publication, based on some of the arguments presented in this paper, to describe in more detail the pathways that will encourage greater engagement with RS in the UK construction industry, and hopefully elsewhere. Futures methods such as scenario planning will be used to develop narratives around the four factors. Readers are invited to contribute thoughts to this debate via the APRES website (http://apres.lboro.ac.uk).

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REFERENCES

P. Appleby, *Integrated sustainable design of buildings*, Earthscan, London, (2011).

Building Research Establishment, *BES 6001: Framework standard for the responsible sourcing of construction products*, Building Research Establishment, Watford, (2009).

British Standards Institution, *BS 8902:2009 Responsible sourcing sector certification schemes for construction products – Specification*, British Standards Institution, London (2009).

J. Glass, "Briefing: Responsible sourcing of construction products", *Proceedings of The Institution of Civil Engineers: Engineering Sustainability*, **164** (3), 164-5 (2011a).

J. Glass, "Responsible sourcing in construction projects: can anything be learned from 'FairTrade' schemes?" *Corporate Responsibility Research Conference 2011*, University of Leeds, UK (2011b).

J. Glass, "Responsible sourcing: a legitimate mechanism for sustainability reporting in the construction products industry?" *Proceedings of the International Centre for Corporate Social Responsibility Conference 2012*, University of Nottingham, UK (2012).

J. Glass, N. Achour, T. Parry, and I. Nicholson, "Engaging small firms in sustainable supply chains: responsible sourcing practices in the UK construction industry", *International Journal of Agile Systems and Management, Special Issue: Sustainable supply chain design and practice*, **5**, 1, 29-58 (2012a).

J. Glass, N. Achour, T. Parry, I. Nicholson, and J. Upstill-Goddard, "Responsible sourcing of construction products and materials: results from an industry survey", *Concrete*, February: 47-49 (2012b).

H M Government, *Strategy for sustainable construction*, Department of Business, Enterprise and Regulatory Reform, London (2008).

K. Livesey and D. Hughes, *Responsible sourcing of materials in construction*, BRE IP 4/13, Building Research Establishment, Watford (2013).

H. Owen, *Open space technology: a user's guide*, 3rd edition, Berrett-Koehler (2008).

J. Upstill-Goddard, J. Glass, A. Dainty and I. Nicholson, "Integrating responsible sourcing in the construction supply chain", *Proceedings of the 28th ARCOM Conference*, Edinburgh, Scotland, 1311-1319 (2012).

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ADDRESSING CRUCIAL RISK FACTORS IN THE MIDDLE EAST CONSTRUCTION INDUSTRIES: A COMPARATIVE STUDY OF SAUDI ARABIA AND JORDAN

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Abstract. *Delay is a key issue in the construction industry globally and the Middle East countries are no exception. Studies of several researchers in the Middle East region have reported that 70% of all public sector construction projects fail to complete on time. This paper documents the results from an investigation into several delay factors in the Kingdom of Saudi Arabia (KSA) and Jordan. The primary data was gathered via questionnaire, by including a list of 63 crucial delay factors and asking respondents to rank each factor according to its frequency of occurrence and degree of impact. The findings are the ranking differences in each country. In addition, it is also found through critical analysis of delay factors that factors extracted using factor analysis are extremely crucial at this time and need to be addressed urgently to avoid further time overruns. The work reported in this paper is part of a PhD study which aims to outline the main causes of delay in public building projects and to develop a risk management framework to mitigate the impact of those delay factors for sustainable building construction.*

Keywords *causes of delay, risk management framework, Middle East*

1 INTRODUCTION

One of the most critical problems of construction industries in developing countries is construction delays (Sweis et al., 2007) that often hinder sustainable construction. The key challenge for construction companies today is to complete projects on time and within the estimated budget. Over the past two decades, construction activities have increased rapidly in developing countries, particularly in the Gulf region as the governments of those countries have announced substantial spending on infrastructure improvement (Samba Financial Group, 2012). On the other hand, however, the issue of delay has created a negative image for the industry. This study aims to outline the main causes of delay in public building projects in Middle East countries with particular focus on the KSA and Jordanian construction industries. In this paper, the ranking results of the causes of delay factors in the KSA are first compared to Jordan, and then factor and correlation analysis is conducted to find the most crucial factors at this time.

2 BACKGROUND STUDIES

Many researchers from different countries have found several reasons for the delays in construction projects. For instance, Assaf et al. (1995) identified 56 key delay factors that were destroying the fabric of the construction industry in Saudi Arabia as ‘cankerworm’. They concluded that changes in design and order, payment delays, and shop drawings were the most significant contractor-related delay factors. Similarly, financing issues, conflict between contractor and consultant, slow decision making from the owner, bureaucracy issues, unskilled labour, and errors in infrastructural design were the other prominent factors that were adversely affecting the construction industry in the KSA. Another study related to Saudi Arabia identified three crucial delay factors, namely problems in obtaining work permits from government and authorities, a low-bid tendering system, and cash-flow problems (Al-Khalil and Al-Ghafly, 1999).

Faridi and El-Sayegh (2006) studied the causes of delay in the building projects of the UAE. They found that the top five critical factors causing delay were: (1) drawing preparation and approval; (2) inadequate and poor planning; (3) lack of quick decision making from the owner; (4) lack of manpower; and (5) lack of proper supervision and management. Similarly, Sweis et al. (2007) outlined five major factors causing delays in the Jordanian construction industry. They were: financial difficulties faced by the contractors; many changes in orders from the client; poor planning and scheduling by the contractor; unskilled labour; and a shortage of technical and skilled professionals.

Razek et al. (2008) from Egypt found that inadequate and improper planning, inexperienced and unskilled contractors, a lack of contract management, and payment delays were the critical delay factors. Similarly, Frimpong et al. (2003) studied the causes of delay in construction projects in Ghana and concluded that financial problems and modifications in the scope of projects were the most influencing factors causing delays. Doloi et al. (2011) outlined many factors causing delays in the Indian construction industry. The top five factors were: delays in material delivery by vendors; late availability of drawings/designs; financial constraints of the contractor; an increase in the scope of work; and obtaining permissions from local authorities. It is learned from the above studies that delay is a common problem that construction industries in the Middle Eastern countries are facing over a long period of time. Although, the causes of delay are different in each country but they ultimately result in cost and time overrun and consequently obstruct sustainable construction.

3 RESEARCH METHODOLOGY

The positivism philosophical paradigm is chosen to conduct this research. Using positivism paradigm, the researchers quantitative addressed research objectives using survey method. On the other hand, the descriptive research design is employed to explain the causes of delay and their possible impact on construction industries in Jordan and Saudi Arabia. The scope of this research paper is limited to public building projects, and a mixture of primary and secondary data is used to identify major causes of delays in the construction industries of the KSA and Jordan. A combination of qualitative and quantitative methods is adopted by looking at the nature of the study. The qualitative approach is chosen to observe the behaviour of construction participants, as well as the patterns, processes and themes of the construction process using literature review. On the contrary, the quantitative approach is employed to analyse the data of delay factors collected through surveys from construction participants in the KSA and Jordan.

3.1 Population

The population of this study is based on construction participants (i.e. owners, contractors, consultants and project managers) in Saudi Arabia and Jordan. Construction professionals and parties with more than 10 years' experience were chosen through sampling method using the following formula:

$$S = CL^2\ EP\ (1 - EP) / CI^2 \qquad (1)$$

Where, S = Sample size required, CL = Confidence level, EP = Estimated prevalence of malnutrition, CI = Confidence interval

3.2 Procedure

The survey method was adopted to identify and inform the most critical delay factors hindering on-time completion of construction projects in the KSA and Jordan. The questionnaire method was mainly used to record the opinions of construction participants from the KSA and Jordan against each delay factor on the basis of its degree of occurrence and impact on construction projects. Consequently, this helped the researchers to rank the delay factors. Table 1 states the number of questionnaires distributed and received.

Participants	Saudi Arabia		Jordan	
	Distributed	Received	Distributed	Received
Owner	72	38	50	32
Contractor	47	29	50	37
Consultant	63	31	50	35
Total	182	98	150	104

Table 1: Respondents profile

The respondents were asked to rank each delay factor according to its frequency of occurrence and degree of impact on projects. The data collected from the questionnaire was analysed in two ways: (1) ranking of delay factors; and (2) critical analysis of the delay factors. Many researchers (e.g. Assaf et al., 1995; Kumaraswamy and Chan, 1998; Iyer and Jha, 2005; Faridi and El-Sayegh, 2006) believe that rating factors according to their means and standard deviations is not an appropriate way to assess overall rankings because in this way the relationships between factors are not reflected. In contrast, other techniques such as weighted average and relative index are commonly used for ranking but do not take into account both the frequency and the impact of each factor. Thus, the researchers used Relative Importance Index (RII) method to rank each delay factor on the basis of its frequency of occurrence as well as the degree of impact. The detail of the formula is as follows:

$$Importance\ Index = (Freq.\ Index \times Severity\ Index) / 100 \qquad (2)$$

Where,

$$Freq.\ Index\ (F.I.) = \Sigma\ [c.\ (a/A)] \times 100/5$$
$$Severity\ Index\ (S.I) = \Sigma\ [c.\ (a/A)] \times 100/5 \qquad (3)$$

'c' is a constant of weighting given to each response (0=unknown, 1=never, 2=low, 3=middle and 4=high), 'a' is the frequency of responses, and 'A' is the total number of responses for this research.

The delay factors were then analysed quantitatively using three statistical techniques which included factor analysis, correlation analysis and reliability analysis. The factor and correlation analyses were performed to extract the most significant factors causing delay and to find the relationship between several seemingly related and unrelated delay factors. Finally, reliability analysis was performed to cross check if the purpose of factor analysis was fulfilled and if it was measured correctly. The Cronbach's alpha (Cα) test using SPSS was used for reliability analysis.

4 RESULTS AND DISCUSSION

4.1 Ranking of delay factors

A total of 63 factors were identified from various sources and included in the questionnaire. Respondents were asked to rank each delay factor according to its frequency of occurrence as well as the degree of impact. RII technique, which has previously been used by several researchers in the past, was used to rank delay factors. Some researchers who have used this technique to rank construction delays are Aibinu and Jagboro (2002), Assaf and Al-Hejji (2006), Sambasivan and Soon (2006), and Doloi et al. (2011). Table 2 illustrates the top 10 causes of delay according to the ranking results.

Causes of Delay	Ranking KSA	Ranking Jordan
Low performance of lowest-bidder contractor in tendering system	1	1
Delay in sub-contractors' work	2	9
Poor qualifications, skills and experience of the contractor's technical staff	3	8
Poor planning and scheduling of the project by the contractor	4	4
Delay in progress payments by the owner	5	2
Design changes by the owner	6	3
Shortage of qualified engineers	7	10
Delay in preparation of shop drawings	8	7
Cash-flow problems faced by the contractor	9	6
Inadequate early planning of the project	10	5

Table 2: Delay Factors

4.2 Factor analysis

Factor analysis is a popular multivariate analytical technique for identifying strong relationships among variables. In this study, Exploratory Factor Analysis (EFA) was conducted because it is based on the common factor model and is useful for identifying seemingly related and unrelated factors (Doloi, 2009). The first step in EFA was to identify and display delay factors in the data matrix, which is a collection of figures arranged into one or more columns and rows (Reymont and Joreskog, 1993). At the next stage, to assess the sufficiency of the questionnaire data for factor analysis, the Kaiser-Meyer-Olkin (KMO) test was carried out. A KMO value near to 1 represents a strong correlation and reliability between attributes. The overall KMO value of the total of 31 extracted attributes is 0.704, which is considered ‘good’.

In this research, 31 out of 63 significant factors were extracted using the Principal Components (PC) method. PC method was preferred because it analyses all variances in the items as well as helping the researcher to minimise several correlated delay factors into a smaller number of underlying factors (Wenbin, 2008).

Factor ID	Factor Description	Factor Loading	Variance Explained
Factor I – Material related			
M37	Delay in materials supply	0.769	10.58%
M58	Rise in the prices of materials	0.759	
M38	Material quality problems	0.741	
M39	Shortage of construction material	0.540	
Factor II – Project related			
P1	Inadequate early planning of the project	0.759	10.97%
P36	Shortage of equipment availability	0.744	
P53	Lack of systematic engineering method to identify the time	0.713	
P15	Low performance of the lowest-bidder contractor in the Government Tendering System	0.625	
P35	Poor manpower productivity	0.606	
Factor III – Contractor related			
CT27	Poor site management and supervision by contractor	0.762	10.92%
CT25	Poor communication by contractor with parties involved in project	0.703	
CT19	Poor qualifications, skills & experience of contractor technical staff	0.687	
CT32	Shortage of qualified engineers	0.661	
CT18	Poor planning and scheduling of the project by the contractor	0.608	
Factor IV – Owner related			
O9	Lack of coordination with contractors	0.682	11.65%
O6	Delay in the approval of contractor submittals to the owner	0.633	
O7	Changes in the scope of the project	0.632	
O10	Breach or modifications of contract by owner	0.623	
O13	Poor qualifications and supervision of owner’s engineer	0.614	
O5	Slow decision-making process of the owner	0.609	
Factor V – Consultant related			
CN49	Poor qualifications of supervisory staff of the consultant engineer	0.827	10.81%
CN42	Delay in approval of shop drawings	0.806	
CN43	Absence of consultant’s site staff	0.722	
CN41	Inadequate qualifications of consultant to the project	0.712	
Factor VI – Design related			

D45	Design errors by consultant	0.848	8.67%
D44	Design changes by consultant	0.845	
D51	Design errors made by designers due to unfamiliarity with local conditions and environment	0.688	
D11	Design changes by the owner	0.621	
Factor VII – External related			
E63	External work due to public agencies	0.834	7.12%
E59	Changes in Laws or regulations by Government	0.743	
E55	Effect of weather conditions on construction activities	0.624	

Overall KMO value = 0.704

Table 3: Factor analysis

4.3 Discussion on extracted factors

4.3.1 Factor I - 'material-related' indicates the issues related to materials that often cause delays in the construction industry. In Table 2, the four most significant material-related attributes are extracted, with a total variance explained of 10.58%. The factor loadings of material-related attributes range from 0.540 to 0.769 where the values of three attributes are more than 0.7. The first and fourth attributes, i.e. '*delay of material supply*' and '*shortage of construction materials*', have great significance in terms of time overrun in the construction process. The second attribute '*rise in the prices of raw materials*' may result in an increase in the cost of the whole construction project. The third attribute '*material quality problem*' is a very serious matter for construction parties and, according to Lewry and Crewdson (1994), construction participants must not compromise on this issue. Overall, ignoring material-related factors may adversely affect the whole construction project.

4.3.2 Factor II - 'project-related' highlights the problems associated with different aspects and levels of a construction project. Five project-related attributes are extracted in Table 2 with an appropriate variance explained value of 10.97%. The first attribute '*inadequate early planning of the project*', with the highest factor loading value of 0.759, is one of the vital reasons of delay which is normally ignored by the construction parties in analysing construction delays (Bramble and Callahan, 2010). '*Shortage of equipment availability*' during construction is a situation caused due to lack of proper equipment planning at the project conception phase. The third attribute, '*lack of systematic engineering method to identify project time*', is generally the result of an unprofessional approach and perhaps a lack of commitment from the engineer or project manager. The fourth project-related attribute, '*low performance of the lowest-bidder contractor in tendering system*', is a very common factor causing delay in the Middle Eastern countries. Most of the public clients in developing countries prefer the lowest bidder without knowing their competencies, experience, and knowledge of project management practices and planning techniques (Agumba and Fester, 2011). Finally, the fifth attribute, '*poor manpower productivity*', results from either a lack of on-site supervision or from employing an unskilled workforce, and affects the quality delivery of the construction project.

4.3.3 Factor III - 'contractor-related' shows delays caused by the contractors or sub-contractors due to a lack of skills, knowledge, experience and competencies. Table 2 illustrates five critical contractor-related delay attributes with a total variance explained value of 10.92%. The first and second attributes, '*poor site management and supervision by the* *contractor*' and '*poor communication by the contractor*', are interrelated with each other. The importance of supervision and communication in achieving cost and time performance in construction projects is explained by several experts (for example, Potts, 2008). In addition, due to a third problematic delay factor of '*poor qualifications, skills and experience of the contractor's technical staff*', the contractors either may not be able to cope with challenges or may not understand the complexity of the project, both of which often result in time overruns. A '*shortage of qualified engineers*' is also another common delay factor in Middle Eastern countries. Many public organisations hire foreign engineers for their large construction projects due to the lack of availability of qualified engineers locally. Finally, '*poor planning and scheduling of the project by the contractor*' can lead to improper estimations about several aspects or situations while carrying out a construction project (Agumba and Fester, 2011).

4.3.4 Factor IV - 'owner-related' explains 11.65% of total variance and has six underlying attributes. Owner-related issues illustrate the importance of decisions and actions taken by the owner before and during the construction period. The first attribute, '*lack of coordination with contractors*', with the highest factor loading value of 0.682, results in failure parameters in construction projects (Doloi et al., 2011). The second attribute, '*delay in the approval of contractor submittals*', is also another aspect of lack of coordination with contractors. The third attribute, '*changes in the scope of the project*', is very common in the Middle East due to project managers having a lack of understanding about the scope or design of the project (Kasimu, 2012). This often causes delays due to reworking, errors, repetition of tasks, lack of motivation, and financial constraints. The fourth attribute, '*breach or modification of contract by owner*', often refers to the selection of amateur or inexperienced contractors with inadequate skills and knowledge (Doloi et al., 2011). The fifth attribute, '*poor qualifications and supervision of owner's engineer*', may lead to great difficulties for the owner, as well as for other construction parties, in achieving their goals in a timely manner. Lastly, the importance of the sixth attribute, '*slow decision-making process of the owner*', can be judged by the rankings of several researchers who placed it within the top five factors causing construction delays in developing countries.

4.3.5 Factor V - 'consultant-related' indicates delay problems associated with the consultants. In Table 2, four significant consultant-related attributes are extracted with a total variance explained of 10.81% of the linear component (factor). The first attribute, '*poor qualification and supervision of staff of the consultant engineer*', can adversely affect the objectives of the client in terms of cost and time. The second attribute, '*delay in approval of shop drawings*', usually occurs due to a lack of communication between the consultant and the approval authority. Similarly, '*absence of consultant's site staff*' should be monitored constantly to avoid time overruns (Assaf and Al-Hejji, 2006). Finally, the last attribute, '*inadequate qualifications of consultant to the project*', highlights the importance of using qualified consultants so that proper project management practices and planning techniques can be employed.

4.3.6 Factor VI - 'design-related' highlights the importance of design-related errors and changes by the consultant and owner due to either unfamiliarity with the local environment and conditions or a lack of communication, skills, education, and experience of working with consultants. The consultant-related attributes show a total variance explained value of 8.67%.

4.3.7 Factor VII - 'external-related' issues refers to work delays due to either changes in government regulations or unforeseen events such as weather or changes to the external environment. In Table 2, the total variance explained value of external-related factors is 7.12%.

4.4 Reliability of factor analysis

In order to check the reliability of the factors, Cronbach's alpha (Cα) test was performed on each factor group to see if they were standardised. The value of Cα should be between 0 and 1 where lower values demonstrate lower internal consistency and higher values illustrate greater internal consistency. In fact, there is no set standard or pre-defined acceptable limit of Cα value. Nevertheless, the following criteria explained by Nunally (1978) for the interpretation of Cronbach's alpha values was carefully undertaken as a rule of thumb: Cα > 0.8 'Excellent'; 0.8 > Cα > 0.7 'Good'; 0.7 > Cα > 0.5 'Satisfactory'; and Cα < 0.5 'Poor'. Table 4 shows that the value of Cronbach's alpha (Cα) for all attributes are computed as 0.930, which is considered to be excellent'.

Factors	Cronbach's Alpha (Cα)	Result
Material related	0.608	Satisfactory
Project related	0.602	Satisfactory
Contractor related	0.755	Good
Owner related	0.813	Excellent
Consultant related	0.881	Excellent
Design related	0.697	Satisfactory
External related	0.668	Satisfactory
All Factors	0.930	Excellent

Table 4: Reliability analysis

4.5 Correlation analysis

In correlation analysis, correlation matrices are developed to identify the factors underlying the attributes. For this purpose, a 'variable reduction scheme' was used to illustrate how different variables are grouped together and correlated with each other (Gorsuch, 1983). The Karl Pearson's correlation coefficient 'r' is considered because it helps to identify linear relationships between delay factors. Table 5 shows that apart from all external-related factors and a few project-related factors, the correlation between other attributes within seven groups is statistically significant at 0.01 and 0.05 significance levels.

5 CONCLUSION

Delay is the key issue that construction stakeholders in Middle Eastern countries, particularly in the KSA and Jordan, are currently facing. This particular issue impedes sustainable building and construction in the region. Hence, this study aimed to identify causes of delay in those countries. In this regard, a survey was conducted to identify the most crucial factors causing delays in public sector projects in the KSA and Jordan. The results reveal that the top 5 factors causing delays in the KSA are: (1) Low performance of the lowest-bidder contractor in the tendering system; (2) delays in sub-contractors' work; (3) poor qualifications, skills and experience of the contractor's technical staff; (4) poor planning and scheduling of the project by the contractor; and (5) delays in progress payments by the owner. In contrast, the five most crucial factors in the Jordanian construction industry context are: (1) the low performance of the lowest-bidder contractor in the tendering system; (2) delay in progress payments by the owner; (3) design changes by the owner; (4) poor planning and scheduling of the project by the contractor; and (5) inadequate early planning of the project. It is found from the ranking and factor analysis that 31 out of 63 delay factors are extremely crucial at this time and need to be addressed urgently to avoid further time overruns in developing countries, particularly in the KSA and Jordan.

	P1	**P36**	**P53**	**P15**	**P35**
P1	1				
P36	.085	1			
P53	-.149	-.086	1		
P15	-.083	-.178	.469**	1	
P35	-.123	.471**	.047**	-.041	1

Project-related factors

	CT27	**CT25**	**CT19**	**CT32**	**CT18**
CT27	1				
CT25	.490**	1			
CT19	.638**	.321**	1		
CT32	.192	-.012	.167	1	
CT18	.672**	.357**	.663**	.004*	1

Contractor-related factors

	CN49	**CN42**	**CN43**	**CN41**
CN49	1			
CN42	.606**	1		
CN43	.518**	.555**	1	
CN41	.612**	.525**	385	1

Consultant-related factors

	O9	**O6**	**O7**	**O10**	**O13**	**O5**
O9	1					
O6	.350**	1				
O7	.424**	.463**	1			
O10	.375**	.331**	.500**	1		
O13	.268**	.404**	.351**	.215*	1	
O5	.400**	.374**	.224*	.239*	.349**	1

Owner-related factors

	M37	**M58**	**M38**	**M39**
M37	1			
M58	.548*	1		
M38	.479*	.278*	1	
M39	.217*	.010	.127	1

Material-related factors

	D45	**D44**	**D51**	**D11**
D45	1			
D44	.696**	1		
D51	.471**	.423**	1	
D11	.333**	.437**	.259**	1

Design-related factors

	E63	**E59**	**E55**
E63	1		
E59	.087	1	
E55	.235	.324	1

External factors

**Correlation is significant at 0.01 level (2-tailed test)
*Correlation is significant at 0.05 level (2-tailed test)

Table 5: Results of correlation analysis

6 FUTURE WORK DIRECTION

Despite a clear understanding of these key factors associated with the construction industries of the KSA and Jordan, a sincere attempt could be made to address the chronic issue of time overrun by developing a risk management framework for Middle Eastern countries. In this way, the lack of construction sustainability issue can also be addressed indirectly.

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REFERENCES

J.B. Agumba and F.C. Fester, "Identifying Tools and Techniques for Managing Construction Project Delivery in Small and Medium Enterprises in UK Construction Industry", *Journal of Social and Development Sciences*, **2**(4), 204-213 (2011).

A.A. Aibinu and G.O. Jagboro, "The effects of construction delays on project delivery in Nigerian construction industry", *International Journal of Project Management*, **20**, 593-599 (2002).

M. Al-Khalil and M. A. Al-Ghafly, "Delay in public utility projects in Saudi Arabia", *International Journal of Project Management*, **17**(2), 101-106 (1999).

A. Al-Kharashi and M. Skitmore, "Causes of delays in Saudi Arabian public sector construction projects", *Construction Management and Economics*, **27**, 3-23 (2009).

S.A. Assaf, M. Khalil, and M. Al-Hazmi, "Causes of delay in large building construction projects", *Journal of Management and Engineering*, **11**(2), 45-50 (1995).

S.A. Assaf and S. Al-Hejji, "Causes of delay in large construction projects", *International Journal of Project Management*, **24**, 349-357 (2006).

B.B. Bramble and M.T. Callahan, *Construction Delay Claims*, 4th edition, Aspen Publishers (2010).

H. Doloi, "Analysis of pre-qualification criteria in contractor selection and their impacts on project success", *Construction Management and Economics*, **27**, 1245-1263 (2009).

H. Doloi, A. Sawhney, K.C. Iyer and S. Rentala, "Analysing factors affecting delays in Indian construction projects", *International Journal of Project Management*, **30**, 479-489 (2011).

A. S. Faridi and S. M. El-Sayegh, "Significant factors causing delay in the UAE construction industry", *Construction Management Economics*, **24**(11) 1167-1176 (2006).

A. Field, *Discovering Statistics Using SPSS*. London: Sage (2005).

Y. Frimpong, J. Oluwoye and L. Crawford, "Causes of delay and cost overruns in construction of ground water projects in developing countries: Ghana as a case study", *International Journal of Project Management*, **21**, 321-326 (2003).

R.L. Gorsuch, *Factor analysis*. 2nd edition. Hillsdale, NJ: Erlbaum (1983).

K.C. Iyer and K.N. Jha, "Factors affecting cost performance: evidence from Indian construction projects", *International Journal of Project Management*, **23**, 283-295 (2005).

M.A. Kasimu, "Significant factors that cause cost overruns in building construction project in Nigeria", *Interdisciplinary Journal of Contemporary Research in Business*, **3**(11), 775-780 (2012).

M.M. Kumaraswamy and D.W.M. Chan, "Contributors to construction delays", *Construction Management and Economics*, **16**, 17-29 (1998).

A.J. Lewry and L.F.E. Crewdson, "Approaches to testing the durability of materials used in the construction and maintenance of buildings", *Construction and Building Materials*, **8**(4), 211-222 (1994).

J. Nunally, *Psychometric Theory*. 2nd Edition, New York: McGraw-Hill (1978).

K.F. Potts, *Construction Cost Management: Learning from Case Studies*. Routledge (2008).

A. Razek, H. A. Bassioni, and A. M. Mobarak, “Causes of delay in building construction projects in Egypt”, *Journal of Construction Engineering and Management*, **134**(11) 831-841 (2008).

R. Reymont and K.G. Joreskog, *Applied factor analysis in the natural sciences*. New York: Cambridge University Press (1993).

Samba Financial Group, “Saudi and GCC Opportunities 2012-16” *Economics Department,* June (2012).

M. Sambasivan and W.Y. Soon, “Causes and effects of delays in Malaysian construction industry” *International Journal of Project Management*, **25**, 517-526 (2006).

J. K. Sharma, *Business Statistics*. 2nd edition, Pearson Education India (2007).

G. Sweis, A. Abu-Hammad and A. Shboul, “Delays in Construction Projects: The Case of Jordan”, *International Journal of Project Management*, **26**(6) 665-674 (2007).

G. Wenbin, “Eigenvector space: the missing concept in exploratory factor analysis”, *International Academy of Business and Economics*, **8**(4), 1546-2609 (2008).

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A CONSTRUCT FOR MEASURING STAKEHOLDER ENGAGEMENT IN SUSTAINABLE CONSTRUCTION DEVELOPMENTS

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Abstract. *Stakeholder engagement is increasingly becoming a core aspect of most sustainable development initiatives. The literature on sustainable development would often incorporate recommendations as well as prescribe input/output guidelines for engaging stakeholders in business activities at strategic and/or operational levels. However, previous work suggests that sustainability assessment in construction organisations is commonly restricted to "green issues" and often do not fully address the socio-economic dimensions required for economic improvement. Specifically, there is a need to provide explicit measurement for assessing the socio-economic dimension of developments to inform strategic decisions exercised by construction organisations. Current literature points to three particularities of the engagement process: the variety of businesses an organisation engages in, the organisation's ability to create value and become a market leader, and the relationship developed with its employees and suppliers viewed as the capacity to attract and retain them. Four principal stakeholder groups, namely: customers, employees, suppliers, and the community, are considered as pertinent to establishing such socio-economic measures for sustainability. This paper sets out the development of a framework that could provide a basis for measuring stakeholder engagement as a significant part of the strategic decisions exercised by construction organisations in their corporate endeavours. The key factors identified as relevant for the design of a stakeholder engagement framework are: the business areas in which the organisation engages, market position and organisational impact. Consequently, beyond compliance with government regulations on green requirements, the socio-economic element plays an important part in the current European development of the built environment. The framework is designed to provide an assessment of the socio-economic dimension of sustainability, which would assist decisions for development and growth in construction organisations.*

Keywords: *construction, sustainability, stakeholders, measurement*

1 INTRODUCTION

Sustainable development is widely described and acknowledged in the World Commission on Environment and Development report which argues that all developments should be done for the purpose of reaching the needs of the present, but recognizing and acting with awareness of the prospective needs of future generations(World Commission on Environment and Development 1987). However, "sustainable construction" was first defined in 1994 by Kibert (2007) and refers to addressing environmental, social and economic issues encountered in the built environment. Furthermore, Hill and Bowen (1997) have developed principles which outline the concept of sustainability in the construction industry and possible methods of attainment.

Various models have been developed to help construction organisations with the implementation of sustainable practices (Tan et al. 2011, Trufil and Hunter 2006) and a common step in every model is to monitor and assess improvement. So far, research on sustainability issues has been mainly concerned with assessing environmental performance (Fergusson and Langford 2006, Kibert 2007, Ding 2008) and little emphasis has been placed set on the measurement of the socio-economic issues regarding sustainability. An analysis of the existing sustainability ranking systems used across all industries or within the construction industry particularly (Lu and Cui 2012) concludes that from all the possible indicators required for a sustainability assessment for construction organisations, more than 70% are unattended in practice and mainly, the socio-economic dimension requires immediate improvement. Also, measuring and monitoring performance on sustainability issues allows businesses to document their concern for sustainability and promote themselves as a sustainability orientated organisation (Pitt et al. 2009).

Constructing Excellence (2004) and the International Institute for sustainable development (2004) build a strong case for engaging with stakeholders, as they are viewed as the primary factors to help detect sustainability issues and attend properly to them. Stakeholder engagement functions both internally by maintaining a good flow of information and knowledge and improving decision making processes and externally by assuring a long term success which comes with maintaining the 'license to operate'. All in all, engagement secures stakeholder buy-in to processes and outcomes of the organization.

Therefore, there is a strong business case for stakeholder engagement and a framework for measuring it should contribute to the lack of indicators needed in assessing organisations on their performance in the socio-economic dimension of sustainability. The Stakeholder Engagement framework is put forward in the shape of tri-axial construct that considers both external and internal factors affecting the organisations prospects.

2 SOCIAL SUSTAINABILITY THROUGH STAKEHOLDER INTERACTION/ ENGAGEMENT

2.1 Sustainability, a financial performance drive

Sustainability has become a general pursuit and the process of integrating sustainable matters in business is assisted by robust frameworks intended for managerial use. While the pursuit starts and is advocated mainly by leadership, establishing the new sustainability identity involves maintaining good relationship with the external factors, engaging employees and developing detailed mechanisms to assess progress. Corporate sustainable behaviour has its determinant factors in establishing a culture of innovation, trust and transformational change (Eccles et al. 2012).

There are a number of theoretical works on the causal relationship between sustainable practices and business competitiveness. First, Wagner and Schaltegger (2004) propose a framework were the interaction between business competitiveness and social and environmental performance considers a series of influential factors which operate at the organisation level. Furthermore, whether sustainable practices drive organisation financial performance or financial performance triggers the integration of sustainable practices is unclear (Ameer and Othman 2011). The answer could be found however in the period of time considered for assessing this relationship. For a period of time of 18 years, there is clear evidence that sustainable organisations outperform financially the non-sustainable organisations (Eccles et al. 2012).

Construction industry research on the relationship between sustainability strategies and business competitiveness is merely demonstrated from the environmental perspective of sustainability (Fergusson and Langford 2006, Testa et al. 2011). With regard to the social aspect of sustainability, within the construction industry the correlation between social responsibility and business performance is still at the initial stage of developing a proper system for weighting corporate social responsibility issues for organisations (Zhao et al. 2012). The emphasis is also set on what are the main drivers for social awareness and which are the benefits deriving from it. Constructing Excellence(2004) and the International Institute for sustainable development (2004) recognize engagement with stakeholders as a main factor in identifying and attending social issues. The relevance of stakeholder engagement for construction developments is argued through various literature discussing on stakeholder management (Newcombe 2003, Olander 2006, Chinyio and Akintoye 2008).

Furthermore, satisfying stakeholder expectations can help reduce costs, minimise risks, build a good reputation and secure a ‘licence to operate’, ìmprove relationships with the public authorities and enhance trust in the organisation’s brand. Therefore, the possibility of improving business performance for construction organisations is recommended through stakeholder engagement which needs further research meant to identify a way to measure it and prove the positive effect on business performance.

2.2 Business areas and the community

A construction organisation closely interacts and influences a variety of other organisations through its business choice of activities, from clients, charities to government’s organisations, NGOs and supply chain. Therefore, it is evident that one specific feature of each organisation is the variety of business areas it can engage, that gives information on the organisation’s proactive attitude in the responsibility it has towards the community.

First of all, an enhanced business scope creates opportunities for gaining competitive advantage by the possible interrelationships that can develop between different business units which share activities along the value chain Porter (1985). Secondly, sustainability is about thriving economically while considering societal and environmental needs and the construction industry is in a continuous interaction with society through the activities it performs. Therefore, shared value becomes a condition for growth, as “social needs create markets” (Porter and Kramer 2011) and ignoring societal demands could result in loss or misuse of resources (Olander and Landin 2005).

Consequently, an organisation with a larger activity spectrum can develop the capabilities to engage a broader range of societal needs and provide products and services which improve the community quality of life, but it can also promote work opportunities to the local community, enhance local economy by utilizing local businesses (Zhao et al. 2012). The wider the business scope the bigger the contribution to creating a harmonious healthy community and the organisation can ensure “a legacy from its commercial activity“ (Balfour Beatty plc. 2012).

2.3 Market and costumers

An organisation's position on the market is sustained by its resources and capabilities and also by the industry structure (Porter, 1985). Also, its ability to engage with a wider number of customers by establishing common goals and creating common value promises long term viability. The construction industry however has a different acceptation of the term costumer as it refers to both clients and future users and an organisation has to address client's demand and secure future user satisfaction. Therefore, engaging with customers in order to differentiate from competitors and establish a good market requires attending to a complex variety of aspects arising both at project and corporation level (Zhao et al. 2012) .

Moreover, the construction industry faces many changes on an international scale (Han et al. 2010). Essentially, engaging local resources reduces time and price, but financial capability and the ability to deliver complete integrated project schemes becomes critical for expanding on other markets. The effects of globalization are transforming the construction industry, softening the cross-cultural and cross-national differences, transforming the means by which engagement with costumers happens. Markets can be expanded by improving relationship with costumers based on attending to ethical issues (Moodley, Smith, and Preece, 2008), developing strategies for innovations in technology and materials and displaying an accurate disclosure on organisations performance (Zhao et al. 2012).

2.4 Impact, employees and suppliers

A construction organisation has an impact on society from an economic, environmental and social point of view. Following Maas'(2009) definition about impact, it is asserted that construction organisations' results are found in the physical structures that are developed, like buildings, roads, bridges, but it is the effects produced by the process to deliver them and through their usage that can be called impact.

Stakeholder engagement happens both at the internal and external level of the organisation (Olander 2006). While assessing impact externally is characterised by high levels of uncertainty and deriving from project environment (Yang et al. 2011), a more consistent impact assessment for stakeholder engagement can be performed at internal level, with a specific emphasis on the outcomes delivered by the organisation within and throughout employees and suppliers. The case for considering employees for the assessment of impact lies in the fact that engaged employees have a major influence to the implementation of business strategies, change and development of a culture of sustainability in the organisation (Eccles et al. 2012). Furthermore, the actions an organisation takes can maintain employees' interest, but also attract new ones based on work policies and practices and acting responsibly (Zhao et al. 2012).

Furthermore, a high level of an organisation's social impact is perceived across its supply chain. Collaborating with suppliers which deliver performance in sustainability matters enhances the positive outcomes which business has over society and helps overcome the circle of blame' existent among stakeholders in the construction industry, generated by a lack of motivation (Feige et al. 2011). It also reaffirms and contributes to developing its identity as a sustainable organisation, because in order to achieve its sustainability goals the organisation needs support and collaboration from its partners on the supply chain (Eccles et al. 2012).

3 DEVELOPMENT OF THE STAKEHOLDER ENGAGEMENT FRAMEWORK

This is a conceptual paper which builds on previous work on stakeholder management in constructions. Olander (2007)proposes a three dimension framework for measuring stakeholder impact which is meant to be used by managers for monitoring and evaluating the effects stakeholders concerns can have on a project. It is an ongoing and retrospective assessment performed at project level which describes the external stakeholders' perspective and possible impact.

The current proposed construct is different from that of Olander (2007) in that firstly, it is aimed at assessing the mutual relationship developed between organisation and stakeholders, addressing both stakeholders' impact on the organisation and the organisation's effects on its stakeholders. Explicitly, the organisation takes actions to hold its stakeholders' interest and trust, therefore impacting on their commitment to the organisation's goals and, accordingly stakeholders react by changing their behaviour and aligning their values to the organisation's culture and further convey them to society. Secondly, it is a monitoring and evaluating framework intended for managerial use for strategic decisions concerning both the organisation and the projects it develops. Thirdly, it considers the degree of engagement with the stakeholders which are closest to an organisation and which generally concur in projects and do not vary according to where it develops its business. This is supported by the fact that each organisation has specific issues to deal with for the context it operates in(Murray and Dainty 2009) and, therefore, for a prevalent assessment of an organisation's stakeholder engagement it is indicated to start with accounting for the ever present stakeholders in a business.

A series of three initial particularities for defining stakeholder engagement is drawn from above: the variety of businesses an organisation engages in, the organisation's ability to create value and become a market leader, and the relationship developed with its employees and suppliers viewed as the capacity to attract and retain them.

Figure 1 reflects the framework for Stakeholder Engagement as it is displayed in three dimensions.

Figure 1: Dimensions of Stakeholder Engagement

First of all, it is recommended to consider the areas for doing business as an implicit requirement in analysing the degree of responsibility an organisation is prone to exert when relating with the consumers and users of the built environment. Therefore the Organisation Activity Attribute is the first characteristic to consider in the Stakeholder Engagement construct. It is expected that the wider the area for doing business, the higher the possibility of acting socially responsible and delivering value to the consumers and users of the built environment, this resulting in a potential to increase the financial performance of the organization.

The second characteristic, Market Position, asserts that an organisation's ability to engage with a wide number of costumers and attend to their extensive integrated demands is a major component of the Stakeholder Engagement construct. Expectations are that a leading Market Position implies a positive customer engagement, which comes with reduced risk, enhanced financial capability and the ability to deliver full and integrated construction projects.

Thirdly, Organisation Impact considers assessing the impact on its employees and on its suppliers and subcontractors on the supply chain, from the possibility of attending to their interests and concerns. How much does the organization do for them and is that enough to develop a long lasting prosperous relationship? This impact ensues from considerations of employee education on sustainability principles, personal development, motivation (and productivity), considerations of demands for a sustainable supply chain which require environmental regulations, compliance from suppliers and their alignment to the organizations practices of sustainability such as health and safety management, quality and ethical policies and life cycle approach considerations in their business processes.

4 PROPOSED METRICS

The following analysis about the above insights draws and develops three characteristics to identify stakeholder engagement as a composite index: Organisation's Activity attribute, Organisation's Position in market, Organisation's Impact with the purpose of measuring it.

The Activity Attribute describes the level of engagement an organisation has with the community by providing services and support for its quality of life through a wide range of business activities. The business scope can be measured by the number of activity codes as they are defined in the activity classification issued by the Statistical Office of the European Communities (Eurostat), and adopted for the Standard Industry Classification (Office for National Statistics 2009).

The Market Position describes the level of engagement an organisation has with its costumers by becoming the leading choice for a customer based on its capabilities and ability to provide quality services. The customers that choose the provider of the services they require, create a market for those services and from this point of view, market share is viewed as "share of potential consumers". Still, the general usage of the term refers to the actual sales for a product or service in a given period and a given geographical area (Cooper and Nakanishi, 1988, p.17).Concerning our current research, the proposed measurement for an organisation's Market Position is by its market share. Each organisation's market share becomes a ratio of its sales to the total industry sales:

$$- \qquad (1)$$

y_i – market share for organisation i (i =1,2,….,total number organisations)

t_i– sales for organisation i (i =1,2,….,total number of organisations)

$T = \Sigma t_i$– the total industry sales

Finally, the Organisation Impact describes the level of impact that results from stakeholder engagement, as perceived through internal stakeholders, by acting ethically and setting common goals for a sustainable development. This characteristic for Stakeholder Engagement can be assessed by measuring employer and supplier turnover on the rationale that positive engagement, by satisfying stakeholder needs and expectation, builds trust and loyalty.

5 DISCUSSION /IMPLICATIONS

Stakeholder engagement is a function of three characteristics (an aggregate metric), which stands for how well an organisation is doing in relating with the external and internal factors that drive its business – community, customers, employees and suppliers and is closely related to measuring the long term effects of corporate social responsibility(a proxy for social engagement). The construct considers the degree of engagement with mainly internal stakeholders of an organisation, which generally concur in projects and do not vary according to where it develops its business in order to overcome the fact that construction developments differ from one to another by time, location or team membership (Zhao et al. 2012). The identified characteristics, which bear completion and adaptation to an organizations business scope, will be correlated with a financial performance indicator. It cannot be stated if these three characteristics are directly traceable to financial results, but the correlation gives clues as to whether acting on that direction is worth an organization's time. A relationship between two data sets, stakeholder engagement and financial performance, which will say that for a given value on one characteristic describing stakeholder engagement, an organisation can get a corresponding result on a key business metric like profit before taxation, will be further investigated.

It should be noted that the correlation assumed above does not necessarily mean that a higher or stronger characteristic causes better financial performance, but simply that the correlation exists and is worth exploring. It should not be assumed that doing more improves financial results. This correlation draws attention on the real world context and possible drivers for the situation and sets the possibility to explore the relationship further.

Finally, the Stakeholder Engagement framework is aimed for assessing the socio-economic dimension of sustainability for construction organisations. Envisioned for use at a strategic level of the organisation, the framework will measure the level of the overall stakeholder engagement of a construction organisation and can inform strategic decisions. It can be used as an indicator to gauge stakeholder engagement against previously agreed best practices on this matter. Also, being able to portray a profile of the organisation's Stakeholder Engagement by the three characteristics describing it: organisation attribute, market position and impact enables businesses to prove care for sustainability, promote themselves as a sustainability orientated organisation (Pitt et al. 2009).

Limitations to the framework exist as not all stakeholders relevant for a construction organisation are considered in the framework. Acknowledging and including all stakeholders can lead to the development of other characteristics for the construct Stakeholder Engagement or it can add to the existent one. For example, the government does not necessarily have direct contractual relationship with construction organisations, but it can influence the characteristic market position that is acquired by stakeholder engagement (Testa et al. 2011). Also collaborating with public authorities and non-governmental organisations can influence the organisational impact (Aaltonen and Kujala 2010) that emerges from the engagement. The difficulty with considering all stakeholders for the framework lies in finding a proper mean of assessing their influence, however it clearly indicates an opportunity for future research.

6 CONCLUSION

Sustainability in construction developments is an ongoing pursuit ever since the concept was first defined, almost two decades ago. The existent approaches for sustainability appraisal vary from tools for assessing the environmental issues which derive from projects in the built environment to possible guidelines to address corporate responsibility and stakeholder management in construction projects. There is a necessity to explicitly define issues which are to be attended from the socio-economic perspective of sustainability.

This paper puts forward a framework that can provide a basis for measuring stakeholder engagement considered as a driving agent for the socio-economic perspective of sustainability. The Stakeholder Engagement framework should inform on strategic decisions exercised by construction organisation for sustainable development and growth.

Future work will focus on empirically investigating the relationship between the tri-axial construct proposed for Stakeholder Engagement and business performance. The final step will be to outline the profile of the organisation with the most recommended level of Stakeholder Engagement.

REFERENCES

K. Aaltonen and J. Kujala, “A project lifecycle perspective on stakeholder influence strategies in global projects”, *Scandinavian Journal of Management*, 26(4), 381–397 (2010). Available at http://linkinghub.elsevier.com/retrieve/pii/S0956522110000941

R. Ameer and R. Othman,”Sustainability practices and corporate financial performance: A study based on the top global corporations”, *Journal of Business Ethics*, 108(1), 61–79 (2011). Available at http://www.springerlink.com/index/10.1007/s10551-011-1063-y

Balfour Beatty plc, “Sustainability”, *Sustainability Report*” (2012). available from: http://www.balfourbeatty.com/index.asp?pageid=6

E.A. Chinyio and A. Akintoye, “Practical approaches for engaging stakeholders: findings from the UK”, *Construction Management and Economics*, 26(6), 591–599 (2008).

Constructing Excellence, “Corporate Social Responsibility fact sheet”, 1–6 (2004). Available from: http://cenew.idnet.net/pdf/fact_sheet/social_responsibility.pdf

L. Cooper and M. Nakanishi, *Market-Share analysis, evaluating competitive marketing effectiveness, J. Eliashberg, ed.*, Kluwer Academic Publishers, London (1988).

G.K.C. Ding, “Sustainable construction - the role of environmental assessment tools”, *Journal of Environmental Management*, 86(3), 451–464 (2008). Available from: http://www.ncbi.nlm.nih.gov/pubmed/17289255.

R. Eccles , K.M. Perkins, and G. Serafeim,. “How to become a sustainable company”, *MIT Sloan Management Review”*, 53(4), 43–50 (2012).

A. Feige, H. Wallbaum and S. Krank, “Harnessing stakeholder motivation: towards a Swiss sustainable building sector”, *Building Research & Information*, 39(5), 504–517(2011). Available from: http://www.tandfonline.com/doi/abs/10.1080/09613218.2011.589788

H. Fergusson and D. Langford,. “Strategies for managing environmental issues in construction organizations”, *Engineering, Construction and Architectural Management,* 13(2), 171–185 (2006). Available from: http://www.emeraldinsight.com/10.1108/09699980610659625

S.H. Han et al., "Strategies for contractors to sustain growth in the global construction market", *Habitat International*, 34(1), 1–10 (2010). Available from: http://linkinghub.elsevier.com/retrieve/pii/S0197397509000423

R.C. Hill and P. Bowen, "Sustainable construction: principles and a framework for attainment", *Construction Management and Economics*, 15(3), 223–239 (1997). Available from: http://www.tandfonline.com/doi/abs/10.1080/014461997372971

International Institute for Sustainable Development, *Issue briefing note: Stakeholder Engagement*, *ISO and Corporate Social Responsability* (2004). available from:http://inni.pacinst.org/inni/corporate_social_responsibility/standards_stakeholder_engagement.pdf.

C.J. Kibert, "The next generation of sustainable construction", *Building Research & Information*, 35(6), 595–601 (2007). Available from: http://www.tandfonline.com/doi/abs/10.1080/09613210701467040

Y. Lu and Q. Cui, "Sustainability rating system for construction corporations: A best practice review", *ICSDC 2011*, 151–160 (2012).

K. Maas, *Corporates performance: from output measurement to impact Measurement* , Rotterdam School of Management (2009). Available from: http://www.hartstichting.nl/9800/13333/13371/proefschrift_karen_maas

K. Moodley, N. Smith and C.N. Preece, "Stakeholder matrix for ethical relationships in the construction industry", *Construction Management and Economics*, 26(6), 625–632 (2008). Available from: http://www.tandfonline.com/doi/abs/10.1080/01446190801965368.

M. Murray and A. Dainty, "Corporate social responsability: challenging the construction industry", *Corporate Social Responsability in the Construction Industry*, M. Murray & A. Dainty (eds.), pp. 3–23, Taylor & Francis, Abingdon (2009).

R. Newcombe, "From client to project stakeholders: a stakeholder mapping approach", *Construction Management and Economics*, 21(8), 841–848 (2003). Available from: http://www.tandfonline.com/doi/abs/10.1080/0144619032000072137

L. Posser , UK Standard Industrial Classification of Economic Activities: Structure and explanatory notes (SIC), Office for National Statistics (2007). Available from: http://www.ons.gov.uk/ons/guide-method/classifications/current-standard-classifications/standard-industrial-classification/index.html.

S. Olander, *External stakeholder analysis in construction project management*, Lund University (2006). Available from: http://www.bekon.lth.se/fileadmin/byggnadsekonomi/research/doctoral_thesis/Summary.pdf.

S. Olander, "Stakeholder impact analysis in construction project management", *Construction Management and Economics*, 25(3), 277–287 (2007). Available from http://www.tandfonline.com/doi/abs/10.1080/01446190600879125.

S. Olander and A. Landin, "Evaluation of stakeholder influence in the implementation of construction projects", *International journal of project management*, 23(4), 321–328 (2005). Available from: http://linkinghub.elsevier.com/retrieve/pii/S0263786305000232.

M. Pitt, et al, "Towards sustainable construction: promotion and best practices", *Construction Innovation: Information, Process, Management*, 9(2), 201–224 (2009). Available from: http://www.emeraldinsight.com/10.1108/14714170910950830.

M.E. Porter, *Competitive advantage: creating and sustaining superior performance*, Export2004 ed., Simon&Schuster, New York (1985).

M.E. Porter and M.R. Kramer, “The big idea - Creating shared value”, *Harvard Business Review* (Jan/Feb 2011).

Y. Tan, L. Shen and H. Yao, “Sustainable construction practice and contractors’ competitiveness: A preliminary study”, *Habitat International*, 35(2), 225–230 (2011). Available from: http://linkinghub.elsevier.com/retrieve/pii/S0197397510000676 .

F. Testa, F. Iraldo and M. Frey, “The effect of environmental regulation on firms’ competitive performance: the case of the building & construction sector in some EU regions”, *Journal of Environmental Management*, 92(9), 2136–44 (2011). Available from: http://www.ncbi.nlm.nih.gov/pubmed/21524840 .

G. Trufil and K. Hunter, “Development of a sustainability framework to promote business competitiveness in construction SMEs”, *Symposium on sustainability and value through construction procurement*, 584–593, Salford, UK (2006).

M. Wagner and S. Schaltegger, “How does sustainability performance relate to business cmpetitiveness?”, *Greener Management International*, (44), 5–17.

World Commission on Environment and Development, Our Common Future (1987). Available from: http://www.un-documents.net/our-common-future.pdf.

J. Yang, et al, “Stakeholder management in construction: an empirical study to address research gaps in previous studies”, *International Journal of Project Management*, 29(7), 900–910 (2011). Available from: http://linkinghub.elsevier.com/retrieve/pii/S0263786310001171.

Z. Zhao, et al, “A corporate social responsibility indicator system for construction enterprises”, *Journal of Cleaner Production*, 29-30, 277–289 (2012). Available from http://linkinghub.elsevier.com/retrieve/pii/S0959652611005774 .

AVAILABILITY OF HOUSING FINANCING FUNDS FOR PRIVATE ESTATE DEVELOPERS IN ABUJA, NIGERIA.

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Abstract. *Government in Nigeria has been encouraging and partnering with private estate developers on mass housing provision in Abuja. This paper assessed the perceptions of the private estate developers on the availability of housing financing funds. A well structured questionnaire was designed and administered to fifty (50) of the private estate developers which were randomly selected. Mortgage banks constituted the most frequently utilized source of housing fund, followed by internal funds, loans from thrift and credit societies; and commercial banks; in descending order of utilization frequency. All the five (5) investigated indices of constraints to housing fund availability- excessive protocol and bureaucracy; collateral requirements; government policy restrictions; high interest rate; and loan ceiling/duration each with Relative Importance Index (RII) approximately equal or greater than (0.80); were perceived as very severe. Among the factors to housing fund accessibility, high cost of fund was found the most severe, followed by high cost of construction and thirdly, difficulties in obtaining certificates of occupancy and building plan approvals. Identified initiatives among the private developers towards enhancing housing fund availability were found not frequently employed. Conclusion was reached that of all the available sources of housing financing funds, only the mortgage banks were frequently utilized. All others had low patronage frequency. Also the constraints to the availability and accessibility to the funds ranged from severe to very severe. Deliberate government efforts towards developing sources of housing finance, creating awareness of their potentials and reducing the constraints to the funds availability and accessibility, were recommended.*

Keywords: *Housing Finance; Housing Fund Availability; Private Estate, Developer; Abuja Nigeria.*

1 INTRODUCTION

Shelter is widely believed to be one of the basic necessities of life. It has been observed that housing is a reflection of the cultural, social and economic values of a society and one of the best historical evidence of the civilization of a country (Olotuah 2000). This has made governments of countries world over to be involved in the provision of housing for the citizens, at least at the policy formulation and regulation levels. Housing has been viewed as the process of providing a large number of residential buildings on a permanent basis, with adequate physical infrastructure and social amenities, in planned, descent, safe and sanitary neighborhoods to meet the basic and special needs of the population (Federal Ministry of Works and Housing, 2002).

Housing deficit, though a universal problem, is quite significant in Nigeria especially in Abuja and the entire Federal Capital Territory (FCT). This is mainly due to rapid urbanization and surging population arising from rural-urban and urban-urban migrations created by the natural tendency for people to gravitate towards the FCT as the seat of the Federal Government of Nigeria. Ajanlekoko (2001) and Oluwasola (2007), observed that housing demand in the FCT had not been matched with adequate supply. The efforts of the Federal Government to address this led to government's encouragement and partnership with private estate developers on mass housing programmes in the FCT (Fortune-Ebie 2006). As at 2010 there were 356 private estate developers in partnership with the FCDA on mass housing programmes, with 4,158 completed housing units as against the projected 35,859 housing units (FCTA, 2010). This gives an achievement of only 11.6% of the targeted housing production.

The challenges facing private estate developers in Abuja have been identified as ranging from: regulatory institutional weaknesses, bureaucratic bottlenecks and failure to provide basic infrastructure on the side of government; to financial incapacitation, and technical/managerial constraints on the side of the estate developers. Generally, finance is known to be a key factor in the success of housing projects since it can be used to acquire most other housing production resources such as: land, building materials, machinery and labour (Sanusi 2003). Ope (2005) identified four sources of funds for housing development in most human societies as: personal savings; public or institutional capital budgetary allocations, loans from mortgage institutions; and donations. Ural (2006) and Gomez (2006) variously identified mortgage finance as a potential major source for mass housing finance but one which people often access with caution.

This paper examines the perceptions of private estate developers on Housing fund availability in Abuja, Nigeria, mainly because of the key role expected of prívate estate developers in government's mass housing programmes; as well as the importance of finance to the success of such programmes. The objectives are to: determine the utilization frequency of available major sources of funds, establish the constraints to housing fund availability and accessibility; and survey current efforts of the private estate developers towards improving housing fund availability. The work was carried out by literature and field/surveys.

2 LITERATURE

2.1 Housing finance in Nigeria

Nigeria has been identified to have a poor savings culture (Moss 2003). This has been worsened by distortions arising from distressed and liquidated banks. Workers in the formal sector of the economy compulsorily contribute into the National Housing Fund (NHF) but still experience difficulties in accessing the fund due to stringent loan conditions. From Finmark Trust (2010) the mortgage sector in Nigeria is still largely underdeveloped, hence housing transactions are still on a "cash and carry" basis, making it beyond the reach of most citizens. The commercial banks and other financial institutions have also been found incapable of granting long-term credit facilities largely because of their nature of operation (Adegbenjo 2000). Housing development funds are therefore difficult to access.

2.2 Sources of housing funds

a. Commercial banks:. These are constrained by their nature of operation with regards to long term loans usually required for housing development (Adegbenjo 2000).

b. Insurance companies: Jinadu (2008) observed that insurance companies have a great role to play in the housing capital market even though the potentials are yet to be fully explored in Nigeria.

c. Federal Mortgage Bank of Nigeria (FMBN): The FMBN commenced operation in 1978 as a direct federal government intervention to accelerate its housing delivery programmes. Its mandate include the expansion and coordination of mortgage lending on a nation-wide basis, using resources from deposits mobilized and equity contributions by the Federal Government and the Central Bank of Nigeria, at interest rates below the market rates.

d. Primary Mortgage Institutions (PMIs): The PMIs came into operation by Decree no. 53 of 1989 which provided the regulatory framework for the establishment and operation of PMIs by private entrepreneurs. The FMBN under the decree became the apex institution, which licenses and regulates the PMIs as second tier housing finance institutions.

e. The Federal Mortgage Finance Limited (FMFL). This was established in 1993 to carry out retail aspect of mortgage financing and provide credible and responsive housing finance services while the FMBN became the nation's apex mortgage lending agency.

f. The National Housing Fund (NHF). This is a mandatory contributory scheme established by decree no. 3 of 1992, to mobilize cheap and long-term funds for housing credits. The NHF was actually the financial component of the National Housing Policy of 1991.

g. Pension Fund Administrators (PFAs). The PFAs collect funds from employers and employees towards their retirement. They are allowed to offer long-term loans to mortgage institutions and building societies.

h. State/municipal government financing: Such funds are often channeled through the states' development finance institutions such as the Housing Corporations or Investment and Property Development Corporations; for lending to individuals for residential building construction.

i. Specialized development banks

This category includes the Nigerian Industrial Development Bank (NIDB), Urban Development Bank etc, which are established to grant long-term finance for up to 25years for industrial, commercial agricultural and housing developments.

j. Cooperative Societies: Cooperative societies are also involved in the provision of credit for housing to their members. Loans are advanced to their members from resources they pool together.

k. Other formal and informal sector institutions. These include: the Nigerian Building Society (NBS), National Housing Trust Fund (NHTF); Real Estate Developers Association of Nigeria (REDAN); and Building Materials Producers Association of Nigeria (BUMPAN)

2.3 Constraints to housing financing funds availability and accessibility

From Sanusi (2003) and Finmark Trust (2010) the constraints to housing financing funds availability and accessibility can be summarized as follows:

a. Macroeconomic challenges

i. Inflation

ii. Government fixed and monetary policy

iii. Retail sales

iv. Interest rates

v. Consumer price index

vi. Employment indicators
b. Policy and regulatory challenges such as
i Land use acts
ii. Taxes, stamp duties and fees
iii. Property regulation
c. Financial sector challenges
i Insufficient capital base
ii. High interest
iii. Lack of efficient secondary mortgage market linked to capital markets and institutional investors
iv. Lack of credit enhancement vehicles for extending mortgages to low-income levels
v. Limited number of requisite skilled manpower necessary for the mortgage market.
d. Housing sector challenges
i. High cost of building materials
ii. Lack of infrastructure (electricity, water supply, sewers and access roads)
iii. Insufficiency of requisite craft-skill manpower

2.4 Private estate developers

Mabogunje (2002) defined a real estate developer as an entrepreneur who is committed to assuming the risks of mass housing production in advance of sale. Gumel (2000) categorized private estate developers as follows:

a. Land Developers: These acquire lands, prepare the plots and make them available for prospective builders.
b. On-site developers: they acquire lands and put up building on them for sale
c. Merchant builders: These are developers who could be local industrialists that build several units of houses of similar design with the aim of achieving economic of scale and sell them to home buyer immediately after completion.
d. Developer-investor: These are similar to merchant builders expect that they retain the ownership of the constructed buildings which are rented out to the users.

The importance of the private estate developers in the realization of Governments mass housing programmes in Nigeria is widely recognized (Fortune- Ebie, 2006; FCTA,2010 and Finmark Trust 2010). They are to promote the development of residential estates in order to increase the supply of affordable housing for all classes of Nigerians.

2.5 The study area

Abuja was pronounced the new capital of Nigeria in 1976, built mainly in the 1980s and officially replaced Lagos as the capital on 12 December 1991. It is located in the centre of Nigeria, within the FCT, bounded on the north by Kaduna State, on the east and south-east by Plateau State and on the south-west by Kogi State. It falls within latitudes $7^0$25' and $9^0$20' North of Equator and longitudes $5^0$45' and $7^0$39'

Abuja is a planned city with an area of 250sqkm out of the 8,000sqkm of the entire FCT. Abuja continues to witness a huge influx of people into the city, leading to the growth of satellite towns such as; Karu, Nnanya, Gwagwalada, Kubwa and Jokoyi.).

Abuja city comprises of six districts namely, central, Gariki, Wuse, Maitama, Asokoro and Gwarimpa districts. The population of Abuja has been estimated to be 2,245,000 as at 2012, making it the fourth largest urban area in Nigeria, only next to Lagos, Kano and Ibadan (Secure Africa, 2012)

3 FIELD SURVEY

The field survey centers on the perceptions of private estate developers in Abuja on housing funds availability and accessibility in the city. A well structured questionnaire was designed and administered to fifty of the private developers which were picked at random. Forty one (41) of the questionnaires were properly completed and returned, representing a response rate of 82%. Major issues addressed in the questionnaire include: sources of housing financing fund and their patronage frequencies; constraints to housing fund availability and accessibility; and the developers' initiatives for enhancing the fund availability. Relevant Secondary data from publications of the Federal Mortgage bank of Nigeria (FMBN) were also obtained and analyzed.

3.1 Data analysis procedure

Most of the questions in the questionnaire involve assessing some indices of housing financing established in literature, on a five (5) point Likert's scale. The data analysis therefore employed the following steps:

a. Computation of the mean using the weighted average formula

$$\bar{x} = \frac{\Sigma fx}{\Sigma f} \qquad (1)$$

Where $\bar{x}$ = mean

x = Point on the Likert's scale (1, 2, 3, 4, and 5)

f = Respondents' frequency of choice of each point on the scale

b. Computation of the Relative Importance Index (RII) for each item of interest, using the formula

$$\text{RII} = \frac{\bar{x}}{k} \qquad (2)$$

Where k = the highest weight on the Likert Scale (i.e 5)

c. Ranking of the items under consideration based on their RII values. The item with highest RII value is ranked first (1), the next (2) and so on.

d. Interpretation of the RII Values:

RII < 0.60, item is assessed to have a low ranking

0.6 ≤ RII < 0.80, item assessed to have high ranking

RII ≥ 0.80, item has very high ranking

4 DATA PRESENTATION AND ANALYSIS

4.1 Data from the questionnaire

Table 1 presents the views of the private estate developers on housing fund sources and utilization frequencies Tables 2 and 3 show the severity of factors militating against the funds availability and accessibility respectively. Table 4 shows the developers' frequency of employing identified initiatives for enhancing housing funds availability.

4.2 Data from Federal Mortgage Bank of Nigeria (FMBN)

Table 5 presents data obtained from the FMBN from which a picture of housing fund availability may be seen by comparing approved loans with disbursed loans for each of the years.

5 DISCUSSION

5.1 Major sources of funds and utilization frequency

It is evident from Table 1 that the mortgage banks constitute the most frequently utilized source of housing fund. This is followed by internal funds, loans from thrift and credit societies; and commercial banks. The low utilization frequency of sources such as: government bonds; shares; and insurance and pension funds is traceable to low awareness of their potentials among the prívate estate developers.

S/No	Sources of Finance	Frequency of Response					∑f	∑fx	Mean $\bar{x}$	RII	Rank
		1	2	3	4	5					
1	Internal Funds	8	4	16	4	8	41	113	2.76	0.55	2nd
2	Loans from thrift and credit societies	8	8	17	8	-	41	107	2.61	0.55	2nd
3	Commercial banks	4	12	17	8	-	41	111	2.71	0.54	4th
4	Merchant banks	8	21	8	4	-	41	90	2.19	0.43	6th
5	Mortgage banks	4	-	8	8	21	41	165	4.02	0.80	1st
6	Insurance and pension funds	21	4	8	4	4	41	89	2.17	0.34	6th
7	Government bonds	21	12	8	-	-	41	69	1.68	0.33	9th
8	Foreign Direct Investment	17	12	4	-	8	41	93	2.29	0.45	5th
9	Shares	21	8	8		4	41	81	1.98	0.39	8th

Source: Field Survey, April (2012)
1=Very infrequently used (<30%); 2=infrequently used (30-39%); 3=Fairly frequently used (40-49%); 4=Frequently used (50-69%); 5=Very frequently used (≥70%)

Table 1: Major Sources of Funds and Utilization Frequency

5.2 Severity of constraints to housing funds availability

All the five identified factors in Table 2: excessive protocol and bureaucracy, collateral requirements government policy restrictions; high interest rate; and loan ceiling/duration obtained RII values approximately equal or greater than (0.80). This implies "very high ranking" meaning that all the constraints are perceived to be very severe by the private estate developers.

S/No	Sources of Finance	Frequency of Response					∑f	∑fx	Mean $\bar{x}$	RII	Position
		1	2	3	4	5					
1	Excessive protocol and bureaucracy	-	4	4	8	25	41	177	4.31	0.86	1st
2	Collateral requirement	4	-	8	8	21	41	165	4.02	0.80	4th
3	Government Policy restrictions	-	8	4	17	12	41	156	3.80	0.76	5th
4	High interest rate	4	-	4	12	21	41	169	4.12	0.82	2nd
5	Loan ceiling and duration	4	-	8	4	25	41	169	4.12	0.82	2nd

Source: Field Survey, April (2012)

1= Very mild; 2= Mild; 3= Slightly sever; 4=Severe; 5= Very severe

Table 2: Severity of the Factors Militating against the availability of funds

S/No	Sources of Finance	Frequency of Response					∑f	∑fx	Mean $\bar{x}$	RII	Position
		1	2	3	4	5					
1	Fund shortage/high cost of fund	4	-	-	4	33	41	185	4.51	0.90	1st
2	High cost of construction	-	4	4	4	29	41	181	4.41	0.88	2nd
3	Delay in certificate of occupancy and building plan approval	4	-	-	12	25	41	177	4.32	0.86	3rd
4	High cost of building materials	-	8	8	17	12	41	160	3.90	0.76	5th
5	Land acquisition problem	4	-	-	21	16	41	168	4.10	0.82	4th
6	Route of infrastructure	-	8	16	-	17	41	149	3.63	0.72	7th

Source: Field Survey, April (2012)

1= Very mild; 2=Mild; 3= Slightly sever; 4=Severe; 5= Very severe

Table 3: Severity of Constraints to the Accessing of Housing Funds by Estate Developers

5.3 Severity of constraints to housing fund accessibility

All the seven identified constraints obtained either the "high ranking" ($0.60 \leq RII < 0.80$) or the '"very high ranking" ($RII \geq 0.80$). High cost of fund however is adjudged the most severe constraint, followed by high cost of construction, and difficulties in obtaining certificate of occupancy and building plan approvals.

5.4 Estate developers' initiatives for enhancing funds availability

Table 4, shows that the available initiatives are only "rarely" (mean score approximately = 2) or at best "occasionally" (mean score approximately = 3) employed.

S/No	Initiatives	Frequency of Response					∑f	∑fx	Mean $\bar{x}$
		1	2	3	4	5			
1	Liaising with interested foreigners in both private and public sector	17	4	8	4	8	41	105	2.56
2	Pulling resources from all potential investors, both local and foreign	4	12	8	4	13	41	133	3.24
3	Providing united front in making recommendation to Government on ways in seeking solutions to the property market	4	4	33	-	-	41	111	2.71
4	Joining resources with other Estate Developers to provide houses in mass.	12	8	13	8	-	41	99	2.41
	Grand mean								**2.73**

Source: Field Survey, April (2012)

5= Always; 4=Often; 3=Occasionally; 2= Rarely; 1= Never

Table 4: Frequency of Employing Initiatives for Enhancing Housing Fund Availability

Activity	**Year**			
	2006	2007	2008	2009
Loan Approved (PMI)	6.12	7.61	8.24	35.92
Loans Disbursed (PMI)	3.59	7.55	6.60	16.88
Loans Approved (EDL)	12.04	38.40	8.05	9.30
Loans Disbursed	5.32	16.69	1.92	0.92

Source: Federal Mortgage Bank of Nigeria (2012)

Table 5: National Housing Fund Loans (Billion Naira)

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The mortgage banks put together is the most important and the most frequently utilized source of housing finance for the private estate developer in Abuja, Nigeria. Other sources such as: internal funds, loans from thrift and credit societies; and commercial banks have low frequency of patronage. The constraints to the funds availability and accessibility range from severe to very severe. Initiatives for enhancing housing fund availability are not frequently employed by the private estate developers.

6.2 Recommendation

The sources of housing finance (listed in Table 1) should be developed and awareness of their potentials increased among the private estate developers. Deliberate government efforts should be deployed in reducing: the bureaucracy and restrictions associated with mortgage loans approval and disbursement; difficulties in land acquisition; obtaining certificates of occupancy and building plan approvals. The private estate developers should be more pragmatic on innovative ways of enhancing housing funds availability.

REFERENCES

A Adegbenjo, Financing Real Estate Development in the 21st Century- Strategies for Capital market Involvement in Funding of Real Estate Projects in Nigeria. NIESV (2000).

J.S. Ajanlekoko Sustainable Housing Development in Nigeria in the Financial and Infrastructural Implication, *International Conference on Spatial Information for Sustainable Development* Nerobi Renya 16 September.(2001)

FCTA, Guidelines for the Mass Housing Programme of the FCTA (2010) [online] Available from www.dailytrust.com [Accessed19September, 2012]

Finmark Trust, Overview of Housing Finance in Nigeria. (2010). [Online] Available from http://www.efina.org.ng [Accessed 8 February, 2013]

S. Fortune-Ebie, The National Housing Policy: The way forward. Paper presented at the *workshop on Mortgage Finance* 29th-30th August,Organized by the Federal Ministry of Housing and Urban Development. (2006)

W. Gomez, Special Focus on Changing the face of the Mortgage Industry in a Developing Economy. Top Shakers and Movers in Nigeria's Housing/Building Industry Directory. Eniola, T and Alabi K (Ed) pp 6-10 (2006).

H.S. Gumel, Strategies for Sustainable and Affordable Housing Delivery in Nigeria. *The Professional Builder, Journal of the Nigerian Institute of Building* June/July pp 3-7 (2000).

A.M. Jinadu, Understanding the Basic Issues of Housing. Jos University Press Limited. Jos (2008)

A.L. Mabogunje "Beyond Housing Delivery: The Challenge of Infrastructure Provision and Orderly Urban Development in Nigeria", SOFF 5 Annual Distinguished Guest Lecture Series and Endowment Fund. (2005)

V. Moss, Preview of Housing Finance Systems in Four Different African Countries: South Africa, Nigeria, Ghana and Tanzania Unpublished Report.(2003) [online]

Available from www.housingfinance.org/pdfstorage/Africa-Preview [Accessed May 2007].

A.O. Olotuah, "The Challenge of Housing in Nigeria". Effective Housing in the 21st Century in Nigeria. *The Environmental Forum, Federal University of technology Akure*, Nigeria. pp.16-21. (2000)

O. Oluwasola, Social Systems, Institutions and Structures: Urbanization Poverty and Changing Quality of Life. Paper presented at the training session of the foundation for environmental development and education in Nigeria. (2007)

K.M. Ope, Analysis of the Financial Allocation by State Government to Housing Construction in Nigeria. An unpublished M. Tech. (Const. Mgt) thesis submitted to the school of postgraduate studies, F.U.T. Minna, Nigeria. (2005)

J.O Sanusi, Mortgage Finance in Nigeria: Issues and Challenges, Paper presented at the 9th John Ekpenyong Memorial Lecturer Organized by NIESV, 29th January (2003).

Secure Africa, . (2012). About Abuja. [Online] Available from http://secureafrica2012.org/index.php/about-abuja [Accessed 8 February, 2013]

The Federal Ministry of Works and Housing Nigeria's Agenda 21. Federal Environment Protection Agency. Abuja. (2002)

O.Ural, (Ed) Construction of Lowering-Cost Housing. (5th Ed). John Willey and Sons, New York USA. (2006)

HOUSING QUALITY IN THE URBAN FRINGES OF IBADAN, NIGERIA

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Abstract. *Recent increases in poverty and inequity combined with rapid population growth in developing countries have created substantial pressures on housing provision. Housing supply shortages and the deterioration in the quality of the housing stock have become serious problems that need to be addressed in these countries. The non-consideration of relevant socio–economical parameters by organizations responsible for housing provision has been identified as one of the major reasons for the housing inadequacies and poor quality in most urban fringes of developing countries - Ibadan inclusive. On this position, paper examines the influence of socio-economic factors in the determination of housing quality in the urban fringes of Ibadan. This study identifies the urban fringes in Ibadan, Oyo state, Nigeria. The paper examines the causes and characteristics of the urban fringes in the assessment of housing quality. The paper identifies the critical factors causing the formation of urban fringe to: (i) poverty; (ii) rapid urbanization and influx of people into urban areas;(iii) growth of informal sector, (iv) war, natural disasters and earthquakes leading to massive movement of people to places of opportunity and safety; (v) Ineffective Housing Policies; (vi) housing shortage; (vii) inefficient public administration, inappropriate planning and inadequate land administration tools. The paper asserts that the urban fringes have serious adverse effects on the people's health, their built environment and housing quality. The secondary data was obtained from books, journals and seminar papers while the primary data relating to housing quality were obtained by means of structured questionnaire. The study revealed a gap in quality between the low- and medium-income resident. This paper suggests the implementation of policies and planning, physical infrastructural development, social-economic improvement, environment and health improvement. Government, private and communities interventions on the urban fringes are required in order to check and prevent further decay for sustainable development. Therefore, government is encouraged to see urban fringes as a solution to new city planning rather than problem to the urban areas.*

Keywords: *housing quality, housing affordability, informal sectors, urban fringes*

1 INTRODUCTION

In developing countries, a substantial and growing proportion lives in or around metropolitan areas and mega cities, including the zone termed the 'urban fringe', where their livelihoods depend to some extent on natural resources such as land for food, water and fuel, and space for living (Adesina, 2007). The population pressure means that resources in such zones are often overexploited. Although heterogeneous in its social composition, the urban fringe constitutes the habitat of a diversity of populations, including lower income groups who are particularly vulnerable to negative externalities of both rural and urban systems. These include; risks to health, life and physical hazards related to the occupation of unsuitable sites, lack of access to clean water and basic sanitation and poor housing conditions. Environmental changes also impinge upon the livelihood strategies of these communities by decreasing or increasing their access to different types of capital.

Nigeria has been experiencing a great transition from rural to urban oriented economy, which has been accompanied by the increasing mobility of production factors such as: capital, labour, technology and information to the urban fringe near these cities such as Ibadan, Lagos, Kano, Benin, Aba, Kaduna etc. Consequence to the wide spread beliefs that the urban fringes are fashionable area in urban literature especially in developed countries. Empirical studies have revealed a contrary view regarding the fate of cities in developing countries (Dupont 2005). The UN-Habitat report (2005) has indicated that, in the year 2025, 61% 0f the 5 billion world population will be urban and most mega-cities will stand in what we call the 'south clusters". About 85% of these development will occurs at the urban hinterland widely referred to as peri-urban, suburbs, urban fringe, city edge, metropolitan shadow amongst other. Because of proximity to the city, and urban bias nature of development policies in Nigeria, the zone experiences much of urbanization processes and serves as buffer for future urban development.

There are forces that shape the urban fringe landscape. One-prominent features in Nigeria, particularly Ibadan is the informal sector activities and its attendant problems on urban fringe political economy, these constitute about 65% of the economy. Informal sector response to the failure of urban governance has various dimensions. Such as the informal residential development, incongruous mixed land uses that inadvertently affected the housing quality and the environment in the area.

1.2 PROBLEM STATEMENTS

The urban fringe is often defined as a conflict zone at the interface between urban and rural landscape. It is frequently ignored as a specific area within the study of Urban Housing. Recently, there has been an extraordinary revival of interest on urban fringe issues as a result of the exceptional evolution in urban growth. However, in spite of multitude of generalizations in urban theories, little is known on the housing quality of this area.

This study therefore, identify the urban fringes, examines the characteristics of the urban fringe with a view to providing explanations on the housing quality of residential buildings in the urban fringe as measured by the physical, socio-economic and environmental conditions in the city of Ibadan-Nigeria. The conceptualization of changes we once had of urban fringe was stereotyped and relatively simplistic, but it is now more complex. There is interest in the discipline of Housing on the physical characteristics of the fringe zone.

This study seeks to fill the gap on the emerging socio-spatial transformations by advances knowledge on the physical structure and socio-economic characteristics of the residents of the urban fringe in developing countries using Ibadan as a case study.

This paper therefore is to examine the relationship between housing quality, informal sectors and urban fringes. Social, economic and cultural characteristics as well as environmental issues associated with people living in this area are to be examined so as to impact knowledge that can transform these areas. This is because, it has been observed that little is known about the people living in the urban fringe of Ibadan and those that have worked on it have not done much on Ibadan fringe but rather on central city slum.

1.3 RESEARCH AIM AND OBJECTIVES:

The aim of the study is to assess the influence of Socio-economic factors on housing quality in the urban fringes of Ibadan. The specific objectives of the study were to:

- To identify the urban fringes in Ibadan
- To examine the causes of urban fringes
- To examine the socio-economic characteristics of the residents in the selected areas
- To evaluate the physical characteristics of residential buildings in the selected areas

1.4 METHODOLOGY

In order to reach the above mentioned objectives, the study will include a study intended to consolidate secondary data. The secondary data will include available land use maps of Ibadan from previous publications and Oyo State Ministry of Land to demarcate fringe areas of Ibadan. The National Population Commission, NPC census figure will be used for projecting population of the area and determination of sample size, official documents, case studies of successful intervention and other relevant secondary literature.

In addition, this assessment will be based on existing information from reports, such as the most recent UN-HABITAT Global Reports on Human Settlements and State of the World Cities Reports. The analysis draws on comparative evaluations on the topic carried out by major international organizations such as UN-HABITAT, the World Bank (ECA), UNHCR, international research institutes, the UNECE Country Housing Profiles and Land Administration Reviews, as well as statistics from officially published sources of information and international databases.

Primary data relating to housing quality were obtained by means of structured questionnaire administered on a systematic sample size of 500 household heads, from a sampling frame of 5000 housing units. The primary data includes five hundred household questionnaires, this will be was used to elicit information on the socio-economic characteristics of respondents of the urban fringe, physical and neighbourhood characteristics and housing quality in the selected six Local Government Areas of Iddo, Lagelu, Oluyole, Akinyele, Egbeda and Ona-Ara of Ibadan metropolitan region.

1.5 EXPECTED CONTRIBUTION TO KNOWLEDGE

The study of housing quality is expected to provide useful information for the implementation of policies and planning, physical infrastructural development, environment and health improvement. The study will also contribute to knowledge by providing understanding on methods of evaluating physical and neighborhood characteristics and housing quality in the urban fringes. This can be used to generate a Housing Quality Index (HQI)/Standards that policy makers and government can use in providing sustainable housing policies.

2 LITERATURE REVIEW

2.1 Housing

The Housing has been universally acknowledged as one of the most essential necessities of human life and is a major economic asset in every nation. Adequate housing provides the foundation for stable communities and social inclusion (Oladapo, 2006). Konadu et al. (1994)

have established a strong correlation between housing, good health, productivity and socio-economic development. Also, Gilbertson et al. (2008) have observed that there is a significant association between housing conditions and physical and mental health of an individual.

Osuide (2004) suggests that: “Having a safe place to live in is one of the fundamental elements of human dignity and this enhances human development”. People’s right to shelter is thus a basic one and the provision of decent housing to all requiring them should be the guarantee of every civilized society and one of the criteria for gauging development.

Furthermore, So and Leung (2004) have also established a significant correlation between the housing quality and the comfort, convenience and visual acceptability of the house. Therefore the significance of adequate housing to the social well-being of the people in any society cannot be overemphasized. However, the provision of adequate housing in Nigeria and other developing nations alike still remains one of the most intractable challenges facing human and national development. Previous attempts by all stakeholders, including government agencies, planners and developers to provide necessary recipe for solving the housing problem have yielded little or no success. Thus, for the past few decades, access to adequate housing has remained one of the most unattainable expectations of the majority of urban dwellers in Nigeria (Jiboye, 2010).

2.1.1 The Housing Situation in Nigeria

The housing situation in Nigeria is characterized by some inadequacies, which are qualitative and quantitative in nature (Oladapo, 2006). While the quantitative housing problem could be solved by increasing the number of existing stock, the qualitative inadequacies are enormous and complex. Despite Federal Government access to factors of housing production, the country could at best expect 4.2% of the annual requirement.

Market failure to provide affordable housing has created problems for households living below the poverty level by forcing them to occupy low-quality and overcrowded dwellings located either in decayed areas within the central city or in informal settlements located at the urban fringe (Meng, Hall, & Roberts, 2006). Inadequate housing affects a large proportion, perhaps more than 50%, of all urban residents in the developing world (World Bank, 2000). Moreover, poor urban infrastructure and deficient services, the absence of formal land titles, and generally poor local environmental conditions are now common characteristics of cities in developing countries.

The social and financial distance between the urban poor and the economically better-off classes are reflected in the limited opportunities for the former to obtain housing through anything other than informal means. This limitation has produced a highly uneven and segregated distribution of housing quality across socio-economic classes and also over space (UNCHS, 2001; Meng et al., 2006). The most negative effect of housing supply shortages and housing inequities in Nigeria is the formation of slum areas at the fringes of virtually all urban areas. These areas are typically occupied by recent rural in-migrants and other low-income groups, and are often abandoned in terms of political and economic support (UN-HABITAT, 2003). High population and dwelling unit densities, poor housing conditions, limited services, high levels of pollution, and a lack of opportunity to obtain jobs, education, and accessible health care has contributed to entrenching a complicated poverty cycle that places great stresses on the health, livelihoods and overall well-being of the urban fringe poor (Andersen, 2003). Effective housing policies are needed to help remediate some of these problems and to close the gaps created by market-based housing shortages. In particular, access to housing of reasonable minimum quality must be promoted for those living below the poverty line.

2.2 Urban Fringe

The term ‘urban’ and ‘rural’ is not new in literature. There is no confusion in the concepts and differences between these two. The sharp distinction between urban and rural settlements generally assumes that the livelihood of rural area is agriculture based whereas the urban area is manufacture and service based. But the recent research suggests that at certain part of the city there is simultaneous existence of two sectors – rural and urban which are neither totally urban nor rural in character. Rather, combination of both, which is often called as ‘urban fringe’.

The term urban fringe has many different indicators in the literature in terms of its definition and characteristics. A study of available literature reveals that the term urban fringe was introduced by Smith (1937) to describe built up area just outside the corporate limit of the city. Later the concept of the 'rural-urban fringe' was formulated by George Wehrwein in 1942 as the area of transition, between well recognized urban land uses and the area devoted to agriculture. After the notable scope of study on urban fringe the term urbanization was introduced by Balk in 1945.

According to Pasquini and Maconachie (2005) studies on urban fringe have been influenced by the optimistic or the pessimistic schools. The optimistic school view urban fringe as capable to evolving in a sustainable way promoting urban and rural livelihoods and coping with the pressures and dynamics of population and land use changes. The pessimists however argue otherwise. Using Malthusian gloom and doom analysis, they argue that urban fringe lead to progressive degradation of the environment, collapse of institutions and put unnecessary pressure on natural and human resources. The varying views expressed by different authors above, show the difficulties in defining the concept of urban fringe. It should be noted that although urban fringe may exhibit similar characteristics, they tend to be quite different in origin, history and functions.

Urban fringe development is not only a process of transition of land from its rural use to urban use; rather, it is a complex process that involves many concerns such as change in landownership pattern, land transfer process, types of development, regulatory measures and their enforcement. The process of fringe development is not monolithic and may be taken place either by rural actors or by urban actors, may be in formal way or in informal way.

2.2.1 Causes of Urban Fringe

There is increasing interest in urban fringe and this evident from the studies and researches that have been carried out on this area in the last twenty years. The interest stems from various reasons, perspective and views that different people and researchers have on urban fringe. For many, urban fringe pose great challenges for resource use and management. To others, it is an area of potential conflicts: social, economic and environmental. There is also concern on the sustainability of urban fringe, and indeed the delicate balance between rural and urban areas within this interface which appears to be collapsing in the midst of an ever increasing pressure of urbanization and urban growth into the urban hinterlands. Yet, there is no acceptable definition of what urban fringe means, their nature, causes, changing dynamics and the factors propelling change and challenges in these areas, how they may change in the future.

The critical factors causing the formation of urban fringe are notably related to several major interrelated changes: (i) poverty; (ii) rapid urbanization and influx of people into urban areas; (iii) war, natural disasters and earthquakes leading to massive movement of people to places of opportunity and safety; (iv) Ineffective Housing Policies; (v) inefficient public administration, inappropriate planning and inadequate land administration tools. Manifestations of informality are attributed to the lack of effective planning, effective land management system and zoning regulations for urban development. According to the United Nations Economic Commission for Europe (UNECE), poverty and social ostracism are the primary causes of urban fringe in most nations.

Rapid urbanization and influx of people into urban areas is another major cause of urban fringe. Rapid industrialization and urbanization have brought an increase in the number of people living in urban areas.

2.2.2 Characteristics of urban fringe

Urban fringe are often studied in the context of informal and formal housing, recognizing the fact that they incorporate predominantly informal housing developments. Urban fringe are mainly characterized by inadequate access to basic services, both social and physical infrastructure and housing finance (Vienna, 2004). Other characteristics of urban fringe include: (i) lack of secure tenure; (ii) housing that contradicts city by-laws; (iii) housing built on land not owned by the housing owner; (iv) lack or inadequate access to basic public services; (v) substandard housing and inadequate building structures; (vi) illegal subdivision of buildings; (vii) poverty, criminality and social exclusion; and (viii) unhealthy living conditions and hazardous locations (UN-HABITAT, 2003 and Payne and Majale, 2004).

USAID has described urban fringe, as areas characterized by uncertain land tenure, inferior infrastructure, low incomes and lack of recognition by formal governments. It is observed that third world cities are made of two distinct elements, the formal and informal; with the urban fringe constituting the informal section where planning and control of development is outside formal public institutions, but where traditions institutions are still strong. Ayorinde who examined urban fringe in Ibadan, Nigeria points out that the areas contain substantial but continuous areas of urban developments mixed with stretches of more extensive and traditional rural areas utilized for agriculture and forestry.

2.3 HOUSING QUALITY

A normative definition of housing quality or housing quality standards generally refers to the grade or level of acceptability of dwelling units and their associated and immediate residential environment, including the design and functionality of housing structures, building materials used, the amount of internal and external space pertaining to the dwelling, housing utilities, and basic service provision (Meng and Hall, 2006). Housing quality standards are often used as norms or measures that are applicable in legal cases where there is some question as to the acceptability of construction relative to prevailing laws or conventions that operate within the residential building industry.

The definition of housing quality embraces many factors which include the physical condition of the building and other facilities and services that make living in a particular area conducive. The quality of housing within any neighborhood should be such that satisfies minimum health standards and good living standard, but should also be affordable to all categories of households (Okewole and Aribigbola, 2006).

However, housing quality is a rather more complex concept with broader social and economic meaning. It accounts for both quantitative and qualitative dimensions of residential units, their immediate surroundings, and the needs of the occupants. Moreover, the concept of housing quality is relative as it relates to local standards and conditions. What is considered to be reasonable quality in one context may be considered poor quality in another context and vice versa.

The quantitative dimension of housing quality refers primarily to objective structural, material, social and economic constituents of housing products or outcomes that can be measured and that result from the performance of the housing sector. These factors include considerations such as price, quantity, tenure, economic impacts, environmental impacts, and structural norms of housing standards. On the other hand, the qualitative dimension is much more subjective and difficult to measure. It represents the perceived meanings and values of factors such as the ‘comfort’ or ‘quality of life’ that are afforded by different dwelling types, lifestyles, and the preferences and expectations of the inhabitants. Obviously, because of the high local and regional variations in the quantitative and qualitative dimensions of housing quality it is not possible to define one standardized set of criteria and indicators that apply equally to all areas at all times.

2.3.1 Indicators for Evaluating Housing Quality

The need to appreciate the relevance of a habitable (qualitative) housing therefore, requires an understanding of the concept of ‘quality ’which according to Onion, cited in (Afon, 2000), is a mental or moral attribute of thing which can be used when describing the nature, condition or property of that particular thing. McCray, cited in (Jiboye, 2004), noted that getting a definition of quality depends not only on the user and his or her desires, but also on the product being considered.

In essence, quality is a product of subjective judgment which arises from the overall perception which the individual holds towards what is seen as the significant elements at a particular point in time (Anantharajan, 1983 and Olayiwola, et al, 2006).In assessing the quality of housing, qualitative studies have identified some criteria as relevant indicators for quality evaluation in residential development. Among such is (Ebong,1983) acknowledged aesthetics, ornamentation, sanitation, drainage, age of building, access to basic housing facilities, burglary, spatial adequacy, noise level within neighbourhood, sewage and waste disposal and ease of movement among others, as relevant quality determinants in housing.

However, Hanmer et al. (2000) conclude that qualitative housing involves the provision of infrastructural services which could bring about sustainable growth and development through improved environmental conditions and improved livelihood. In determining the quality of residential development, Neilson (2004) stipulates five basic criteria which provide that housing must be in compliance with tolerable standard, free from serious disrepair, energy efficient, provided with modern facilities and services, and that it must be healthy, safe and secure.

These indicators consist of variables such as; access to basic housing and community facilities, the quality of infrastructural amenities, spatial adequacy and quality of design, fixtures and fittings, building layout and landscaping, noise and pollution control as well as security. There are however indications from these various studies that a single variable may not be sufficient to assess the qualitative nature of residential development; therefore, housing acceptability and qualitative assessment should also take into account type of constructions, materials used, services, spatial arrangement and facilities within dwellings, function and aesthetics, among others (Olu-Sule and Gur, noted in Jiboye, 2004).

Previous studies have indicated that a more appropriate method of evaluating the quality of the built environment is through the affective responses based on the user's assessment (Weldemann and Anderson, 1985; Ilesanmi, 2005). In this study therefore, qualitative evaluation will be based on user's assessment of the physical criterion of housing. This will consider among other variables identified above, the quality of housing in terms of adequacy of basic infrastructures, suitability of the building design; integrity of the building elements, as well as that of fixtures within the dwellings.

2.3.2 Housing Quality Criteria

Four criteria provide the basis for identifying indicators to produce a meaningful Housing Quality Indicator, namely; objective criteria, scientific/technical criteria, management criteria and social and cultural criteria (Hall and Meng, 2006). Each class of criteria has its own considerations that govern the selection of specific indicators from available data resources, as noted below:

Objective criteria indicators should:

- represent the local environment and should be comprehensive enough to address issues that include poverty and inequity in the housing sector;
- be sensitive to changes between different socio-economic classes, especially in terms of economic status indicators such as accumulated wealth and income.

Scientific/technical criteria indicators should:

- be separable into geographically localized components and should be based on household-level data so that they can be measured both locally and globally as well as spatially in order to identify statistical and spatial distributions of the HQI within a study area;
- be technically feasible to measure.

Management criteria indicators should:

- be easy to obtain from available data and subsequent calculations;
- be easy to understand, and cost-effective so that the analysis of housing quality and housing segregation can be effectively utilized by policy makers;
- be consistent and comparable so that housing quality and housing segregation can be monitored over time and can be compared between cities.

Social and cultural criteria should:

- include the preferences and priorities of the community in the housing programs;
- enable local participants to evaluate indicators selected from the above criteria to make housing improvement proposals acceptable relative to local norms and expectations.

2.4 URBANIZATION IN NIGERIA

The phenomenon of urbanization is a consequence of population increase and migration from rural to urban areas and growth-centres. The urban growth rate in Nigeria today is put at 5.8% per annum (Draft NUDP, 2004). Rural economy is principally agricultural. But, under conditions of increasing population and diminishing rural resources, some contingent of rural population migrates to urban areas for helpful job security, higher education, higher income, better health and linger life. The result usually is disappointed and disillusion as the poor in some cities have a better life than those in rural areas. Old settlements are congested and crowded, new formations emerge without preliminary design and planning, and without preliminary design and planning, and without infrastructure.

The problem of uncontrolled urbanization in Nigeria is already with us in all our cities. The Draft National Urban Development Policy (NUDP, 2004) notes that, Nigeria towns are growing without adequate planning. Millions of Nigerians live in sub-standard and sub-human environment, plagued by slum, squalor and grossly inadequate social amenities (Amao, 2012a). The result is manifested in growing overcrowding in homes and increasing pressure on infra-structural facilities and rapid deteriorating environment.

In Europe, urbanization brought increased wealth and economic earnings, higher education, lower fertility, better health, longer life and more amenities. But in Africa, and indeed, in Nigeria, the opposite is the case.

2.4.1 Urbanization and Urban Growth

Nigeria has been experiencing a rapid rate of urbanization. In 1952, 10% of the population lived in urban centres with a population of 20,000 people and above. This increased to 20 and 38% in 1970 and 1993 respectively. By the year 2010, it is estimated that 60% of the population will live in cities. The growth in the size of cities has been equally rapid, in 1960; Lagos and Ibadan were the only two cities with more than 500,000 people. The number increased to 9 by 1980, and 14 by 1990. This is expected to rise substantially by 2010 (UNCSD, 1997).

A feature of urban environments, especially in Africa is the influx of rural dwellers into the urban areas in search of jobs. These jobs are sometimes unavailable and large segments of the unemployed in this migrant group are usually without a sustainable means of livelihood and may eventually be classified among the urban poor, thereby making up a part of the estimated 70% of the urban population that live in unplanned squatter settlements with no basic infrastructural services in cities (NHCS, 1998).

2.4.2 Urbanization, Urban Growth and Urban Fringe in Nigeria

Rapid urbanization has changed the urban landscape of most Nigerian cities. There have been the processes of concentration and congestion in inner cities and the opposite process of dispersal at the urban fringes. The process of growth was stimulated during the colonial period as new towns were planted adjacent to traditional cities to avoid direct contact with the indigenous people based on the policy of indirect rule and residential segregation. Urban growth had led to even higher densities of population and physical developments in the urban fringe.

2.4.3 Urbanization and Housing Quality

As a result of urbanization and lack of economic opportunities in rural areas, many people move to the cities. They move to the cities that are already dealing with issues of overcrowding, infrastructure and high cost of living. This forces them to seek shelter in slums and urban fringe. United Nation Habitat in 2006 found that 90% of slum residents are in the developing countries with struggling economies. In addition, cities were not mean to handle millions of people streaming in when designed. This impact the availability and affordability of housing, forcing millions to live in substandard dwellings with poor housing quality (Amao, 2012b). This is mainly because substandard accommodation there is very cheap. Substandard housing is the type of housing that does not meet the standards for living by people. These standards are usually set by governments and deal with how safe the dwelling is for people to live.

REFERENCES

A. Adesina, *Socio-spatial transformations and the urban fringe landscape in developing countries*, United Nation University Institute for Environment and Human Security (UNU-UHS) Summer Academy on Social Vulnerability and Resilience Building in Mega city, Munich, Germany (2007).

F.L. Amao, "Urbanization, housing quality and environmental degeneration in Nigeria", *Journal of Geography and Planning Sciences*, 5(16), 422-429 (2012).

F.L. Amao, "Housing quality in informal settlements and urban upgrading in Ibadan, Nigeria (A case study of Apete in Ibadan)", Developing Country Studies, 2(10) (2012).

H.S. Andersen, *Urban sores: On the interaction between segregation, urban decay and deprived neighbourhoods*, Ashgate, Aldershot, England (2003).

D. Ayorinde, "Controlling development at the urban fringe: A case study of Ibadan, Nigeria", *In Urban management and urban violence in Africa*, vol. 2, I.O. Albert, J. Adisa, T. Agbola and G. Herault (eds.), IFRA-Ibadan (1994).

M.O. Ebong, "The perception of residential quality: A case study of Calabar", Third *World Planning Review*, 5(3), 273-285 (1983).

J. Gilbertson, G. Green, D. Ormandy and H. Thomson, *Good housing and good health: A review and recommendations for housing and health practitioners*, A sector study housing corporation, UK (2008).

Housing Corporation, *Housing quality Indicators (HQI)*, version 4 (For NAHP 08 10) (2007).

A.O. Ilesanmi, *An evaluation of selected public housing schemes of Lagos state development and property corporation*, unpublished Ph.D. Thesis, Department of Architecture, O.A.U. Ile-Ife, Nigeria (2005).

A. Jiboye, *An assessment of the influence of socio-cultural factors on housing quality in Osogbo, Nigeria*, unpublished M.Sc. Thesis, Department of Urban and Regional Planning, Obafemi Awolowo University, Ile-Ife, Nigeria (2004).

A.L. Mabogunje, *Urbanization in Nigeria*, University Of London Press, London (1978).

G. Meng, G.B. Hall, and S. Roberts, "Multi-group segregation indices for measuring ordinal classes", *Computers, Environment and Urban Systems*, 30, 275–299 (2006).

NPC, *National Population Commission*, Official Gazette, Abuja, Nigeria (2006).

I.A. Okewole and A. Aribigbola, "Innovations and sustainability", in HousingPolicy Conception and Implementation in Nigeria", *The Built Environment: Innovation Policy and Sustainable Development*, Okewole I. A. (eds.) Covenant University Ota, Ogun State, Nigeria, 414 – 420 (2006).

A.A. Oladapo, "A study of tenant maintenance awareness, responsibility and satisfaction in institutional housing in Nigeria", *International Journal Strategic Property Management*, 10, 217-231 (2006).

S.O. Osuide, and K.O. Dimuna, "Effects of population growth on urbanization and the environment in Nigeria", *Proceeding of year 2000 National Seminar on Population, Growth, Architecture and the Environment, S.O. Osuide (ed.)*, 27-33, Rasjel Publishers, Ekpoma (2005).

UN-HABITAT, *The Challenge of Slums - Global Report on Human Settlements* (2003).

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LATERITE BUILDING MATERIAL AND SUSTAINABLE HOUSING PRODUCTION IN NIGERIA

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Abstract. *Public Housing provision in Nigeria has not yielded much. This arises because of high cost of provision due to utilization of conventional building materials and the disregard for alternative avenue of housing provision which make sustainable housing development a mirage in the country. However, it is believed that if importation of expensive construction materials could be substantially reduced using locally available alternatives such as Laterite that are based on appropriate construction technology, such a measure can reduce cost of construction, increase housing stock and also increase foreign reserve of the economy of the country.*

It is against this background that the paper makes a case for the incorporation of the building material into Housing policies in Nigeria. It therefore, conducted an opinion survey based on the utilization experience of developed countries of the world such as America and Brazil by assessing the willingness of people to utilize the material for housing construction. The study uses Ogbomoso, the seat of Ladoke Akintola University of Technology which is the best State University in Nigeria and where Housing problem is pronounced as a case study. Multistage random sampling was used in selecting 216 respondents from the two local government areas in the city while the questionnaire forms the basic instrument for data collection. The data collected were analyzed using Frequency counts, Percentage and Chi-square.

The paper found out that the knowledge of people concerning the material is high and that people are willing to utilize the material. However,, the limiting factors of utilization are non-incorporation in the National Housing Policy by the government, Gender, Level of Education and Society status as these are all significant at 0.05 level of significance. The paper concludes based on the findings above, that in order to achieve sustainable housing provision in Nigeria, the material should be incorporated into housing policies and programs which should not be at the exclusive preserve of Federal Government and at the exclusion of State and Local governments.

Keywords: *Public housing provision, Conventional building material, Laterite, incorporation, Sustainable housing provision.*

1 INTRODUCTION

A lot of human activity revolves around housing that it contributes 3 to 8 percent of the Gross Domestic Product (GDP) in many African countries and usually above 8 percent in many industrialized countries (Aina, 1990). More significantly, housing is the dominant component of the construction industry.

However, in the developing countries of the world, as important as housing is, the problem of Housing caused by urbanization has become an everyday discussion in all quarters of the public and private services (Aribigbola, 2000).. It has become increasingly glaring that most of the urban population live in dehumanizing housing environment while those who have access to average housing do so at abnormal cost (Dosumu, 2002).

In Nigeria, for example, housing problem is essentially an urban problem (Onibokun, 1985; Agbola and Olatubara, 1992 and Agbola, 2001). However, most authors have analyzed this from various perspectives, with most of them giving it a quantitative pre-eminence. Also, they have, at different times, revealed the problems associated with production among which is construction cost.

In Nigeria, for example, in the past, technological advancement made it possible to acquire building materials from the developed countries. However, the economic crisis befalling the country one after the other made Government to realize that importing building materials for the industries is beyond means (Okunola, 1998, Dosumu, 2002 and Agbola, 2001).

In order to solve the problem however, several measures were put in place such as the Structural Adjustment Program (SAP) of 1986 and National Housing Policy of 1991which were meant to reduce housing problems (Odunjo, 2006 and Arayela, 2005). The policies were not able to make remarkable impact on the growth and development of housing sector. This led to the subsequent establishment of some relevant programs and Institutions like the Site and Service program as well as the Nigerian Building and Road Research Institute meant to undertake research in the areas of housing. Unfortunately, nothing was heard after the first set of Brick houses was produced by the Institute despite the fact that 25 brick factories were established for the purpose throughout the nation.

Regrettably, housing problems which result from urbanization are still unsolved up till today due to the fact that the focus has always been on the use of conventional building materials. According to Dosumu (2002), the focus on this sector alone will always lead to high cost of building materials and consequently make housing unaffordable to the generality of the people. In fact, Onibokun and Ogbuozobe (1985) supported this when they opined as follows: “The higher the cost of building materials, the higher the cost of housing construction; the fewer the number of people who can afford the desired houses, the slower the rate of housing supply. The fewer the supply, the more competitive the housing market becomes and the greater the problems of housing especially to the lower income sector of the population”.

According to Onibokun (1985), the factors that affect the cost of housing include the cost of land, construction cost, housing finance and administrative and management costs. In order to reduce the cost of housing, efforts should be made to reduce cost in all these areas. Construction cost can be reduced through the use of Laterite, an indigenous building material (Dosumu, 2002;Arayela, 2005; Odunjo, 2006 and Wahab, 1992).

The advantages of laterite as a building material are quite many. In spite of the fact that it had been used in the construction of numerous buildings throughout the world since pre - historic times. Today, this material needs some re – evaluation in Nigeria, especially now, that economic consideration has begun to dictate the choice of building materials.

Approximately, half of the world’s population of over 6 billion people still inhabits dwellings made with soils harvested from the earth’s crust. Laterite houses are appropriate for a variety of climates and are ideally suited for passive solar heating and cooling. The interior of such buildings stay warm in cold seasons and cool in the hot seasons with little, if any, need for auxiliary energy. Built largely from soil excavated on site, laterite houses require substantially less fossil fuel – derived energy to build than the conventional concrete buildings commonly found in many urban centers in Nigeria (Arayela, 2005). Materials used for laterite building construction are collected locally and the construction of houses is user – friendly while most laterite building techniques require very little skill and are ideally suited to owner – building projects. One can learn what one needs to know in a week – long workshop. Laterite building material continues to predominate in the other parts of Africa, the Middle East, Brazil and nearly the whole of Latin America.

Amongst industrialized countries today, there are two aspects to the current revival of interest in laterite buildings. The first, which emerged in the south–western states of the United States of America (USA), is a response to the desire for a more "humane" environment, an alternative to the cold and soulless technology which has come to be symbolized by concrete, plastic and glass, those synonyms of modern progress.

In the south western part of USA, particularly in New Mexico, Arizona and southern California, adobe (sun – dried brick) construction is currently witnessing an ever – increasing popularity. As at the year 2000, there were more than forty (40) adobe brick manufacturers in the region, as well as many small – scale professional. Laterite construction technology is today sufficiently confident to compete against conventional materials and it is time, Nigerians re–appropriate the technical skills needed for their own development.

This paper therefore, assesses the willingness of people to utilize laterite, for Housing construction in Nigeria. The paper uses Ogbomoso city, one of the largest city in the country as a case study and at the end, it highlights the hindrances to the utilization of the material and make suggestions towards solving the problem.

2 METHODOLOGY

Data collected were majorly primary data which were collected through questionnaire administration. The questionnaires were administered in order to obtain information on the knowledge and attitude of people to utilize the material as well as the reasons why the material is not being utilized by people.

However, Ogbomoso city consists of two Local Government areas; Ogbomoso north and south local governments and each local government area consists of ten wards. The sampling technique used was multistage random sampling. The first stage involved random sampling of twelve wards where questionnaires were administered. Thus, six wards were selected from each of the two local government areas.

However, the wards are almost homogenous with respect to spatial extent and population size. Thus, eighteen questionnaires were administered in each of the selected wards as shown in Tables 1 and 2. In selecting the respondents in each ward, the major streets were identified and every 5^{th} house alternately on each side of the road was chosen for questionnaire administration. Data collected were analyzed through frequency counts, percentage and chi-square.

3 FINDINGS AND DISCUSSIONS

Out of the respondents, 147 (69.61%) are males while 60 (28.8%) are females. This is as a result of the fact that men are associated with house provision than women and therefore, are the head of the family. Thus, this set has the tendency of being directly affected by housing cost which makes them to be more interested in housing than their female counterparts. However, the ages of the respondents show that 70 (32.86%) of the respondents are between 21-40 years of age and 21 (9.86%) are between 51-60 years. Only 12 (5.63%) have ages that are over 60 years. Fig. 1 shows the Age distribution of respondents.

Name of ward	Population	Number of questionnaire
1. Sabo/Taraa	7,760	18
2. Osupa	10,082	18
3. Okelerin	10,148	18
4. IsaleAfon	7,782	18
5. Aguodo/Masifa	10,103	18
6. Jagun	12,384	18
Total	58,289	108

TABLE 1: Wards selected at Ogbomoso North Local Government.
(Source: Author's field survey, 2013)

Name of ward	Population	Number of questionnaire
1. Lagbedu	12,435	18
2. Arowomole	10,538	18
3. Alapata	11,042	18
4. Isoko/Ola	10,868	18
5. Akata	10,293	18
6. Ijeru 1	10,402	18
Total	65,578	108

TABLE 2 Wards selected at Ogbomosho South Local Government.
(Source: Author's field survey, 2013)

The implication of this finding is that majority of the respondents are adults who are matured and are capable of being mentally aware of changes in the society and the effect such changes could have on the economy as well as lives of people. Also, majority of the respondents (96.70%) have one form of formal education or the other while only 3.3% are not educated. This shows that the respondents are generally educated; thus, the inference could be drawn that since the respondents attain a certain level of education, they would know the implication of the usage of the building material and the relationship with housing. However, 184 (86.38%) of the respondents has knowledge of the material while 29 (23.61%) are not aware of Laterite and the effect it could have on the cost of housing. Out of the 184 respondents that have knowledge of the material, 53.26% are ready to utilize based on quality and 9.78% due to the fact that it is cost effective. Only 19.02% of the respondents will utilize based on availability while the level of income will make 13.59% to use the material for housing construction. Only 4.35% will utilize based on recommendation (Table 3).

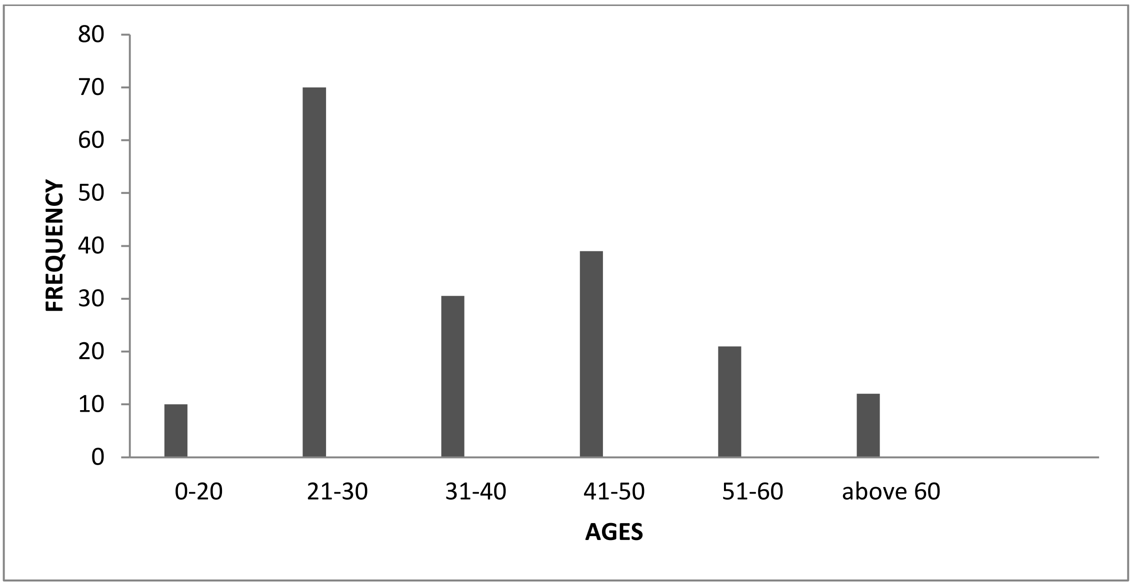

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Fig. 1`Age distribution of Respondents.
(Source: Author's field survey, 2013)

Criteria for Utilization	Frequency	Percentage
1. High quality	98	53.26
2. Cost effectiveness	18	9.78
3. Availability	35	19.02
4. Level of income	25	13.89
5. Recommendation	8	4.35
Total	184	100.00

Table 3 Willingness of Utilization of Laterite in Ogbomoso, Nigeria
(Source: Author's field survey, 2013)

Also, analysis shows that lack of Information, Education and Communication (IEC) resulting from non - incorporation into the National Housing Policy by the government, after the first set of brick houses were produced on the capability of indigenous building materials, gender, level of education as well as society status are the limitations to utilization n as shown in Table 4.

Variables	X^2Cal	X^aTab	d^0f	Remark
Non – utilization by government	6.28	5.01	1	S*
Gender	4.98	3.26	1	S*
Level of education	5.34	3.55	1	S*
Society status	5.04	4.32	1	S*

S*-significant at $P \leq 0.05$
d˚f –degree of freedom

Table 4: Chi-square test of relationship between variables and willingness of utilization of Laterite. (Source: Author's field survey 2013).

The implication of this is that, insincerity on the part of Government arising from non – incorporation into the National Housing Policy, after the first set of Brick houses were produced, gender, level of education and society status affect the utilization of laterite for housing construction as each of this is significantly related to the utilization of the material.

4 CONCLUSION

This paper has shown that people are ready to utilize Laterite for housing construction in Nigeria. This is because the material has high quality, readily available and is cost effective; therefore, it could be used to achieve sustainable housing for all in terms of quality and quantity.

In order to increase housing stock in Nigeria, create a more conductive living environment as well as develop an appropriate housing construction technology, there is the need to incorporate the material into the formulation and implementation of housing policies and programs. This should be done at all levels of government that is, Federal, State and Local governments. Thus, there is a need now, for the Federal government to reach out and effectively involve the people and governments at grassroots levels in the formulation of housing policies.

REF ERENCES

Agbola, Tunde and Olatubara, C.O (1992): "Housing Subsidy Mortgage Difficulties and Housing Reliability in Nigeria: A Case Study of the Public Housing Delivery System". *Urban Quarterly*, Volume 4, Nos. 1 and 2. Pp. 90-96.

Agbola, Tunde (2001): "Housing Strategies. In: Agbola", Tunde (ed.) *Readings in Urban and Regional Planning.* Macmillan Nigeria Publishers Limited. 188-192.

Aina, T.A (1990): "The Politics of Sustainable World Urban Development." In: *The Living City*, Towards a Sustainable Future, Cadman D. and G. Payne, eds. Routledge, London and New York.

Aribigbola, A. (2000): "Conceptual Issues in housing and Housing Provision in Nigeria" In: Akinbamijo, Olumuyiwa Bayo, Fawehinmi, Abayomi Steven, Ogunsemi, Deji Rufus and Olotuah, Abiodun (eds). *Effective Housing in the 21st Century, Nigeria*. AKT Ventures Limited. P.1.

Arayela, Olatunde (2005): "Developing Appropriate Housing Construction Technology for Medium and Low Income Earners in Africa: Focus on Nigeria" *Africa Union of Architects Conference Proceedings*, Talos Press. Pp.10-11.

Dosumu. N.A (2002): "Non-Conventional Building Materials and Housing Affordability in Nigeria". Master of Urban and Regional Planning Thesis, Center for Urban and Regional Planning, University of Ibadan, Ibadan. Pp.1-3.

Odunjo, O. Omolola (2006): *Utilization of Indigenous Building Materials As A Means of Improving Housing Affordability in Nigeria*. *A Case Study of Ogbomoso*. M.Sc. Thesis, Department of Urban and Regional Planning, University of Ibadan, Ibadan. Pp.2-3.

Okunola, M.T (1998): *An Appraisal of the Problems Associated with the Use of Local Building Materials in the Construction Industry.* A Project Report for Higher National Diploma in Quantity Surveying, The Polytechnic, Ibadan. Pp.1-2.

Onibokun, A.G. (1985): *Housing in Nigeria.* A Book of Readings, NISER, Ibadan.

Onibokun, A.G. and Ogbuozobe, J.E (1985): Trends in the Prices of Building Materials in Nigerian Urban Centers. In: Omange, G.N (ed.) *Proceedings of the Seminar on the Use of Clay Bricks and Blocks for cheaper and durable Housing.*, Nigerian Building and Road Research Institute (NBRRI), Lagos.

Wahab, K.A (1992): Prototype Designs for Low Cost Housing: An Experimental Study. In: Costa, R. and Wahab, K.A (eds.) *Environment Design in West Africa*. Proceedings of the 1st Cooperative Housing for Nigeria Conference, Obafemi Awolowo University, Ile-Ife.

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HOUSEHOLDS' PERCEPTIONS ON SUSTAINABLE HOME BEHAVIOUR AND IMPROVEMENTS IN AUSTRALIA

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Abstract. *The consumption of energy in the residential building is a major contributor to Australia's stationary energy greenhouse gas emissions. With the aim of investigating the householders' motivations and perspectives on sustainable home improvements, this study, by using an online survey instrument, collected more than 500 sets of questionnaire data from households in the state of New South Wales, Australia. Through statistical analysis of the data collected, this research has found that construction cost and government incentive were considered as major influence factors on achieving energy efficient residential building development, and the lower bills from reduced energy and water consumption were considered as the most important benefits from the households' perspectives. The research also found that although many households exhibited a high level of awareness or had implemented some sustainability improvements, the total number of potential improvements scored poorly. A suggestion, based on these research findings, is that the government should promote the reasons and benefits for sustainability home improvements that are identified in this research paper, and try to reduce material costs and improve government incentives.*

1 INTRODUCTION AND RESEARCH AIMS

Climate change is recognized as one of the greatest challenges facing the world. In Australia, its carbon pollution represents around 1.5 per cent of the global greenhouse gas emissions, and this makes the country one of the top 20 polluting countries in the world. In fact, Australia's per capita greenhouse gas emissions are among the highest in the world (Garnaut, 2008). With the introduction of the Clean Energy Future plan, the Australia federal government recognised the growing consensus that the climate is changing and high levels of carbon pollution risk environmental and economic damage (Commonwealth of Australia, 2011).

The consumption of energy in the residential sector is a major contributor to Australia's stationary energy greenhouse gas emissions (Department of Climate Change and Energy Efficiency, 2010). Therefore, there is a need to understand how to facilitate more efficient use of resources through (1) installation of devices that promote resource conservation and efficiency, and (2) changed household practices (Fielding et al., 2010). Installation of devices and applying innovative technologies for low-carbon residential buildings need strong support from householders. Steg (2008) pointed out that many devices/tools have been developed to influence householder energy use; however, there is a lack of understanding about the extent to which people know and are willing to use such devices/tools. In other words, there is a householder perception and behaviour issue with the use of sustainable energy and water technology. Therefore, for policy makers and construction professionals, a clear understanding of householders' perception in relation to energy and water saving and consumption can help them not only to identify the gaps in current policies and develop potential new technologies, but also to analyse householders' knowledge and preference for sustainable measures and possibly educate the householders regarding their ignorance.

Previous studies have shown that about half of the domestic residential energy consumption depends on the design characteristics of the houses and their devices, while the rest half depends on householders' behaviour (Janda, 2009). In particular, householders influence the energy use of a dwelling by both their purchase of energy-use appliances and through their use of these appliances (Abrahamse et al, 2005; Firth et al., 2007). Gill et al. (2010) investigated the contribution of householder behaviour to actual building energy consumption and their results showed that energy-efficiency behaviors account for 51%, 37% and 11% of the variance in heat, electricity, and consumption respectively in different buildings. To change householders' energy consumption behaviour, Stevenson and Leaman (2010) found that it is important to understand householders' attitudes and perceptions regarding green building development, especially to identify the constraints and opportunities for achieving sustainable homes from householders' perspective.

Although there is a growing body of research investigating the green technologies and householder behaviour, very little has been conducted on householders' perceptions on sustainability practices in Australia. This paper aims to understand householders' perspectives on sustainable home improvement. Starting from the data collected in the state of New South Wales, Australia, using an online questionnaire survey, this paper analyse (1) the levels of householders' knowledge about sustainability measures, (2) the extent of the constraint experienced by households in terms of sustainable home improvement, and (3) the reasons toward having a sustainable home.

2 SURVEY QUESTIONNAIRE DESIGN AND IMPLEMENTATION

To achieve the research aim, survey questionnaires were designed, developed and implemented to obtain data. A survey design was preferred over the other research designs (i.e., archival research and historical research, experimental research, and case study research) in this research, for its ability to provide a relatively quick and efficient method to (1) obtain information from the targeted sample, and (2) generalise the research findings based on the samples involved.

Five questions relating to householders' perceptions on sustainable homes were included in the questionnaire:

1. To what extent do the following best describe your household knowledge about sustainability measures (*Single choice*)?
    - We know at least 4 ways to reduce our household impact on the environment
    - We know at least 3 ways to reduce our household impact on the environment
    - We know 2 ways to reduce our household impact on the environment
    - We only know 1 way to reduce our household impact on the environment
    - We are not sure how to reduce our household impact on the environment

2. Further to the above questions, please list the sustainability measures that you have implemented at home (e.g. Installation of photovoltaic/Solar panels) (*Open ended question*)
3. To what extent do you think the following have hindered your household's efforts to achieve sustainable home and lifestyle (*5 point Likert Scale*)?
   - Attitudes of governmental agencies
   - Attitudes of building certifiers
   - Knowledge of building certifiers
   - Attitudes of designers/ architects/engineers
   - Knowledge of designers/ architects/engineers
   - Availability of governmental incentives for being sustainable
   - Availability of green technologies
   - Availability of relevant training/education programs
   - Information about long- term energy and water savings strategies
   - Availability of building products and materials
   - Availability of relevant construction/building service equipment
   - Construction Material costs
   - Documentation and certification costs
   - Marketability of a sustainable house
4. To what extent do you think the following methods/strategies, as reasons, are effective towards having a sustainable home (*5 point Likert Scale*)?
   - Becoming a responsible household
   - Educating our future generation the importance of sustainability
   - Increasing property price of a sustainable home
   - Improving our household's quality of life
   - Improving the quality of life among our community
   - Meeting future environmental regulations
   - Meeting the needs of the present without compromising the ability of future generations to meet their own needs
   - Reducing energy consumption and hence utility bills
   - Reducing water consumption
5. Further to the above question, please list other opportunities, which you perceive, of having a sustainable house (*Open ended question*).

Before embarking on the full-scale data collection, pilot test was undertaken, where ten householders were invited to fill out the online questionnaire and provide their feedback on: (1) the clarity and flow of the questionnaire; and (2) the functionality of the online survey platform. In general, all participants considered the questionnaire to be comprehensive.

The survey was open online publically, but specifically targeted the regions in representative areas of metropolitan and regional NSW. Hard copy flyers, containing the survey information and website address, were designed, printed, and sent out by the Australian Post Office to the selected residents' letterboxes inviting them to participate in the online survey. To attract more participation, incentive in the form of being eligible for entering a lucky draw was provided, if the response is valid. In total 504 responses were collected. It is worth noting that it is not possible to calculate the responding rate since the survey was online. However 504 sets were seen to be sufficient for statistical analysis.

Ahire et al. (1996) believe that if the measurement items in the survey "adequately cover the content domains or aspects of the concept being measured", an instrument has content validity. Gotzamani and Tsiotras (2001) and Wong and Aspinwall (2005) also have clarified that "it [the number of data sets collected] is not assessed numerically, but can only be subjectively judged by the researchers". The options listed in this survey were identified by a review of relevant literature and validated by several interviews with the professionals in green building development. Therefore, the content validity of the whole questionnaire is confirmed.

3 RESULTS AND DISCUSSIONS

3.1 Householders' knowledge and behaviour about sustainability measures

The participants were asked to describe their knowledge of sustainability measures that could reduce household impact on the environment. Table 1 shows the distribution of householders' knowledge range, indicating that 75.9% of the respondents knew 2 or more ways to reduce household impact on the environment. This suggests that most householders have some degree of awareness and education on environment protection. However, there were 11.4% of the householders who were unsure of any ways to reduce their impact on the environment.

Householders' knowledge about sustainability measures	Frequency	Percentage (%)
Know at least 4 ways to reduce household impact on the environment	275	55.8
Know at least 3 ways to reduce household impact on the environment	99	20.1
Know 2 ways to reduce household impact on the environment	49	9.9
Know 1 way to reduce household impact on the environment	14	2.8
Not sure how to reduce household impact on the environment	56	11.4

Table 1 Householders' knowledge of sustainability measures (Sample size – 493)

In the open ended question, 353 respondents (ie 70.0%) provided answers of the measures that they had implemented to improve the sustainability of their homes. The measures identified by these respondents were grouped into two main categories of sustainable behaviour or sustainable devices, and listed in a descending order of frequency in Table 2. It is obvious that most of the theses answers are not unexpected for both energy and water saving behaviour. Among all, it is identified that 'switching appliances off at the wall (ie at source)' was the most commonly cited as a sustainable behaviour measure (31.4%), which reduces the energy consumption of idle systems and appliances otherwise left in 'standby' mode. It is also identified that the most commonly cited sustainable device measures were 'using energy saving bulbs' (35.4% of responses) and 'using solar power (32.9%)'. Again most of the answers are within the expected range of options.

Category	Identified measures	Sample comments	Number of responses	Percentage (%)
Sustainable Behavior	Switch off appliances at wall (source)	‘turn all electrical devices off at the wall’, ‘turn off appliances at switch when not in use’, ‘turning off "stand by" mode on appliances not in use’	111	31.4
	Minimise the use of heating systems	‘keep blinds closed’, ‘keep cooling and heating appliances on a set temperature recommended by the manufacturer’	41	11.6
	Turn off unused lights	‘turning off lights when we are away’, ‘turn off lights when leaving rooms’	40	11.3
	Use recycled water	‘use of recycled water for gardening’, ‘reusing grey water from showers’, ‘recycle grey water for use on lawns’	36	10.2
	Take shorter showers	‘reduce time for showers’	33	9.3
	Wash clothes using cold water	‘cold water laundry washing’, ‘using cold water to wash our clothes’	33	9.3
	Use full load washing	‘only wash when I have a full load’	9	2.5
Sustainable Devices	Energy saving bulbs	‘LED Reading lights’, ‘replaced most incandescent lighting with energy efficient lighting’	125	35.4
	Solar power	‘we have 1.5 KW solar system’, ‘use solar hot water system’, ‘solar panels for electricity production’	119	33.7
	Roof and ceiling insulation	‘roof insulation’	45	12.7
	Water tanks	‘water from tank in washing machine & toilets’	41	11.6
	Insulation equipment on windows	‘using curtains to retain heat and cool in house’, ‘Use of blinds to keep heat in and cold air out’	34	9.6
	Water saving fixtures	‘water-saving shower heads’, ‘water saving fixtures’	33	9.3
	Water and energy star-rated appliances	‘water efficient washing machine’, ‘low power dishwasher & washing machine (front loader)’	16	4.5

Table 2 Sustainability measures implemented at home (Sample size, 353)

3.2 Factors hindering household efforts to achieve sustainable home

The participants were asked the extent to which they thought the 14 different factors listed in the survey had hindered their household's efforts to achieve a sustainable home and lifestyle. The respondents ranked their answers on a scale of 1 ('never') to 5 ('seriously hindered'), with a neutral value of 3 ('tolerable').

Table 3 shows the responses in descending order of mean perceived hindrance. A mean value above 3 indicate that the respondents, on average, considered that factor to be of some to serious hindrance, and mean values below 3 indicate that factor is of negligible to no influence.

Factors hindering achievement of a sustainable home	Number of responses	Mean	Rank
Construction material costs	454	3.41	1
Availability of governmental incentives for being sustainable	457	3.16	2
Availability of green technologies	450	2.83	3
Documentation and certification costs	438	2.78	4
Attitudes of governmental agencies towards sustainability	457	2.78	4
Information about long-term energy and water saving strategies	443	2.63	6
Availability of training/education programs	449	2.58	7
Availability of relevant construction services (e.g. green development consultants and specialists)	441	2.45	8
Availability of sustainable construction products and materials	441	2.42	9
Marketability of a sustainable house	442	2.29	10
Knowledge of designers/ architects/engineers	436	2.20	11
Knowledge of building certifiers	439	2.15	12
Attitudes of designers/ architects/engineers	440	2.14	13
Attitudes of building certifiers	443	2.14	13

Table 3 Factors hindering household efforts to achieve sustainable homes

The means for the 14 factors ranged from 2.14 to 3.41, suggesting that the respondents generally considered all the 14 factors to hinder the achievement of sustainable homes to little or some degree. The highest ranked hindrance by respondents is 'construction material costs' (mean value of 3.41), and thus is considered the major influential factor to the achievement of a sustainable home in this survey. The second highest ranked factor is 'availability of governmental incentives for being sustainable' (mean value of 3.16).

Although 'availability of green technologies' (mean value of 2.83), 'attitudes of governmental agencies' and 'documentation and certification costs' (both with mean values of 2.78) were ranked third and fourth, their mean values were less than the 'tolerable' neutral value of 3, and so these factors are not considered as influential in hindering sustainable home development.

From the concerns demonstrated by householders in these responses, it shows that cost and government support can significantly influence householders' attitudes regarding sustainable home development. In addition, it is worth noting that all household respondents perceived the attitudes and knowledge of building certifiers, designers and architects as the least influential factors.

To determine the level of agreement amongst respondents over the importance of the 14 factors and ensure the mean does not reflect widely ranging answers, Kendall's Coefficient was calculated. Where 0 indicates full agreement and 1 indicates no agreement, the Kendall's Coefficient of Concordance compared the number of identical answers with the number of different answers to the 14 factors in Table 3. The subsequent value was close to full agreement at 0.146, with statistical significance at 1% (i.e., $p<0.01$, demonstrating a 99% confidence in the similarity of the rankings). This suggests that there was a general agreement among the respondents in their ranking; that is, the respondents shared similar values/views about the relative importance of all 14 factors.

3.3 Reasons for having a sustainable home

Participants were asked to what extent the 9 factors listed in the survey they would consider as valuable reasons for achieving a sustainable home, on a scale from 1 ('never') to 5 ('always'), with a neutral value of 3 ('somehow'). Table 4 shows the results in ranking based on their mean values, which range from 3.30 to 4.38. These mean values are above the neutral value of 3 hence indicate that the respondents generally considered all 9 reasons as likely rewards for household sustainability. The highest ranking by all respondents was for 'reducing energy consumption and hence utility bills' (mean value of 4.38), followed closely by 'reducing water consumption' (mean 4.30) and 'educating our future generation the importance of sustainability' (mean 4.17). 'Increasing property price of a sustainable home' is ranked at the bottom of the list, but still at a value of 3.3.

The Kendall's Coefficient of Concordance was used here to determine the rate of agreement amongst rankings of the 9 reasons/benefits presented. The calculated coefficient value was 0.185, close to the 0 value of full agreement amongst respondents, and statistically significant at 1% ($p<0.01$). This suggested that there is a general agreement among the respondents on ranking of the 9 reasons.

Reasons	Number of responses	Mean	Rank
Reducing energy consumption and hence utility bills	476	4.38	1
Reducing water consumption	472	4.30	2
Educating our future generation the importance of sustainability	477	4.17	3
Becoming a responsible Australian household	479	3.88	4
Meeting the needs of the present without compromising the ability of future generations to meet their own needs	471	3.88	4
Improving our household quality of life	472	3.88	4
Improving the quality of life among our community	467	3.8	7
Meeting future environmental regulations	473	3.68	8
Increasing property price of a sustainable home	471	3.3	9

Table 4 Reasons toward having a sustainable home

Space was provided for the respondents to list other reasons and as results, there were 135 responses and their responses are summarized in Table 5. The most commonly raised one is ‘better energy and water saving devices’ (29.6%) and the others include: ‘better house design, planting vegetables, better energy saving behaviour, policy promotion, and better education’.

Reasons for having sustainable homes	Descriptions	Number of responses
Better energy and water saving devices	‘Recycle and reuse grey water’; ‘Solar powered systems’, ‘rain water receivers and distributors’	40
Cost-benefit incentives	‘Giving awards to sustainable house’; ‘financial incentives’	20
Better education	‘The biggest saving we have is in that the children are home educated’; ‘educating people on the full facts’	18
Plant own food	‘Composting all vegetable and fruit scraps’; ‘growing own vegetables’	15
Better energy saving behavior	‘Healthier lifestyle’; ‘happier, healthier, lower environmental impact’	12
Policy promotion	‘The government should be focusing on implementing more sustainable housing technologies and building techniques’	8
Better house design	‘Greater availability and publicizing of sustainable building materials’; ‘choosing to build in a north facing aspect’	8

Table 5 Reasons for having sustainable homes proposed by respondents

3.4 Discussions

The results show that: (1) More than three quarters of the householders know more than 2 ways to reduce household impact on the environment, indicating some level of householder awareness and knowledge on sustainability; the most commonly cited behavoural methods to reduce impacts were using energy efficient bulbs, solar power, and switching appliances off at the wall. (2) Construction costs and government incentives were considered the major influences on achieving sustainable households. (3) Lower bills from reduced energy and water consumption was considered the most important reasons/benefits for sustainable households.

Although many households demonstrated a high level awareness or had already implemented a number of sustainability improvements, particularly the use of energy efficient bulbs, gas hot water, or avoiding idle ‘standby’ power use by switching appliances off at the wall, a number of possible improvements scored poorly, which may be due not only just to a lack of awareness, but also due to prohibitive construction costs or a lack of government incentives (these two were perceived as major hindrances to achieving sustainable households). Therefore, a suggestion from this research is that the government should promote reasons and benefits for sustainability improvements identified in the survey and reduce material costs and improve government incentives for designing and adapting green technologies that lead to energy and water savings.

4 CONCLUSIONS

With the aim of investigating householders' perspectives on sustainable home improvements, from both technology and behavioural perspectives, this study collected data from more than 500 households using an online survey in New South Wales, Australia. Based on the survey data, this paper used descriptive methods to analyse (1) the levels of householders' knowledge about sustainability measures, (2) the extent of the constraint experienced by households in terms of sustainable home improvement, and (3) the important reasons toward having a sustainable home. The respondents identified 14 sustainability measures and 16 reasons for sustainable home development. Among the various factors hindering household efforts to achieve sustainable homes, most of the respondents considered construction cost and government incentives could significantly influence their behaviour.

In conclusion, while the households have some knowledge on how to save energy and water, in order to achieve sustainable home development and behaviour, it is important that material costs are reduced and government incentives introduced, coupled with education on reasons and benefits of having sustainable homes.

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REFERENCES

W. Abrahamse, S. Steg, C. Vlek, , and T. Rothengatter, (2005). "A review of intervention studies aimed at household energy conservation." *Journal of Environmental Psychology* 25:237-291.

S.L. Ahire, D.Y. Golhar, and M.A. Walker, (1996) Development and validation of TQM implementation constructs, *Decision Sciences*, 27(1), 23-56.

Commonwealth of Australia (2011) *Securing a clean energy future: The Australian government's climate change plan*, CanPrint Communications Pty Ltd.

Department of Climate Change and Energy Efficiency. (2010). *Reducing Australia's emissions*. http://www.climatechange.gov.au/government/reduce.aspx.

K.S. Fielding, A. Thompson, W.R. Louis, and C. Warren, (2010). *Environmental sustainability: Understanding the attitudes and behaviour of Australian households*. Australian Housing and Urban Research Institute.

S.Firth, K. Lomas, A. Wright, and R. Wall (2007). "Identifying trend in the use of domestic appliances from household electricity consumption measurements." *Energy and Building* 40:926-936.

R. Garnaut, (2008). *The Garnaut Climate Change Review*. Cambridge University Press: Melbourne.

Z.M. Gill, M.J. Tierney, I.M. Pegg, and Allan, N. (2010), "Low-energy dwellings: the contribution of behaviours to actual performance." *Building Research & Information*, 38(5):491-508.

K.D. Gotzamani, and G.D. Tsiotras, (2001) An empirical study of the ISO 9000 standards' contribution towards total quality management, *International Journal of Operations & Production Management*, 21(10), 1326-1342.
L. Steg (2008). "Promoting household energy conservation" *Energy Policy* 36:4449-4453
F.Stevenson, and A. Leaman (2010). "Evaluating housing performance in relation to human behaviour: new challenges." *Building Research & Information*, 38(5): 437-441.
K.B. Janda (2009). "Building don't use energy: people do", *PLEA 2009: 26th Conference on Passive and Low Energy Architecture*, QUEBEC City, Canada, 22-24 June 2009.
K.Y. Wong and E. Aspinwall, (2005) An empirical study of the important factors for knowledge-management adoption in the SME sector, *Journal of Knowledge Management*, 9(3), 64-82.

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EXPLORING THE RELATIONSHIPS BETWEEN LINKED OPEN DATA AND BUILDING INFORMATION MODELLING

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Abstract. C*urrently, the UK Architectural, Engineering and Construction (AEC) industry is facing huge challenges in delivering construction projects. The industry is required to (i) increase: productivity, efficiency, infrastructural value, quality and sustainability; (ii) reduce: lifecycle costs, lead times and duplications; (iii) minimise or eliminate waste. In industry and government departments, Building Information Modelling (BIM) is being hailed as the solution to overcome these challenges. A common definition of BIM is a "digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition". Also, Linked Open Data (LOD), an emerging paradigm rooted on Semantic Web - the next generation of Web is currently been advocated by governments and Semantic Web communities as a means to render domain data linked or connected and free for public consumption. BIM and LOD provide opportunities to foster collaboration highly needed to overcome challenges that have plagued the construction industry for so long. Yet, studies about the relationship between BIM and LOD are scarce. A comprehensive understanding of the relationship can be of mutual benefits to BIM and LOD experts in developing collaborative and interoperable intelligent knowledge systems for managing building information. For example, a building BIM model can be explored in developing an intelligent cost or energy efficient LOD system for free use by end-users. The objectives of this study are three-fold. Firstly, BIM and LOD technologies are investigated. Secondly, based on the first objective, the relationships between BIM and LOD will be investigated. Emphases will be placed on BIM and LOD interoperable language specifications. Thirdly, a case study will be used to further gain insights into the relationship between BIM and LOD and their application in managing building information.*

Keywords: *BIM, Buildings, Linked Open Data, UK AEC industry*

1 INTRODUCTION

For a while now, the UK AEC industry has been striving to improve productivity, efficiency, reduce construction cost, improve profit margins, deliver projects within budget and schedule and minimise impacts on the environment. Various approaches have been adopted to deal with the afore-mentioned challenges plaguing the AEC industry. Amongst these approaches, information and knowledge management have been considered as being crucial overcoming these challenges. BIM has been hailed as being pivotal in the management of construction information. Also, on a separate note, LOD recently emerged and is currently being popularised as an innovative technology in exposing, sharing and providing data to end-users. While BIM might have been developed for the construction industry, LOD was not. However, both have the same ultimate objective - that of seemingly optimising the use and applications of domain information and knowledge.

The aim of this study is to conduct an exploratory study on ways of maximizing on how both LOD and BIM can be of mutual benefits in managing construction information.

2 WHY BIM/LOD IN SUSTAINABLE BUILDING DESIGN

Based on the literature, there is no agreed definition for sustainable construction (Wong and Fan 2013). However, concepts of sustainable construction often encapsulate the application of the principles of sustainable development throughout the lifecycle of build assets. BIM is increasingly gaining popularity for use in sustainable building designs. In particular, recent literature has revealed the use of BIM in demonstrating how building can be designed to comply with energy performance. Also, BIM has been used in quite easily managing Mechanical, Electrical and Plumbing (MEP) information thereby facilitating the task of MEP engineers.

In a nutshell, digitizing buildings and enriching them with rich data including energy and environmental information can be very useful in sustainable building design decision-making process. If fully understood, BIM and LOD can be of immense importance in digitizing buildings and hence can greatly contribute to sustainable building design decision-making processes.

3 LINKED DATA TECHNOLOGIES

Common terminologies often used in Linked Data parlance are Open Data, LOD, Open Government Data and Semantic Web. For clarity, these terminologies will be examined. Open Data is data which can be used more or less freely. Linked Open Data is Linked Data that can be used more or less freely. Open Government Data is government Open Data. Linked Government Data is government Linked Data. The term “Semantic Web” refers to W3C’s vision of the Web of data. Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data. "Linked Data provides a publishing paradigm in which not only documents, but also data, can be a first class citizen of the Web, thereby enabling the extension of the Web with a global data space based on open standards - the Web of Data (Heath and Bizer 2011). Therefore Linked Data is a concrete means to achieve (a lightweight version of) World Wide Web (W3C)’s of the Semantic Web. Thus as reported, “Linked Data lies at the heart of what Semantic Web is all about: large scale integration of, and reasoning on, data on the Web"(Campbell and MacNeill 2010).

Based on the literature common languages and format of data expressions for exposing data are Excel, PDF, Extensible Markup Language (XML), comma-separated values (CSV) and RDF. RDF is a standard model for data interchange on the Web. Although datasets can be linked through Excel, XML and CSV; RDF is the most current and successful ways of developing Linked Data. In order words it is a useful data-structure for creating interoperable data for human consumption and machine processing. Hence, more emphasis will be laid on RDF.

To facilitate automation, common ontology tools are now being used in developing RDF ontologies for used in enhancing Linked Data technologies. Some examples of ontology development tools already featuring in Linked Data sphere include Protégé, OpenCalais and TopBraid Suite. Protégé is a free, open-source platform that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies. OpenCalais uses natural language processing, machine learning and other methods to analyze content and return the entities it finds, such as the cities, countries and people with dereferenceable Linked Data style URIs (3kbo 2009). The entity types are defined in the OpenCalais RDF Schemas. TopBraid Suite is a family of integrated tools developed by TopQuadrant, Inc. Its key components are TopBraid Composer, an RDF Schema and Web Ontology Language (OWL) ontology editor and TopBraid Live, a Semantic Web application server. Also, a wave of browsers for exploring RDF data over the Web is now common in the Linked Data domain. These browsers can be used in the construction of powerful "datameshups" across heterogeneous data source collections without requiring any programming experience (ODE 2012). Some main browsers are Marbles RDF browser, Zitgist RDF browser, OpenLink Data Explorer previously known as OpenLink RDF browser, Disco Hyperdata browser, Fenfire RDF browser and Tabulator. While most of the Semantic Web browsers have been developed to interface with data sources, the OpenLink Data Explorer and Tabulator are generic browsers that can be used to browse RDF data on the Web (Berners Lee et al. 2006). Although not all browsers; Google Refine and RDF Refine are becoming popular and widely used for developing Linked Data. Google Refine is a powerful tool for working with messy data, cleaning it up, transforming it from one format into another, extending it with Web services, and linking it to databases like Freebase. RDF Refine is a Google Refine extension for exporting RDF. Freebase is a collaborative knowledge base built on structured data harvested from many sources, including individual wiki contributions.

4 BIM TECHNOLOGIES

The Royal Institute of British Architects (RIBA), Construction Project Information Committee (CPIC) and buildingSmart jointly proposed a definition of BIM for UK construction industry, as a starting point for discussion and refinement. They have defined "BIM as a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition". BIM has the potential to (i) increase: productivity, efficiency, infrastructural value, quality and sustainability; (ii) reduce: lifecycle costs, lead times and duplications; (iii) minimise or eliminate waste. It offers opportunities for multiple disciplines to share and exchange data. In construction projects BIM can be applied to solve so many construction problems and also facilitate certain mundane tasks. These include 3D-rendering, drawing extraction, cost estimation, quantity take-off and clash detection. The most widely BIM authoring tools are Revit, Tekla, Digital Project, Microstation, Allplan, Bentley Building Suite, Vectorworks, ArchiCAD. As suggested by Aubin et al. (2012), the most powerful aspect of BIM lies in the "I" standing for Information. The "I" embodies Information which can be either graphical or non-graphical; either contained directly in the building model or accessible from the building model through linked data that is stored elsewhere (ibid). Interoperability challenges have often hindered the optimal exploitation of linking BIM data to other datasets. Unfortunately, this setback has been one of the key barriers hindering the uptake of BIM in the AEC industry.

Seventy eight per cent of construction professionals have expressed their frustration for the limited interoperability amongst BIM tools (McGraw Hill Construction 2009). This raises a number of challenging issues in an industry already inundated by various players with different background. Firstly, how can architects pass building design information to energy and cost consultants for analysis per say? Secondly, how can energy and cost consultants return their analysed results back to architects? To minimise interoperability challenges, language specifications have emerged and being used in the AEC industry.

4.1 Common AEC interoperable language specifications

The three most commonly used languages in the AEC are Green Building (gbXML) schema, Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie). The Green Building XML schema, referred to as "gbXML", was developed to facilitate the transfer of building information stored in CAD building information models, enabling integrated interoperability between building design models and a wide variety of engineering analysis tools and models available today (gbXML 2013). IFC has become a neutral interface to integrate building data including geometric and semantic information to realise interoperability among object-oriented BIM tools. An IFC format file is a plain text file with .ifc file extension. An IFC building model normally contains both product information like IfcWall, IfcWindow, IfcRoof, etc. (BuildingSmart 2007) that can be visualised in an IFC viewer or a BIM authoring tool, and non-product information such as cost, project plan, energy, etc. that mainly describes features and properties of the product and project information. Because it integrates both product and non-product information, IFCs can formulate project repositories to serve information throughout building lifecycles. Besides popular BIM authoring tools with IFC import/export features, traditional computer-aided design (CAD) tools, e.g. Autodesk Architecture, also provide IFC-compliant features to generate IFC models from entity-based CAD environments.

In addition to the fundamental IFC format that is suitable for building data exchange using design software, two evolved formats are available for Web applications and human understanding. The formats are ifcXML and ifcZIP. ifcXML is the format more suitable for the Web based applications to implement IFC features. It takes XML elements into IFC data descriptions such that the building model data can be exchanged and parsed more easily on the Web. Because of the extra tag data embedded into ifcXML files, it can sometimes make the file size very large. Therefore, the .ifcZIP file format can help compress the data using .ZIP formatting and often results in a substantial reduction in file size. On the other hand, as most contractors ask for data hand over, e.g. equipment lists, product data sheets, preventive maintenance schedules, etc. at the construction phase, COBie provides a convenient way to capture and record project handover data from IFC for contractors. Since most of the information can be available before construction, it thus can be obtained directly from the IFC model data by retrieving related information.

4.2 Weakness of IFC, gbXML and COBie

There is no doubt that IFC, gbXML and COBie have so far played a great role in fostering interoperability between systems for exchange of AEC information. However, their limitations have been noted (Pauwels et al. 2011a) requiring further research for improvement. The first limitation is related to the technological weakness inherent in interoperable language specification. For example, IFC constrains users to a certain level of expressiveness. It is not possible to design the most unique building elements, including sloped walls, 3D curved roofs with window elements and still expect the model to be described in IFC (Pauwels et al. 2011b). With regards to gbXML, very few applications support heating, ventilation, and air conditioning (HVAC) information generated by gbXML

(O'Donnell et al. 2011). Furthermore, gbXML fails to preserve geometric relationships as specified in IFC (ibid). Although, literature about the limitations of COBie is sketchy, it can already be noted that Fallon and Feldman (2011) have reported that some Revit families do not translate COBie correctly. The second weakness is related to the varying degree of syntax and semantics used in the description of 3D geometry. Several diverse schemas and file formats can be deployed to describe geometry, depending on the application domain in question. In a multidisciplinary domain such as the domain of AEC, this range of specialized schemas makes file format conversions inevitable. The approach adopted by current conversion tools, however, often results in a loss of information, most often due to a "mistranslation" between different syntaxes and/or semantics, leading to errors and limitations in the design conception stage and to inefficiency due to the required remodeling efforts (Pauwels et al. 2011a). Thirdly, the existence of many stakeholders with different backgrounds in construction projects leads to different types of information and interpretations. Based on the fact that Semantic Web enables the description of information together with its underlying semantics, it offers opportunities to improve the limitations discussed in the preceding sections. Although, more research is still needed to be done to realise the Semantic Web potentials, recent studies reveal that Semantic Web can improve interoperability information in the AEC industry (Pauwels et al. 2011a;b; O'Donnell et al. 2011; Nemirovski et al. 2012). In the ensuing sections we will examine common technologies between BIM and LOD (i.e. technologies rooted in Semantic Web), that can be exploited to enhance BIM interoperability and vice versa.

5 COMMON GROUND AND OPPORTUNITIES

Comma-separated values (CSV): The Wikipedia defines CSV as a common, relatively simple file format that is widely supported by consumer, business, and scientific applications. Data stored in CSV format can be read by Excel. Storing data in CSV and/or hence Excel can easily be shared between ontology engineers or Semantic Web experts and construction professionals through the use of appropriate tools. For example, DataMaster, a plug-in in Protégé can read CSV and/or Excel files while Revit can generate BIM model information in CSV. Also, Google Refine can read CSV files.

XML: XML is well-established Markup language in the Semantic Web domain. Domain knowledge can be generated and read by most ontology engineering tools such Protégé and TopBraid Suite. Also, Google Refine can read and generate data in XML format. On the other hand most BIM tools can generate BIM model data through enhanced standards such as ifcXML and gbXML.

RDF: Similar to XML, RDF is a well-established technology in the Semantic Web and Linked Data domain. Protégé and Google Refine can easily generate RDF domain data models. On the other hand, there are available tools to convert IFC files to RDF data models.

IFC-To-RDF and IFC-To-XML

IFC can be converted into RDF follows an approach of applying the Web Ontology Language (OWL). It can take the place of underlying EXPRESS schema using OWL to represent IFC such that building information can be represented according to the IFC schema in a semantic web format. Hence it creates an opportunity to link alternative representations of building information to show potential interrelationship among diverse sources of information in a building project. Similar strategy is implemented to adopt XML schema into IFC representation so that IFC data can be interpreted by the Semantic Web.

Having established the common grounds where both technologies meet, the major challenge which is that of how end-users can exploit these common interoperable relations remains. The key questions are two-fold. To answer the questions requires an understanding of language specification formats, BIM and Semantic Web tools, how experts use the process information. Firstly, it is possible for a building to be modelled in a BIM authoring tool and converted to any of the exchange formats such as gbXML or ifcXML. The gbXML and ifcXML building information can be read using any ontology development tool. When in an ontology development tool, the building model can be enriched by an ontology engineer who is efficient in ontology design using ontology tools. We can enrich the building model by including Semantic Web rules which can enhance reasoning in the building BIM model. Such reasoning task can be used in the estimation of construction cost (e.g. Abanda et al. 2011; Fidan et al. 2011). To complete the loop, the enriched BIM knowledge model is exported back into a BIM authoring tool for a BIM expert to explore the model for any decision analysis. In the ensuing section, a hypothetical case study will be used to illustrate the preceding discussion including various decision options.

6 CASE STUDY APPLICATIONS

Given that this study is exploratory, we have chosen a familiar domestic dwelling such that information generated can easily be interpreted. The building has been used by one of the authors of this paper in teaching and demonstrating the use of a BIM authoring tool to undergraduate students in Construction Communication and Technology module in the Department of Real Estate & Construction, Oxford Brookes University. The 3D and plan view of the building is presented in Figure 1a & b. The dwelling is a single 2-floor family house with a total gross floor area of 188.62 m^2. The BIM model of this dwelling has been designed using Revit, which is one of the most popular BIM authoring tool in the UK.

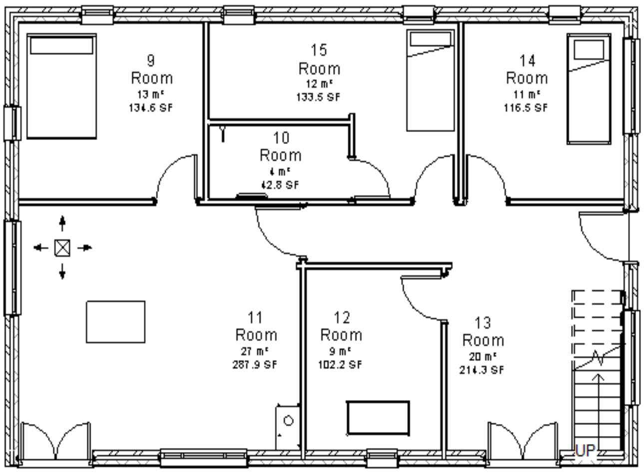


Figure 1a: Distribution plan

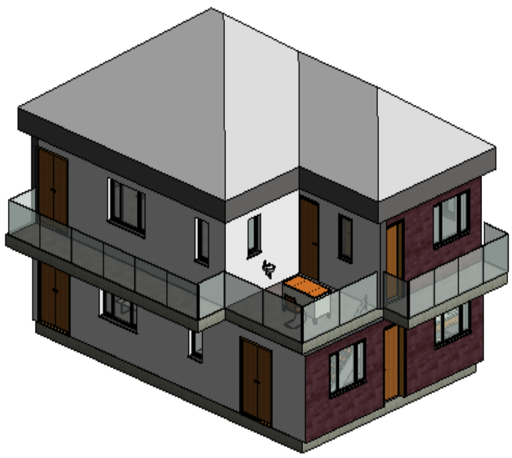


Figure 1b: 3D view

The BIM model is converted into gbXML as shown in Figure 2. To ensure data required for energy analysis is complete, we have randomly chosen Headington, Oxford in the UK.

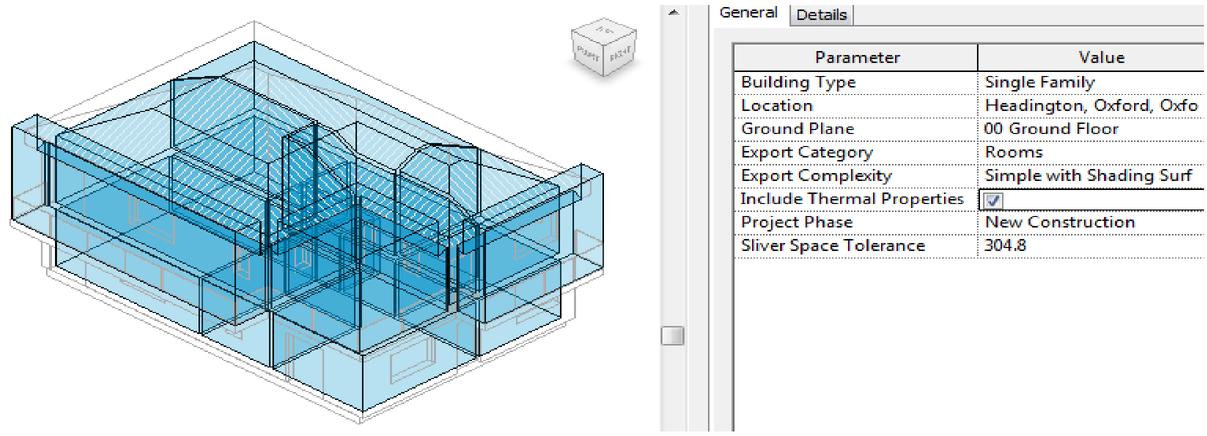


Figure 2: gbXML BIM model for energy analysis

When the model is fully converted into gbXML, a complete XML-based code is generated. To explore the XML-based code, it is imported into either Protégé-OWL 3.4.8 with the help of XML Tab. XML Tab, a plug-in that enables users to import an XML document into Protégé, creating a set of classes and instances in a knowledge base which correspond to the entries in the XML document.

As discussed in the last paragraph of section 5, the major challenge is for end-users to exploit interoperable outputs (e.g. a Single Family building model in Figure 2). When the building model is imported into Protégé-OWL, all data type properties are appear as “string” by default as indicated in Figure 3. Therefore, manual editing is required to ensure appropriate data type properties are attributed to the different data types.

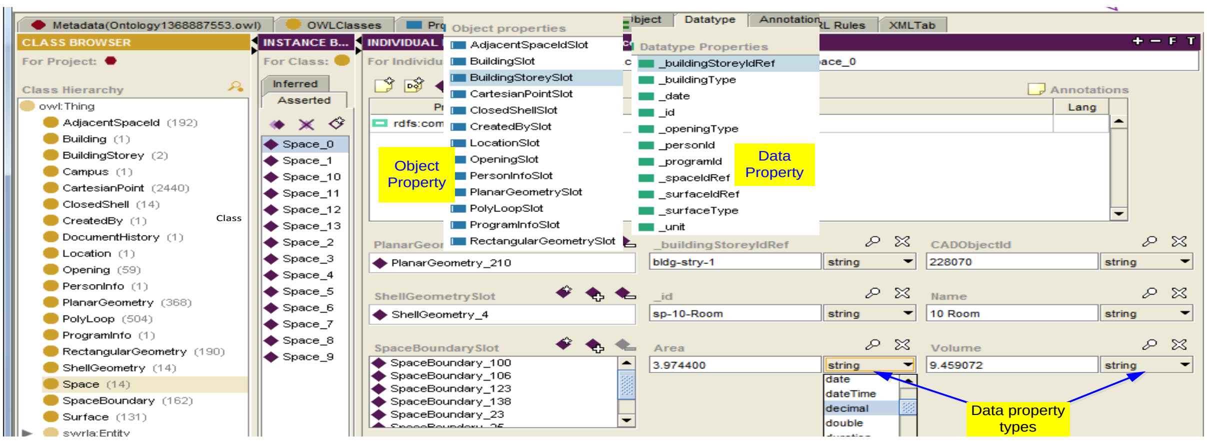


Figure 3: Single Family building ontology as imported from Revit facilitated by gbXML

The imported model (see Figure 3) does not contain household appliances that can support MEP analysis. This implies that these components need to be edited in Protégé-OWL if any meaningful MEP computations are to be conducted (e.g. determination of energy consumption of the building). This is where Open Data is employed. For example, household appliances from Department of Energy & Climate Change (DECC 2012) that is freely available is structured into an OWL ontology and linked to the Single Family dwelling gbXML geometrical model. The allocation of appliances is logically conducted. For example sinks are allocated to the kitchen and bathrooms; and televisions to the lounge and some rooms. The additional OWL household appliance ontology is indicated in Figure 4.

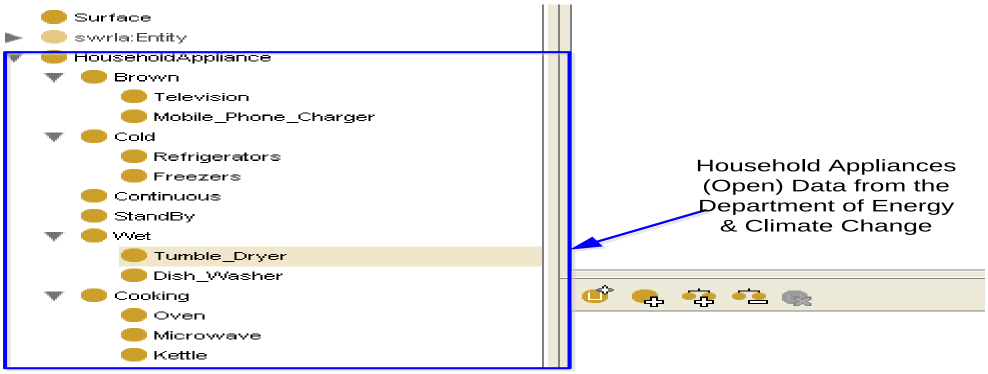
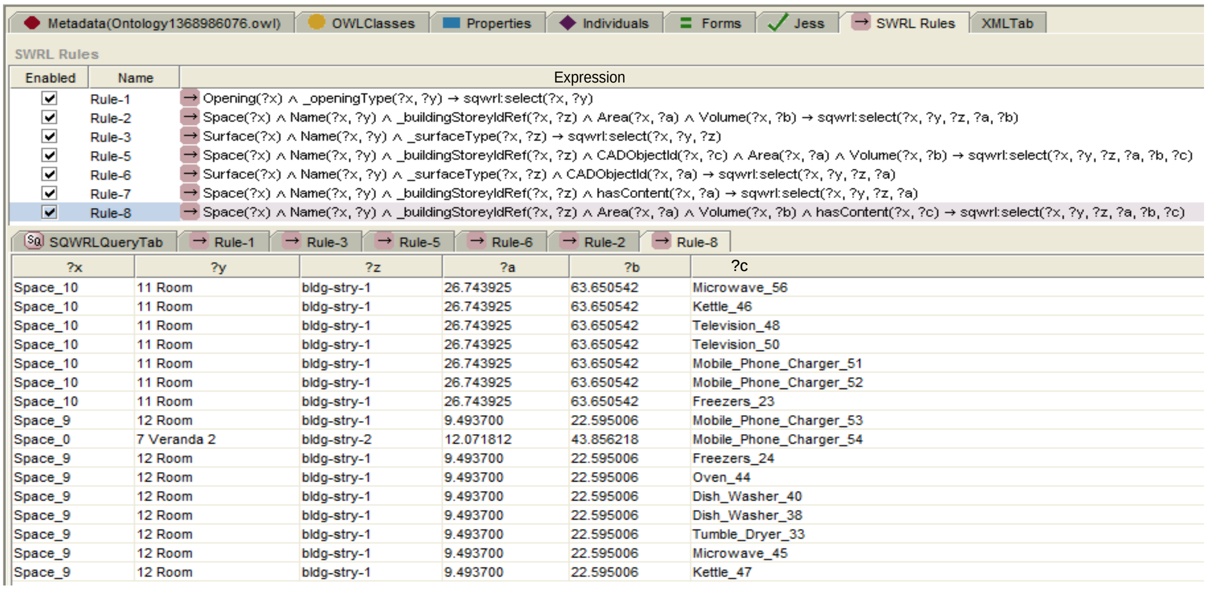


Figure 4: Household appliances' ontology

In Protégé-OWL 3.4.8, plug-ins such as pellet 1.5.2 reasoner, SWRLTab and JessTab can be used to intelligently query the building model. The SWRLTab is a development environment for working with SWRL rules in Protégé-OWL. A key strength of rules is their use in conflict resolution. Its application in BIM can be used to determine clashes between the three trades, i.e. mechanical, electrical and plumbing. SWRL rules can also be used in listing different elements of or in a building, a process commonly known as "scheduling". We will focus on the later for illustrative purposes. Based on a high-level abstract syntax for Horn-like rules- a subset of predicate logic (Antoniou and van Harmelen 2008), SWRL rules have been written to query the Single Family dwelling (see the results of Rule-8 in Figure 5).



Enabled	Name	Expression
☑	Rule-1	Opening(?x) ∧ _openingType(?x, ?y) → sqwrl:select(?x, ?y)
☑	Rule-2	Space(?x) ∧ Name(?x, ?y) ∧ _buildingStoreyIdRef(?x, ?z) ∧ Area(?x, ?a) ∧ Volume(?x, ?b) → sqwrl:select(?x, ?y, ?z, ?a, ?b)
☑	Rule-3	Surface(?x) ∧ Name(?x, ?y) ∧ _surfaceType(?x, ?z) → sqwrl:select(?x, ?y, ?z)
☑	Rule-5	Space(?x) ∧ Name(?x, ?y) ∧ _buildingStoreyIdRef(?x, ?z) ∧ CADObjectId(?x, ?c) ∧ Area(?x, ?a) ∧ Volume(?x, ?b) → sqwrl:select(?x, ?y, ?z, ?a, ?b, ?c)
☑	Rule-6	Surface(?x) ∧ Name(?x, ?y) ∧ _surfaceType(?x, ?z) ∧ CADObjectId(?x, ?a) → sqwrl:select(?x, ?y, ?z, ?a)
☑	Rule-7	Space(?x) ∧ Name(?x, ?y) ∧ _buildingStoreyIdRef(?x, ?z) ∧ hasContent(?x, ?a) → sqwrl:select(?x, ?y, ?z, ?a)
☑	Rule-8	Space(?x) ∧ Name(?x, ?y) ∧ _buildingStoreyIdRef(?x, ?z) ∧ Area(?x, ?a) ∧ Volume(?x, ?b) ∧ hasContent(?x, ?c) → sqwrl:select(?x, ?y, ?z, ?a, ?b, ?c)

?x	?y	?z	?a	?b	?c
Space_10	11 Room	bldg-stry-1	26.743925	63.650542	Microwave_56
Space_10	11 Room	bldg-stry-1	26.743925	63.650542	Kettle_46
Space_10	11 Room	bldg-stry-1	26.743925	63.650542	Television_48
Space_10	11 Room	bldg-stry-1	26.743925	63.650542	Television_50
Space_10	11 Room	bldg-stry-1	26.743925	63.650542	Mobile_Phone_Charger_51
Space_10	11 Room	bldg-stry-1	26.743925	63.650542	Mobile_Phone_Charger_52
Space_10	11 Room	bldg-stry-1	26.743925	63.650542	Freezers_23
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Mobile_Phone_Charger_53
Space_0	7 Veranda 2	bldg-stry-2	12.071812	43.856218	Mobile_Phone_Charger_54
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Freezers_24
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Oven_44
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Dish_Washer_40
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Dish_Washer_38
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Tumble_Dryer_33
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Microwave_45
Space_9	12 Room	bldg-stry-1	9.493700	22.595006	Kettle_47

Figure 5: Sample SWRL rules for querying the Single Family dwelling

On implementing and running rule 8, in SWRLTab, the results are presented in the bottom part Figure 5. The results provide the room name (?y), where the room is located, i.e. level 1 or 2 (bedg-stry-1, 2), floor area (?a), room volume (?b). Furthermore it list the appliances in the different rooms (?c).

7 CONCLUSIONS AND FUTURE RESEARCH

This study is exploratory and still in its infancy. Our goal was to investigate the opportunities that can enhance the capabilities of both BIM and Semantic Web technological paradigms. The study was guided by questions which underlined the exploration and exploitation of knowledge from both BIM and Semantic Web experts without each sacrificing too much time to learn the skills of the other. We illustrated the possibility of using both technologies to enhance each other's capabilities by exploring information exchange languages specification. As part of future studies the investigation is still ongoing and full findings will be submitted to a journal for peer-review. We are also investigating possibilities of on how to exploit household energy appliances' information to determine consumption rates. For example, can rules be written to determine other related information of appliances as depicted in Figure 5? Also, having included the household appliances concept to enrich the gbXML model in Protégé-OWL, we are investigating whether the updated model can be exported back into Revit. Furthermore, data scalability, persistence and execution run-time of intelligent rules in the different paradigms will be investigated.

REFERENCES

3kbo, *Understanding the OpenCalais RDF Response* (2009) http://blog.3kbo.com/2009/09/26/opencalais-response/ [February 2013].

F. H. Abanda, J.H.M. Tah, C. Pettang and M. B. Manjia, "An ontology-driven building construction labour cost estimation in Cameroon", *ITcon*, **16**, 617-634 (2011).

G. Antoniou and F. van Harmelen, *A Semantic Web Primer, second ed.* The MIT Press, Massachusetts, USA (2008).

P. Aubin, D. McClelland, M. Schmid and G. Stanley, *Revit MEP 2013*, USA, G3B Press, (2012).

T. Berners Lee, Chen Y., Chilton L., Connolly D., Dhanaraj R., Hollenbach J., Lerer A. and Sheets D., "Tabulator: Exploring and analyzing linked data on the Semantic Web", In *Proceedings of the 3rd International Semantic Web User Interaction Workshop*, Georgia, USA, November 6 (2006).

BuildingSmart, *Industry Foundation Classes IFC2x Edition 3 Technical Corrigendum 1*, BuildingSMART International Ltd. (2007) http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/index.htm [February 2013].

L.M. Campbell and S. MacNeill, "The Semantic Web, Linked and Open Data", *JISC Cetis*, (2010).

DECC, Energy consumption in the UK (2012) https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/energy-consumption-in-the-uk [May 2013].

K.K. Fallon and R.A. Feldman, *Experimental building information models: Using Autodesk Revit for COBie-compliant designs*, US Army Corps of Engineers (2011).

G. Fidan, I. Dikmen, A.M. Tanyer and M.T. Birgonul, "Ontology for relating risk and vulnerability to cost overrun in international projects", *Journal of Computing in Civil Engineering*, **25**, 302-315(2011).

gbXML, *About gbXML* (2013). http://gbxml.org/aboutgbxml.php [February 2013].

T. Heath and C. Bizer, Linked *Data: evolving the Web into a global data space synthesis lectures on the Semantic Web: Theory and Technology*, Morgan & Claypool, 138 (2011).

McGraw Hill Construction, *The business value of BIM: Getting Building Information Modelling to the Bottom Line*, (2009). http://www.trane.com/architect/Files/PDF/SMR%20BIM%2009%20FINAL%20rev.pdf [February 2013].

J. O'Donnell, R. See, C. Rose, T. Maile and V. Bazjanac, "SIMMODEL: A domain data model for whole building energy simulation", In *Proceedings of Building Simulation 2011:12th Conference of International Building Performance Simulation Association*, Sydney, Australia, November 14-16 (2011).

ODE, The OpenLink Data explorer extension (2012). http://ode.openlinksw.com/ [May 2013].

P. Pauwels, D.V. Deursen, J. De Roo, T.V. Ackere,, R. De Meyer, R.V. de Walle and J.V. Campenhout, "Three-dimensional information exchange over the semantic web for the domain of architecture, engineering, and construction", A*I EDAM*, **25**, 317-332 (2011).

P. Pauwels, D.V. Deursen, J. De Roo, R. Verstraeten , R. De Meyer, R. V. de Walle and J.V. Campenhout, "A semantic rule checking environment for building performance checking", *Automation in Construction*, **20**, 506-518 (2011a).

P. Pauwels, R. De Meyer, R.V. de Walle and J.V. Campenhout, "Linking a game engine environment to architectural information on the Semantic Web", *Journal of Civil Engineering and Architecture*, **5**, 787-798 (2011b).

SWEO, SWEO Linking Open Data community project, (2006). http://linkeddata.jiscpress.org/sweo-linking-open-data-community-project/ [May 2013].

K. Wong and Q. Fan, "Building information modeling (BIM) for sustainable building design", *Facilities*, **31**, 3/4, 138-157 (2013).

EXPLORING THE POTENTIAL OF BIM-INTEGRATED SUSTAINABILITY ASSESSMENT IN AEC

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Abstract. *Worldwide, the need for designing and constructing more sustainable buildings is constantly growing. Although the most critical time to make decisions on a building's sustainable features is during the early stages of design, building performance analysis is usually performed after the design and construction documents are produced. This practice results in lost opportunities to maximise the use of energy efficient building design and technology options. Along with that, it is widely documented that productivity in the AEC/FM industry has been hampered by fragmentation, low innovation, adversarial relationships and slow adoption of Information Communication Technologies. Building Information Modelling (BIM) can promote integration among building professionals and improve design goals by allowing multi-disciplinary information to be integrated within one model. This creates an opportunity to conduct the analysis throughout the design process, concurrently with the production of the design documents. Despite the expected benefits of BIM and sustainable performance analysis, their practices have not been widely embedded within the UK AEC/FM industry. In order to achieve the change in current processes for optimal results, there is a need to define a number of aspects. These include the drivers, actions, good practices, impacts and benefits of sustainability analysis integration in the BIM-collaborative processes on one hand, and the barriers, limitations and deficiencies of current practice on the other. This paper is an early contribution to this ongoing research to improve the way of conducting BIM-based sustainability analysis and communicating the results among the various AEC participants. To achieve that, the processes, skills and resources concerning sustainability assessment have to be defined at the pre-construction stage of the decision making process. The findings indicate that there is no single tool that can be utilised to assess the full range of criteria required for achieving sustainability. It is also demonstrated how the capabilities of BIM-related sustainability software can be used to predict a number of the BREEAM rating system categories criteria.*

Key words: *Sustainability, BIM, building simulation, integration, collaboration, BREEAM*

1 INTRODUCTION

Currently, sustainable performance of buildings has become a major concern among AEC (Architecture, Engineering and Construction) professionals for a variety of reasons. Those include the growing awareness concerning the impact of construction on environmental deterioration which has also led to a number of measures such as building legislation and assessment in addition to a number of national and regional drivers and targets (Schlueter et al. 2009).

In order to address this issue, many countries and international organisations have initiated rating systems to assess sustainable construction. Some examples are United Kingdom's

BREEAM (Building Research Establishment's Environmental Assessment Method), United States' LEED (Leadership in Energy and Environmental Design), Australia's GREEN STAR and Japan's CASBEE (Comprehensive Assessment System for Building Environmental Efficiency). Most of these systems take into account similar sustainable criteria such as energy consumption, material use, water efficiency and indoor visual and thermal comfort (Azhar 2011).

Sustainable analysis tools can aid professionals predict a building's performance from the early stages of design and significantly ameliorate both quality and cost during its life cycle. A number of studies have emphasised the importance of early informed decision making before and during the design process (Schlueter et al. 2009; Azhar 2011; Azhar et al. 2008).

Traditionally, the RIBA Plan of Work (1964) is architect-lead while the structural engineer, mechanical engineer, contractor, client and project manager have supplementary roles in the design process. A number of studies have noted that building design is a multi-disciplinary process that requires contribution from a wide range of specialists, the AEC industry is hampered by fragmentation (Charalambous et al. ; Bouchlaghem et al. 2005) resulting in poor outturn performance and the need for extensive modifications afterwards. In order to move towards the future of collaborative design the roles need to be re-defined and changed. An Integrated Design Team (IDT) that contributes throughout the whole life-cycle of a facility is the target.

Building Information Modelling (BIM) is considered to be one way to address the deep rooted fragmentation problem in the AEC industry by being a computer intelligible approach to exchange building information in design between disciplines (Sacks et al. 2010). This is considered to be the one step forward towards the long term vision of Integrated Project Delivery (IPD). Moreover, it offers the possibility to manage project information throughout the whole life-cycle of the building from cradle-to-grave.

Following the recommendations by the BIM Working Group, the government has mandate the use of fully collaborative 3D BIM for its projects by 2016 (BIS 2011). BIM can be the answer to the need for increased productivity and low margins that lead to significant time and cost savings. As a result, the number of people that are aware and currently using BIM rose from 13% to 31% from 2010 to 2011(NBS 2012).

So as to make one step forward towards sustainable development (SD) assisted by the new technological improvements (software, hardware and networks) and adapt to this technological evolution, there is the need to specify the process of sustainable performance analysis within BIM-collaboration. The challenge that this incorporation faces is the effective orchestration and co-ordination of all the available elements which are necessary to achieve optimum results. This paper is intended to identify the main elements that will constitute effective sustainable assessment within the design process.

2 NEED FOR SUSTAINABILITY ASSESSMENT IN BIM

The NBS Sustainability Survey 2012 (NBS 2012) illustrates some very interesting results concerning the current state, attributes and practices of construction professionals in the UK. Their roles concerning sustainability are green product selection, Client Advisor on sustainability, energy calculations, project assessment, managing corporate sustainability, Green Deal Advisor, none or other. It showed that even if more than 50% acknowledged the importance of all three aspects of sustainability (environmental, economic and social) and followed a sustainability policy, a very small number of them offer an environmental assessment service. It is apparent that the simplistic Green Overlay to the RIBA Outline Plan of Work (RIBA 2011) along with the BIM Overlay that are currently widely adopted need clarification concerning the sub-processes of sustainable design.

Although a lot of research has been done concerning BIM collaborative design and the efficient use of BIM technology, there is little known about the incorporation of sustainable performance analysis into these processes. Some recent research studies have resulted in producing conceptual frameworks to test interoperability and capabilities of common simulation tools (Azhar et al. 2008; Azhar et al. 2009a; Azhar et al. 2009b; SuperBuildings 2011; Moakher et al. 2012; Bazjanac 2008; Bazjanac 2008; Che et al. 2010; Hetherington et al. 2011; Hamza et al. 2007; Magent et al. 2010; Lee et al. 2007; Maile et al. 2007); some BIM related frameworks are also based on the international assessment rating systems (Biswas et al. 2009; Biswas et al. 2008; Wong et al. 2012; Nofera et al. 2010; Lützkendorf et al. 2006; Sinou et al. 2006; Ghosh et al. 2011) and others have created tools that are integrated into building information modelling (Schlueter et al. 2009; Welle et al. 2011; Feng et al. 2012; Huber et al. 2011; Mahdavi et al. 2001).

Despite these efforts, there is still no comprehensive and structured process to assist professionals to perform sustainability analysis from the early stages of design so as to harness the talents of all building professionals' disciplines and achieve optimum results. The importance of incorporating all disciplines from the early stages of design is widely acknowledged and documented (Bouchlaghem et al. 2005) along with how crucial early decisions are in order to achieve sustainability in the resulting design outcome (Schlueter et al. 2009).

Even though the efficient co-ordination of people, tools and technology can lead to significant benefits in the quality and performance of buildings, there are many challenges to be faced. An integrated design process, interdisciplinary collaboration, complex design analysis, careful material and system optimisation are required to solve this problem (Nofera et al. 2010).

3 PROJECT AIM

The main aim of this ongoing research is to ameliorate the way of conducting sustainability assessment within BIM collaborative environment in order to achieve leaner and thus more efficient processes. The main concept is to clarify the sub-processes and create a framework that identifies the challenges that need to be overcome.

4 METHODS AND RESEARCH DESIGN

In this paper, a comprehensive literature review takes place so as to evaluate the current state of collaborative BIM-enabled sustainability assessment and identify the elements that need to be integrated. That serves to understand and define the impacts, drivers and benefits of sustainability analysis integration in the BIM-collaborative processes as well as identify the barriers and limitations of current practice and the need for change. Aspects such as people, process, technology, policy and information are reviewed and analysed. Moreover, a number of BIM related performance analysis software is also presented in relation to the BREEAM rating system.

5 ELEMENTS OF BIM-INTEGRATED SUSTAINABLE DESIGN

This section answers to a variety of questions in relation to BIM-based sustainability assessment (who, what and how). Firstly, the aspects that are considered to constitute sustainable design are discussed. Secondly, the sustainable analysis software that can be related to BIM is presented in relation to the minimum standards of the BREEAM rating system categories. That consists also of BIM software itself as sustainable way of working compared to the traditional methods. Thirdly, the means to communicate the sustainable information are discussed. ICT, OCP, interoperability, technology infrastructure and maturity are the technological enablers of BIM collaborative processes. Finally, the various stakeholders in the design process are identified.

5.1 Definition of sustainable development and aspects of sustainable design

The most widely accepted definition of sustainable development (SD) is given by the Brundtland Report (1987); it states that SD is the kind of development that satisfies the needs of the present generations without compromising the chance of future generations to satisfy theirs. The construction industry, as one of the main sectors of the national industry is expected to contribute more towards this direction (Nofera et al. 2010).

The three main pillars of sustainability (environmental, social and economic) can be further analysed in a variety of perspectives which are human well-being, climate change mitigation, environment protection, fossil fuel replacement, security of supply and living standards (Clarke 2012). All those perspectives are necessary to achieve sustainable design but sometimes they become conflicting.

Recent research has acknowledged the complexity of the process of ecological design and identified the most important clusters of eco-determinants to be the following: (i) design aspects and strategies, (ii) environmental impacts, (iii) design environmental strategies, (iv) social aspects, (v) site analysis and (vi) economy (Vakili-Ardebili et al. 2010).

Kriegel and Nies (2008) indicate that BIM can aid in the following aspects of sustainable design: (i) building orientation (selecting a good orientation can reduce energy costs), (ii) building massing (to analyse building form and optimise the building envelope), (iii) daylighting analysis, (iv) water harvesting (reducing water needs in a building), (v) energy modeling (reducing energy needs and analyzing renewable energy options can contribute to low energy costs), (vi) sustainable materials (reducing material needs and using recycled materials), (vii) site and logistics management (to reduce waste and carbon footprints) (Krygiel and Nies 2008).

All these factors are considered to be necessary in the quest towards sustainability and should be taken into consideration during the design of a high performance facility. This task can be challenging since many times there is a conflict between them which leads to the need for a holistic point of view from the early stages of design. However, BIM combined with a range of sustainability performance analysis software that support interoperability standards can manage the sustainable information through a building’s life cycle. A dynamic procedure is essential in order to assess and re-assess those aspects during the design process.

5.2 BIM software and building simulation tools

A main difference between assessment and rating tools is that the former can provide evidence of quantitative performance while the latter determine performance of a building in a more simplistic way such as rating with stars (Ding 2008). For that reason simulation tools can produce a more informed and detailed analysis by giving exact numbers which can be translated in the more simplistic version of the BREEAM assesment (BREEAM 2012) (oustanding, excellent, very good, good and pass) and this way they can help to predict a facility's rating from a very early design stage.

From the wide range of building simulation tools that are available in the market now, there are a number of reports and studies that have tested both technical aspects such as interoperability with BIM (SuperBuildings 2011) and their capabilites in analysis (Crawley et al. 2008) while others have examined qualitative aspects like the users preferences concerning Usability and Information Management (UIM) of interface and the Integration of Intelligent design knowledge-Base (IIKB) (Azhar et al. 2011; Attia et al. 2009). Another important recommendation of those studies is that the users have to consider adopting a variety of tools which would support a wider range of simulations that a single tool cannot offer due to the lack of extensiveness (Crawley et al. 2008; Attia et al. 2009).

In view of the above, the tools presented in Table 1 have been chosen to explore their informing possibilities regarding the BREEAM sustainable categories. Table 1 presents the capabilities of seven (7) building simulation tools in addition to the sustainable features that the BIM Autodesk Revit software itself offers. The analytical names of the acronyms presented are: Green Building Studio (GBS), Energy 10 (E10), Home Energy Efficient Design (HEED), Design Builder (DB), Ecotect Analysis (ECOTECT), QUick Energy Simulation Tool (eQUEST) and Integrated Environmental Solutions Virtual Environment (IES VE). The categorisation between early design phases and conceptual design and development phase is based on a survey on the users' preferences (Attia et al. 2009).

In Table 1, it is apparent that BIM software can facilitate in predicting most of the "Management" category credits without the assistance of any other tool. Moreover, the "Health and Wellbeing" and "Energy" categories are being sufficiently covered by the simulation software. Furthermore, "Water", "Materials", "Land Use and Ecology", Pollution" and "Innovation" are also considered by the software in the assessment of sustainability. On the other hand, it is worth noting that on the "Transport" and "Waste" categories, the above mentioned tools appear to have no capabilities in predicting a building's performance regarding those issues.

BIM-based sustainability analysis and the BREEAM rating system (SuperBuildings 2011, BREEAM 2012, Crawley et al. 2008, Azhar et al. 2011, Attia et al. 2009).									
Relationship between BIM-based sustainability analysis & minimum standards by BREEAM rating level		Sustainable design related performance analysis software							
		BIM	Early design phases				Conceptual & design development phase		
		Revit	GBS	E10	HEED	DB	ECOTECT	eQUEST	IES VE
Categories	Weighting & Credits								
Management	**12%**								
Man 01 Sustainable	1-2	X							
procurement		X							
Man 02 Responsible	0-2								
construction practices									
Man 03 Construction site	0-1	X							
impacts		X	X	X					
Man 04 Stakeholder									
participation									
Man 05 Life cycle cost and									
service life planning									
Health and Wellbeing	**15%**								
Hea 01 Visual comfort	Required					X	X		X
Hea 02 Indoor air quality			X		X	X	X	X	X
Hea 03 Thermal comfort			X	X	X	X	X	X	X
Hea 04 Water quality	Required								
Hea 05 Acoustic							X		
performance									
Hea 06 Safety and security									
Energy	**19%**								
Ene 01 Reduction of	0-10		X	X	X		X	X	X
emissions									
Ene 02 Energy monitoring	0-1			X			X	X	X
Ene 03 External lighting			X	X			X	X	X
Ene 04 Low and zero carbon	0-1								
technologies									
Ene 05 Energy efficient cold									
storage									
Ene 06 Energy efficient									
transportation systems									
Ene 07 Energy efficient									
laboratory systems				X		X	X	X	X
Ene 08 Energy efficient									
equipment									
Ene 09 Drying space									
Transport	**8%**								
Tra 01 Public transport									
accessibility									
Tra 02 Proximity to									
amenities									
Tra 03 Cyclist facilities									
Tra 04 Maximum car parking									
capacity									
Tra 05 Travel plan									

Table 1: Categories that BIM-based performance analysis aids to predict performance for a number of BREEAM sustainability factors (continue)

Water	**6%**								
Wat 01 Water consumption	**0-2**		**X**						**X**
Wat 02 Water monitoring									
Wat 03 Water leak detection and prevention	**None – Criterion 1 only**								
Wat 04 Water efficient equipment				**X**					
Materials	**12.5%**								
Mat 01 Life cycle impacts									
Mat 02 Hard landscaping and boundary protection									
Mat 03 Responsible sourcing of materials									
Mat 04 Insulation	Required	X							
Mat 05 Designing for robustness		X		X	X		X	X	X
Waste	**7.5%**								
Wst 01 Construction waste management	0-1								
Wst 02 Recycled aggregates									
Wst 03 Operational waste	0-1								
Wst 04 Speculative floor and ceiling finishes									
Land use and Ecology	**10%**								
LE 01 Site selection		X					X		
LE 02 Ecological value of site and protection of ecological features									
LE 03 Mitigating ecological impact				X			X	X	X
LE 04 Enhancing site ecology	0-1								
LE 05 Long term impact on biodiversity									
Pollution	**10%**								
Pol 01 Impact of refrigerants									
Pol 02 NOx emissions			X						X
Pol 03 Surface water run off									
Pol 04 Reduction of night time light pollution									
Pol 05 Noise attenuation									
Innovation	**10%**								
Inn 01 Innovation	(additional)	X							X

Table 1: Categories that BIM-based performance analysis aids to predict performance for a number of BREEAM sustainability factors

5.3 Technological enablers for collaborative design

A major enabler to achieve integration of sustainability asssessment with BIM collaboration is interoperability. Interoperability is defined as the ability to manage and communicate electronic product and project data between collaborating firms; which means that data interoperability is the ability of different software to use common data formats (Charalambous et al.). One major interoperability standard is the Industry Foundation Classes (IFC). A number of schemes have also been developed for extracting the environmental data in a neutral format; the gbXML, ecoXML, IFCXML, greenbuildingXML, ecoXML are other interoperability standards that can enhance data integration.

For the communication of those information among different disciplines from the early design phase, the use of OCPs (Online Collaboration Platforms) is essential. OCPs enable both the synchronous and asynchronous collaboration that is needed in BIM collaborative processes (Anumba et al. 2002). The procesing power of computers, server capacity, networks and internet connection are additional aspects that need to be considered to achieve intergration. The existing technological maturity creates the need to rethink and redesign the traditional collaborative processes so as to enhance the centrality of information and exploit all the potential benefits of mobilisation and cloud computing. The use of this new technology will help transform the current perception of the industry by enabling the mapping of the collaborative processes and leading to the future Integrative Project Delivery (IPD) approach.

5.4 People perspectives and collaboration

It is documented that despite the obvious benefits of collaborative BIM-based sustainability analysis, its use is still not widely adopted; the e-readiness of construction companies to adopt new technologies is a major concern among researchers (Ruikar et al. 2006). Especially in the case of high performance buildings, the need to increase collaboration and coordination between structural, envelope, mechanical, electrical and architectural systems increases. This interaction requires attributes such as the early involvement of participants, team experience, levels and methods of communication and compatibility within project teams (Nofera et al. 2010). Several authors have acknowedged the significance of managing decision-making process when diverse experts have conflicting proposals (Plume et al. 2007).

Communication problems can be addresseed by providing an audit trail (how it is done) where except for the explicit knowledge (who did what when) also accounts for the tacit knowledge (why was it done) (Cerovsek 2011). A recent research revealed that the current capabilities of BIM are very limited concerning the “how” and absent concerning the “why” leading to inefficiency to solve the emerging problems that occurred during the design process (Dossick et al. 2011).

Currently, the new roles of all the stakeholders of the integrated design process are not yet been defined. For the integrated design of a sustainable building except of the traditionally involved participants of the RIBA Plan of Work (client, architect, structural engineer, mechanical and electrical engineer, contractor) the role of new ones have to be considered such as the Model Manager (of the BIM model) (RIBA 2012). Furthermore, several studies have focused on the importance of the occupant consensus in the design of a building; user behaviour and their perception of comfort can make a critical difference in the operation of a facility (Wei et al. 2011; Andersen et al. 2009; Andersen 2009).

6 CONCLUSION

This paper discussed the drivers, aspects and other factors of BIM-based sustainable assessment into collaborative design. The technology, tools and project participants were also presented. In order to achieve the effective integration of the above elements for leaner design, the sub-processes need to be clarified. Defining the above processes will accelerate and streamline the design process as well as encourage the adoption of the new technology widely into the construction industry.

REFERENCES

R. V. Andersen. "Occupant behaviour with regard to control of the indoor environment." *Department of Civil Engineering, Technical University of Denmark* (2009).

R. V. Andersen, J. Toftum, K. K. Andersen, and B. W. Olesen. "Survey of occupant behaviour and control of indoor environment in Danish dwellings." *Energy Build.*, 41(1) , 11-16 (2009).

C. Anumba, O. Ugwu, L. Newnham, and A. Thorpe. "Collaborative design of structures using intelligent agents." *Automation in Construction*, 11(1), 89-103 (2002).

S. Attia, L. Beltrán, A. De Herde, and J. Hensen, "Architect friendly: a comparison of ten different building performance simulation tools", *Proceedings of IBPSA '09 Buildings Simulation Conference*, pp. 204-211 (2009).
S. Azhar, M. Hein, and B. Sketo, "Building information modeling (BIM): Benefits, risks and challenges," *Proceedings of the 44th ASC Annual Conference*, pp. 2-5 (2008).
S. Azhar, "Building Information Modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry", *Leadership and Management in Engineering*, 11, 241 (2011).
S. Azhar and J. Brown. "BIM for sustainability analyses", *International Journal of Construction Education and Research*, 5(4), 276-292 (2009a).
S. Azhar, J. Brown, and R. Farooqui, "BIM-based sustainability analysis: An evaluation of building performance analysis software", *Proceedings of the 45th ASC Annual Conference*, pp. 1-4 (2009b).
S. Azhar, W. A. Carlton, D. Olsen, and I. Ahmad, "Building information modeling for sustainable design and LEED ® rating analysis", *Automation Construction*, 20(2), 217-224 (2011).
V. Bazjanac. "IFC BIM-based methodology for semi-automated building energy performance simulation." *Proc.of CIB-W78* (2008).
BIS, *BIM management for value, cost and carbon improvement,* A report commissioned by the Department of Business, Innovation and Skills (2011).
T. Biswas and R. Krishnamurti, *Framework for Supporting Sustainable Design*, School of Architecture, pp. 46 (2009).
T. Biswas and R. K. Tsung-Hsien Wang, *Integrating sustainable building rating systems with building information models* (2008).
D. Bouchlaghem, H. Shang, C. J. Anumba, M. Cen, J. Miles, and M. Taylor, "ICT-enabled collaborative working environment for concurrent conceptual design", *Architectural Engineering and Design Management*, 1(4), 261-280 (2005).
BREEAM, "*New Construction for Non-Domestic Buildings. Technical Manual Version SD5073 Issue 3.0*", BRE Global Ltd. (2012).
T. Cerovsek, "A review and outlook for a 'Building Information Model'(BIM): A multi-standpoint framework for technological development", *Advanced engineering informatics*, 25(2), 224-244 (2011).
G. Charalambous, P. Demian, S. Yeomans, T. Thorpe, C. Peters, and N. Doughty, "BIM and Online Collaboration Platforms–An investigation into emerging requirements." .
L. Che, Z. Gao, D. Chen, and T. H. Nguyen, "Using building information modeling for measuring the efficiency of building energy performance", *Proceedings of the International Conference on Computing in Civil and Building Engineering (ICCCBE)*, Nottingham, 165-170 (2010).
J. Clarke, "Lecture on Integrated Building Performance Simulation. Loughborough University, United Kingdom." unpublished.
D. B. Crawley, J. W. Hand, M. Kummert, and B. T. Griffith, "Contrasting the capabilities of building energy performance simulation programs." *Build. Environ.*, 43(4), 661-673 (2008).
G. K. Ding. "Sustainable construction—The role of environmental assessment tools." *Journal of Environmental Management*, 86(3), 451-464 (2008).
C. S. Dossick and G. Neff. "Messy talk and clean technology: communication, problem-solving and collaboration using Building Information Modelling", *Engineering Project Organization Journal*, 1(2), 83-93 (2011).
C. Feng, O. Mustaklem, and Y. Chen, "The BIM-based information integration sphere for construction projects", *Proceedings of the 28th ISARC Conference,* Seoul, Korea, pp. 156-161 (2012).
S. Ghosh, S. Negahban, Y. H. Kwak, and M. J. Skibniewski, "Impact of sustainability on integration and interoperability between BIM and ERP-A governance framework," *Technology Management Conference (ITMC), IEEE International*, pp. 187-193 (2011).
N. Hamza and M. Horne, *Building Information Modelling: empowering energy conscious design* (2007).

R. Hetherington, R. Laney, S. Peake and D. Oldham, *Integrated building design, information and simulation modelling: the need for a new hierarchy* (2011).

D. Huber, B. Akinci, A. Oliver, E. Anil, B. Okorn, and X. Xiong, "Methods for automatically modeling and representing as-built building information models", *Proceedings of NSF CMMI Research Innovation Conference* (2011).

E. Krygiel and B. Nies, *Green BIM: successful sustainable design with building information modeling.* Sybex (2008).

G. Lee, R. Sacks, and C. Eastman, "Product data modeling using GTPPM—A case study", *Automation in Construction*, 16(3), 392-407 (2007).

T. Lützkendorf and D. P. Lorenz, "Using an integrated performance approach in building assessment tools". *Building Research and Information*, 34(4), 334-356 (2006).

C. S. Magent, S. Korkmaz, L. E. Klotz, and D. R. Riley, "A Design Process Evaluation Method for Sustainable Buildings", *Gestão & Tecnologia de Projetos*, 4(2), 142-142 (2010).

A. Mahdavi, R. Brahme, and S. Gupta, "Performance-based computational design via differential modeling and two-staged mapping", *Proceedings of the CAAD Futures Conference*, Eindhoven, The Netherlands, pp. 667-680 (2001).

T. Maile, M. Fischer, and V. Bazjanac, *Building energy performance simulation tools-a life-cycle and interoperable perspective*, Center for Integrated Facility Engineering (CIFE) Working Paper, vol. 107 (2007).

P. E. Moakher and S. S. Pimplikar. "Building Information Modeling (BIM) and Sustainability – Using Design Technology in Energy Efficient Modeling", *IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE)*, 1(2), 10-21, July-Aug (2012).

NBS, *National BIM Report 2012*, National Building Specification, London (2012).

W. Nofera and S. Korkmaz, "Design Process Integration for Sustainable, High Performance Buildings." *Proceedings Editors* (2010).

J. Plume and J. Mitchell. "Collaborative design using a shared IFC building model—Learning from experience." *Automation in Construction*, 16(1), 28-36 (2007).

RIBA, *BIM Overlay to the RIBA Plan of Work*, Royal Institution of British Architects (2012).

RIBA, *Green Overlay to the RIBA Plan of Work*, Royal Institution of British Architects (2011).

K. Ruikar, C. Anumba, and P. Carrillo, "VERDICT—An e-readiness assessment application for construction companies", *Automation in Construction*, 15(1), 98-110 (2006).

R. Sacks, I. Kaner, C. M. Eastman, and Y. Jeong, "The Rosewood experiment—Building information modeling and interoperability for architectural precast facades" *Automation in Construction*, 19(4), 419-432 (2010).

A. Schlueter and F. Thesseling, "Building information model based energy/exergy performance assessment in early design stages", *Automation in Construction*, 18(2), 153-163 (2009).

M. Sinou and S. Kyvelou, "Present and future of building performance assessment tools", *Management of Environmental Quality: An International Journal*, 17(5), 570-586 (2006).

SuperBuildings, *Deliverable 3.3: Needs, levels and potentials of integrating SB assesssment and benchmarking with BIMs* (2011).

A. Vakili-Ardebili and A. H. Boussabaine, "Ecological Building Design Determinants", *Architectural Engineering and Design Management*, 6(2), pp. 111-131 (2010).

S. Wei, R. A. Buswell, and D. L. Loveday, "Factors affecting'end of day'window position in non-air-conditioned office buildings." (2011).

B. Welle, J. Haymaker, and Z. Rogers, *ThermalOpt: A methodology for BIM-based passive thermal multidisciplinary design optimization*, Center for Integrated Facility Engineering Technical Report, no. 200 . (2011).

K. A. Wong and Q. Fan, "Building Information Modelling (BIM) for Sustainable Building Design", *Facilities*, 31(3/4), 3-3 (2012).

BIM IMPLEMENTATION: FROM CAPABILITY MATURITY MODELS TO IMPLEMENTATION STRATEGY

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Abstract. *There have been very few empirical studies that attempt to delineate the critical issues that drive successful implementation of BIM in construction organisations. The purpose of this paper is to develop a systematic approach to BIM implementation via a series of steps designed to synchronise BIM solutions and organisational change processes. The paper reviews a number of BIM capability maturity protocols and methods and draws the attention on a number of reasons why these protocols cannot enter the mainstream organisational practices without devising implementation strategies. Based on the findings of an exploratory study using semi-structured interviews with 10 BIM-enabled construction organisations, a four-stage implementation strategy is proposed; comprising brain storming, concept building, realisation and manifestation stages. Each of the stages represent a distinct milestone in the implementation process, thus a condition for achieving overall success is to pay full attention at each stage of the process. The proposed implementation strategy can be used as a basis for integrating the existing and emerging list of construction IT solutions (e.g., BIM, Artificial Intelligence, Virtual Construction, Computer Information Construction, and Sharepoint Project System) and organisational change process.*

Keywords: *Building Information Modelling, capability model, implementation process, construction industry*

1 INTRODUCTION

The face of design and production of facilities in the architecture, engineering and construction (AEC) sector is changing according to the trend of the 21st century. As the world's population continues to grow at the rate of about 1.4 million people per week, the challenge for building more sustainably and using a better means of construction has become apparent (Hardin 2009). In essence, the sector needs to use the right tools to create less waste, better utilise materials and build more sustainable facilities to meet the increasing demands. Some of the main solutions to the challenges faced by the construction sector may lie in the rapidly evolving technologies, such as BIM, green-tech, integrated databases, e`lectronic data interchange (EDI), artificial intelligence, laser scanning, rendering and visualisation, and innovative solutions to building processes and products. It has been reported that, construction related technologies have recently been gaining momentum (e.g., NBS 2012). Pike Research (2012), a consulting team that provides in-depth analysis of global clean technology markets has also characterised the global BIM market as 'nascent' but 'evolving rapidly'. They have predicted that by 2020, annual worldwide revenue for BIM products and services solutions will grow from $1.8billion in 2012 to almost $6.5 billion 2020.

As such the real challenge for the AEC sector is to develop innovative strategies on how to manage and use the available technological tools and knowledge of BIM to create more efficient and sustainable facilities in ways that might not have been possible in the past. Nevertheless, technological implementation has proven to be a difficult challenge for organisations in the past. For example, in 2010, NBS (2011) research indicated that 62% of people aware of BIM anticipated to use it in 2011, but only 41% ended up using it in 2011 (NBS 2012). Weston (2001) has previously emphasised that organisations that realise full benefits of a technology are those that make necessary changes in their organisational structures, strategies and processes. A survey conducted by Austin et al (2003) revealed that notwithstanding the high investments in enterprise systems, implementation of these systems are still mired by cost and schedule overruns, resistance to business process change, absence of adequate skills, and overall underachievement comparative to the expectation of benefits accruing from the technology. The critical challenge in BIM implementation is to first identify the gaps between the generic functionality of the chosen BIM system and the specific organisational requirements (Soh, et al., 2003). Too often, implementing organisations fail to understand business requirements which the BIM processes are expected to address (Azhar, 2011). Ehie & Madsen (2005) have suggested that the fundamental business practices embedded in the technology has to replace the existing practices in the implementing organisation if the functional benefits of the system are to be realised.

Ultimately, mobilising technological solutions for the delivery of sustainable construction projects call for companies to gain better understanding of the concomitant innovative processes that are associated with the technology. It is thus important for organisations to be aware of critical issues affecting the implementation of such integrated IT systems and give careful considerations to these issues. To improve the odds of BIM success, construction organisations perhaps need a shift in paradigm from viewing BIM implementation as a large-scale IT infrastructure upgrade to a holistic business resurgence. Thus, through an empirical study, this research proposes a framework for BIM implementation.

2 THEORETICAL CONTEXT

2.1 Construction Technology Transformation Timeline

When the construction sector moved from the drawing board (manual delivery) to “electronic delivery” CAD systems, the products were initially the same, it took about a decade to develop the CAD system from 2D to PC driven basic 3D drafting (Bevan 2012). Just as the drawing board was once the accepted technology prior to CAD, the era of BIM has begun – but this time, the change is revolutionary (table 1 elaborates on construction technology timeline). The reality with the CAD system is that, too often, fragmented, unreferenced, and inaccurate data is distributed between the construction team and then handed over to the owner to be used as information for maintenance of the facility (Hardin, 2009). Unlike CAD, a BIM project is not drawn in a traditional sense with lines, dots, and texts in multiple documents. Instead it is built digitally as a database in a BIM-based platform. BIM has been referred to as ‘a revolutionary building design and construction technology’ (Osan et al., 2012), because it is purported to bring wholesale changes to every phase of the project delivery lifecycle.

Numerous suggestions have been put forward on how BIM could be integrated into the construction processes. These include the AEC (UK) BIM protocol (AEC (UK) CAD, Standard Initiative, 2010), Mervin Richards' BIM standard framework and guide (Richards, 2010), BIM implementation planning guide - proposed by Pennsylvania State University (The CIC Research, 2012), and BIM overlay to the RIBA outline plan of work (RIBA, 2012).

Others have also defined different BIM maturity stages, with each stage exhibiting disparate competences (e.g. Succar 2010; NBS 2012). In general the progressions from low to higher levels of maturity indicates 1) better predictability and forecasting by lowering variability in competence, performance and costs; and 2) greater effectiveness in reaching defined goals and setting new more ambitious ones (Succar, 2010).

2.2 BIM Maturity Capability Models

In 2008, Mark Bew of BuildingSmart and Mervyn Richards of Construction Product Information Committee (CPIC) developed the BIM Maturity Diagram model, (Richards, 2010), which is now a well-known diagram. It acknowledges the impact of both data and process management of BIM and defines three different levels of maturity for BIM. In essence, level 0 provides 2D unmanaged CAD with electronic paper as the likely data exchange format. Level 1 provides 2D or 3D managed CAD with standalone standard data packages with no integration. Level 2 BIM provides information in a 3D format, with the various members of the project team creating and maintaining their own individual models. These federated models are interoperable in a Common Data Environment (CDE) or with the use of proprietary interfaces. The level 3 on the other hand, utilises a single project model, accessible by all the participating project team members. It is an open process and data integration is enabled by web services compliant with existing and emerging IFC standards, managed by a collaborative model server. Level 3 has also been regarded as "iBIM" or integrated BIM, potentially employing concurrent engineering processes.

There is also a BIM capability stages developed by Succar (2009). It defines the minimum BIM requirements or the major milestone that need to be reached by organisations as they implement BIM technologies and concepts. There are 5 BIM stages as shown in figure-1. The starting point represents the pre-BIM stage, and it identifies with the status of the industry prior to the emergent of the BIM concept (as captured in table-1). According to Succar (2010) BIM stages 1 to 3 are defined by their minimum requirements for BIM uptake. As an example, for organisation to be at stage-1 (object-based modelling), it need to have BIM authoring software similar to Vectorworks, Bentley, ArchiCAD, or Revit. At this stage however, data exchange between project stakeholders is unidirectional and communications are asynchronous and disjointed. At stage-2 (model-based collaboration), an organisation needs to operate BIM effectively on a multidisciplinary collaborative BIM project. At BIM capability stage-3, an organisation needs to be using a network-based repository platform to share object-based models. At this stage, interoperable data interchange across discipline is possible. The final stage (post-BIM) encompasses a variable ending point with ever evolving connotations, which deploys virtual-integrated Design, Construction and Operation (viDCO) tools and concepts (Succar 2010). At this stage, model deliverables extend beyond semantic object properties, incorporating all the design information required at each stage of the lifecycle of a facility to include business intelligence, green policies, whole lifecycle costing etc. each stage has different prerequisite for technological, process and policy structures.

Time	Pre 1980s	1980s	1990s	2000s	2010s	Future Anticipation
Practice	Drawing board	Computer Aided Drafting (CAD)	Basic Computer Aided Design (CADD)	Increased Computer Aided Design (CADD)	BIM Stages	Post BIM
Features	• Manual scheduling • Manual collaboration • Constant duplication • Zero transparency • Limited efficiency	• Primarily 2D • Mainframe driven • Limited compatibility • Limited collaboration • Relatively reduced duplication	• Basic 3D visualisation • PC driven • Consultant centric • Relatively better consistency • Limited collaboration	• Increased 3D modelling • LANs – Networked PCs • Project centric • Increased collaboration • Improved coordination	• Single disciplinary use of object-based 3D modelling • WAN network and federated repositories • Limited multidisciplinary sharing of BIM-models • 4D &5D benefits – time/cost • Full coordination • Increased efficiency	• Integrated practice • Multidimensional federated model • Synchronous communications • Virtual integrated Design, Construction and Operation (viDCO)

Table 1: Construction technology transformation timeline (From drawing board to BIM) Adapted from Bevan (2012) and Succar (2010)

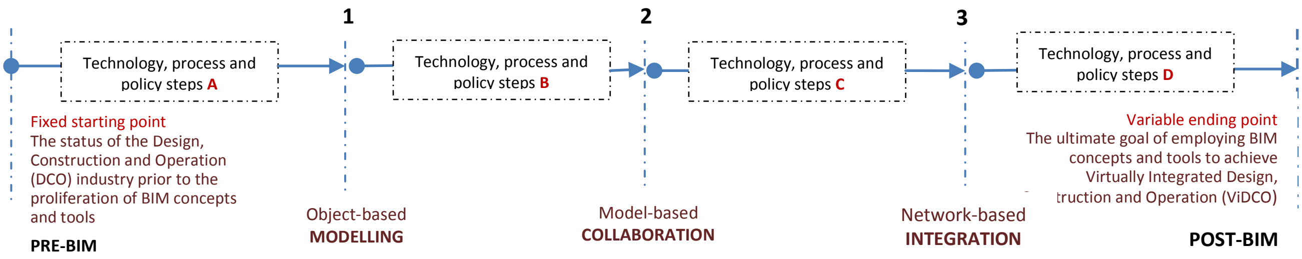

Figure 1: BIM Capability stages (Adopted from Succar 2010)

The maturity model and Succar's (2009) 5-BIM capability stages as discussed are examples of how BIM is anticipated to drive construction improvement in quality and efficiency and also, bringing about wholesale process changes for the different phases of a project lifecycle. Without BIM standards and benchmarks, organisations are not able to assess their BIM competences, and also to measure their successes or failures, these capability levels are therefore a prerequisite for BIM performance improvement. These frameworks are rather more descriptive than the sort of coherent implementation approaches needed to deal with the organisational challenges as a result of introducing BIM. Unfortunately, there are several publications pointing out the inexpediencies relating to the use of technologies in organisations (e.g., Azhar, 2011; Ehie & Madsen 2005; Weston 2001).

In general, implementation of information systems is challenging and suffers from high failure rates, failure to either deliver design objectives, intended benefits, failure to deliver on time or budget (e.g.,Markus & Benjamin, 2012). While it is important to develop maturity diagrams and stages of BIM capabilities, it is equally important to establish implementation processes consistent with maturity stages and adaptable by different organisational sizes. This is vital to laying the foundation for organisations to develop their BIM competency. An implementation strategy, such as the one proposed here, is a timely contribution to the debate on how the sector can move forward with BIM.

3 METHOD

This paper attempts to develop an approach to BIM implementation that synchronises BIM solutions and organisational change processes. The process is developed based on evidence gathered from construction organisations that have developed their organisational BIM capabilities and are involved in BIM projects. Given the exploratory and interpretive focus of this research, i.e., how construction organisations manage the implementation of BIM as a core process for project delivery, a qualitative enquiry is deemed appropriate. A qualitative research approach is considered an effective method to obtain meaning via involvement in the practice and as such is appropriate for answering questions relating to "why" and "how" (e.g., Fellows & Lui 2008). Given the nascent but rapid evolution of BIM utilisation within some construction practices, it was deemed necessary to target organisations that have implemented BIM within their organisations and have demonstrable BIM projects. The participating organisations were selected based on the evidence they displayed at a recent BIM event. In November, 2011, Construction Mobile IT (COMIT) in collaboration with University College London, (UCL), organised the "delivering the value of BIM" seminar at UCL. 10 different organisations presented various ways BIM tools were being applied in their respective organisations. Invitations were sent to the 10 organisations and seven were willing to participate in this research. Access to three additional BIM-enabled organisations was also secured bringing the total number of participant organisations to 10, 4 represented contractor organisations, 5 were design and engineering firms, and 1 was a project management firm. The data collection effort took place over 8 month span. The respondents from the participating organisations held various professional roles in their respective organisations. They included group level directors, middle managers (e.g., BIM coordinators), operational site-based managerial staff (e.g., site engineers), and other professionals such as architects, quantity surveyors, MEP and structural engineers.

The data collection involves semi structured interviews, and BIM documentations. Interviews lasted 30 minutes to 2 hours, with the average interview lasting 1 hour. Interviews were audiotaped and transcribed. To enable triangulation and reveal contradictions, the interview transcripts and the BIM documents were integrated into a research database and analysed. The overarching aim was to gather information on how the participating organisations tackle their BIM implementation procedures. The participants were asked to discuss the extent to which BIM has been implemented within their organisations and on their respective projects. Informants were also able to spontaneously discuss topics that they felt were important regarding their implementation process. From the interviews, an understanding of how a typical construction organisation successfully implements BIM was gathered. A framework was then developed; it represents a common strand of the implementation processes from the various viewpoints. Interview quotes that specifically respond to interview questions on implementation issues were included in the qualitative content analysis. As suggested by Ryan & Bernard (2003) the key word in context (KWIC) technique was used for the data analysis. With the KWIC technique, all instances of key phrases and in their immediate context, relating to successful BIM implementation were coded into a spreadsheet. The KWIC technique has been used to generate a more concise understanding of various viewpoints, it helps to encapsulate a complete thought that could be compared and contrasted with other quotations to formulate constructs. The quotes were then systematically analysed using constant comparative method (CCM) to identify patterns in an axial coding process (Corbin & Strauss, 1990), thereby developing and refining the KWIC spreasheet. CCM ensured that the KWIC spreadsheet was constantly revisited until it was clear that no new theme was emerging. This enabled the attainment of a profound understanding of the participating organisations' viewpoints and hence the extractions of issues relating to BIM implementation.

4 FINDINGS AND DISCUSSION

Implementing BIM successfully is considered important to competitive strategy for construction organisations. Bringing organisation's BIM standard into an acceptable capability status (Succar 2010) is a comprehensive task that requires paying attention to some critical processes. The participating organisations discussed a number of peculiar construction related issues capable of posing a challenge to BIM implementation. These are competence issues, problems relating to information sharing, especially across different disciplines, choice of BIM authoring tools, and difficulties in crossing boundaries from familiar to uncertain and ambiguous work practices. The extent of change (as quoted below) perhaps contributes a great deal in making the implementation more challenging.

"…but, when we moved to BIM, it was a wholesale change in all respects. New hardware, new software, new processes, new training required, new mind-set required, new possibilities,

different ways to communicate, different ways to collaborate, different outcome, everything is different. It is a game changer" (Technical advisor).

Barger (1995) has cautioned that changing from old to new work processes come with ambiguity and uncertainty which has to be managed. As a means of addressing these challenges, the organisations inculcated measures as part of their overall BIM-enabled organisational practices. From the interviews, the implementation strategy employed by participant organisations focuses on measures such as: establishing BIM implementation plan; consulting the workforce to include their interests in the plan; conducting training for all affected stakeholders and selection of appropriate BIM authoring tools specific to a particular organisational niche. While the implementation approach considerably differed from one organisation to another, there were also common strands across the participating organisations. The following four key stages exemplify the implementation processes of BIM in the participant organisation as inferred from the from the empirical data:

1. Brainstorming stage
   A managing director expressed the need to "*...get heads together at day one to deliberate the huge nature of the change*".
2. Concept building stage
   "*a strategic team was put together … a 60page paper was prepared, based on the report, targets on how BIM should be embraced have been set by the board all the way down and agreed by all managing directors*" (Head of BIM)
3. Realisation stage
   "*…everybody in this office went on a 3-day training course, it gave us the basics of the skills we need. But you need to work on at least two or three projects, I have been working on it for like four years, but anytime I go back, it just gets better, and I am still getting better at it*" (BIM coordinator).
4. Manifestation stage
   "*from logical and common sense point of view, adopting BIM is completely the right thing to do, but it is about continuous cycle of change, we've got to be flexible to change anytime until the BIM benefits fully manifests in this organisation" (Director).*

One prior condition to the viability of the organisational BIM implementation process is the existence of a valid and clear mission or business strategy for the organisation. As one BIM manager simply puts it: "*…. So you need a vision. If you try to implement BIM without a vision you are actually not going to get there really. It is more of if we are going to do it, this is the reason and an appropriate implementation plan with a realistic milestone and budget lay out to the company, to say, this is what we need to do"(BIM manager).* This perspective resonated across the views of the other participants. The process coordinates measures from the organisations' own practices and those which stem from academic literature, in particular, the AEC (UK) CAD standard. This standard is in accordance with BS1192, and is intended to support all BIM work undertaken within a practice to, "realise a unified, usable, coordinated approach to Building Information Modelling in a design environment" (AEC (UK) CAD Standard Initiative 2010).

Each implementation stage represents a distinct milestone in the BIM process. It is important that at the end of each stage, there is a review to make sure that there is consensus on the outcome before proceeding to the next stage. This ensures that there is unanimity and mutual understanding for the way forward. The implementation process therefore begins with an assessment and discussions of a company's current status and strategic enterprise and surrounded by change management and business development components. This brainstorming stage examines the driven motive for implementing BIM, and the extent of anticipated changes. The established implementation motives coupled with the extent of change seek to integrate the resource dimension and coordinate daily operations. The concept building stage involves people handling leadership roles. It requires both top-down level of support and bottom-up involvement, establishing implementation feasibility, budget targets, and defining timeline and implementation plan to be followed. Assessing the organisational situation in terms of available resources, and a better appreciation of '*what is in it for key stakeholders*' (senior quantity surveyor) determines the scope, timing, and viability of the BIM implementation initiative.

In the realisation stage, the analysis of the existing organisational functions provides the background for vendor selection and choice of specific BIM software to support the business operations. The realisation stage ensures that the appropriate BIM station is configured into the organisation systems, and the supporting computer systems have to be viable with efficiency. A BIM coordinator described that, "… *prior to this, my old laptop had 32bits OS and 3gig RAM which is ok for a laptop, but with Revit civil 3D, which is a big package, you've got to have 64bits OS and 8gig RAM, so the machine you see here is viable with efficiency*". Simultaneously, the people intended to use the system and those influenced by it have to go through education and training needed to understand how to operate the new work station and how information flow at each point of the supply chain has been affected by the new process. A Manager emphasised: "….*from my experience, i can say, some people embrace it quickly, and yet, others need a bit of coaching to take it through. Because what a coach does is not only train how to play football but he coaches them to play better football. The same applies to BIM*" (head of BIM).

The extensive education and training on functionality and configuration give people the needed insight to map the new process, designed to suit their work routine. This occurs at the manifestation stage. At this stage, it is also very critical to apply the knowledge on a pilot project. This marks the beginning of an ongoing BIM-learning cycle. A sound strategic-level support acts as a significant condition for achieving overall success with BIM uptake. The final phase emphasises knowledge flow optimisation and continuous expansion of the system to ensure new competitive advantage. Knowledge gained from each stage of the process is stored, and is easily accessible and retrievable by other employees. It serves to improve and reshape the implementation cycle. As summarised by a BIMM Manager, "*we will not spend that fortune and throw half of the learning out. We are taking it in stage by stage and keeps on feedback(ing) what's gone wrong so we can learn from them*'. The knowledge bank is thus an integral part of implementing other BIM maturity models and subsequent improvement.

The process actions required at each of the 4 stages of the BIM implementation as evident from the interviews and documentation analysis and discussed above can be synthesised into a process map as shown in Figure 2 which represents a BIM Implementation Framework. The process actions within the framework ranges from establishing the driving motives of the implementation, vision statement, to the enforcement of change management and business process development in the implementing organisation.

5 SIGNIFICANCE OF FINDINGS

The framework as shown in figure-2 synthesises preconditions and process actions for an effective BIM utilisation as practiced by the BIM-enabled organisations that participated in the study. The actual use or adaption of the BIM process starts with a particular professional context: architecture design, mechanical and electrical design, or structural design. In this way, the organisation can acquire the relevant BIM authoring tools and develop the necessary knowledge, and internally use the acquired knowledge on the first few BIM projects. For example, an architect will develop an internally consistence BIM model for a new project, but will also have to issue 'non-BIM' project documents which is in compliance with ongoing project specifications and contractual arrangements. Practitioners often call this stage, 'lonely BIM stage. This is usually the beginning of the learning process; it provides opportunity for those who have been trained on the use of new BIM software solutions to practice the process on a real project. At this stage, BIM is used for internal coordination purposes and the mode of communication is asynchronous. That is, background information from the model, which do not exist previously, such as 3D graphical images and textual data are generated and reviewed for internal coordination purposes, and can also be used to support internal capacity for subsequent improvement/development. Applying the BIM knowledge on some pilot projects and few early BIM projects could assist organisations to develop competency in BIM level-1 which typifies 2D or 3D managed BIM authoring software with standalone standard data packages but no integration (e.g., Richards 2010; Succar 2010). BIM however, consist of the use of 3D, real-time intelligent model to facilitating successful coordination and collaboration among the heterogeneous project stakeholders (e.g., Holness 2008). The real benefit of BIM cannot therefore be realised at maturity level one or at the 'lonely BIM' stage, because of the lack of coordination and collaboration with other BIM users.

In order to move beyond lonely-BIM, communication mode has to be synchronous and BIM coordination has to occur beyond one professional organisation domain. At this stage, 'real-time' interaction between BIM-enabled heterogeneous project members is possible, where project information is shared and used on a common project repository for the benefits of both the project and all the project stakeholders. The coordination can however, only occur between organisations that have developed internal BIM implementation process. Nevertheless, each capability maturity level requires the need to upgrade the implementation process with additional knowledge and additional technical artifacts. For example, at the moment, no two different BIM authoring tools can be coordinated without reliant on an open standard specification such as the IFC (Industry Foundation Classes), which in itself, is going through an improvement cycle. Also, if the model is expected to be handed over to the client to help manage the post-construction operation and maintenance, then there is a need to comply with the Cobie (Construction, Operations and Building Information Exchange) standard, which provides a framework for a robust information organisation for facilities management (NBS 2012). The Cobie standard is one of the key requirements contained in the UK BIM task group report (2011). This suggests that, every level of the BIM maturity hierarchy requires the need to accordingly upgrade the internal BIM process with new technological artifacts and new competency or trainings that suits the particular maturity level. The reconfiguration of the process should be designed to reflect the heterogeneity of the knowledge boundaries – multiple actors with different functions and different artefacts involved. However, achieving a competency at one level of BIM maturity hierarchy and retaining all the necessary knowledge within the implementation process could act as a springboard to the next maturity level.

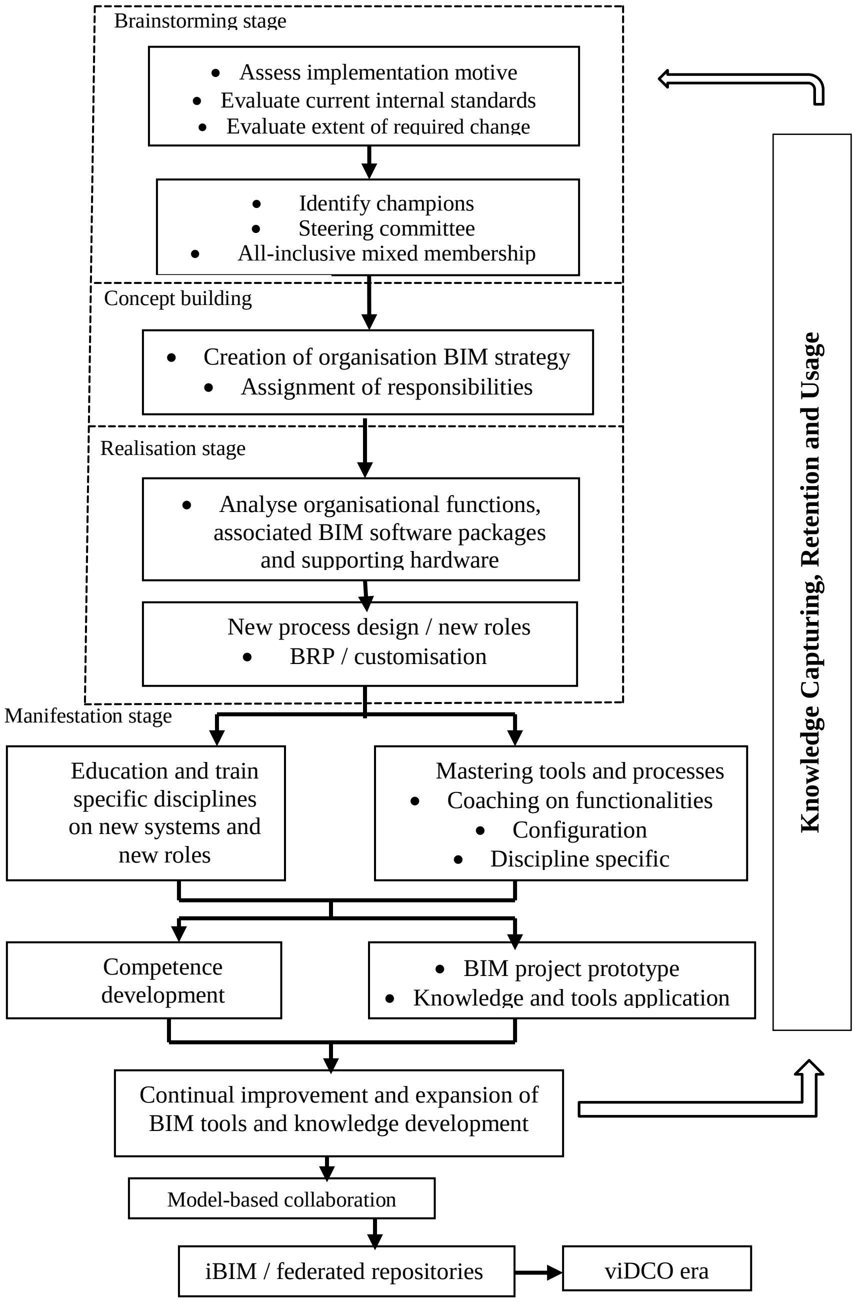

Figure 2: BIM implementation framework

6 CONCLUSIONS AND FURTHER RESEARCH

The paper has reviewed some recently developed BIM capability models from literature. There rarely exists any strategy or approach that can steer or guide organisations to successfully implement these BIM capability models. BIM Implementation process model is presented, and it is based on the recommendations for a good implementation process as evident in the exemplar BIM utilisation strategies of construction organisations who participated in this study. The success of BIM implementation depends on many factors. Both top-management commitment and operational (shop-floor) level BIM champions driving the implementation effort is found to be very essential. People at both strategic and operational levels, who have different roles, but may be affected by the process, have to be represented in the design process. End users are to have adequate amount of training to ensure that they perceive themselves to be competent when performing their roles under the new organisational protocol. It is beneficial to pilot-test the strategy on a typical project. It is also important to aim for gradual and continuous change process not just an episodic change. Evaluation, development and sustenance of the implementation process via knowledge retention could guide the path towards higher maturity levels. This paper provides a useful framework and baseline for construction organisations trying to identify a niche or a starting point for BIM uptake. It is however believed that the framework developed through this exploratory study requires further interrogation in BIM-enabled construction contexts to enhance its validity and reliability.

Nonetheless, BIM implementation is not only about ‘logically laid-down’ processes that should be followed. It also involves several sociological or people issues and technical challenges. These could affect the implementation outcome in fundamental ways (e.g., Markus & Benjamin 2012). Future research should examine in tandem, the complex nature of the sociotechnical interplay among the people attributes, the technical interface and the new processes involved. This could expand our understanding of the mutual adjustments required among the sociotechnical antecedents through which the BIM concept and other emerging construction technologies can successfully be implemented.

REFERENCES

AEC (UK) CAD *Standard Initiative*, *A workable implementation of the AEC (UK) BIM standard for the architectural, engineering and construction industry in the UK* (1.0th ed.) (2010).

B. Hardin, *BIM and construction management: Proven tools, methods, and workflows* Sybex (2009).

B. Succar, "Building information modelling framework: A research and delivery foundation for industry stakeholders", *Automation in Construction,* ***18***(3), 357-375 (2009).

B. Succar, "The five components of BIM performance measurement", *Proceedings of CIB World Congress, Salford* (2010).

C. Soh, S.K. Sia, W.F. Boh and M. Tang, "Misalignments in ERP implementation: A dialectic perspective", *International Journal of Human-Computer Interaction,* 16(1), 81-100 (2003).

D. Bevan, *BIM for dummies,* A CH2M Hill Company, London (2012).

D.R. Osan, M.A. Hule, Q. Nguyen and D.A. Gaitan, "The BIM revolution: building information modeling expands benefits to hospital design and operations", *Health Facilities Management*, 25(3), 27-31 (2012).

F. Weston, "ERP implementation and project management", *Production and Inventory Management Journal*, 42(3/4), 75-80 (2001).

G.W. Ryan and H.R. Bernard, "Techniques to identify themes", *Field Methods,* 15(1), 85-109 (2003)

I.C. Ehie, and M. Madsen, "Identifying critical issues in enterprise resource planning (ERP) implementation", *Computers in Industry,* 56(6), 545-557 (2005).

J.M. Corbin and A. Strauss, "Grounded theory research: Procedures, canons, and evaluative criteria", *Qualitative Sociology,* 13(1), 3-21 (1990).

M. Markus and R. Benjamin, "Change agentry–the next information systems frontier", *Strategic Information Management*, 113 (2012).

M. Richards, *Building information management: A standard framework and guide to BS 1192* BSI Standards (2010).

NBS, *National BIM report*, London: National Building Specification (2011).

NBS, *National BIM report*, London: National Building Specification (2012).

Pike Research, *Building information modelling market value forecast* (2012). Retrieved on 6th Nov. 2012 at http://www.pikeresearch.com/newsroom/building-information-modeling-market-to-reach-6-5-billion-worldwide-by-2020,

R.D. Austin, M.J. Cotteleer and C.X. Escalle, *Enterprise resource planning: Technology note* Harvard Business School Publishing (2003).

RIBA, In Sinclair D. (Ed.), *BIM overlay to the RIBA plan of work*, RIBA Publishing, London (2012).

S. Azhar, "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry", *Leadership and Management in Engineering*, 11, 241, (2011).

The CIC Research, *BIM planning guide for facility owners*, The Pennsylvania State University (2012).

THE ORGANISATIONAL AND PROJECT ADDED VALUE OF BUILDING INFORMATION MODELLING IN THE AEC SECTOR

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Abstract. *This paper explains analytically how integrated collaborative technologies i.e. Building Information Modelling (BIM), impact Architect Engineering and Construction companies and projects at a strategic level. BIM at both project and organisational level has played a significant role in increasing the competitive advantage of construction companies so as to design, schedule and construct an effective project process strategy. For this purpose, research has been conducted to present the added value of BIM at a project strategic level. The results show that the added value of BIM is in influencing project progress, to sustain the economic viability of a project/investment, to develop human behaviours to project progress, to share project information and to design sustainable procurement strategies.*

1 INTRODUCTION

The most well know integrated collaborative environment is Building Information Modelling (BIM) which aims to improve the process of generating and managing building data during project's life cycle (Lee et all, 2006). The impact of Integrated Collaborative Technologies i.e. BIM in the economic business environment is to adopt collaboration by top management as part of organisational strategy; in efficient performance of risk management, change management and value management; effective organisational readiness, conflict reduction and efficient problem resolution; effective partner and staff involvement, ownership of business problems, information access, business interoperability, reduction of degree of complexity, understand of client requirements; cost reduction; effective calculation of Return of Investment (ROI) as well as to deliver effective and efficient performance on product or service design securing successful projects. However, what is not clear in the literature review is how these technologies will affect the design the strategic management in both the AEC community and society following the delivery of the strategic added value of integrated collaborative technologies to support construction project team.

2 STRATEGIC MANAGEMENT IN THE AEC COMMUNITY AND SOCIETY

They key aspect for successful strategic management in the AEC community and society is the ability of project teams to plan and execute projects. The PESTEL analysis will assist key stakeholders in identifying the key risks and challenges of a project by using BIM. In particular:

2.1 Political Impact of BIM in AEC community and society

One aspect of project management duties involves the necessity of mastering the art of influence and political behaviour, while technologies have played an important role in influencing decision making (Arayici et al, 2011). Kapogiannis (2013) found that BIM influences project process (scheduling), resource and document management (information management). Nevertheless it is often negotiation of the political terrain that can be a greater challenge than the technical details of the project itself. All projects have numerous stakeholders. The political processes that characterise interactions between project managers and senior managers are becoming ever more important to the success of new forms of organisations such as project management offices or Virtual Organisations. Wreden (2002) supported that one solution to enhancing the project management process from the power and politics perspective is the involvement of an executive champion. Champions can often serve to alleviate some of the political headaches that project managers accrue by serving as the bridge between the project and the key stakeholders group. Champions exert their own kind of influence on behalf of the project, due to their authority and status, and are in a better position to help the project along. Kapogiannis (2013), during his research, found that by using BIM at the design, planning and construction phase of a project, a project manager avoids conflicts and is in a capable position to make efficient negotiations. In addition, with BIM use, in a case where a problem occurs, the project manager is more capable (to know how to use the accurate information) to give correct directions and to make exacting changes according to a requested time period. Additionally, accessibility to knowledge or successful past projects gives the Project Manager the ability to act without being asked. Access to information allows a Project Manager to act anticipatively and to feel sufficiently confident to control project progress effectively and efficiently, while gaining knowledge and wisdom. Also, this situation allows a project manager to design and execute effective and efficient changes during and after the PMLC progress.

2.2 Economic Impact of BIM in AEC community and society

Specifically, economic sustainability verifies social impacts and the behaviour of the stakeholder will obviously have a positive influence on the business life cycle. By reducing the risk assessment at operational management level and improving decisions at organisational management level by using BIM, the possibility of any random variations in budget planning (keeping the costs low and better control management) will subsequently be cut. Therefore, the Profit and the Return on Investment (ROI) for each project will run at a more positive and constant level for a longer time. As result, it will be easier to build scenarios in short (target) and long (vision) time periods. Kapogiannis (2013) found that both project costs and the ROI can be identified at an early stage, resulting in project economic flow that would meet organisational goals and strategies. By using the economic infrastructure within the project life cycle, project managers will work in a safer mode rather than at a level of high risk. Project managers are therefore working proactively, which acts as a preliminary stage of the operational process of a project. This provides added value in that correct decisions on project investments are taken. In this way project managers are able to see the progress of the project life cycle in advance, and ensure a high level of client satisfaction.

2.3 Social Impact of BIM in AEC community and society

Social infrastructure impacts in achieving the identification of customer needs (by answering questions such as what, why, how, who, etc). Kapogiannis et al (2010) stated that social infrastructure represents a part of the information quality validation during the process of a project. Another impact of the social impact of BIM on community and society is to provide transfer of responsibility from the sponsor to the customer/stakeholder. In getting the customer/stakeholder involved during the decision-making process, added value is achieved, and stakeholders have a more active role during the project progress. This, in turn, motivates them to collaborate and make more successful decisions; they are more communicative and so build trust with their partners more successfully. What is observed from the above is a greatly reduced project risk compared to classic quantitative approaches, since qualitative approaches access more real facts and customer awareness, thoughts, ideas, etc. As a consequence, there is input in the organisational culture, in terms of acting as customers and suppliers, and the project manager is more responsible, accountable, and authoritative, and allows proactive behaviour.

2.4. Technological Impact of BIM in AEC community and society

Information validity can be achieved at operational project management levels with the assistance of integrated technological (software and hardware) solutions, i.e., BIM. The BIM model must be designed and developed according to Human Computer Interaction standards. Using BIM allows for data collection for capturing customer's needs and better control of the project in terms of budget (cost), time and quality of the product (Kapogiannis et al, 2010). By providing high quality of data (data mining - qualitative and quantitative) and by analysing the information at a high level (decision support systems, expert systems, intranet, and collaborative tools) - information maturity - the end managers will have the knowledge (tacit and explicit) to enter into a control process (support the economic and social object). The added value of the technological support provides the additional benefit of addressing problems, when and as they occur, and discussing modifications and uncertainties from anywhere, effectively and efficiently. It also ensures that managers, customers and stakeholders in the collaboration are aware of what is happening, thereby allowing them to be proactive.

2.5 Environmental and Sustainable Impact of BIM in AEC community and society

The UK Government's (2010) aim is to reduce wasted resource and cost on construction projects by using resources more efficiently. The environmental impact of BIM in community and society would be supported and enabled by a thriving, low carbon, and environmental goods and services sector. Environmental damage would be reduced, while energy security, resource efficiency and resilience to climate change would all be increased. In addition construction firms could secure opportunities offered by sustainable products or ways of working. Moreover, the same strategy aims to enhance companies' image and profile in the marketplace by addressing issues related to Corporate and Social Responsibility.

In detail, the environmental and sustainable impact of BIM in community and society is to:

- Enhance the procurement strategy by encouraging the adoption of Construction Commitments in both the public and private sectors and throughout the supply chain.
- Enhance the project design standards of buildings, infrastructure, public spaces and places

so that they are buildable, fit for purpose, resource efficient, sustainable, resilient, adaptable and attractive. BIM incorporates those parameters into 'objects' where the end user could tackle the above according to project/client requirements.

- Enhance innovation within construction companies in both process and its resultant assets.
- Enhance project team members' commitment to project/client requirements by Continued Professional Development (CPD), Life Long Learning (LLL), Investors in People, etc. As a result, team members can be more productive, efficient and effective or in a word: lean.
- Reduce by 25% the administrative burdens affecting the private and third party sectors, a 30% reduction in those affecting the public sector by 2010. Today, in 2013, this has been increased by 5%.

Sustainability is a journey that an organisation embarks on in order to understand and integrate the relationship between sustainability and the company's strategic direction. The UK Green Building Council (2008) helps to formalize sustainability within a construction organization or a project. It stated that 'a product of this journey is a regular (usually annual) snapshot of strategy and performance where an organisation publicly discloses its economic, environmental, and social performance, forming a key communication with stakeholders. As a result, implementing sustainability at an organisational level requires organisational configuration between strategy and policy, processes, structures, tools and people. These will enable the organisation to define where it is, where it aims to be and the opportunities for improvement.

2.6 Legal Impact of BIM in AEC community and society

The human resource function of a project is being designed more carefully to expedite project team development and staffing. The PMBOK (PMBOK Guide, 2008, 2004, 2000 Editions) suggests the following major processes concerning project human resources management: a) organisational planning b) staff acquisition c) team development. Another way in which human resources is becoming more attuned to project management by using BIM is through the considerations of legal issues, compliance and health and safety in the workspace. In general, there is an opinion among the collaborative communities that human resources need to be trained in order to be collaborative and have a true team working relationship. This can be seen in past applications of Total Quality Management (TQM) and this is the major impact of BIM in community and society from a legislation perspective.

3. RESEARCH: THE ORGANISATIONAL AND PROJECT ADDED VALUE OF BUILDING INFORMATION MODELLING IN THE AEC INDUSTRY

Research has been conducted between 24 project managers from 20 different architectural, engineering and construction companies. Their role was 'Project Manager'. The data collection method was qualitative. For the data interpretation the content analysis technique has been used. The aim of this research was to identify the added value of Integrated Collaborative Technologies (ICT), i.e., Building Information Modelling to the project team members, (stakeholders).

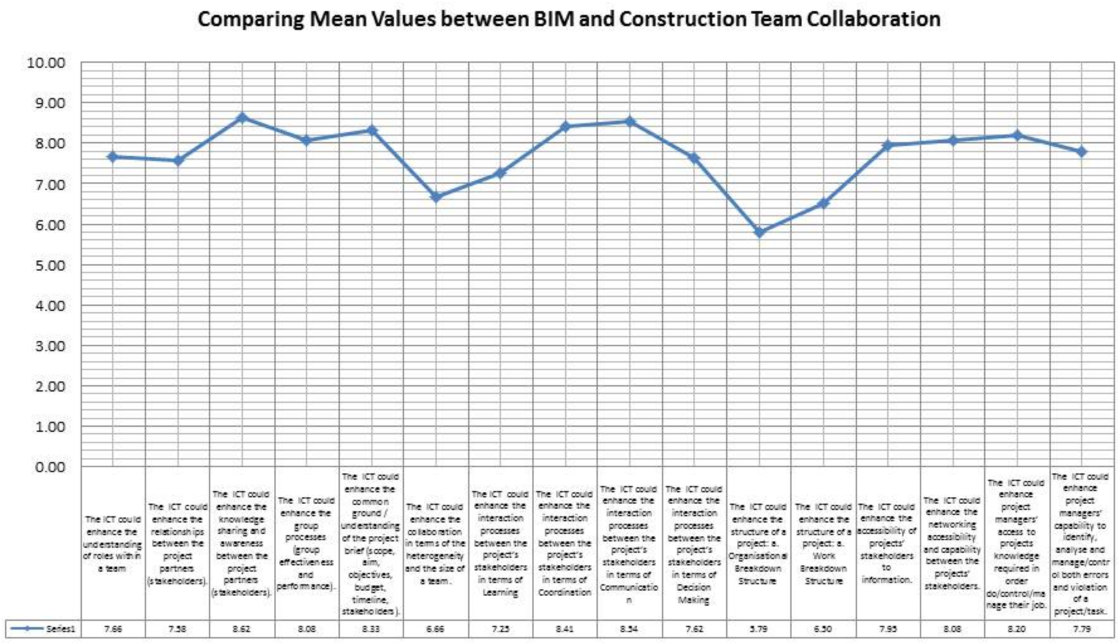

Figure 1: Strength of Building Information Modelling and team construction collaboration

The results of this research displayed that Integrated Collaborative Technologies, i.e. BIM can enhance:

- the understanding of roles within a team.
- the relationships between the project partners (stakeholders).
- knowledge sharing and awareness between the project partners (stakeholders).
- the common ground/understanding of the project brief (scope, aim, objectives, budget, timeline, stakeholders).
- the group processes (group effectiveness and performance).
- the collaboration in terms of heterogeneity and team size
- the interaction processes between the project stakeholders in terms of
  - Learning
  - Coordination
  - Communication
  - Decision Making
- the design of a project:
  - Organisational Breakdown Structure
  - Work Breakdown Structure
- the accessibility of project stakeholders to information.
- the networking accessibility and capability between the projects' stakeholders.

- project managers' access to project knowledge required in order do/control/manage their job.
- project managers' capability to identify, analyse and manage/control errors of a project/task.

In the above Figure 1 it is observed that the maximum mean is μ=8.64, that is the strength of influence of the link in enhancing knowledge sharing and awareness between project stakeholders and the use of integrated collaborative technologies within a construction environment. The second highest mean value is μ=8.54, showing the influence of the link in enhancing the interaction process between project stakeholders in terms of communication and the use of integrated collaborative technologies within a construction environment. Moreover, the mean with least impact on the degree of influence of the integrated collaborative technologies on team collaboration is the design of the organisational breakdown structure, where μ=5.79. As a result, it is initially clear that there is a need to continue investing in integrated collaborative technologies, i.e., Building Information Modelling, to be able to support team collaboration within a construction project. The benefit will impact on the project's process and deliverable due to the direct impact of team performance. In addition, there is clearly an impact on sustainable design and construction. This is one of the aims of the Good Practice Guidance-Sustainable Design and Construction (Building Research Establishment, 2012) where stakeholders can optimise the design process, visualise the details and check whether the project is aligned with buildings regulations, analyse the energy of the project and advise the client. The team can also compute material quantities in detail, (this will secure the project to be aligned with LEED - Lead in Energy and Environmental Design and BREEAM – Building Research Establishment Environmental Assessment Method certification), and can reduce waste and inefficiency, (lean management). Therefore stakeholder team members must use Integrated Collaborative Technologies, i.e. BIM, where there is a requirement for project information to be distributed amongst them appropriately.

4 CONCLUSIONS

To sum up, there is an dependency on the AEC insutry to implement the use of Building Information Modelling.. This dependency is at a project and organisational level. Team collaboration in particular is a key aspect of keeping this dependency alive and hence enhancing project and organisational control/management. Consequently, the relevant risks are reduced significantly because information is shared while there is an effective way of performing efficiently, project complexity is reduced and problems are prevented. So the biggest asset of integrated collaborative technologies, i.e. BIM, at an organisational and project level is not the actual pre-identification of project time, cost, quality and business performance, but the deployment of construction project managers' proactive behaviour antecedents through the support of collaboration. Therefore, there is a need to start to move from 'Information Modelling' towards 'Knowledge Modelling' in order to understand and use the right information for sustainable decisions. Hence, within the next few years, we could be speaking about Building Knowledge Modelling (BKM).

REFERENCES

Y. Arayici, P. Coates, L.J. Koskela, M. Kagioglou, C. Usher and K. O'Reilly,

Automation in Construction, 20 (2), pp. 189-195 (2011).
Building Research Establishment, *Good Practice Guidance: Sustainable Design and Construction* (2012).
G. Kapogiannis and C. Piddington, “Challenges on managing projects”, In: Panetto, H. and Boudjida, N. ed. *Interoperability for Enterprise Software and Application*. Wiley Publications, pp 61-67 (2010).
G. Kapogiannis, *Enhancement of proactive behaviour in construction projects by using integrated collaborative technologies*. PhD Research Thesis, University of Salford, (2013, in progress).
G. Lee, R. Sacks and C.M. Eastman, “Specifying parametric building object behavior (BOB) for a building information modeling system”, *Automation in Construction*, 15(6), 758-776 (2006).
P. Morrell, *Low Carbon Construction*, HM Government, London (2010).
Project Management Institute, *A Guide to the Project Management Body of Knowledge*, USA, (2008).
N. Wreden, *Executive champions: Vital links between strategy and implementation*, Harvard Management Update (2002).

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CHARACTERISING THE RELATIONSHIP BETWEEN RESPONSIBLE SOURCING AND ORGANISATIONAL REPUTATION IN CONSTRUCTION FIRMS

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Abstract. *Responsible Sourcing (RS), the ethical management of sustainability issues through the construction supply chain, first achieved national prominence in the UK 2008 Strategy for Sustainable Construction. This set a target for 25% of all construction products to be sourced from schemes recognized for RS by 2012. The Building Research Establishment (BRE) published a framework standard, BES 6001, in 2009 to enable construction firms to certify their products as responsibly sourced to help achieve this target; since then, 80 BES 6001 certificates have been issued to around 40 companies in the UK. RS has its roots in the corporate social responsibility (CSR) agenda and, although it has become a distinct focus within procurement and sustainability management practices in some firms, it is still an under-theorised concept; understanding the role it plays in relation to an organisation's reputation is a subject area that is noticeably absent from the literature. Although it has been suggested that robust links between the broader CSR agenda and corporate reputation are yet to be established, there is evidence that reputational protection is a key driver for an organisation to engage with RS. Based on a critical review of the literature, this paper aims to stimulate debate on the characteristics of organisational reputation in construction firms and understand the relationship between RS and reputation. It takes into account internal and external stakeholders' perspectives and the extent to which focussing on protecting reputation can or should take precedence over bottom-line benefits.*

1 INTRODUCTION

Sustainability has, in recent years, become a core focus of the construction industry. When compared with other sectors however, the industry has struggled to implement sustainability principles (Glass 2011). Furthermore, the industry has been identified as one of particularly high social and environmental impact, given the life-cycle of its operations (Murray and Dainty, 2009), its high proportion of greenhouse gas (GHG) emissions (Greenwood *et al.* 2011) and its role in providing employment for c.3million people in the UK (Equality and

Human Rights Commission, 2010). As a result, Sev (2009) and Hawkins and McKittrick (2012) have suggested that construction is important in the context of the three pillars of sustainability; i.e. environmental impacts, impacts upon society and its economic significance. Following recognition that the sustainability performance of the sector was wanting, the Strategy for Sustainable Construction (HM Government, 2008) was developed to bridge the gap between actual and desired industry performance. Within the strategy, a number of commitments were agreed between industry and government, with overarching targets. One of these targets, under the Materials heading, was for the industry to source 25% of materials from schemes recognised for responsible sourcing (RS) by 2012. However, understanding and awareness of responsible sourcing is somewhat lacking Glass *et al.* (2012).

Many construction organisations have already achieved certification to the Building Research Establishment (BRE) developed framework standard for responsible sourcing, BES 6001 (BRE, 2009). Furthermore, the BRE Environmental Assessment Method (BREEAM) awards credits under the Materials section for RS, which obliges some construction organisations to engage with RS, in response to clients' demands to achieve these credits. Similarly, credits for RS of materials are also available in the Code for Sustainable Homes, and the Civil Engineering Environmental Quality Assessment Scheme, CEEQUAL. RS has its roots in the broad and ever-growing corporate social responsibility (CSR) agenda, within which current debates consider CSR to be a form of corporate philanthropy, or a means of generating revenue (Murray and Dainty, 2009). Currently, opinion is rather divided on this and this debate can be similarly attributed to RS. Although there is an expanding body of research on RS, mainly through the Action Programme for Responsible Sourcing (APRES; APRES, 2013) network, an Engineering and Physical Sciences Research Council (EPSRC) funded research project, there is a noticeable absence of literature which considers RS as representing corporate philanthropy; one of the key agendas being the link with corporate reputation. RS is inexorably linked to reputational theory, given that one dimension of organisational behaviour is striving to be seen to have a positive impact upon society and the environment and hence good relationships with stakeholders. Ensuring that they also maintain a good reputation is seen as key to their success as a business, and given the current widespread focus on sustainability issues, engaging with sustainability and showing a proactive approach to it is seen as a key means of maintaining a positive reputation.

This paper critically reviews the concepts of reputational theory and behaviour, and through a thorough review of the literature and by use of examples, the links between reputation and CSR will be discussed. Furthermore, this link will be considered in the context of the RS agenda, given its focus upon ethical issues, as well as those affecting the environment and society. This is a timely contribution to the literature, given that the RS agenda is becoming increasingly important for the construction industry and strong links between RS and CSR have already been established (Upstill-Goddard *et al.* 2012).

2 ORGANISATIONAL BEHAVIOUR: A MORAL ISSUE?

Organisational behaviour and the relative importance of reputation within a company are arguably influenced by the individuals that make up the organisation. Successful introduction of sustainability principles – which can be considered as an organisational innovation – depends on employees' attitudes and support. This point is made by Thomas and Lamm (2012) who also suggest that organisational efforts to develop strategies to support sustainability would benefit from an increased understanding of attitudes that contribute to the legitimacy of sustainability. Large and multinational organisations are often found in the public spotlight and operations are scrutinised by consumers, competitors and the media; ensuring that they only appear in the public eye for the right reasons has become a key part of doing business. Previous research (Freeman 1984; Orlitzky *et al.* 2003; Porter and Kramer 2003) has established that stakeholders value sustainability; while this may resonate with the attitudes of the organisation, it does not always translate into practice. Traditional methods of engaging with sustainability have focused upon environmental issues, such as reducing waste or energy, whereas organisations should take a broader view of sustainability, addressing economic and social aspects holistically. It could be argued that many companies are engaged with environmental issues due to heightened public awareness. For example, many companies are reporting carbon footprints at organisational and product level. The major societal focus on carbon in recent years is a key driver behind this; many individuals and companies have some awareness of carbon and how it contributes to climate change. Essentially, this comes down to the organisation's perception of risk, and what it considers high and low risk issues. For instance, it could be suggested that the carbon issue has become one of higher risk and so therefore organisations are more likely to identify it as a high risk issue affecting the business. Many of the aforementioned issues however, such as waste, carbon and energy, largely concern environmental impacts. Of equal importance, but of much less frequent consideration are social issues, such as ensuring fair labour practices and the effect that organisations have on local communities. Maintaining high social standards is a key risk issue as consumers and customers are increasingly considering ethics when making purchasing decisions.

There have been numerous examples of this company exposure in other sectors; Nike were exposed in the mid-1990's for use of child labour and sweatshops in Asian manufacturing sites, and Primark were exposed in the UK press as recently as 2009 for alleged use of illegal immigrants and poor working conditions at one of its UK suppliers (McDougall, 2009). This links directly to the concept of reputation; in the case of Nike, sales were reported to have fallen by 8% from 1998 to 1999 and stock fell by 15% (Wazir, 2001). Such exposure affects a significant number of consumers; Nike-branded apparel is popular on a global scale and linking the production of this to unethical treatment of workers and low levels of pay can cause consumers to deem ownership of such apparel as a statement of support or lack of care for such situations; they then seek out alternative companies to avoid being linked with such unethical practices. The underlying premise is that transparency should be key; an open, honest approach to how a company conducts its operations is more likely to resonate in a positive way with society. Doorey (2011) suggests that transparency can provoke learning and positive change within the organisation and that introducing some form of mandatory reporting for organisations might cause management within the company to focus on improving performance in areas such as ethics, thus reducing the likelihood of being exposed in the way that Nike and Primark were. Further to this, a high level of corporate social and environmental performance is often regarded as a potential source of competitive advantage (Thomas and Lamm, 2012). Similarly, a recent documentary looked at the human rights and ethical issues associated with the mining of coltan and cassiterite in the Democratic Republic of Congo (DRC). These metals are used in the production of mobile phones. The issues raised in this documentary should resonate with the vast majority of consumers, given that in 2011, global mobile phone subscriptions reportedly rose to c.6bn (McQueeney, 2012). The documentary highlighted that ownership of a mobile phone, and sustained consumer demand for the latest upgrades and models is funding a war in DRC. There is currently relatively low awareness around these ‘conflict minerals’ however, and, unlike the case with Nike, it is unlikely that mobile phone companies will see a fall in consumer demand for new mobile phones. Worryingly, the documentary found little evidence that mobile phone companies were taking any action.

Of comparably low awareness are ethical issues within the construction supply chain. Many raw materials, such as natural stone or sand from quarries for example, have been found to be of high risk for exhibiting similar human rights and ethical issues. Vee and Skitmore (2003) find that 84% of respondents to a survey consider good ethical practice as a key organisational goal, and that 93% agree that organisational ethics should be driven by personal ethics. Clearly, the construction industry has a degree of ethical behaviour in place, but due to the high social risk that many construction materials exhibit, it is interesting to determine whether incidents of poor ethical behaviour exist. Ciliberti *et al.* (2008) find that companies in the developed world use various different strategies and tools to address CSR issues within their supply chains, such as management strategies for compliance and awareness-raising. For example, one of the major UK natural stone suppliers discovered on a routine visit to its suppliers’ sites in Asia that, nearby, young children were actively working on site with no use of personal protective equipment (PPE). In this case, the company worked with local agencies to raise awareness and provide new PPE. Although the company addressed this issue largely due to morals, there is an argument that the company could have walked away from that particular supplier and opted to source its materials from elsewhere. While working and health and safety conditions were clearly in need of improvement, it is valid to suggest that without the UK company’s custom, the supplier would suffer reduced business or not remain in business, which could impact in other negative ways, such as through causing employees to lose their jobs. Although in developed countries working conditions such as these would be deemed unethical, in many developing countries where poverty is commonplace, working in such conditions is actually preferable as it still provides a basic income, whereas the alternative may be a life of poverty in large cities.

It follows that companies that experience such ‘success stories’ would strive to publish such issues through case study reporting; a suitable means of which could be through corporate sustainability reporting. Indeed this form of disclosure arises from the social theory that the organisation owes a duty to society (Reynolds and Yuthas, 2007). A recent survey (Kiron *et al.* 2012) reported that 70% of respondents felt that sustainability is important to their organisation and that it is necessary in order to appear competitive. The same survey also found that on the management agenda, sustainability ranks only eighth in importance. Morality and legitimacy can be linked to reputation, as high morals on the part of the organisation should have a positive effect on corporate image. Deephouse and Carter (2005) suggest organisational legitimacy is emphasised by social acceptance that results from adherence to social norms and expectations. In other words, legitimacy can be linked to ethical and moral norms, as these are influenced by society. They also infer that organisational reputation is a relative measure, as it considers a comparison between two or more organisations. This would appear to suggest that engaging with sustainability could increase an organisation’s legitimacy, but an organisation’s reputation would only increase provided that competitors of that company did not engage with the same level of sustainability. This would also imply that an organisation cannot have a reputation in the absence of other organisations, but can be seen as being a legitimate organisation. Perhaps, in that case, it should be argued that sustainability increases an organisation's legitimacy, as it enables the firm to be seen to be taking a positive approach to eradicating environmental and social issues within the supply chain. Society creates pressures for organisations to adopt sustainability practices (Caprar and Neville, 2012) and so an organisation that does not actively engage with sustainability may well be viewed as being less legitimate, and hence, may suffer a poorer reputation as other organisations and competitors do so.

However, despite this apparent link, corporate reputation is often considered as a particularly key intangible asset of organisations (Roberts and Dowling, 2002; Hillenbrand and Money, 2009). Linking to the work by Deephouse and Carter (2005), Bromley (2002) indicates that reputation is a concept 'held in the minds of stakeholders'. Previous studies have considered the stakeholder dimension as being entirely homogenous with regard to corporate responsibility expectations (Hillenbrand and Money, 2009), which presents a number of issues when considering corporate reputation, particularly in the context of Bromley's (2002) indication. Stakeholders cannot be regarded simply as homogenous entities due to the variety of complex social interactions that they experience which influence individuals' perceptions of an organisation. Thus morals and perceptions of social good are individual-level considerations and should be considered as such when considering reputation. This perhaps highlights the reason why a number of researchers have struggled to link CSR and reputation.

3 RESPONSIBLE SOURCING: A REPUTATIONAL INSURANCE POLICY?

3.1 Responsible sourcing and corporate social responsibility

Responsible sourcing (RS) of materials is the management of sustainability issues through the construction supply chain, often from an ethical perspective (Glass *et al.* 2011). It has become a defined area of interest in the construction industry since the Strategy for Sustainable Construction (HM Government, 2008) was published in 2008, which set a target for 25% of construction materials to come from schemes recognised for RS by 2012. The commitment to such a target led to the publication of the Building Research Establishment (BRE) standard BES 6001 (BRE, 2009), which provides a framework for construction organisations to gain RS certification for product(s). At the time of writing, around 80 certificates had been awarded to 40 companies. The standard covers many issues, grouped into three main sections: organisational management requirements, supply chain management requirements and environmental and social requirements. Certification to BES 6001 (BRE, 2009) is particularly sought after, as it provides a company with the knowledge that constituent materials have been sourced from suppliers where traceability and transparency can be proved. It not only evidences proactive consideration of the ethical issues in its supply chain, but also that it is tackling the wider sustainable agenda through implementation of suitable quality, environmental and health and safety management systems.

However, Glass *et al.* (2011) highlighted that knowledge and awareness of RS is relatively low and hence there is an absence of a focused research agenda. Furthermore, RS is neither mandatory nor embraced outside of the UK (Glass, 2012) and so there has been little to no consideration of the agenda on an international scale, which further impedes its uptake due to the international nature of many supply chains. Furthermore, Upstill-Goddard *et al.*, (2012) suggest that five key problems exist within the RS agenda, namely its under-emphasis within the construction industry, low levels of awareness and understanding, the issue of risk with regard to a company's products, asymmetry and its potential to be considered as a form of corporate philanthropy. This final point often leads to its relegation to a secondary priority until it is demanded by clients. Klassen and Vereecke (2012) do, however, indicate that many multinational companies are beginning to actively monitor ethical issues in their supply chains and so it appears that at least some of the principles of RS are being applied. RS is part of the broader corporate social responsibility (CSR) agenda, which lends itself to many different interpretations due to a lack of a commonly accepted definition for CSR. It has been argued that the construction sector is one to which the greatest level of attention should be devoted, due to the significance of its operations and as a provider of employment (Murray and Dainty, 2009). Currently, CSR is seen from two key perspectives; as a revenue opportunity, or a form of corporate philanthropy. Much of the CSR literature considers morality and legitimacy; Upstill-Goddard *et al.* (2012) suggest that businesses should engage with it for moral reasons alone. Indeed certification to BES 6001 could be seen as philanthropy, as it shows the organisation possesses high morals and ethical values. Likewise, it can also be seen as a means of increasing revenue, as society is more likely to purchase products from companies with higher ethical values. It is also true that often, construction supply chains are relatively straightforward, and so enacting RS principles throughout these supply chains should be a relatively easy process, when compared with other high-technology sectors, for example. However, the construction supply chain still relies on sourcing some material from outside the UK, and as such, construction organisations can become part of global networks, and hence depend upon other members of the same network for knowledge and resources (Christopher and Gaudenzi, 2009).

It appears therefore that there are a number of benefits for an organisation in engaging with the sustainability agenda, although Caprar and Neville (2012) highlight that, despite the fact that these organisations are often subject to the same institutional pressures, some organisations implement sustainability in their activities, yet others do not.

3.2 Linking responsible sourcing to reputation

It has already been established that the responsible sourcing (RS) agenda sits within the corporate social responsibility (CSR) movement (Upstill-Goddard *et al.* 2012). Many past studies have sought, but struggled, to link CSR with high level of reputation (Hillenbrand and Money, 2009). Good reputation management is of high importance for organisations due to the increasing complexity of the social environments in which they operate where ever-more demanding standards are used to evaluate organisational performance (Bahr *et al.* 2010). As discussed, poor handling of social, ethical and environmental issues can have detrimental effects on corporate reputation. The examples given are just a few of the incidents that have occurred and have or could result in a reduced corporate reputation. Linking RS to reputation thus becomes complex due to its relatively recent emergence as a concept. Glass *et al.* (2012) present findings from two industrial surveys which considered, among others, the current scope of RS, drivers, benefits and barriers for engaging, and the future for RS within the construction industry. Within this survey, 50% of respondents believed that RS is important for the company brand; a key driver for influencing stakeholder perceptions of that firm. Furthermore, 67% of respondents stated that adopting a proactive approach to implementing RS would have a positive effect on the company. Fundamentally, RS introduces a high degree of transparency and traceability with regard to materials; the Global Reporting Initiative (GRI; 2010) highlight the importance of transparency in gaining customer trust.

The degree of customer and stakeholder trust determines the legitimacy of an organisation, and hence can impact significantly upon corporate reputation. For instance, CSR has been defined as ‘reputation insurance’ (Unerman, 2008) so being able to evidence that the firm is involved with the CSR agenda can act as a means of suppressing issues that may arise. In the case of an organisation that operates an environmental management system (EMS), for example, it may be eligible to have reduced fines if it can prove that an EMS was in operation at the time of an environmental incident. This could be argued to derive directly from an improved reputation that that firm may have received due to the environmental commitment that an EMS evidences. Similarly, engaging with RS should act as a form of insurance, if the organisation is subjected to ethical or social exposés, as certification should demonstrate organisational commitment to ethics and transparency. For example, Marks and Spencer’s Plan A programme (Marks and Spencer, 2010) have set a number of targets round many of the principles of RS, such as reducing energy consumption, committing to zero operational and construction waste to landfill and embedding social equality in its supply chain by helping clothing suppliers pay a fair living wage in manufacturing countries, such as Bangladesh and India. Such targets are applicable to both Marks and Spencer’s retail and property programmes and the recently constructed Cheshire Oaks Eco Store has won awards for its sustainability, with the store recognised as one of the largest sustainable retail stores globally (Marks and Spencer, 2013). This example highlights a client with RS well embedded in its processes and the reputational benefits that can flow from such an approach.

3.3 Reputation in the context of business priorities

Managing reputation has been suggested in preceding sections to be important for the firm, and for construction organisations, the RS agenda provides a means for them to demonstrate the importance that is given to social and environmental issues. However, it must also be considered that certification to the RS framework standard BES 6001 (BRE, 2009) can cost an organisation thousands of pounds. This may represent a significant challenge for smaller companies, which often struggle to provide adequate financial and other resources to implementation (Upstill-Goddard *et al.* 2012). Often, legislative demands take precedence over the corporate social responsibility (CSR) agenda as many CSR activities remain voluntary. It is also significant to add that many small and medium sized firms (SME) require a short-term pay back on investments, but large investments in sustainability certification schemes may be ‘paid back’ over a period of years. It therefore becomes considerably more difficult for an SME to manage its reputation, as the priority for any business is to make profit, especially so for an SME, given its limited resources. In the case of larger organisations however, there are considerably more resources available to devote to CSR schemes, and hence, there may be more scope to devote resources to reputation management. CSR activities such as publishing sustainability reports increase the reputation of the firm, as they directly report to stakeholders the actions that a firm is taking, to ensure that it is seen to be a considerate organisation. Working to improve corporate reputation by engaging in CSR should in the long term increase profits; indeed Du *et al.* (2010) argue that engaging in CSR can generate positive attitudes among stakeholders and in the long term improve corporate image and relationships with stakeholders. Yet the relatively low awareness of CSR among stakeholders impedes the realisation of the business benefits, which would suggest that there is currently a mismatch between CSR and gaining a return on the investment in these activities. This, however, is an area that warrants further research.

4 CONCLUSIONS

This review paper has demonstrated that an inherent relationship exists between corporate reputation and responsible sourcing (RS). The move of the construction industry towards considering RS on projects and in sourcing of materials for manufacture of construction products is a relatively recent development, and as such we have highlighted that a focused research agenda is lacking; although the APRES network (APRES, 2013) has sought to address this and has hosted to date two successful conferences aiming to stimulate debate and thinking on an RS agenda. Given the past experiences of a number of organisations from other sectors, the construction industry can learn much from the results of the exposés of companies such as Nike. Construction is a sector of high social and environmental impact and thus it is important that construction organisations 'insure' themselves against unethical or irresponsible practices being unearthed in their supply chains. Specifically, due to the traceability requirements within BES 6001 (BRE, 2009), organisations can be assured that constituent materials are sourced from locations where the environment, the supply chain and health and safety have all been assessed and deemed satisfactory. However, RS does not presently make provisions for chain of custody (especially important for more complex supply chains) or materials that are procured by the organisation, but do not form part of the final product, such as personal protective equipment (PPE).

Reputation management, however, requires time and financial resources to enact within the firm, much like the CSR agenda. Implementation and documentation of RS principles within the organisation, such that they are of an appropriate standard to enable certification, is a time and cost intensive process. However, given the argument that a firm's reputation is dependent upon the presence of other firms, engaging with RS may not necessarily improve a firm's reputation, but it will improve its legitimacy because transparency and accountability has increased. A legitimate organisation can stand alone, as the literature has suggested, but the degree of this is influenced by the social acceptance that results from adherence to social norms and expectations (Deephouse and Carter, 2005). Equally, reputation is a relative measure and so engaging with RS would only improve the reputation of that firm should its direct competitors not achieve certification. It has been derived from this review, that although very little literature considers the link between CSR and reputation, there is a clear relationship between them, and future research should explore this in greater detail.

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REFERENCES

APRES, *Action Programme for Responsible Sourcing* (2013). Available online at: http://apres.lboro.ac.uk/

M. Bahr, J. Warburton, Y. van Gellecum and M. Shapiro, "Stakeholder perspectives of organisational reputation". *In "R. E. Hicks (Ed.), Personality and individual differences: Current directions"*, Bowen Hills: Australian Academic Press, 214-224 (2010).

Building Research Establishment (BRE), *BES 6001: Framework standard for the responsible sourcing of construction products,* Building Research Establishment, Watford (2009).

D. Bromley, "Comparing corporate reputations: league tables, quotients, benchmarks or case studies?", *Corporate Reputation Review,* **5**(1), 35-50 (2002).

D. V. Caprar and B. A. Neville, "'Norming' and 'Conforming': Integrating Cultural and Institutional Explanations for Sustainability Adoption in Business", *Journal of Business Ethics*, **110**, 231-245 (2012).

M. Christopher and B. Gaudenzi, "Exploiting knowledge across networks through reputation management", *Industrial Marketing Management*, **38**, 191-197 (2009).

F. Ciliberti, P. Pontrandolfo, B. Scozzi, "Investigating corporate responsibility in supply chains: a SME perspective", *Journal of Cleaner Production*, **16**, 1579-1588 (2008).

D. L. Deephouse and S. M. Carter, "An Examination of Differences Between Organizational Legitimacy and Organizational Reputation", *Journal of Management Studies*, **42** (2), 329-360 (2005).

D. J. Doorey, "The Transparent Supply Chain: from Resistance to Implementation at Nike and Levi Strauss", *Journal of Business Ethics*, **103**, 587-603 (2011).

S. Du, C. B. Bhattacharya and S. Sen, "Maximizing Business Returns to Corporate Social Responsibility (CSR): The Role of CSR Communication", *International Journal of Management Reviews*, **12** (1), 8-19 (2010).

Equality and Human Rights, Commission *Inquiry into Race Discrimination in the Construction Industry: Action Plan* (2010). Available online at: http://www.equalityhumanrights.com/uploaded_files/action_plan_v3.pdf

R. E. Freeman, "Strategic management: A stakeholder approach", Boston: Pitman (1984).

J. Glass, "Extending the concept and validity of responsible sourcing certification through environmental product declarations", *1st Building Sustainability Assessment Conference,* Porto, Portugal (2012a).

J. Glass, "The state of sustainability reporting in the UK construction industry", *International Journal of the Smart and Sustainable Built Environment*, **1** (1), 87-104 (2012b).

J. Glass, N. Achour, T. Parry and I. Nicholson, "The role of responsible sourcing in creating a sustainable construction supply chain, CIB W65 Supply Chain integration workshop, Amsterdam, Netherlands (2011).

J. Glass, N. Achour, T. Parry, I. Nicholson and J. Upstill-Goddard, "Responsible sourcing of construction products and materials – results from an industry survey", *Concrete,* February 2012, 47-49 (2012).

Global Reporting Initiaitive (GRI), "The Transparent Economy – Six Tigers Stalk the Global Economy and How to Tame Them", *Global Reporting Initiative, Amsterdam* (2010).

D. Greenwood, Z. Alwan, G. Hudson, M. Siddall, P. Walker, "A process model for sustainable design of buildings – towards an adaptable 'route map' for green code compliance", *Built and Natural Environment Research Papers,* **4** (1), 11-19 (2011).

J. Hawkins and B. McKittrick, "Construction Sector Transparency Initiative: making construction more accountable", *Proceedings of the Institution of Civil Engineers, Civil Engineering*, **162** (CE2), 82-88 (2012).

C. Hillenbrand and K. Money, "Segmenting stakeholders in terms of Corporate Responsibility: Implications for Reputation Management", *Australasian Marketing Journal*, **17**, 99-105 (2009).

H M Government, *Strategy for sustainable construction,* Department of Business, Enterprise

and Regulatory Reform, London (2008).
D. Kiron, N. Kruschwitz, K. Haanaes and I. von StrengVelken, "Sustainability nears a tipping point", *MIT Sloan Management Review*, **53** (2), 69-74 (2012).
R.D. Klassen and A. Vereecke, "Social issues in supply chains: Capabilities link responsibility, risk (opportunity) and performance", *International Journal of Production Economics*, **140** (1), 103-115 (2012).
D. McDougall, "Primark in storm over conditions at UK supplier", *The Observer*, Sunday 11th January (2009). Available online at: http://www.guardian.co.uk/business/2009/jan/11/primark-ethical-business-living
K. McQueeney, "Disconnected: One Billion people still don't own a mobile phone, and a third of the world does not have access to the internet", *Mail Online*, Friday 12th October (2012). Available online at: http://www.dailymail.co.uk/news/article-2216625/Report-shows-1billion-people-dont-mobile-phone-half-world-access-internet.html#axzz2KgsuUMnJ
Marks and Spencer, "Doing The Right Thing – Our Plan A Commitments 2010-2015", *Marks and Spencer Group Plc.* (2010). Available online at: http://corporate.marksandspencer.com/documents/publications/2010/planacommitments2010
Marks and Spencer, *Cheshire Oaks Eco-Store*, (2013). Available online at: http://plana.marksandspencer.com/we-are-doing/climate-change/cheshire-oaks
M. Murray and A. Dainty (Eds.), *Corporate Social Responsibility in the Construction Industry*, Taylor and Francis Group (2009).
M. Orlitzsky, F. L. Schmidt and S. L. Rynes, "Corporate social and financial performance: A meta-analysis", *Organization Studies*, **24** (3), 403-441 (2003).
M. Porter and M. Kramer, "Creating shared value", *Harvard Business Review*, **89** (1/2), 62-77 (2011).
M. Reynolds and K. Yuthas, "Moral Discourse and Corporate Social Responsibility Reporting", *Journal of Business Ethics*, **78**, 47-64 (2007).
P. W. Roberts and G. R. Dowling, "Corporate reputation and sustained superior financial performance", *Strategic Management Journal*, **23** (12), 1077-1094 (2002).
A. Sev, "How can the Construction Industry Contribute to Sustainable Development? A Conceptual Framework", *Sustainable Development*, **17**, 161-173 (2009).
T. E. Thomas and E. Lamm, "Legitimacy and Organisational Sustainability", *Journal of Business Ethics*, **110**, 191-203 (2012).
G. Unerman, "Strategic reputation risk management and CSR reporting", *Accounting, Auditing and Accountability Journal*, **21** (3), 362-364 (2008).
J. Upstill-Goddard, J. Glass, A. R. J. Dainty and I. Nicholson, "Integrating responsible sourcing in the construction supply chain", *Proceedings of the 28th Annual ARCOM Conference*, Edinburgh, UK, 1311-1319 (2012).
C. Vee, M. Skitmore, "Professional ethics in the construction industry", *Engineering, Construction and Architectural Management*, **10** (2), 117-127 (2003).
B. Wazir, "Nike accused of tolerating sweatshops", *The Observer*, 20th May (2001). Available online at: http://www.guardian.co.uk/world/2001/may/20/burhanwazir.theobserver

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A CRITICAL REVIEW OF THE BARRIERS TO THE INTEGRATION AT SITE LEVEL OF SUSTAINABILITY PRACTICES INTO UK CONSTRUCTION PROJECTS

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Abstract *Construction practices are an important part of the grand sustainability agenda of enabling a safe and viable environment for future generations. Despite the significantly high amount of research on sustainability issues, there is a lack of detail relative to factors preventing its development and implementation at the level of construction project site practices. The aim of a literature search, which is being reported, was to investigate information and research into the barriers to the adoption of sustainable construction practices on projects with emphasis on those affecting the introduction of appropriate practices. Significant literature has been found on global barriers such as cost, supply chain issues and lack of knowledge. However, the effect of these on the inception of sustainable construction at the project site level has received a small fraction of the attention. In this regard, barriers have been found to be diverse ranging from stakeholder issues through to the attitude of individuals. To aid the future investigation of their applicability to projects these barriers have been broadly categorised as being either external (supply, demand and trading environment) or internal (resources, cultures, systems and human nature) to the project. However barriers which are applicable at the project site level are poorly defined with little clarity as to the magnitude of their effect on preventing sustainable construction occurring. In addition to commonly reported barriers such as Client and stakeholder desires, less commonly reported social and behavioural factors are discussed. This review and paper provides a basis of further studying the key barriers working against the achievement of sustainability as well as specific site practices which will deliver this goal as a first step towards the development of a strategy to achieve this in practice.*

1 INTRODUCTION

Kibert (1994) produced one of the seminal definitions of sustainable construction as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles." This is one of a significant number of definitions of sustainability and the number of which continues to grow and is of current academic interest (Zabihi et al., 2012). This was heralded as a new paradigm (Bordeau et al 1998) that the industry needed to address as one of the largest consumers of natural resources (Griffiths, Smith and Kersey 2003). However the entire issue is encapsulated by Bidarianzadeh and

Fortune (2002, p. 569) as "the construction industry, undeniably, has a huge impact on the environment and the term 'sustainable construction' may seem to contain an oxymoron can an industry such as construction traditionally so thoroughly dependent on the use of nature's resources and concerned primarily with creating new structures, answer increasing societal and, in turn governmental demands for a sustainable industry?"

Kibert’s (2007) work follows up on earlier work and the changes that have occurred over the past decade and particularly notes that there are shortcomings in relation to legislation and perception. The industry has gotten to grips with the general terminology and the issues which are present however there has been a limited uptake of the issues into the mainstream. This is backed up by a claim that the industry needs to move away from a voluntary system of sustainability assessment and towards a legislation driven agenda.

The basic principle of sustainability is built on the three pillars of environment, economics and social issues however there is an absence of balance (Dewick and Miozzo 2002) in the UK with slow progress towards the inclusion of social and environmental considerations compared to other European countries. It should be noted that those countries considered as European is not clear and has changed over time with the expansion of the E.U. Balance needs to be maintained in all aspects of the inception of sustainability. The need for balance is highlighted by Young's (1997) definition of sustainability "as a three legged stool, with a leg each representing ecosystem, economy and society. Any leg missing from the 'sustainability stool' will cause instability because society, the economy and the ecosystem are intricately linked together.” Zabihi et al (2012, p. 575) illustrate the changes in balance which have occurred "at first the important point was emphasis on resources limitation namely energy and the method for reduction of its impact on natural environment. In the past decade, the emphasis was on technical issues of building and construction such as materials, building parts and components, construction techniques and energy. Today, most of non-technical issues were taken into consideration and social development was raised as sustainable development indices”.

This paper looks at the main issues that have been highlighted relative to barriers to the inception of sustainable construction as found via a literature review and especially applicable to practices at site level. Section 2 covers construction sustainability practices; section 3 commonly reported barriers to sustainability and section 4 further historical and behavioural barriers.

2 CONSTRUCTION SUSTAINABILITY PRACTICES

Table 1 shows the overall project to produce a series of site practices relative to the inception of sustainable construction at site level. This paper deals with a subset of the research. In order for construction projects to address the requirements of sustainability there is a need for a clear series of practices which bring about the required end result. These practices or the potential range of practices have not been defined in peer reviewed literature, authors have however highlighted the key roles that construction sustainability practices need to fulfil. Khalfan et al, (2002, p. 8) encapsulated the six key requirements of sustainability as being:

- Minimisation of resource consumption;
- Maximisation of resource reuse;
- Use renewable and recyclable resources;

- Protect the natural environment;
- Create a healthy and non-toxic environment; and
- Pursue quality in creating the built environment.

Literature review	**Area of interest**	**Potential areas applicable**
Site working methods	Economic	Lean construction, value engineering
	Social	Health and safety, apprenticeship schemes
	Environmental	Pollution management, Dust management
Perception of barriers at site level	Internal	Lack of knowledge, cost distribution
	External	Regulatory restrictions
Perception of drivers at site level	Internal	Cost saving/operational efficiency, competitive edge, company survival, reduction of legal risks
	External	Government regulation, client procurement policy, peer pressure

Table 1: Outline of overall research project

The BREEAM system (BRE, 2011, 42) encourages responsible construction practices, specifically looking at the measurement of:

- Monitoring energy consumption on the site.
- Monitoring of water consumption on the project.
- Monitoring of transport to and from site including the quantities of waste from the site.
- Use of sustainable timber.
- Having an environmental management system.

Whilst the BREEAM system gives a list of specific actions that should be followed in order to bring about the goals of sustainable construction it does not show balance in relation to the three pillars; with no clear link to the environmental pillar (unless the monitoring actions lead to the reduction of resource usage which in turn can be realised as a reduction in costs) and no social effects. It could be argued that the BREEAM system addresses the social pillar through the development of a better working environment for the final users of the building or via the social benefits that are attached to the Considerate Constructors Scheme which is advocates.

Labuschagne at al (2005) looked at the various levels of operational sustainability within a corporation and highlighted the need for economic stability to include financial health; economic performance and potential financial benefits, whilst environmental stability was based on air resources; water resources; land resources and mineral and energy resources. The social pillar being dependent on internal human resources; external pollution; stakeholder participation and macro social performance. Whilst these are a useful starting point as they are descriptive of the sustainability areas that need to be addressed they do not give real detail as to the associated practices which are effective for achieving the required result.

3 COMMONLY REPORTED BARRIERS TO SUSTAINABILITY

Following extensive searches in relevant subject areas on the ScienceDirect, ProQuest, ingentaconnect and Web of Knowledge search engines 17 primary sources were found and reviewed dealing with barriers to sustainable construction these were categorised using the areas listed in Figure 1. Two of these studies have provided ranked information on the barriers. One of these, Williams and Dair (2007) presented twelve barriers:

- Sustainability measure was not considered by stakeholders
- Sustainability measure was not required by client
- Stakeholder had no power to enforce or require sustainable measure
- One sustainability measure was forgone in order to achieve another (traded)
- Sustainable measure was restricted, or not allowed, by regulators

Adetunji et al. (2003) on their part carried out a detailed literature review and interviews (with 26 contractors of £500 to £100 million turnover, and engaged in road construction) to generate the following barriers to sustainably:

- Lack of knowledge of sustainability
- Cost of third party certification
- Distribution of cost-benefits
- Cost as a barometer of success
- Limitation of procurement policy
- Narrow and patchy focus
- Industry culture; fragmented nature of industry, short term focus and conservatism

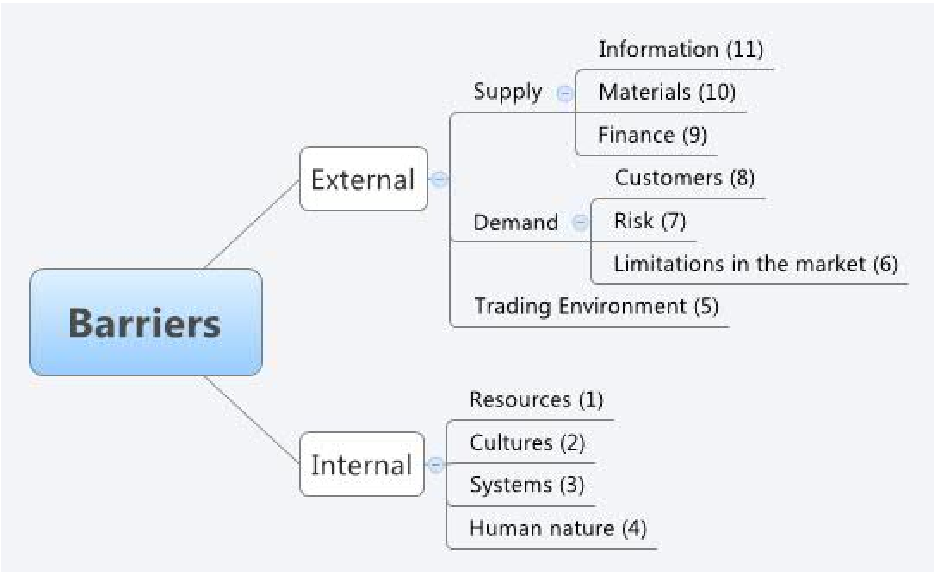

Figure 1: Categorisation of barriers

One of the lowest ranked barriers is supply chain management. As will be argued below the issues presented appear to be high level and not indicative of the potential issues at the site level. This may be due to the study participants being high level managerial or technical staff in the health and safety, environmental and sustainability disciplines rather than site based personnel such as site managers. However, a review of parallel issues to the inception of new construction practices highlighted a number of issues such as historical issues in the supply chain. These are detailed below and suggest a number of areas which need to be investigated at the site level which are not represented by previous studies regarding barriers to sustainable construction.

The identified barriers to sustainability can be provisionally summarised as:

- Many of the barriers are related to the decisions of the client through their purchasing influence. This could also be seen from the alternative direction as to whether without the effects of clients' requirements or government intervention there would be any significant level of sustainability being practiced or considered on projects.
- Risk and its avoidance is a strong barrier to sustainability.
- Government intervention is not a major barrier to sustainability.
- The majority of the barriers are external to the company.

Sustainability is based on the three pillars of social, economic and environmental factors. However there are a number of areas that are perceived as less important to sustainable construction. Whilst Clients and government intervention are significant in relation to decisions about sustainable construction and thus the economic pillar there seems to be less reported relative to the environmental and social pillars.

4 FURTHER BARRIERS TO SUSTAINABILITY

As already noted an important part of the inception of sustainable construction practices is an understanding of the hurdles which will need to be cleared to allow site practices to be adopted and changed to meet the new challenges that are ahead. This section of the paper looks at the issues that have been raised in relation to these barriers based on an in-depth literature review in this area. Research in the area has shown that the range of barriers is wide and varied. Further barriers are detailed below which relate to society, historic working conventions and behaviour of individuals. The authors suggest that additional factors will come into play at the site level, based on a review of parallel issues relating to social interaction and issues at the site level, these are expanded on below.

Table 2 summarises potential barriers that previous studies of barriers to sustainability have not alluded. An on-going effort is seeking to investigate some of the gaps which have been found and attempt to develop information on the inception of sustainability practices within the design and construction stages of projects, especially at the site level.

4.1 Social and behavioural factors

Looking at the barriers to the public engagement of the UK population with the Climate Change agenda, Lorenzoni et al. (2007, p. 445) summarised that, "A number of common barriers emerge from the three studies, which operate broadly at 'individual' and 'social' levels." Stoll-Kleemann, O'Riordan and Jaeger (2001) look at the psychological barriers distance and denial as to the need for behavioural change relative to the alternative energy debate, indicating a desire to remain with the Status Quo even in the face of evidence that this is not a tenable future and cannot be maintained indefinitely. There will be a significant barrier at site level to the engagement with the concept of sustainability and the need for the inception of modified working practices.

Loosemore and Andonakis (2007) looking at the nature of barriers to the implementation of Occupational Health and Safety Reforms in Australia noted that there are significant difficulties with the implementation of reforms due to the culture of risk transfer in the industry, with risk being passed down the contractual chain via contracts. The change in regulations in health and safety in Australia has highlighted a number of issues in relation to the inception of regulations due to the sub contracting nature of the industry.

Issue	**Reference**
Social and behavioural	
Lack of engagement with climate change issues	Lorenzoni, Nicholson-Cole and Whitmarsh , 2007
Distancing from sustainability issues	Stoll-Kleemann, O'Riordan and Jaeger, 2001
Risk transfer through supply chain	Loosemore and Andonakis , 2007
Supply chain issues (fragmentation)	Briscoe, Dainty and Millett , 2001
Confrontation and adversarial nature of construction	Yitmen , 2007
Historic	
Forming the required contracting team	Egan, 1998 and Latham, 1994
Productivity and resistance to change	Winch , 2003

Table 2: Potential alternative barriers to sustainability

The issues of the supply chain have been highlighted as significant when it comes to the inception of change due to the continuing adversarial nature of the relationships (Briscoe, Dainty and Millett 2001, p. 251). It has been noted that there has been a significant amount of information produced in terms of the barriers to sustainability the largest proportion address the national and international barriers. A lesser amount has been written about the project or site level barriers to the inception of sustainability. The issues outlined below point to the influence of human factors which is in contrast to the high level barriers to inception sustainable construction practices detailed by earlier studies.

4.2 Historic barriers to change in construction

When looking at the barriers to sustainability it should be noted that the barriers need to be viewed in the context of the historical barriers to progress and innovation which are an integral part of the industry as a whole. There have in the past been a number of major reports that have looked at issues in relation to the way in which the construction teams in the industry work and the formation of a working framework. These have been headed up by Egan (1998) and Latham (1994).

It has been noted by Dulaimi et al. (2002) that these are not new issues and that there is a deeper historical basis that has prevented innovation and change in the construction industry. The issues raised by Latham and Egan were raised by Banwell, (1964), however, without the profile of the newer reports and their Government backing these issues and the concerns that were raised were given little heed to. The overall effect has been that change has occurred but this has not been as far reaching as the report authors would have liked and as a consequence suggests some of the challenges that will be faced in trying to bring about new construction practices to align with the needs and requirements of the sustainability and green agendas.

Yitmen (2007, p. 1319) commenting on the work of Barrett (2004) notes that "Construction is often typified as: confrontational, lacking vision, risk averse and engaged in cut throat competition, exacerbated by a lack of trust, inappropriate tracts and poor communications, involving uninformed team members and widespread organizational amnesia." It is against this backdrop that sustainability needs to be incepted.

Winch (2003) comments that the construction industry has a low level of productivity and clarity compared to other industries, something that is put down to the low rate of innovation that is prevalent in the industry. Construction can be considered backwards when compared to other industries that have gone through many changes to bring about a streamlined and efficient manufacturing process. The research will need to look in depth at the potential effect that any remaining historical issues will have on the inception and ability of construction firms to undertake sustainable construction. For sustainable construction practices to be incepted these issues will need to be overcome and the lack of recognition in previous studies shows clear need for the issues to be raised and understood such that the barriers presented can be addressed.

4.3 Barriers in health and safety lessons for sustainable construction inception

Loosemore and Andonakis (2007) looking at the nature of barrier to the implementation of Occupational Health and Safety shows a method of contracting which parallels the makeup of the UK industry and therefore some of the issues that arise will be similar; the issues of dealing with on site multi trade workers and their ability to change without significant input from the principal contractor. How the small trade contractors will be brought along to achieve the overall goal of sustainability is a question that will need to be addressed.

These parallel issues have been investigated to look for insight into the potential issues that may be faced in bringing about new construction practices to align with the requirements of sustainable construction. In particular health and safety has the image of an undesirable regulatory barrier in the construction industry. Therefore there may be things to be learnt from these other construction related items that will assist in finding out the issues that are faces and may also give some insight into what will be required to overcome some of them.

Frazier et al (2013) looked extensively at safety culture and its implementation which presents information on parallel issues when looking at the development of a sustainability culture on site. The primary issue of a site based culture is to ensure that employees are all involved. This is important as Kotter and Haskett (1992) highlight that the alignment of employee and management goals provides strong and positive outcomes. Similarly Hayter et al (2002) note motivated and engaged employees can have a positive impact in business performance.

In addition a positive culture will allow the end goals to be achieved without significant monitoring and management. Therefore if sustainable construction practices are to be enacted management will need to develop a suitable culture and need to engage employees and also as noted below the supply chain.

4.4 The supply chain as a barrier

The nature of contracting, a principal contractor taking the lead and employing a delivery team of subcontractors is a much used method of procuring a project. The contractor is therefore a sum of its parts.

Briscoe, Dainty and Millett (2001, p. 251) undertook a review of construction supply chain partnerships and concluded that on, the basis of their analysis of a series of interviews that they showed, "how significant attitudinal barriers are present between many of the SME suppliers and the main contractors." Whilst this is a study which is now dated it shows the continuing adversarial relationship and issues in construction that earlier research has highlighted. Thus the supply chain partnerships may well present a significant barrier to sustainability. The following review of literature will show minimal coverage of this issue which is fundamental to site level sustainability practices.

Van Bueren and De Jong (2007, p. 549) commenting on the work of (Rittel and Webber, 1973; Connolly, 1983) points out that, "Sustainable development is a contested or wicked concept." This is further elaborated on by looking at the imbalance between the needs of sustainable construction and the drivers of any work that of generating a profit. They conclude from the work that was reviewed that, "Everyone seems to be in favour of the goals, but it is very difficult to implement tangible policies and objectives. When priorities have to be set and concrete choices made (such as the allocation of profits and losses), the concept alone cannot reconcile conflicting values." However, the baseline research is somewhat historic and may not take into account the changing aspirations of the public and the ever growing Corporate Social Responsibility Agenda.

One of the barriers to movement in this field will be the inability of the industry, company or supply chain to adapt to the need to innovate.

Kibert (2007) in a review of sustainable construction notes the changes that have occurred since the Latham (1994) and Egan (1998) reports and the developments in construction supply chain management, however, based on the information presented it is clear that the construction process is about the establishment of a supply chain with a significant proportion of work being undertaken by companies who work on a construction management basis. Therefore most of the UK's construction companies can be seen only as the sum of their parts with the majority of contractors being defined by their supply chain. It is therefore important for the supply chain to be robust and in the context of this paper the requirement for the supply chain to take on the requirements of sustainable construction practises.

The take up of supply chain management has been slow within the construction industry potentially due to the continually changing nature of the supply chain with each new project.

Kibert (2007) asserts that the biggest barrier to implementing a successful supply chain partnership was a lack of top management commitment, followed by the poor understanding of the concept and an inappropriate organisation structure to cope with the changes.

It is clear that construction firms are normally the sum of their parts with the majority of contractors being defined by their supply chain. It is therefore important for the supply chain to have the same goals and understanding of the main contractor; this presents a barrier to the efficient and timely uptake of new innovation and in the context of the research the new and ongoing changing requirements of sustainable construction.

Loosemore and Andonakis (2007, p. 581) reviewing the way in which project teams are assembled from a health and safety perspective notes that, "Trade subcontracting is a key feature of the construction industry, providing economic flexibility and specialist expertise for principal contractors in a highly competitive, uncertain environment of increasing technical complexity. However, trade-subcontracting has also created many management problems for principal contractors which have been widely recognised as contributing to inefficiencies in the industry, not least in the area of OHS because of the complex web of constantly changing contractual relationships which can confuse responsibilities for OHS management and reporting." This directly relates to the social pillar of sustainable construction. There is additionally noted to be barriers in the form of implementation costs, language and educational barriers and a fear of change.

5 CONCLUSION

The change in health and safety regulations in Australia has highlighted a number of issues regarding the sub-contracting nature of the industry. The issues that arise therein are similar to those in the UK construction industry as their methods of contracting are likewise parallel. The issues of dealing with a fragmented supply chain may come to the forefront as may the ability of supply chain partners to change without significant control from the principal contractor. A question that future research needs to address is how will the small trade contractors be brought along to achieve the overall goal of sustainability?

Whilst there has been a significant amount of research in relation to the barriers to the inception of sustainability and even to a degree the barriers at the site level, it is argued that there are specific barriers which may be present and have not been reviewed due to the lack of research at the site level rather than within the central management functions of contracting organisations.

It has been noted from the literature reviewed that there are a number of gaps in the current research. From these many gaps, the principal areas that have been chosen by the authors for further investigation are;

- Development of practices which when enacted will have the largest potential to bring about sustainable construction at the site level.
- Understanding the drivers which significantly affect the inception of sustainability at the site level
- Identifying factors which mitigate the inception of sustainability in projects.

These issues have significant importance to contractors and design teams in their attempt to bring about sustainability in construction. They thus provide a strong basis for the targeted investigation of the barriers that are present at the site or project level.

REFERENCES

I. Adetunji, A. Price, P. Fleming, and P. Kemp, "Sustainability and the UK construction industry—a review", *Engineering Sustainability*, **156**, 185 (2003).

B. R. E. Global, "BRE Environment & Sustainability Standard (BES 5055: ISSUE 2.0) BREEAM New Construction", (2011).

H. Banwell, *The Placing and Management of Contracts for Building and Civ Engineering Work: Report of the Committee* (1964).

R. Bidarianzadeh and C. Fortune, "Lean Thinking and the Delivery of Sustainable Construction Projects", *Association of Researchers for Construction Management Conference* (2002).

G. Briscoe, A.R.J. Dainty, and S. Millett, "Construction supply chain partnerships: skills, knowledge and attitudinal requirements", *European Journal of Purchasing & Supply Management*, **7**, 243 (2001).

P. Dewick and M. Miozzo, "Sustainable technologies and the innovation-regulation paradox", *Futures*, **34**, 823 (2002).

M.F. Dulaimi, Y.L.F. Y, G. Ofori, and N. De Silva, "Enhancing integration and innovation in construction", *Building Research and Information*, 30, 237 (2002).

J. Egan, *Rethinking Construction: Report of the Construction Task Force* (HMSO, London, 1998).

C.B. Frazier, T.D. Ludwig, B. Whitaker, and D.S. Roberts, "A hierarchical factor analysis of a safety culture survey", *Journal of Safety Research*, **45**, 15 (2013).
P.I.J. Griffiths, R.A. Smith, and J. Kersey, "Resource flow analysis: measuring sustainability in construction", *Engineering Sustainability*, **156**, 147 (2003).
M.M.A. Khalfan, D.M. Bouchlaghem, C.J. Anumba, and P.M. Carrillo, "A Framework for Managing Sustainability Knowledge-The C-SAND Approach." (2002), pp. 19–21.
C.J. Kibert, "Establishing principles and a model for sustainable construction", *Proceedings, First International Conference of CIB Task Group 16 on Sustainable Construction* (Tampa, Florida, 1994), pp. 3–12.
C. Kibert, "The next generation of sustainable construction", *Building Research & Information*, **35**, 595 (2007).
J.P. Kotter and J.L. Heskett, *Corporate Culture and Performance* (Simon and Schuster, 1992).
C. Labuschagne, A.C. Brent, and R.P.G. van Erck, "Assessing the sustainability performances of industries", *Journal of Cleaner Production,* **13**, 373 (2005).
M. Latham and others, *Constructing the Team* (HM Stationery Office, 1994).
M. Loosemore and N. Andonakis, "Barriers to implementing OHS reforms-The experiences of small subcontractors in the Australian Construction Industry", *International Journal of Project Management* **25**, 579 (2007).
I. Lorenzoni, S. Nicholson-Cole, and L. Whitmarsh, "Barriers perceived to engaging with climate change among the UK public and their policy implications", *Global Environmental Change*, 17, 445 (2007).
S. Stoll-Kleemann, T. O'Riordan, and C.C. Jaeger, "The psychology of denial concerning climate mitigation measures: evidence from Swiss focus groups", *Global Environmental Change*, **11**, 107 (2001).
E. Van Bueren and J. De Jong, "Establishing sustainability: policy successes and failures", *Building Research & Information*, **35**, 543 (2007).
K. Williams and C. Dair, "What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments", *Sustainable Development*, **15**, 135 (2007).
G. Winch, "How innovative is construction? Comparing aggregated data on construction innovation and other sectors - a case of apples and pears", *Construction Management and Economics*, **21**, 651 (2003).
I. Yitmen, "The challenge of change for innovation in construction: A North Cyprus perspective", *Building and Environment*, **42**, 1319 (2007).
H. Zabihi, F. Habib, and L. Mirsaeedie, "Sustainability in Building and Construction: Revising Definitions and Concepts", *Int. J. Emerg. Sci* **2**, 570 (2012).

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CLOSED-LOOP MATERIALS SYSTEMS

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Abstract. *The concept of waste does not really exist in nature. All material is used in some way; the residual products from one species are utilised by another. Yet the way we design and construct our buildings creates a huge amount of waste and uses large amounts of non-renewable, primary materials, which are extracted with great environmental damage. With concerns about the sustainability of our current approaches to buildings, the traditional wasteful approach to resources is becoming increasingly untenable and we need to develop closed loop systems for our materials and components. Nevertheless, we are surrounded by a sea of discarded materials and components that offer considerable design opportunities (and challenges) for use in buildings. Recycling of materials and reuse of components can significantly reduce environmental impacts and can generate economic benefits. Designing components with secondary uses can also reduce primary resource use. However, the practical, environmental, social and economical aspects, and advantages of reusing components and recycling materials have yet to be fully understood and become common building practice. Designers who have attempted such an approach say that "using reclaimed materials adds a whole new level of complexity to the project". So, what are the implications on the building performance and the design and construction process when we develop closed loop systems? This paper addresses how we can build our buildings using reclaimed components from demolition and what are the implications of establishing closed loops for the flow of materials in construction. It considers the implications of various strategies that redirect construction resources away from disposal to maximise their potential economic and environmental value and help addrtess issues of susstainability. This affects the way buildings are designed, built, maintained, managed and procured, and challenges many stakeholders in the industry to create a mind-shift that leads to greater reuse of whole buildings, salvaged components and recycled materials, with the supporting infrastructure that this requires. The paper discusses the building process issues that need to be addressed when developing closed loop materials systems and thereby raise understanding and awareness among designers, materials producers and other parties involved in construction about how to work with reused components to ensure high quality buildings.*

1 INTRODUCTION

The way we build cities requires vast volumes of new materials and leads to huge amounts of waste. Construction and demolition waste contributes about 35% of the total waste stream in Canada (CCA, 2002) and the Worldwatch Institute estimates that by the year 2030 the world will have run out of many raw building materials and we will be reliant on recycling and mining landfills (Brown, 1990). Demand is growing for many construction materials due to the ever-expanding economies and populations of the world putting enormous pressure on natural resources. Thus, resources may be far more costly and limited in the future, and the implications on materials availability and thus building construction will be significant. Nowadays, materials come from all over the world but in future, supply, particularly of bulky, low value construction materials may be far more dependent on local proximity and availability. The need to maximise building efficiency and establish closed loop systems for reuse of building materials at the end of their life are likely to become key drivers for building design, and provide new design opportunities. Already green building rating systems such as LEED (CaGBC, 2009) encourage the use of strategies such as use of regional materials and reused components to move towards closed loop systems for materials supply.

Traditionally architecture has been considered permanent. However most building lives do not generally maximise the usefulness of their components, and it is very difficult to foresee which buildings will be preserved, maintained and treasured while others are taken down and replaced. Material efficiency means maximising materials services while reducing demand for energy intensive primary materials. There are two approaches to using material efficiently: one is to design for endurance and lasting building life, the other is to design for a limited existence with the intention of reusing components. Both aim to extend the useful life of the components that make up the building.

Thus, material efficiency, a key aspect of sustainable design, can be obtained by providing a longer original life (in the original building), or by allowing for product life extension (use components in a new building). It is the goal of this paper to discuss extending component life through reuse as a viable design strategy. This requires a comprehensive understanding of the potential benefits available, as well as an understanding of the barriers to this approach, and, most critically, a procedure through design and construction methods to overcome barriers.

2. CURRENT CONSTRUCTION

Current construction practices typically aim to create buildings with a functional life of 50 to 60 years, although many buildings are demolished after much shorter lives (Durmisevic & Yeang, 2003). Demolitions and renovations typically account for more projects than new builds each year. In the United States, 1.75 billion square feet of building stock are torn down each year, 5 billion are renovated, and 5 billion are built new (Architecture 2030, 2011). Programmatic needs change, technical innovations render older systems obsolete, and materials are damaged and deteriorate.

Obsolescence leading to demolition can arise at a variety of scales: from small scale causes due to “building materials, parts and elements, building construction systems (structure, fabric, mechanical and electrical, etc.)” to the scale of an entire building, block or neighbourhood (Thomsen and van der Flier, 2011, p.353). Buildings can be rendered obsolescent due to physical factors such as poor design and material wear, behavioural factors such as change in use, damage by occupants, or external factors such as changing physical and behavioural conditions in the surrounding environment such as new technologies, traffic, nearby buildings and social deprivation. The physical factors of the building can be controlled through design and management, but behavioural factors tend to be beyond control of the owner, and external factors are too complex to be tackled by the owner or foreseen by the architect (Thomsen and van der Flier, 2011). These factors make it near impossible to design a long lasting building, but designing a solution that is capable of change and adaptation could extend usefulness. McDonough and Braungart (2002) question the benefit of building lasting forms, claiming that to build for permanence is arrogant and selfish, and that we should allow future generations to conceive and create their own products and architectures.

Disassembly principles that need to be more widely explored include: layering of assemblies, working with uncut standard forms, employing homogeneous materials instead of composites, using non-permanent connections, using recyclable components, and selection of material based upon expected lifetime of the building.

3 DISASSEMBLY

Durmisevic and Brouwer (2002) describe three alternative scenarios for the life-cycle of materials in contemporary buildings when comparing the functional life (how long the function is needed) with the technical life (how long it can carry out its purpose) of the component:

- The functional durability of the material/component is short compared to its technical life cycle, (functional lifecycle < technical lifecycle). In this case components last longer than their original use so ideally buildings would be disassembled into reusable components for reuse.
- The functional durability is expected to be longer than the technical life cycle, (Functional lifecycle > technical lifecycle). In this case a long building life means that many components will need replacement. Thus materials should be composed of replaceable and recyclable materials
- The functional and technical life cycles are equivalent. Technical life cycle can be considered the expected length of time the building will be used for its intended purpose (Functional lifecycle = technical lifecycle). In this case recycling of materials is most appropriate.

Durmisevic and Brouwer (2002, p.14) claim that a significant part of our built environment falls into the first scenario, that the second scenario involves monuments that are critical to maintain and the third scenario includes temporary buildings that should be designed for recycling. They believe the more separate life-cycle layers a building is designed to accommodate the more likely it is open to transformation and longer life before obsolescence.

4 COMPONENT REUSE EXAMPLES

Deconstruction and reuse of buildings is not a new concept as many structures such as travelling exhibitions, trade fairs, expos, protected gathering places and sports facilities (tents and air supported structures), and warehouses are designed as temporary buildings with a view to relocation. These buildings are often fabricated away from the site, packaged, transported, and erected. Often these buildings are designed by well-known architects and are therefore considered as culturally significant and worthy of preservation. After a relatively short life on the original location, the buildings are dismantled, packaged, and transported for re-erection at the new site. These temporary structures are designed with due consideration of loads in different locations, size of components suitable for transportation, and ease of erection and dismantling.

Other temporary structures are taken down and the material reused in more permanent buildings. For example, at the Vancouver Expo 86 many of the smaller countries used standardized modules for their pavilions with the intention to resell the structure for reuse after the event. The intent was to use these standardized modules throughout the province after the Expo for tourism and other provincial needs. The structures therefore needed to offer modular adaptability. It was later realized that the design for snow load in many provincial locations was much higher than the loadings that were used for design of the Expo structures in Vancouver (designed for one winter snow rather than for 30 years). Thus, the structures had to be redesigned for the use in other regions. Another example is the structure over the Cloverdale Rodeo in Vancouver which reused steel from the RCMP musical ride at Expo 86. Initially, this was to be a simple rebuild of the original Expo structure but due to changes in requirement and the need to accommodate higher loads in a permanent structure than was necessary in the temporary Expo structure, the steel had to be adapted for the new use. Other lessons from this project include the need for care in the transport and storage of materials to minimize damage, and the need for the involvement of structural engineers to ensure that the reuse is consistent with the capacity of the original structure. Deconstruction has been successfully practised in Canada for pre-engineered, standardised "Butler" type buildings (single storey, portal frame buildings of moderate single spans).

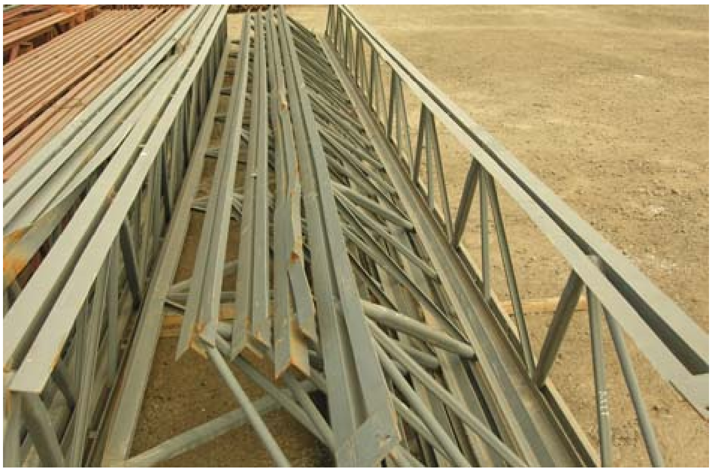

Figure 1: Open web steel joists can often be dismantled for reuse, but the new structure needs to be based on the available spans

5 AVAILABLE MATERIALS FROM A TYPICAL HOUSE TYPE

A simple inventory of the materials available in a typical 1.5-storey home with a usable floor area of about 111m^2 built in the 1950s in Toronto is presented in Table 1 along with the potential of each material for reuse (see Ergun & Gorgolewski 2013 for more details).

These homes are now typically being demolished and replaced by larger more valuable houses. The demolition process is typically destructive with little separation of materials, and minimal attempt to realize the value of the materials. However, there is potential for considerable amounts of material to be extracted from these buildings. About 67,000 such homes were built between 1945 and 1960, so if the above figures are scaled up to the total stock and assuming an overall reclamation rate of 75%, in total over 525,000m^3 of timber and 427,000 m3 of bricks may be available for construction of new buildings. There may also be considerable amounts of other materials such as asphalt shingles and gypsum drywall that could go for recycling which is more appropriate for those materials.

Element	Material	Volume (m^3)	Reuse Potential	Comment
Dimensional Lumber	Various sizes of 50mm lumber	10.1	Strong	D-nailing is the main issue
Doors	Solid Wood	0.15	Medium	Quality of old doors will be variable
Subflooring	25mmx152mm Wood Panels	1.55	Medium	Some problems with clean extraction
Hardwood Flooring	Wood	1.9	Strong	Depending on ease of extraction from the building
Cladding	Brick and Mortar	8.65	Strong	Depending on mortar strength
Windows	Single Pane Glass	0.13	Weak	Better suited for recycling
Window Frames	Average 35mm Wood	0.52	Weak	Quality may not meet current standards
Sheathing	Plywood or Tongue and Groove Sheathing	5.09	Weak	Over time, building paper melts onto sheathing
Roof Insulation	Mineral Wool	10.84	Weak	Mostly recycling or small DIY projects
Drywall	Gypsum	1.20	Weak	Suitable for Recycling
Roofing	Asphalt Shingles	3.13	Weak	Suitable for recycling
Foundation Slab and footings	Concrete	8.48	Weak	Can be down cycled to aggregate

Table 1. Material inventory of archetype wartime house

6 BARRIERS TO BUILDING OR COMPONENTS REUSE

Based on a series of studies in Canada (Gorgolewski et al, 2006, Public Architecture, 2010) the following issues have emerged that limit component reuse:

6.1 Documentation

Lack of documentation (as-built drawings, specifications, material test data, and shop drawings) makes a feasibility study into component reuse longer and more expensive, and may create a barrier against reuse. Very importantly, lack of documentation may result in structural components being recycled rather than reused or, in the worst case, being sent to landfill. Problems arise more often in older buildings. Project documentation has often disappeared over the years. The lack of knowledge about the state of the industry and standards of that particular period may lead to a conclusion that components are unsuitable for reuse.

6.2 Perception

Reuse of components faces many challenges, especially in North America since “new” is valued above the used and fixed and, therefore, there has been a tendency to demolish and dump. In order to overcome this wasteful attitude, it is necessary to document and show case study projects which demonstrate component reuse and, through these, educate both members of the public as well as the profession about the potential for reuse. It is also very important to link the projected reuse to the environmental issues related to the availability of natural resources, green house gas emissions, and waste disposal.

For a number of reasons, professionals in the construction industry have not shown a lot of enthusiasm for component reuse. The economics of reuse when considered without environmental sustainability may not show any benefits. There may be an increased liability for the professionals involved, due to the fact they deal with systems and components of incomplete or inadequate documentation. The design process is often more challenging and time consuming. However, professional reluctance is slowly changing and now most environmental assessments address the issue of reuse. For example, reuse is encouraged in the Materials & Resources section of the LEED.

6.3 Spatial/ Planning issues

When reusing building components, their length and size define the grid pattern and thus may impose some limitations on spatial planning. Most economic approaches are to base the grid dimensions on the reuse component sizes. However, this assumes that the components are known and available at the time of detail design. This is rarely the case.

6.4 Codes

National standards and codes encourage new construction and use of new materials. The third revision of 1990 NBC included for the first time the relationship between NBC and other standards, testing and certification organizations, defining for designers authorities which can assist them to determine equivalencies. The 1995 Code was accompanied by the Structural Commentaries on the National Building Code of Canada (1995) which for the first time included a section entitled “Application of NBC Part 4 for the Structural evaluation and Upgrading of Existing Buildings”, assisting designers to deal with issues related to buildings designed to previous codes in the context of Part 4. Used materials and systems are permitted if they comply with the NBC requirements for new construction. There is reasonable freedom given to designers to prove equivalency but the problem is that it is a departure from prescriptive, requirement based process. The non-prescriptive approach challenges building department’s officials leading to inconsistent interpretation and varying attitudes and requirements. From the designer’s point of view it results in uncertainty about what may be required and acts as a deterrent to taking an alternative design approach (Straka, 2007).

6.5 Design process

Surveys of existing projects that focused on component reuse indicate that it is important for the design team to accept that this may require the team to adapt the normal working practices, and be prepared to take the initiative when it comes to overcoming the unpredictable hurdles that may present themselves (Gorgolewski & Morettin, 2009). This is clearly linked to remuneration and design fees, but as noted above, if decisions are made early enough the additional design costs need not be substantial.

Previous experience of design consultants with the use of salvaged materials, or willingness to accept the concept and adapt their processes is important. Some firms hire a specific person to source reused materials. Similarly, the commitment of contractors and sub-contractors to the process is recommended as they can assist or be responsible for the sourcing of suitable materials and components. This may require that contractors become involved during the schematic design/design development phases since material acquisition happens much earlier than for typical projects.

Beyond having potential contractual implications, inexperienced or disinterested contractors may have a negative influence on the project team in their use of pressure tactics such as increasing the construction costs due to ‘unfamiliar practices’ or by not being able to properly locate salvaged/recycled materials. This results in the undermining of the project’s intentions by reverting back to new materials and components, albeit with more familiar methods. Thus, the goals of the project need to be clearly explained to, and embraced by, potential contractors before or during the time of tender or contract negotiation.

For structural components a structural engineer is needed with expertise in appraising the structural potential of salvaged components and, if necessary, defining work to be undertaken to make the structure reusable.. Again however there is the potential issue of an engineer’s reluctance by disputing or dismissing the need to properly assess and approve the conditions of potential materials and components. It may be necessary that other building science expertise be sought to also appraise the existing building services, envelope and other features, and to define work to be undertaken to make them reusable, depending on the scope of the reuse.

6.6 Sourcing reused materials and components

Sourcing salvaged materials requires designers to foster new relationships with organizations they may not traditionally be in touch with. Some demolition contractors, and salvage companies now have sales staff specifically intended to identify and market construction components they have identified as of value to the building industry. These may range from whole buildings, such as prefabricated industrial buildings that can be readily dismantled, to individual components such as beams, stair cases, doors, etc. They often know beforehand when existing buildings are scheduled to be demolished, so establishing contact with them can provide sources for appropriate materials. However, briefing demolition contractors to ensure minimum damage to components scheduled for reuse is sometimes necessary. The UK's National Green Specification (NBS), for example, calls for demolition contractors to indicate what is to be reclaimed and produce a method statement indicating how the goods will be extracted in good condition, palletized and protected during transportation and storage.

Designers may have to visit local used building materials yards, demolition contractors and salvaged materials suppliers to establish general availability and quality of materials, and to discuss the scope of their project and provide a preliminary list of materials that they are looking for. Larger, or more committed design firms are beginning to develop an expertise in locating salvage components, and may have dedicated staff for this purpose.

Local municipal departments may know when demolitions are likely to occur and can direct design teams to potential sources of materials and components. Furthermore, there are an increasing number of locally based materials exchange schemes often web based that provide access to a range of materials sometimes for free.

Both reconditioned goods and recycled content building products (RCBPs) can generally be sources in the same way as regular materials and components, although additional research may be necessary to identify appropriate suppliers. RCBPs and reconditioned goods are generally easier to acquire due to their availability, and can be incorporated and procured in a similar way to new material up to and during the schematic design phase. For reconditioned goods, during schematic design, responsibility for component acquisition would still need to be allocated as there may be additional tasks associated with locating appropriate supplies. It needs to be established who will source the particular components? Will the design team specify the performance requirements and pass this function on to the contractor with a general requirement that reconditioned components should be used, or will the design team locate the specific component? Based on a survey they carried out in Canada Gorgolewski & Morettin, (2009) suggest that in existing projects building components are generally defined by a performance specification and that the contractor is responsible to source the components. This would therefore require that the specification, in addition to a performance statement similar to goods made with new materials, indicate either the amount of recycled content required within the material or that the component be reconditioned.

If the intention is to reuse all or part of an existing building in situ, the search for available existing buildings for reuse in their entirety will need to commence at the pre design stage of the project. Once an existing structure is identified, a full survey of the building to be reused is needed and if possible, original drawings and specifications should be located to assist with identifying potential material re-use opportunities and dismantling efforts.

7 CONCLUSIONS

Increasingly, as we try to make the building industry more sustainable we need to move towards industrial ecology principles of closed loop cyclical systems. Existing buildings should be treated as sources of materials for our future building projects. The conservation of resources and energy in order to prolong life on this planet will demand that we follow this course of action. A design approach that considers the end of the life of a project requires strategies different from those of a conventional project, but it is a feasible, and necessary, alternative which will require that we change the way we approach projects in the future. Reused components have different patterns of availability which need to be accommodated. Also, the limited range of components requires the design team to be more flexible and to develop the building design around the available reused components rather than the traditional process of designing the main features of the building and then identifying the components that will meet the required specifications. This means that ideally the specific reused components need to be identified at an early stage in the design process, perhaps when traditionally a contractor may not yet be involved.

Although designing with reused components may appear problematic, a variety of examples show that suitable technologies are available to building designers to integrate components into buildings that can be readily disassembled and reused. However, it is important that these are considered during the preliminary design stage of the project. Such an approach must be a collaborative effort of the entire design team. When considerations for reuse are implemented early in the design process, cost implications can be negligible. There may be cost benefits. The main considerations which have to be addressed are the longevity of the skin combined with the ease of replacement of its components, flexibility of interior spaces for maximum adaptability, integration of mechanical and electrical systems, and selection of a structural system which allows for strengthening as well as for disassembly. The resulting design encourages adaptive reuse and when that alternative is not feasible, it allows for deconstruction so that the individual building components can be reused.

REFERENCES

Architecture 2030, March 14 (2011). Retrieved from www.architecture2030.org/home/html.

L. Brown, *The state of the world*, Worldwatch Institute, Washington, DC (1990).

CaGBC, *LEED Canada NC 2009*, Canadian Green Building Council, Ottawa (2009).

CCA, *A best practice guide to solid waste reduction*, Standard Construction Document CCA 81, Canadian Construction Association (2001).

E. Durmisevic and K. Yeang, “Designing for Disassembly (DfD)”, *Architectural Design*, 79 (6), 134-137 (2009).

E. Durmisevic and J. Brouwer, *Dynamic versus static building structures*, Delft University of Technology, Netherlands (2002).

D. Ergun and M. Gorgolewski, Quantification and characterization of materials suitable for reuse in Toronto’s wartime housing, *R+R 2013 Reclaim and Remake International Symposium*, Washington, DC, 11-13 April (2013).

M.T. Gorgolewski, V. Straka, J.K. Edmonds and C. Sergio, *Facilitating greater reuse and recycling of structural steel in the construction and demolition process*, Ryerson University report to NRCan and CISC (2006).

M.T. Gorgolewski and L. Morettin, “The process of designing with reused building components”, *CIB115 Construction Materials Stewardship International Conference and annual meeting*, Enschede, The Netherlands (2009).

W. McDonough and M. Braungart, *Cradle to cradle*, North Point Press (2002).

Public Architecture, *Design for reuse primer*, (2010). See: http://www.publicarchitecture.org/reuse/

A. Thomsen and K. van der Flier, “Understanding obsolescence: A conceptual model for buildings, *Building Research & Information*, 39(4), 352-362 (2011).

V. Straka and M. Gorgolewski, “Adaptive building reuse and component reuse”, *1st International Structural Specialty Conference*, Calgary, May (2006).

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APPLICATION OF ISO14001 FOR COMPOSITES WASTE MANAGEMENT

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Abstract. *The European Union Framework Directive identifies waste prevention as the most preferred option in the waste management hierarchy. Innovative waste management methods will have positive impacts on energy consumption. Environmental, social and economic factors, which are the components of sustainability, are drivers for an effective waste management framework in every organisation. The paper discusses a research project which analysed composites of waste management using IS014001.*
Primary data was sourced through preliminary site visits, personal observation and unstructured interviews. Information was also gathered on the various industrial processes of CFRP and GFRP respectively. It involved the monitoring of the production processing and keeping records of the observed factors that contributed to the generation of waste. The attitudinal approach of the employees to waste reduction was also catalogued. The results showed that there was minimal commitment from the board members and the production staff in the area of waste management despite the organisation's compliance with all legal waste management requirements. The production staff are aggrieved because of the lack of incentives from the management and sustainability knowledge is very low among production staff. The research concluded that through imaginative implementation of ISO14001, cost could be saved on the production process as this acts as an incentive for members of staff and helps gain their commitment. It also aids in the promotion of corporate image and leads to an increase in patronage for the organisation. This will in turn help create extra savings for the organisation through reduction in raw materials usage and lesser waste disposal costs.

Keywords: *Sustainability, industrial processing, ISO14001, waste management,*

1 INTRODUCTION

Waste, as a phenomenon is broad in definition and description. It encompasses resources in the environment that is either lost, idle, over consumed or unutilised (Sushil, 2007). Ashby (2009) argues that it is an understatement to say that the natural materials are used for the industrial processing, rather industrial processing is totally dependent on these materials. The present world consumption of natural materials is at a threshold that is diminishing the present quality of life as well as threatening the well-being of future generations (Ashby 2009). The effect of the trend is noticeable on the land where materials are sourced as bi-products of the system. Global average temperature is also projected to rise between 2 and 6°C above pre-industrial level (Smith, 2007). Hyde *et al*, (2011) further elaborated on the components of the environment, which are air, water and land and their influence to the survival of humans. Since the industrial revolution, there has been a massive shift from labour intensive mode of production of goods to the application of machineries for industrial processing. The rise is not unconnected with the continuous rise in the percentage of greenhouse gases in the atmosphere through which more heat is trapped and radiated to the earth. In this context, (Whitelaw,

2004) defined environmental management as the process whereby organisations assess, in a methodical way, the impact of their activities on the natural environment, and take action to minimise these impacts. It is a system that allows organisations to control its environmental impacts and reduce such impacts continuously. Cheremisinoff, *et al* (2001) also viewed environmental management systems as a planning and implementation system employed by an organisation that impacts on the natural environment.

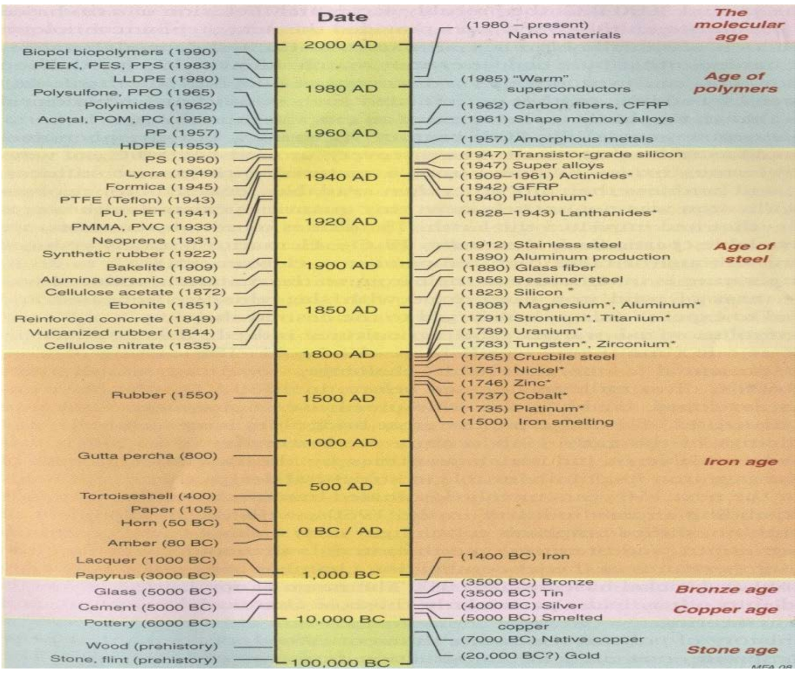

Figure 1: The materials timeline
(Source: Ashby 2009)

Figure 1 shows the shift in the application of materials before and after industrial revolution. It catalogues the timeline in the application of materials in industrial processing which is dated back to 100000BC. The commonly used material in industrial processing was stone. Though stones are sustainable in nature; it can easily be recycled and constitutes high embodied energy in the overall supply chains. The continual reliance on polymer in 2000AD is the results of highly flexibility of the application in tooling, automobile and construction. It is light weight with energy savings in the application. This is evident in auto mobile where the light weight product helps in aerodynamic, which conserve energy. The materials however are sourced from non-renewable and are non-degradable. An effective management strategy requires waste reduction to avoid consequential effects of waste disposal either by landfill or incineration.

It requires regular internal and external audits, through which organisation's measure and monitor their performance and complies with regulations. Edwards (2004) in his work listed reasons an organisation should engage in environmental management which included ethical, economical, legal and commercial performance. Nunes, *et al*, (2010) argues that the public pressure, legislation, possible cost reduction and improved company image constitutes genuine reasons to improve environmental performance. Without an environmental management system (EMS) an organisation can only react to environmental regulations and disasters. The consequences could be disastrous and costly and may involve severe threats of fines and lawsuits as well as undercut by more efficient competitors.

The UK governmental strategy for composites identifies increasing sustainability and recycling as one of the three major goals for the composites industry. Environmental penalties and regulations such as Landfill tax, Pollution Prevention and Control Act, Packaging waste Regulation and Landfill Regulations are all aimed at guiding the impacts of the human activities on the environment (Edwards, 2004). The waste management hierarchy, as established by the EU Framework Directive, identify waste prevention as the most preferred option in waste management. The paper therefore presents a research project which analysed composites waste management using IS014001.

2 RESEARCH METHODOLOGY

Having developed an in-depth theoretical knowledge through the relevant literature review, mixed research method was adopted for the inquiry. The decision on the choice of research method was not made until an overview of research questions was performed and the objectives had been reviewed. The process involved review of literature on sustainability, industrial processing and ISO14001 and waste management. Available data on barriers to the environmental management revealed potential human factors on industrial waste generation. List of corporate organisation, whose activities have significant impact on the exploitation of natural resources and environmental pollution were examined. The cross examination of selected corporate annual report shows minimal compliance with waste management legislation and implementation of ISO 14001.

This informed on the importance of the application of unstructured interview and personal observation on the inquiry. An unstructured interview was conducted based on the observed interaction of employees involved with the production process. The production section is divided into ‘material’ and engineering’ sections and consists of 2 departmental head and 6 machines operators and 3 team leaders. A total of 9 people were interviewed comprising of 3 managers, 3 machines operators and 3 team leaders. The interview was focused on general awareness to climate change, waste management strategy, training on waste management, sustainability, conflict resolution and employees satisfaction. The researcher was involved with the production process for three days within the organisation. During the process random semi-structured interviews were conducted with senior and production staff. It allowed for subjective emphasis on the relevant questions for the research project. This includes employees’ welfare and incentives for continual waste minimisation and collaboration between employees and management. Observation was focussed on attitudinal behaviour, waste segregation, coding of waste collection kits and materials handlings. The method provided an in-depth investigation of production processing within the bigger industrial system. It also provided a great amount of description and details about the relevant stakeholders in the production process.

3 DISCUSSION AND ANALYSIS

The ISO14001 standard specifies the requirements for an environmental management system (EMS) for small to large organisations. An EMS is a systemic approach for handling environmental issues within an organisation. The ISO14001 standard is based on the Plan-

Check-Do-Review-Improve cycle. The Plan cycle deals with the first stages of an organisation becoming ISO14001 compliant and the Check cycle deals with checking and correcting errors. The Do cycle is the implementation and operation of the ISO14001 standard within an organisation. The Review cycle is a review of the entire process by the organisation's top management and the Improve cycle is a cycle that never ends as an organisation continually finds ways to improve their EMS.

Table 1, shows the breakdown of all the input into the production processes and their environmental impact. EMS target is set by the corporate Health and Safety Manager, based on 20% annual reduction target. The objectives being to reduce the environmental impact in the use of raw fibres and to educate the staff on implications of the climate change law and their operations. ISO14001 assessor formulates measurable and achievable goal and targets for organisations. The assessor prepares ‘waste management manual’, after which waste internal audit is carried out. The ‘environmental policy’ is presented on the corporate notice board. Planning and Implementation Procedure’ are prepared in the form of ‘charts’ and a copy were presented to staff member. This cut down bureaucracy in communication and production staffs are fully represented during management review. The standard is integrated with other management functions and helps in meeting environmental and economic goals.

Activities	Environmental aspects	Environmental impacts
Use of paper	Consumption of wood	Little: trees obtained from renewable source. Wastes are recyclable. Recycle becomes difficult if wastes are not segregated
Use of polythene	Extraction from the earth	Non-renewable source. Waste goes to landfill. Waste is non-biodegradable
Polymer	Extraction from the earth	Non-renewable source. Waste go to landfill
Use of carbon fibre	Extraction from the earth	Non-renewable source. Tonnes of waste are generated. Large embodied energy is involved in the supply chain. Carbon waste has a market value only if it is segregated from other industrial waste during the production process, otherwise all wastes go to landfill
Use of glass fibre	Extraction from the earth	Non-renewable source. Tonnes of waste are generated. Large embodied energy. Presently, it is not economical to recycle glass fibre. 100% wastes go to landfill
Energy consumption	Use of resources: Gas & Electricity	Production relies solely on the consumption of non-renewable energy. High carbon emissions during the production. The production requires minimal water demand
Product finishing operations	Production of prepregs composite materials	Application in the production of components, light weight vehicles. The application reduces the consumption of fuel and promotes sustainability
Visual impact	Structures	No visual impact in terms of physical structures
Visual impact/ Nuisance	Gas, smoke, dust	Gas, smoke or dust during the production process are captured from the source
Waste generation	Wastes mixed together	Wastes are not properly segregated from the source. This imposes very high negative environmental impacts because recyclable wastes end up in landfill.

Table 1: Life Cycle Assessment of CFRP and GFRP

This initial environmental review is important in the formulation of the framework as it establishes the relationship between activities of the organisation, the products, services and the environment. It also identifies all the applicable legislation and code of conduct.

The company used for the case study is a leading manufacturer of advanced composite carbon and glass fibre reinforced plastic pre-impregnated materials in a diverse range of industries. The products are used in motorsport, aerospace industry, marine, automotive, construction, wind energy, defence, sports and building construction industries. The company was used since it specialises in the production of components that support sustainable development. The components promote renewable energy generation and low emission in automobiles. The initial investigation revealed that the organisation did not have in place formal waste management policies despite having high volume of recyclable waste that ended up as landfill waste.

Four key areas (Whitelaw K, 2004) were examined namely: examination of existing environmental practices and procedures, identification of significant environmental aspects, assessment of previous incidents and legislative and regulatory requirements.

Examination of existing environmental practices and procedures - The existing environmental practices and procedures are 'informal with no environmental mission statement or measurable target. There was also no corporate statement on waste management and no segregation on both the recyclable and non-recyclable wastes that go to land fill site. Production staffs lack basic training in sustainability. In fact 85% of the respondents knew little or nothing about climate change phenomenon.

Identification of significant environmental aspects - The volume of wastes that are being disposed on landfill are significantly being reduced as a result of segregation of recyclable wastes from the source, including wood, papers and unprocessed carbon fibres.

Assessment of previous incidents - There was no recorded incidence on the violation of environmental law. Both the liquid and solid wastes were disposed in a safe procedure, which complied with legal requirement and procedure.

Legislative and regulatory requirements - The new regulation on 'Carbon Disclosure Protocol' imposes challenges on the organisation with regards to the overall carbon prints on energy consumption and the waste disposal. The minimum legal requirements are being adhered to by the organisation.

The site investigated is involved in the production of Carbon Fibre Reinforced Polymer (CFRP) and Glass Fibre Reinforced Polymer (GFRP) which are reinforced plastic prepregs. Prepregs is a common term for "pre-impregnated" fibres composites. Gil (1972) describes pre-impregnated fibre as products that contain fibres which had been coated with matrix but has not been fully cured. The flexibility of the aggregate allows for engineering applications, especially where complex engineering shapes are required. The aim here is to achieve an effective and continuous fibres waste management policy through ISO14001. The fibres waste is made up of 'prepregs', unprocessed fibres and finished composites products. The organisation and management of waste products revolves around the following raw materials:

- Woven and Uni-Directional glass fibre fabric
- Woven and Uni-Directional carbon fibre fabric
- Paper
- Polythene
- Release paper
- Coated paper

Usually a large quantity of variables has to be passed through the entire production process. Figure 2 represent resources that were input into the process besides energy and raw materials.

Raw materials like glass and carbon fibres are input into the production process in the form of woven or uni-directional fabric. This is determined by the required mechanical properties and job specifications.

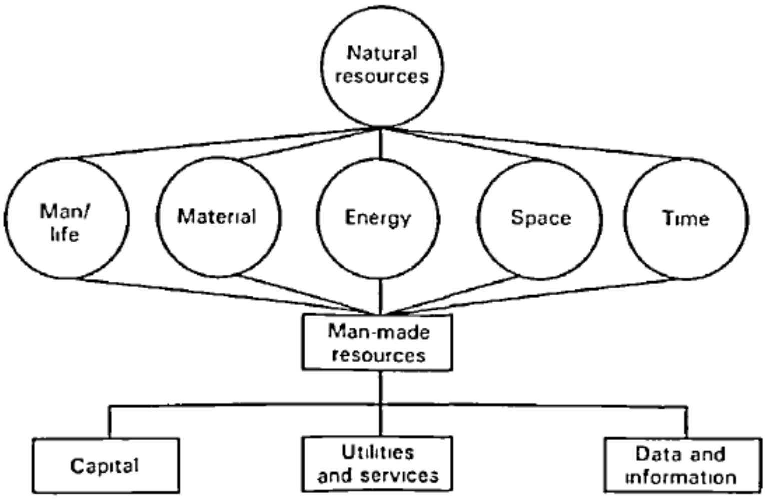

Figure 2: Basic production resources
(Source: Sushil, 2007)

The production stages start with the input of design plans into the computer, which send the patterns to ‘prepreg cutting machine’. During the moulding process (figure 3), pressure is applied to the prepregs that are mounted on the mould to consolidate the lamination process. Autoclave mould is placed in the oven to initiate and maintain the curing reaction.

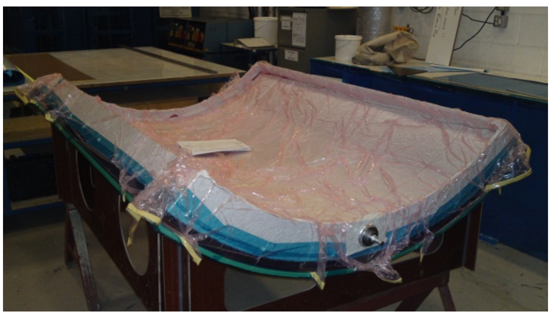

Figure 3: Vacuum bagging and autoclave moulding

Figure 4, shows how the recycled fibres are degraded in quality. This figure shows low quality of recycled carbon fibres composites. Disposal of this type of degraded materials by landfill is harmful to the environment and not economical.

During the interview, it was stated by the Health and Environmental manager of the company that the organisation did recognise the impact that their actions have on the environment in the use of raw materials for industrial processes and the wastes that are generating. The company however has in place a well-developed environmental policy for composite wastes management that seek to reduce the amount that is generated.

There is an effective waste recycle system through waste segregation from the source.. There is also a commitment by the company to educate and train employees, thereby enabling them to work within the corporate environmental policy.

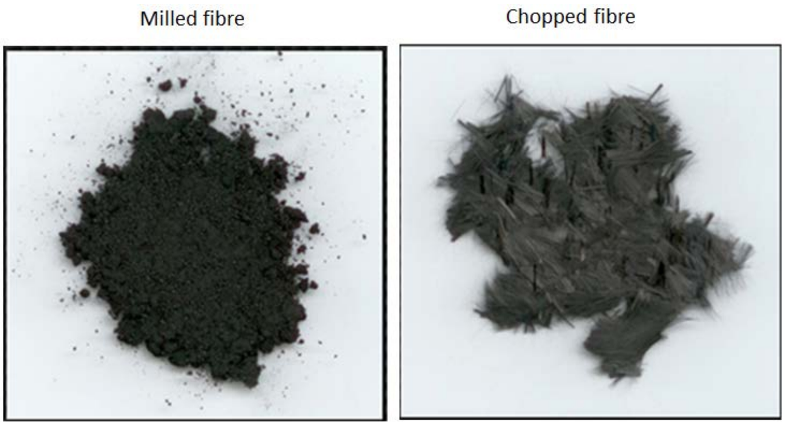

Figure 4: Recycled carbon fiber
Sources: ELG Carbon fibre ltd: (www.elgcgf.com/product-range.html)

It is believed that this action helped in reducing the demand for the raw materials and in energy during production. Information gathered however, revealed that the top management priority was focused on the quality of finished products. This was evidenced in the huge investment on high-tech machineries and equipment. Wastes in the organisation are generated mostly by culpable acts of the employees and unused finished products rather than on waste management. The production staff commitment to waste management were however compromised by lack of motivation from the top management, bureaucracy, inadequacy in the provision of modern facilities for the segregation of waste, non-availability of documentation on waste generation and shallow understanding of environmental management issues. During the interview also, it was established that only the health and safety manager had once been sponsored by the organisation on environmental management training.

The data from the interview with machine operators shows that there was no clear company policy statement on the impact of composites waste. There was also no statement or procedure in place specifically focused on waste management or defined roles and responsibilities on all stakeholders in the production process to minimise impacts of the activities on the environment and commitment for continual improvement.

There was clear evidence of non-commitment from the top management towards EMS as there were no measurable EMS objectives and targets and no representative monitoring company's activities on a regular basis. There was also inadequate provision of bins with appropriate colour code and no motivation from the production staff. The health & safety manager however, provided information on the volume of waste that is generated monthly.

4 CONCLUSION AND RECOMMENDATIONS

Environmental performance assessment template such as ISO14001 provides a medium for continual improvement on waste management, which on its own is a long term investment for a corporate organisation. Reduction in volume of waste will save cost on waste disposal in the long term.

At the conceptual stage of the inquiry, the organisation annual cost for waste disposal and energy bills was estimated to be between £70,000.00 and £750,000.00. Reduction in the volume of waste will not only reduce the cost of energy bill but the overall cost of production. Volume of waste is directly linked to lack of training and education on the environmental management.

The success of the ISO14001 is dependent on the commitment of the top management and cooperation of the production staffs. Senior management is responsible for the creation of enabling working environment through the provision of resources for waste segregation. It is important that effective environmental policy is communicated to employees and copies of the policy presentation in a simple and friendly manner. The policy could be displayed on the notice board which would be used to update staff on the progress of the waste reduction strategies. It is important also to show statistical figures on a monthly basis on all wastes generated to help inform staff of the improvement made on waste segregation strategies and on the effectiveness of the waste management strategies and the improvement to the programme.

The ISO14001 standard presents a unique methodological framework for the design and the implementation of an effective environmental management system. The initial environmental review is important in the formulation of ISO14001 framework as it establishes the relationship between activities of the organisation, the products, services and the environment and helps in identifying all the applicable legislation and code of conduct. The adoption of the guideline for the implementation was based on a simple but expanded interlinks phases through which organisational environmental management could be accessed and improved upon continually. The requirement in each phase was critical in this exercise.
Literature in this area reveals both tangible and intangible benefits that an organisation would derive from the implementation. In the context of the inquiry, ISO 14001 models can best be described as a strategy to achieve continual reduction in quantity and quality of composite waste. There are various models for the implementation of EMS and a key area for improvement in many companies is the requirement for the environmental management to be taken using a systemic approach, i.e. analysing how decisions will impact not only on environmental aspects but also on the overall business and operations strategy. The success of the ISO14001 is dependent on the commitment of the top management and cooperation of the production staffs. Investment on ISO14001 will potentially give large rewards to organisations implementing it in the long term. Senior management is responsible for the creation of an enabling working environment through provision of the required tools and equipment for waste segregation. The research also demonstrates that legal requirements can only achieve minimal reduction in waste reduction in an organisation.

It is recommended that the IS014001 policy once formulated is reviewed at least once every six month in order to update new legal requirements to maintain a continual improvement. Management review should also be carried out on monthly basis.

It should be emphasised that the conclusion drawn from this study is based on a limited sample response from one leading manufacturer and therefore, maybe biased. For this reason, further on-going research based on large-scale survey is continuing.

REFERENCES

A. J. Edwards, *ISO 14001 Environmental Certification Step by Step. Oxford*, Elsevier Butterworth-Heinemann (2004).

B. Nunes and D. Bennett, *Green operations initiatives in the automotive industry; an environmental reports analysis and benchmarking study*. An International Journal Vol. 17 No. 3, 2010 pp. 396-420. Publisher Emerald Group Publishing Limited (2010).

K. Whitelaw, *ISO 14001 Environmental Systems Handbook (2nd ed).* Oxford, Elsevier Butterworth-Heinemann (2004).

M.F. Ashby, (2009) *Materials and the Environment; Eco-Informed Material Choice*, Oxford. Butterworth-Heinemann (2009).

M.R. Gil, *Carbon Fibres in Composite Materials*. London, The Butterworth Group (1972).

N. P. Cheremisinoff and A. Bendavid-Val, *Green Profits; The Manager's Handbook for IS014001 and Pollution Prevention.* Burlington, Butterworth-Heinemann (2001).

P. F. Smith, *Sustainability at the Cutting Edge; Emerging Technologies for low energy buildings* Elsevier (2007).

P. Hyde and P., *Reeve Essentials of Environmental Management (3rd ed).*Wigston, IOSH Services Limited (2011)

Sushil, *Waste Management: A Systems Perspective*. Emerald Backfiles (2007).

ADDRESSING EMBODIED ENERGY FROM A CONTRACTOR'S PERSPECTIVE

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Abstract. *Despite the need for enhanced energy efficiency within the UK non-domestic sector, it seems limited effort is currently directed towards reducing embodied energy as opposed to operational energy levels. Embodied energy relates to the indirect and direct energy inputs required for various forms of construction. Contractors have a vested interest within embodied energy performance due to their significant involvement within project procurement, pre-construction and on-site construction activities. The key challenges and opportunities are investigated for addressing embodied energy levels within UK non-domestic projects from a contractor's perspective. A case study containing two desk studies is presented. The first desk study reviewed the relative significance of individual life cycle energy phases within existing LCA studies, whereas the second desk study appraised the practical challenges within a large UK principal contractor's on-site current practices to support an embodied energy assessment. Weaknesses are identified within existing LCA studies which makes it difficult to understand the significance of individual life cycle energy phases and help formulate energy reduction targets for future projects. Findings identified at present the fragmented nature of data presented within LCA studies and the contractor current practices limits project decision makers to fully understand the implications of potential design or material changes in terms of total project life cycle energy.*

1 INTRODUCTION

There is a current requirement within the UK non-domestic sector to enhance energy efficiency. The sector is accountable for 18% of the UK's total CO_2 emissions (operational and embodied) (BIS 2010; Carbon Connect 2011). Project life cycle energy is derived from operational energy and embodied energy (Dixit et al. 2012). At present there is limited data which supports the capture and assessment of embodied energy throughout the construction process (Van Ooteghem and Xu 2012). A contractor is typically responsible for pre-construction and on-site construction activities; all of which can influence project life cycle energy (Li et al. 2010). Traditionally clients are focused towards reducing project operational energy use, though it seems contractors have a vested interest within embodied energy levels due to their role within project procurement. It appears improved knowledge and opportunities to reduce overall project life cycle energy could be obtained if energy consumption per individual life cycle phase and the relationship between them is reviewed

(Optis and Wild 2010; Ramesh et al. 2010). Therefore, this research aims to investigate the key challenges and opportunities for addressing embodied energy levels within UK non-domestic projects from a contractor's perspective.

2 ROLE OF THE CONTRACTOR

The construction of a building includes activities such as planning, design, on-site construction, operation and maintenance. Generally, the contractor is responsible for pre-construction (i.e. selecting construction methods) and on-site construction activities (i.e. installation of building materials and services) (Li et al. 2010). Though, the role of the contractor and their influence over design varies according to the particular project procurement method. During the 'traditional method' of procurement the architect is expected to have completed the design before the contractor gets involved, leading to detailed prescriptive specifications being produced that limits the flexibility of the contractor to involve their own supply chain. In contrast, the 'design-and-build method' provides the contractor with opportunities to involve their own supply chains earlier during design development and 'value engineer' designs to reduce potential project design risk (Latham 1994; Hamza and Greenwood 2009).

3 DEFINING AND ASSESSING EMBODIED ENERGY

There is an increasing need to assess the environmental impact of projects through a life cycle perspective. Operational energy relates to energy use during building occupier activity, whereas embodied energy relates to energy use within the extraction, manufacture, transportation and assembly of raw materials required for construction, renovation, maintenance, refurbishment, modification and demolition (Dixit et al. 2012; RICS 2010). Embodied energy can be separated into initial, recurring and demolition embodied energy. In particular interest of a contractor, initial embodied energy includes energy use during material (i.e. procurement of raw materials), transportation (i.e. transport of project resources such as materials, plant and equipment, and operatives), and construction (i.e. on-site assembly) life cycle phases up to project practical completion (Cole and Kernan 1996; Chen et al. 2001).

Generally, challenges and opportunities to tackle project life cycle energy are highlighted through a Life Cycle Assessment (LCA) which is defined as a *"compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle"* (British Standard 2006:2). Traditionally embodied energy is expected to represent a smaller proportion of project life cycle energy as opposed to operational energy, though some studies have recognised the proportional relationship between operational and embodied energy levels can differ depending on certain project characteristics (i.e. project type, location and environmental agenda) (Thormark 2002; Gustavsson et al. 2010; Ramesh et al. 2010). Capturing embodied energy data appears difficult namely due to project nature, timescale and complexity; hence currently there is no standardised method for capturing data throughout the whole construction process (Langston and Langston 2008; Van Ooteghem and Xu 2012). Practitioners commonly rely on project data derived from contractor and supply chain current practices in order to assess embodied energy levels (Kofoworola and Gheewala 2009; Chang et al. 2012).

4 DRIVERS FOR CONTRACTORS

4.1 Policy and Legislative

The European Union (EU) and the UK government have recently established numerous measures intended to drive Greenhouse Gas (GHG) (namely CO_2) and energy consumption reduction within the UK non-domestic sector. The EU Renewable Energy Directive, the Energy Performance of Buildings Directive (EPBD), the UK Low Carbon Transition Plan (LCTP), the Climate Change Act 2008, and the UK Building Regulations are to name a few (Legislation 2008; DECC 2009; DIAG 2011). However, these measures are primarily focused towards reducing operational impacts, overlooking embodied impacts. Nonetheless, recent evidence suggests a change in focus is likely in the future as operational impacts are expected to reduce over time owing to increased energy efficiency and effective building design, thus increasing the significance of embodied impacts (Fieldson and Rai 2009; BIS 2010; Rai et al. 2011).

4.2 Financial and Business

Due to future energy price rises UK contractors are more conscientious of the need to reduce energy demand and improve the energy efficiency of their operations (SFfC, 2010). The introduction of carbon taxation through the Carbon Reduction Commitment (CRC) Energy Efficient Scheme has emphasised that the cost of poor energy efficiency is likely to escalate in the future (Carbon Connect, 2011). The CRC enables contractors to consider a proportion of project life cycle energy due to the capture and assessment of fuel consumption on-site. Moreover, in recent years, contractors have focused efforts towards reducing their CO_2 and energy consumption levels and encouraging supply chains to follow suit in order to ascertain repeat business (SCTG 2002; Bansal and Hunter 2003; BIS 2010).

5 CHALLENGES FOR CONTRACTORS

5.1 Financial and Business

Seemingly the environmental practices currently undertaken by project decision makers are insufficient towards reducing CO_2 emissions (Morton et al. 2011) and it seems environmental practices are only adopted if they are financially viable (Sodagar and Fieldson 2008). During a price sensitive market, manufacturers have little incentive to develop products, materials or renewables which are vastly more efficient than their competitors (Hinnells 2008). Nonetheless, due to high energy prices and the lack of legislative measures surrounding renewable technologies, improved energy efficiency from building services is more economically attractive to a client than a wide application of renewables (Tassou et al. 2011). Even though embodied impacts can increase due to the installation of energy efficient building services, Halcrow Yolles (2010) argued embodied impacts cannot be justified as a reason not to install renewable technologies.

5.2 Design and Technical

Currently there are multiple schemes and standards available intended to support environmental reporting and management, though the wide variations within these measures make it difficult to evaluate the environmental impact of key project stakeholders (IEMA

2010; Carbon Connect 2011). The inconsistency has created unfamiliarity throughout the supply chain as designers are unsure about the impact of their decisions (BIS 2010). Hence, there is a clear need for improved awareness of the implications of building design towards project life cycle impacts. It seems the choice of building material can significantly influence project embodied and operational impacts (Halcrow Yolles 2010).

At present within the UK construction industry it seems there is a deficiency of available, robust project data which provides awareness of how energy is consumed within different building types across various project life cycles (Dixit et al. 2012). Buildings themselves provide the biggest obstacle as they are complex in terms of form, function, life span, and end user requirements (Scheuer et al. 2003; Van Ooteghem and Xu 2012).

6 OPPORTUNITIES FOR CONTRACTORS

6.1 Financial and Business

Contractors are influential towards promoting sustainable development due to their responsibility and impact on society and the environment. Despite compliance with environmental regulation being portrayed as a costly action, contractors can obtain enhanced environmental protection, increased competitiveness and improved environmental performance (SFfC 2008; Tan et al. 2011).

Globalisation has encouraged contractors to create vast networks of suppliers and distributors intended to improve the efficiency of material, labour and energy use. Increased cooperative relationships with suppliers can enable contractors to increase their ability to manage environmental issues more effectively; empowering contractors to improve quality and become future industry leaders (Lee 2010; Parmigiani et al. 2011). If contractors are more forceful towards encouraging clients to adopt environmental practices this could support enhance stakeholder relationships, company profile, reputation, and competitive advantage (Hirigoyen et al. 2005; Morton et al. 2011). Moreover, due to contractor involvement within project procurement multiple advantages can be obtained from reducing project transportation requirements, such as: reduced fuel and delivery costs; increased delivery reliability; reduced cost for parking; and increased profitability (BRE 2003).

6.2 Design and Technical

Previous research has highlighted the importance of the design stage when tackling the project embodied impacts (Scheuer et al. 2003; Goggins et al. 2010). The design stage provides project decision makers with an opportunity to consider both embodied and operational impacts through the principle of bioclimatic design and selection of low carbon materials and energy efficient building services (Halcrow Yolles 2010; Rai et al. 2010). A reduction in embodied energy can be obtained through the incorporation of waste minimisation, reduced material use, increased recycled content and specifying materials with low embodied impact per weight (Chen et al. 2001; Harris 2008; Rai et al. 2010). The choice of material can not only influence embodied impacts, but also construction methods, operational use, maintenance cycles and building life span (Fieldson and Rai 2009).

If a contractor can manage the construction process in a safe, efficient and effective manner, this will provide opportunities to save time and cost affiliated to fuel usage and logistics (Sodagar and Fieldson 2008). The efficient use of plant and equipment during on-site construction can provide savings in fuel use, cost and improve site safety. An earlier connection to the national electricity grid can provide savings in fuel use, security costs, space required for generators, and improve site safety (RICS 2008; Ko 2010). In addition, a contractor can reduce temporary site accommodation energy requirements if accommodation is well designed, positioned and managed. The use of energy efficient site accommodation can increase operative comfort levels, productivity and reduce absenteeism (Ko 2010).

7 METHOD

The research applied a case study methodological approach consisting of two desk studies. The first desk study was based upon a review of existing LCA studies which focused towards embodied energy assessment. This review aimed to highlight the extent of existing knowledge surrounding the relative significance of individual life cycle energy phases. The second desk study was undertaken within a large principal contractor based in the UK. A series of current practices employed by the contractor during the construction phase of a UK non-domestic sector project were appraised post-construction. This appraisal aimed to determine the practical challenges surrounding the contractor's current practices towards potentially supporting an embodied energy assessment within future projects. The explored UK non-domestic sector project was a recently finished design and build industrial warehouse located within the south of England.

8 RESULTS AND DISCUSSION

8.1 Review of existing LCA studies

It was previously highlighted improved knowledge and opportunities to reduce overall project life cycle energy could be obtained if energy consumption per individual life cycle phase and the relationship between them is reviewed (Optis and Wild 2010; Ramesh et al. 2010). Hence, attempts were made to highlight the relative significance of individual life cycle energy phases and identify areas of improvement within industry knowledge.

A total of 16 existing LCA case studies which focused towards embodied energy assessment were reviewed. These studies varied in terms of project scope, type and geographical location. Attempts were made to focus on non-domestic sector projects although a significant proportion of existing LCA studies have assessed residential buildings (Adalberth 1997; Fay et al. 2000; Chen et al. 2001; Mithraratne and Vale 2004) hence this data was also considered to potentially highlight the significance of project type. Table 1 illustrates the impact of total project or specific construction materials in terms of individual project life cycle phases (i.e. material, transportation, and construction), total embodied energy, or total life cycle energy levels (i.e. embodied plus operational energy). Evidently, limited studies illustrated impacts relative to individual project life cycle phases. Although the review did highlight the impact of transportation and construction energy as small in comparison to material related energy, as supported by Adalberth (1997), Cole (1999), Chen et al. (2001) and Gustavsson et al. (2010). Each study differed significantly in terms of parameters such as the selection of system boundaries, calculation methods and data sources. Hence it is difficult to understand or even compare data amongst similar project types, which is an issue previously highlighted by Optis and Wild (2010) and Dixit et al. (2012). Nonetheless, a wide range of inconsistent values were used to portray the significance of embodied energy relative to total project life cycle energy across assorted project types. For instance, Scheuer et al. (2003) suggested embodied energy represents 2.2% of total project life cycle energy for an educational building within USA whereas Huberman and Pearlmutter (2008) reported embodied energy represents 60% of total project life cycle energy for an apartment building within Israel. Overall, the varied format of data presented within the existing LCA case studies (Goggins et al. 2010) seems to limit the use of existing knowledge to formulate robust benchmarks and targets for future energy reduction within construction projects, which is a impending requirement supported by BIS (2010).

8.2 Appraisal of contractor current practices

In line with existing LCA studies, contractor current practices which provided information suitable to assess the embodied energy performance of the project (material characteristics, transport vehicle type, transport distance travelled, on-site fuel type and consumption etc.) were appraised. It was discovered the contractor used a programme of works (PoW) in order to help coordinate the development and delivery of the project. Although, there was no direct link between the construction activities and the sub-contractors responsible for their completion within the PoW. Hence, as all other current practices captured data relative to sub-contractors not construction activities, it seems the PoW provides limited use to help coordinate the capture of data relative to certain construction activities. Additionally, the contractor used a plant register in order to document and maintain the operational performance of on-site plant and equipment. The information captured from the sub-contractors, which used on-site plant and equipment, varied significantly in terms of content, detail, legibility and terminology. It was discovered there was no clear correlation between the plant and equipment used and the specific construction activities undertaken by the sub-contractors. Moreover, the bill of quantities (BoQ) and design drawings were used by the contractor to coordinate project cost and design and also provide information on material characteristics and specification. Although, it appeared the material characteristics within these current practices was displayed in no consistent format (i.e. mm, m, m^2, m^3, tonne, kg) which could be used to compare against data within existing LCA studies.

The contractor used two versions of sign-in sheets; one version was used to capture operative man-hours and man-days per sub-contractor whereas the other version was used to capture visitor and material transport to and from site. Both versions captured a varied degree of complete, valid information. It could be argued the mixed success of the sign-in sheets was due to their respective locations. Both sheets were located within the contractor’s on-site accommodation though, as opposed to the operative entrance, the material delivery entrance was the other side of the site. Furthermore, the contractor used a unique management procedure intended to capture and assess fuel consumption during on-site construction. It was discovered the data captured from the sub-contractors was not examined in the same manner as the contractor’s personal data (i.e. limited fuel delivery tickets provided). Hence, vast ambiguity surrounding sub-contractor data was discovered in terms of the quantity of fuel delivered, when fuel was delivered and how much fuel was consumed during periodic intervals.

MAT[1]	TRAN[1]	CON[1]	Total EE[1]	Total OP[1]	Pro Type	Results per…
			15% LCE		Dwelling	Total Project
10% LCE	<1% LCE	1% LCE		85% LCE	Dwelling	Total Project
90% EE	4% EE	6% EE	6.3 GJ/m^2		Educational	Total Project
90.7% EE	7.4% EE	1.6% EE			Residential	Total Project
		8-20 MJ/m^2			Multi Office	Timber Frame
		3-7 MJ/m^2			Multi Office	Steel Frame
		20-120 MJ/m^2			Multi Office	Conc' Frame
			4.54 GJ/m^2		Multi Office	Timber Frame
			5.13 GJ/m^2		Multi Office	Steel Frame
			4.79 GJ/m^2		Multi Office	Conc' Frame
	5-8% LCE				Multi Office	Conc' Frame
			10.1 GJ/m^2		Commercial	Total Project
			8.0 GJ/m^2		Commercial	Total Project
			6.9 GJ/m^2		Residential	Total Project
			14.1 GJ/m^2		Residential	Total Project
			975kWh/m^2		Apartment	Timber Frame
			60% LCE	40% LCE	Apartment	Total Project
			8.0 GJ/m^2		Apartment	Total Project
			15% LCE	81% LCE	Office	Total Project
16.8% LCE	0.6% LCE				Office	Total Project
			6.8 GJ/m^2		Office	Total Project
			4.4-5.0 GJ/m^2		Dwelling	Total Project
			34% EE		Dwelling	Floor
			43% EE		Dwelling	Walls
			38% EE		Dwelling	Roof
			5.7-8.2 GJ/m^2		Dwelling	Total Project
31% EE					Warehouse	Steel Frame
17% EE					Warehouse	External Wall
2% LCE	0.1% LCE	0.1% LCE	7.0 GJ/m^2		Educational	Total Project
			2.2% LCE	97.7% LCE	Educational	Total Project
			40% LCE	60% LCE	Apartment	Total Project
			9% LCE	91% LCE	Retail	Total Project
			52% EE		Retail	Roof
			9% EE		Retail	Frame
			13% EE		Retail	Foundations

(cradle-to-end of life); EE, Embodied Energy.

Table 1: Review of 16 exisitng LCA studies

Overall, based upon the type and level of data captured within the current practices it seems difficult at present for the contractor to truly evaluate the embodied impact of different aspects of a building. It appears the inconsistencies within the data make it difficult for any decision maker to accurately understand the significance of potential design or material changes, an issue acknowledged by BIS (2010) and Halcrow Yolles (2010). In addition the lack of a clear relationship between data, sub-contractors and construction activities seems to limit the possibility of formulating energy reduction targets for future projects (BIS 2010).

9 CONCLUSIONS

The research investigated the key challenges and opportunities for addressing embodied energy levels from the perspective of a large principal contractor based in the UK. The initial desk study highlighted the need for improved consistency within LCA studies in order to better understand the relative significance of individual life cycle energy phases and the relationship between them. As noted by literature, this could potentially highlight improved knowledge and opportunities to reduce total project life cycle energy. Though, due to the inconsistent research approaches and data format, it seems difficult at present to use knowledge within existing LCA case studies to help formulate robust benchmarks and targets for future energy reduction within construction projects.

From the findings it seems likely contractors could potentially lead the industry towards improved embodied energy awareness simply due to their significant involvement within project procurement. However, from the second desk study it appears significant changes are required to contractor current practices in order to improve their overall usefulness, in particular: linking sub-contractors to construction activities within the programme of works; maintaining consistent terminology within the plant register; capturing improved transportation data within sign-in sheets.

Evidently, it seems the fragmented nature of data present within LCA studies and the contractor current practices makes it difficult at present for project decision makers to fully understand the implications of potential design or material changes in terms of total project life cycle energy. Hence, considering the research findings and current knowledge within literature, there appears to be limited understanding of the possible implications which could occur from targeting improved embodied energy efficiency throughout different project life cycle phases. Attempts to reduce embodied energy of a particular building aspect (i.e. frame, roof, external walls) could lead to material transportation difficulties and changes in the impact of different project life cycle phases. Design changes intended to provide clients with improved operational energy efficiency could impact a contractor’s control over procurement and construction methods in addition to overall building maintenance cycles and life span. Nonetheless, it seems the current lack of UK legislative measures is impeding embodied energy consideration throughout the construction process.

REFERENCES

K. Adalberth, “Energy use during the Life Cycle of Buildings: a Method”, *Building and Environment*, **32(**4), 317-320 (1997).

P. Bansal and T. Hunter, “Strategic explanations for the early adoption for ISO 14001”, *Journal of Business Ethics*, **46**, 289-299 (2003).

British Standard, *BS EN ISO 14044:2006 Environmental management. Life cycle assessment. Requirements and guidelines*, The British Standards Institution, London (2006).

Building Research Establishment (BRE), *Construction site transportation: the next big thing*, Building Research Establishment, Watford (2003).

Business, Innovation and Skills (BIS), Low carbon construction, innovation and growth team, final report, BIS, London (2010).

Carbon Connect, *Energy efficiency, the untapped business opportunity*, Carbon Connect, London (2011).

Y. Chang, R. Ries and S. Lei, “The embodied energy and emissions of a high-rise education building: A quantification using process-based hybrid life cycle inventory model”, *Energy and Buildings*, **55**, 790-798 (2012).

T. Chen, J. Burnett and C. Chau, “Analysis of embodied energy use in the residential building of Hong Kong”, *Energy*, **26**, 232-340 (2001).

R. Cole and P. Kernan, “Life-cycle energy use in office buildings”, *Building and Environment*, **31**(4), 307-317 (1996).

R. Cole, “Energy and greenhouse gas emissions associated with the constriction of alternative structural systems”, *Building and Environment*, **34**(3), 335-348 (1999).

R. Crawford, “Validation of hybrid life-cycle inventory analysis method”, *Journal of Environmental Management*, **88**, 496-506 (2008).
Department of Energy and Climate Change (DECC), “The UK Low Carbon Transition Plan, National strategy for climate change and energy”, DECC, London (2009).
Directive Implementation Advisory Group (DIAG), *Building Performance Directive Implementation Advisory Group* (2011), Available: http://www.diag.org.uk/.
M. Dixit, J. Fernandez-Solis, S. Lavy and C. Culp, “Need for an embodied energy measurement protocol for buildings: A review paper”, *Renewable and Sustainable Energy Reviews*, **16**, 3730-3743 (2012).
R. Fay, G. Treloar and U. Raniga, “Life-cycle analysis of buildings: a case study”, *Building Research & Information*, **28**(1), 31-41 (2000).
R. Fieldson and D. Rai, “An assessment of carbon emissions from retail fit-out in the United Kingdom”, *Journal of Retail & Leisure Property*, **8**, 243-258 (2009).
J. Goggins, T. Keane and A. Kelly, “The assessment of embodied energy in typical reinforced concrete building structures in Ireland”, *Energy and Buildings*, **42**, 735-744 (2010).
L. Gustavsson, A. Joelsson and R. Sathre “Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building, *Energy and Buildings*, **42**, 230-242 (2010).
Halcrow Yolles, “Embodied Carbon Sustainable Offices: a supplementary report”, Swindon: Halcrow Yolles (2010).
N. Hamza and D. Greenwood, “Energy conservation regulations: Impacts on design and procurement of low energy buildings”, *Building and Environment*, **44**, 929-936 (2009).
M. Hinnells, “Technologies to achieve demand reduction and microgeneration in buildings”, *Energy Policy*, **36**, 4427-443 (2008).
J. Hirigoyen, G. Chant-Hall and S. Reid, S, *Investing in tomorrow’s company: Improving sustainability communications between real estate and construction companies and the investment community*, CIRIA, London (2005).
N. Huberman and D. Pearlmutter, “A life-cycle energy analysis of building materials in the Negev desert”, *Energy and Buildings*, **40**, 837-848 (2008).
Institute of Environmental Management and Assessment (IEMA), *Special report*, GHG Management and Reporting, Lincoln (2010).
J. Ko, *Carbon: Reducing the footprint of the construction process*, Construction Products Association, London (2010).
O. Kofoworola and S. Gheewala, “Life cycle energy assessment of a typical office building in Thailand”, *Energy and Buildings*, **41**, 1076-1083 (2009).
Y. Langston and C. Langston, “Reliability of building embodied energy modelling: an analysis of 30 Melbourne case studies”, *Construction Management and Economics*, **26**(2), 147-160 (2008).
M. Latham, *Constructing the team: Final report of the government/industry review of procurement and contractual arrangements in the UK construction industry*, HMSO, London (1994).
K. Lee and R. Ball, “Achieving sustainable corporate competitiveness: strategic link between top management’s (green) commitment and corporate environmental strategy”, *Greener Management International*, **44**, 89-104 (2003).
Legislation, *Climate Change Act*, (2008). Available: http://www.legislation.gov.uk/ukpga/2008/27/contents

X. Li, Y. Zhu and Z. Zhang, "An LCA-based environment impact assessment model for construction processes", *Building and Environment*, **45**, 766-775 (2010).

N. Mithraratne and B. Vale, "Life cycle analysis model for New Zealand houses", *Building and Environment*, **39**, 483-492 (2004).

J. Monahan and J. Powell, "An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework", *Energy and Buildings*, **43**(1), 179-188 (2011).

A. Morton, P. Bretschnedier, D. Coley and T. Kershaw, "Building a better future: An exploration of beliefs about climate change and perceived need for adaptation within the building industry", *Building and Environment*, **46**, 1151-58 (2011).

M. Optis and P. Wild, "Inadequate documentation in published life cycle energy reports on buildings" *The international Journal of Life Cycle Assessment*, **15**(7), 644-651 (2010).

A. Parmigiani, R. Klassen and M. Russo, "Efficiency meets accountability: Performance implications of supply chain configuration, control, and capabilities", *Journal of Operations Management*, **29**, 212-223 (2011).

D. Rai, B. Sodagar, R. Fieldson and X. Hu, "Assessment of CO2 emissions reduction in a distribution warehouse", *Energy*, **36**, 2271-77 (2011).

T. Ramesh, R. Prakash and K. Shukla, "Life cycle energy analysis of buildings: An overview", *Energy and Buildings*, **42**, 1592-1600 (2010).

Royal Institution of Chartered Surveyors (RICS), "Redefining Zero", RICS, London (2010).

C. Scheuer, G. Keoleian and P. Reppe, "Life cycle energy and environmental performance of a new university building: modelling challenges and design implications", *Energy and Buildings*, **35**(10), 1049-1064 (2003).

B. Sodagar and R. Fieldson, "Towards a sustainable construction practice", *Construction Information Quarterly (CIQ)*, **10**(3), 101-108 (2008).

Strategic Forum for Construction & Carbon Trust (SFfC), *Construction carbon 15% target by 2012: Scoping paper*, (2010) Available: http://www.strategicforum.org.uk/pdf/0010%20SFfC%20Carbon%20Trust%20scoping%20paper%20Rev%20A%20for%20public%20release.pdf.

Sustainable Construction Task Group (SCTG), *Reputation, risk and reward: The business case for sustainability in the UK property sector* (2002). Available at: http://projects.bre.co.uk/rrr/RRR.pdf

Y. Tan, L. Shen, and H. Yao, "Sustainable construction practice and contractors' competitiveness: A preliminary study", *Habitat International*, **35**, 225-230 (2011).

S. Tassou, Y. Hadawey and D. Marriott, "Energy consumption and conservation in food retailing", *Applied Thermal Engineering*, **31**, 147-156 (2011).

C. Thormark, "A low energy building in a life cycle - its embodied energy, energy need for operation and recycling potential", *Building and Environment*, **37**(4), 429-35 (2002).

K. Van Ooteghem and L. Xu, "The life-cycle assessment of a single-storey retail building in Canada", *Building and Environment*, **49**, 212-226 (2012).

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ASSESSING BUILDING PERFORMANCE: DESIGNED AND ACTUAL PERFORMANCE IN THE CONTEXT OF INDUSTRY PRESSURES.

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Abstract. *This paper explores the relationship between designed and actual building performance as represented in an RIBA and CIBSE backed web-based comparison platform and the industry perception of the pressures surrounding building performance assessment. European directives and UK parliamentary acts have made reductions in building related carbon emissions a necessity and has resulted in the implementation of a range of mechanisms aimed at encouraging monitoring of energy consumption, responsive management and evidence based design. Web-based feedback platforms aim to pass evaluation data back to industry anonymously to address the energy gap at design stage. However, there exists a range of barriers and disincentives that prevent widespread and habitual engagement with building evaluation. Using data from the CarbonBuzz platform and a series of semi-structured interviews, a mixed-methods study has been carried out. Analysis of the characteristics of the existing energy discrepancy between designed and actual performance shows where variance typically occurs. Interviews with industry actors presents a synopsis of the perceived and actual legislative and procedural pressures that exist in relation to building performance assessment. The conclusions of this paper identify weaknesses in the current legislative and incentivisation mechanisms with regard to targeting building performance and broader industry engagement. Recommendations are made for adjustments to the procurement framework to increase participation in meaningful building evaluation targeted at specifics of the energy gap and the motivations of industrial actors.*

1 INTRODUCTION

The European Union Energy Performance of Buildings Directive (EPBD obliges member states to try to improve the energy performance of buildings through standardised calculation methodologies, certification schemes, maintenance programmes and national performance targets (The European Parliament and The Council of the European Union 2010). In response the 2008 Climate Change Act has committed the United Kingdom to delivering an 80% reduction in CO_2 emissions by 2050 relative to 1990 levels (Climate Change Act 2008). In the UK energy used in buildings accounts for 45% of all carbon emissions (Department of Trade and Industry (DTI) 2007).

Legislative efforts to achieve reductions through building regulations and other mechanisms has led to reductions in the *anticipated* energy use of building designs rather than the subsequent *actual* energy consumption (Day et al 2007) . Bordass et al have identified some of the reasons that this discrepancy exists, they include: using incorrect assumptions in design calculations; making changes during construction; a poor design; poor management of the finished building; or a combination of some or all of the above (Bordass et al 2010). The drivers behind the discrepancy are complex as the design, construction and management of buildings is not a simple set of economic interactions; the procurement process is carried out by a socially regulated network of decision makers (Lutzenhiser 1994). This paper explores the impact that the relationship between the legislative framework and the pressures within this 'socially regulated' network may have on building energy consumption.

2 METHODS

This study employs a mixed methods approach*"combining qualitative and quantitative approaches concurrently so that the overall strength of the study is greater than an individual method"* (Creswell 2009). The study was carried out in three phases: a legislation and literature review identified formalised methods of encouraging reductions in energy consumption and the use of feedback; second, an analysis of the data contained in CarbonBuzz, a design versus actual comparison website (www.carbonbuzz.org), using some of the themes identified by the literature and legislation review as an analytical starting point; the final phase was a series of semi-structured interviews with a range of industry actors, again using the review derived themes. Beginning with the broader 'structural conditions' allows contextualisation of peoples' actions (Strauss and Corbin 1990).

3 LITERATURE AND LEGISLATION REVIEW

3.1 Regulation and Statutory Approval

In the UK, proposals for new or refurbished buildings are regulated by the Building Regulations. Approved Document Part L (Office of the Deputy Prime Minister 2006) set standards for building fabric and fixed buildings services, plug loads are not taken into account. CO_2 is the compliance metric; a kg CO_2/m^2 'Building Emission Rate'. Planning approval is also required for new (or substantially altered) buildings in the UK which often includes an energy target. The most prominent example of local authority energy policy is the 'Merton Rule', developed in Merton, south London; similar schemes have been adopted across the country. The rule states that any development of 10 dwellings or $1000m^2$ of non-domestic space or more is required to generate at least 10% of required energy through the use of on-site renewable sources (Merton Council 2013). There is no obligation to evaluate the success, or accuracy, of either standard through regulations or planning policy.

3.2 Certification

The main mandatory feedback mechanisms in the UK implemented in the wake of the EPBD are Display Energy Certificates (DECs). DECs use actual energy consumption records, benchmarked as an 'Operational Rating' and apply to non-domestic public buildings larger than $1000m^2$ (Department for Communities and Local Government 2008).

The voluntary Building Research Establishment Environmental Assessment Method (BREEAM) (Building Research Establishment n. d.) and the Code for Sustainable Homes (CSH) (Building Research Establishment n. d.) are used quasi-legislatively; often planning approval or public funding is dependent on commitment to a certain score. Both schemes use a range of indicators of environmental ‘sustainability’ including transport, biodiversity, water use and energy consumption to calculate the overall sustainability award.

3.3 Financial Incentives

Financial incentives are aimed at both the commercial and domestic sectors. The Carbon Reduction Commitment (CRC) targets organisations that do not already fall under other CO_2 emissions legislation. They used tax rebates to encourage management based year on year carbon reductions until they were removed in late 2012 (Department for Energy and Climate Change 2012a). Enhanced Capital Allowances (ECAs) are similarly aimed at commercial organisations and are a tax incentive for the purchase of efficient service equipment. In the domestic sector, energy suppliers have a duty to reduce the carbon emissions associated with their customers (Department for Energy and Climate Change 2012b). Supplier Obligations (SO) place the onus on energy suppliers and have become one of the most important carbon reduction policies in UK housing (Rosenow 2012). The Energy Company Obligation (ECO) replaced the Carbon Emissions Reduction Target (CERT) in January 2013 and continues the principle of corporate responsibility for carbon reductions with emphasis on those in low income households. Feed in Tariffs (FITs) allow households to sell renewably generated electricity to the grid (Department for Energy and Climate Change 2013a). The Green Deal is a government run scheme to fund energy efficiency improvements through long term payments linked to energy bills(Department for Energy and Climate Change 2013b).

3.4 Benchmarks and Guidance

The Chartered Institute of Building Services Engineers’ (CIBSE) Technical Memorandum (TM)46 electricity and gas benchmarks are the basis for DEC benchmarking. One of the stated purposes of TM46 is to provide designers and managers with a yardstick against which designs and records can be measured: it is *“all about tracking performance and identifying opportunities for improvement”* (CIBSE 2008) . TM 46 consumption figures are categorised by building use and are based on data used for early office building benchmarks in ECON 19 (BRESCU 2003), supplemented with data for other building uses and with some amendments to provide better support to Display Energy Certificates (CIBSE 2008).

3.5 Operational Processes and POE

The Soft Landings framework aims to improve the handover of new buildings and allow design team to learn about the performance of finished buildings. It is designed as a ‘golden thread’ linking the design and procurement and occupation process. A member of the design team moves into a building with the first occupants to answer questions and troubleshoot problems (BSRIA 2009). Soft Landings aims to counter Bordass et al’s observation that building occupants’ knowledge and the tacit knowledge of design teams is not being integrated into improvements to buildings performance (Leaman and Bordass 2004).

3.6 Assessment Methods and Reporting Tools

A number of methods exist to assess, track and record energy consumption, CIBSE TM 22 ‘Energy Assessment and Reporting Methodology’ is one. It has three stated aims; to identify poorly performing buildings and systems, to indicate the cause(s) of poor performance and to benchmark operating procedures. TM22 can be used to assess building designs or occupied buildings in use (CIBSE 2006). Web based tools aim to compile this data into anonimised databases; CarbonBuzz *"collects anonymous building energy consumption data to highlight the performance gap between design figures and actual readings*" (www.carbonbuzz.org). iSERV is aimed at heating and ventilation systems and shows*"the practical operation and benefits of an automatic monitoring and feedback system"* (http://www.iservcmb.info/).

3.7 Disincentives to using energy data

Despite the above mechanisms, there are a number of reasons why building assessment is not habitually carried out forming the 'social regulations'. They include: a reluctance to pay for the evaluation to be carried out; Clients' inability to see the benefit (financial or othersise) as their building is 'finished'; a lack of engagement with the building occupiers on the part of commercial Clients; uncertainty about how to carry out an evaluation (Bordass und Leaman 2005); a perception from within industry that gathering 'evidence' of a building not functioning as intended might expose practitioners to extra work or even litigation (Jaunzens et al 2003); a perceived lack of value in the information gathered; the commercial benefits are not perceived to match the outlay (Jaunzens et al 2003); finally, a practical issue: POE information is often published in places that are not often accessed by industry (such as academic journals) and practitioners are often left to use previous ideas (Vischer 2009).

4 SAMPLES

4.1 CarbonBuzz

The CarbonBuzz sample comprised of 575 registered users in July 2012, across 17 company categories. The major organisations registered were architects (141 practices), engineers (82 practices), universities (74) and 'consultants' (59). Other organisations include central and local government, construction companies, manufacturers, management companies and quasi-governmental organisations. Less than 10% of organisations contribute design and actual data is (46 of 575). These 46 had submitted a total of 381 individual project records. Of these, 62 were identified as 'Test' projects. Table 1 outlines the analysis subsets.

Step	Subset Characteristics	Sample size
1	Initial dataset	381
2	'Test' projects removed	319
3	Subset 1 buildings with design and actual total Electricity use and Heat consumption > 0	37
4	Subset 2 buildings with Fossil Heat and Fossil Hot Water>0 and Lighting and Equipment or Applianceloads>0	10

Table 1: Data selection process

Only those with design and actual data were retained for analysis, leaving 37 projects in Subset 1, plotted in Figure 1. The second subset is those buildings which have disaggregated energy data in both design and actual categories including an unregulated energy use. The four categories were fossil fuel heating, fossil fuel hot water use, (electric) lighting and (electric) equipment and appliance use (an unregulated end-use). This left 10 buildings for further analysis as Subset 2 these are explored in Figures 2 and 3.

4.2 Interviews

17 semi-structured interviews were carried out in parallel to the energy analysis. The sampling strategy was determined by two considerations; the first practical consideration was that access was required to the participants for a face to face interview; the second selection consideration was purposeful and manifest as the selection of appropriate participants to fill in gaps in the data through the selection of different actor types (Furniss et al 2011). All interviews were recorded and transcribed verbatim. Respondent validation (sending transcripts to participants for comment, correction and clarification) was used to verify the text, Torrance (2012) has identified this as a means checking for accuracy, encouraging participants to reflect on what they have said alter their contribution.

The participants were six architects, three mechanical engineers (one working for a large developer, one as an energy consultant), 2 design managers (one employed by a large developer, the other by a multinational contractor), two energy consultants (one specialising in sustainability), two local authority policy makers (one ‘energy conservation officer’) and one central government policy maker.

5 RESULTS AND DISCUSSION

The proportion of projects with data in the CarbonBuzz database is low; the series of interviews gave some indication why this is the case. The logistics of carrying out Post Occupancy Evaluation were often cited by interviewees as a reason for not being able to collect data. From procurement relationships; “*we only tend to revisit buildings when there is something wrong,”* to the impact that the client type has on access *“we have got more schools who are always a bit more enthusiastic about letting you come back than say offices…we can ask if we can come back but they are not always interested.”* However, most cited costs and liability as the main reasons for not collecting data, one architect in a small practice with an interest in low energy buildings related profits and liability*” you know we don’t make profit, all we do is pay the salaries, I think there is that kind of, if you start kind of poking around too much…you are opening yourself up to sort of liability”.* A number of interviewees indicated that although they may collect information about their buildings, it is most often informally and is not used analytically. Most gained tacit knowledge throughout a design or management process and applied this informally to future projects. One architect typified the arrangements: *“It is kind of learning by experience, yes we don’t really formalise the knowledge other than… er building it into the next project if you see what I mean”.*

5.1 Design v Actual

Figure 1 shows that 95% (35 of 37) of projects have an actual electricity use greater than the design prediction and 46% (17 of 37) have an actual consumption figure over 200% of the prediction. In contrast, 60% (22 of 37) of projects have an actual heat consumption greater than the design value with 38% (14 of 37) over 200%. 4 projects’ actual heat consumption is lower that 50% of the design prediction, this is true of only 1 projects’ electricity value. The regression lines show that as both the design and fossil fuel predicted consumption increases, the trend is for the relative actual consumption to reduce; in the case of electricity, the relationship between design an actual predictions gets closer to equal. With heat consumption, the higher the prediction, the lower the actual figure, the regression lines drops below ‘equal’ at approximately 180KWh/m^2. The difference between design and actual exists for a number of reasons, possibly linked to the calculation method. Building Regulations only account for fixed building services and building fabric measures with some adjustment for occupancy patterns.

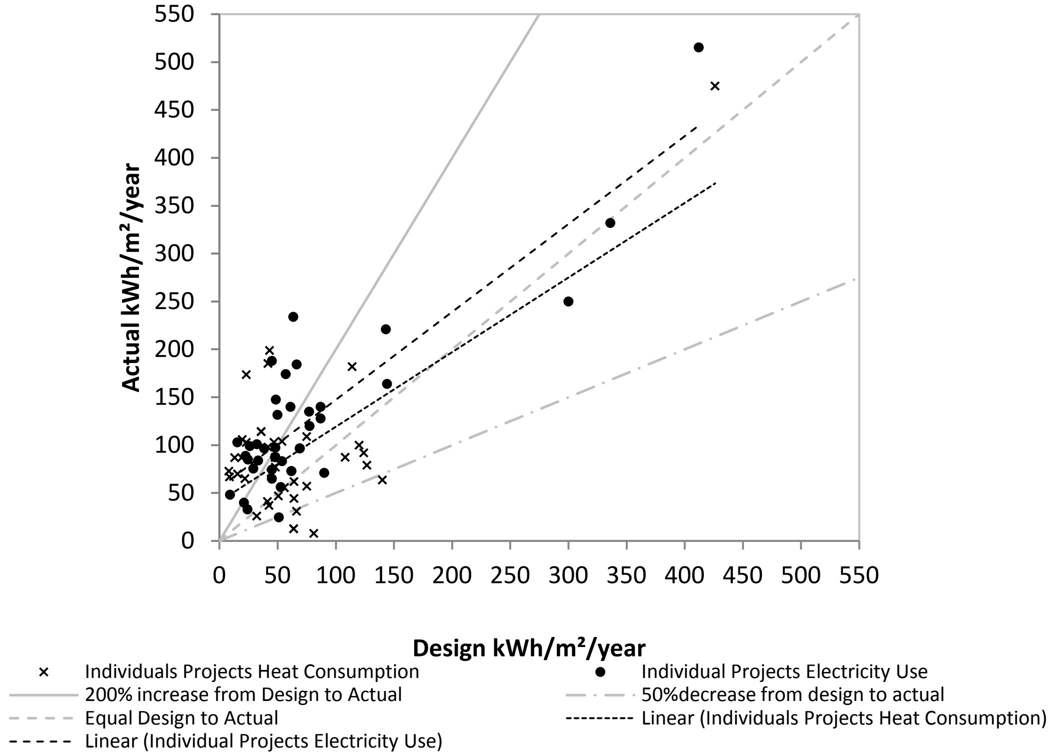

Figure 1: Design v. actual heat and electricity data - all non-test Education projects

Interviewees indicated that often the national calculation method is the way that assessments are made of designs, but the calculation methodologies are often used in unexpected ways. An engineer talked about the use of assessment methods as exploratory mechanisms for identifying optimum performance: *"we found tightening up the fabric actually had very very little effect on the overall performance of the building whereas when we trimmed down the lighting loads that had a massive effect on the building"*.

5.2 Disaggregated Data

Figure 2 shows the disaggregated data in the 10 projects in Subset 2. These are projects with design and actual 'Fossil Heating', 'Fossil Hot Water', 'Lighting' and 'Equipment or Appliances' data above zero, several projects have data in more categories than this. The total mean figures are also shown, the mean total design figure is 108KWh/m^2 the total actual mean figure is 228KWh/m^2. Project 10 shows the greatest increase in total energy consumption, an approximate 5 fold increase.

All projects show an increase from design to actual, however the relationship between components of the total energy value are more complex. Project 5 shows the closest total design and actual values (135 KWh/m^2 versus 144), however the proportions of energy consumption making up the total are very differnt; 'Cooling' has a design value of only 6KWh/m^2 (4% of the total) and 38KWh/m^2 (28%) in the actual record whereas 'Heating

Fossil' is 75 KWh/m^2 (55%) at design and 7.1 KWh/m^2 (4.8%) in the actual record. The difference in the proportions of data relating to each use could be explained by designers using industry benchmarks as guidance in which changes in regulations and occupant behaviour are not yet reflected. Robertson and Mumovic (2013 forthcoming) have shown that the benchmarks do not necessarily reflect actual energy consumption.

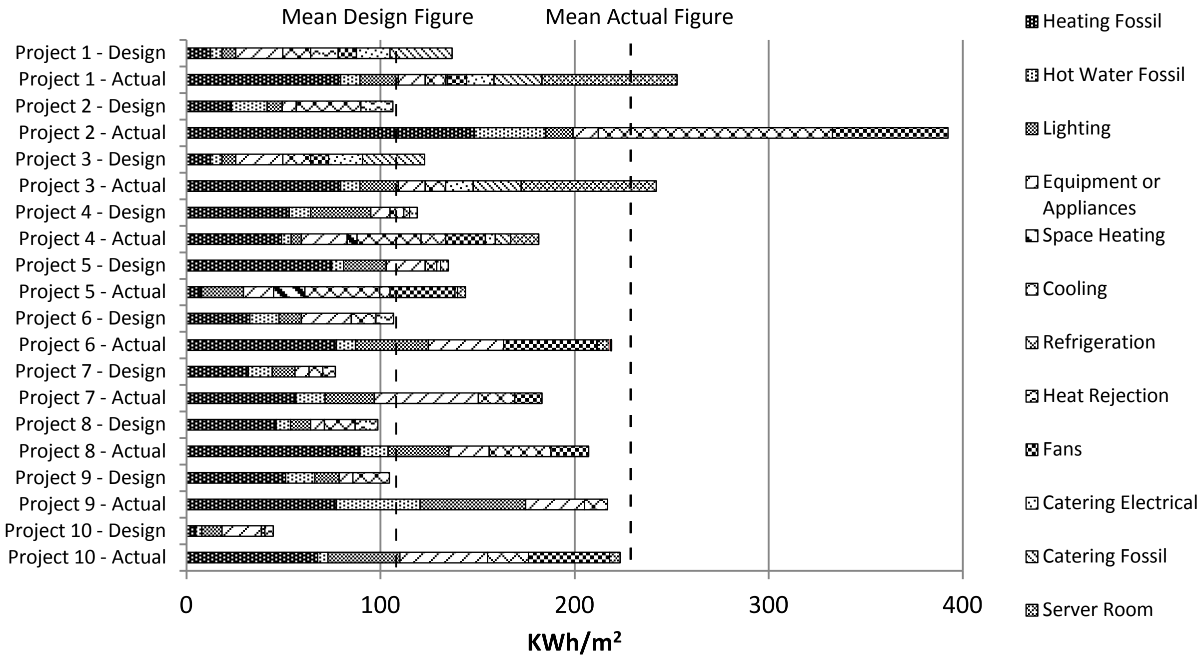

Figure 2: Subset 2 design and actual energy breakdown

Interviewees however did not often cite CIBSE benchmarks as a source of design predictions, more often citing default settings and tacit knowledge as the basis for their models. A sustainability consultant said *"I don't think there has been a lot of comparison to how our past projects perform compared to how they are initially modelled… we haven't really done that work."*

Figure 3 is a box plot of the *difference* between design and actual energy consumption figures for the four energy consumption factors used to select the projects for Subset 2; and other categories that had enough entries to analyse; 'Cooling' and 'Fans'. The chart shows the 1st and 3rd quartile, median, mean, maximum and minimum values for the differences. A negative difference shows a reduction from design to actual, positive figures show an increase. The consumption categories represents end uses of various magnitudes, therefore the figures have been normalised as mean variance as a percentage of the mean actual consumption; this is shown on the secondary axis.

All energy uses showed a reduction in consumption from design to actual in at least one building. All figures show a positive mean figure, indicating that the trend is for an increase from designed to actual consumption across these categories. 'Heating Fossil' shows the greatest spread of difference between design and actual figures. Cooling has the next largest range followed by fans and lighting. Equipment or Appliances and Hot Water Fossil have the smallest ranges. Equipment is an unregulated energy use. The normalised percentage figures show that fixed building services still have the greatest change; fans show a near 100%

increase from design to actual and 'Heating Fossil' and over 50% change. 'Hot Water Fossil' and unregulated 'Equipment or Appliances' show mean variance figures as the lowest proportion of the mean actual consumption figure, approximately 33 and 40% respectively.

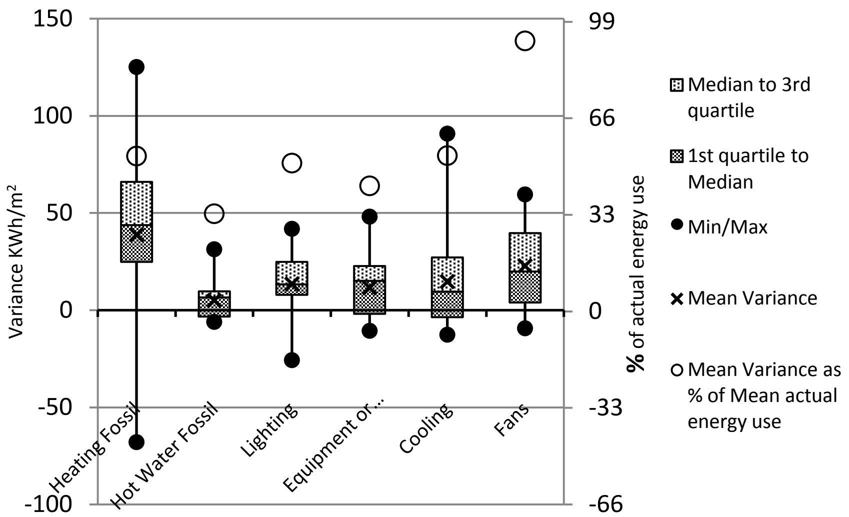

Figure 3: Differences in design and actual energy consumption

Reasons why the change in unregulated energy and user operated uses may be lower than that in regulated or large building systems may come from the focus in the legislation on fixed building services. When talking about using certification schemes, a sustainability consultant said *"... in both those cases you are really only focussing on regulated energy. Both BREEAM and LEED have ways of adding up unregulated energy but they are much cruder tools."* It might be that actors have to develop more accurate information on user controlled end-uses to feed into models that they do with service systems where they can simply apply benchmarks. A consulting engineer described the thought process that goes into producing energy predictions with a caveat for building users; *"[they are] based on the information you've given us…our experience, based on what we know, this is what we anticipate it being. But obviously if people forget to switch the lights of or leave their computers running all night or what have you…that's, that's going to affect it."*

5.3 Disincentives

Interviewees indicated a similar set of barriers as defined by the contextual pressures: cost, reputational concerns and concern over liability. Often they were unable to cite specific examples but developers were keenly aware of impacts to their businesses. One used the example of a district heating scheme; *"the pressure goes down … an automatic disabling of all the boilers…on a Sunday night and then somebody won't find out about it until resident complains about it the next morning and the systems been off for 12 hours plus …that has happened on one of schemes four times including on Christmas eve…you can be bloomin' sure that all of these people are running around telling their friends to never get involved in buying a house in a scheme that has community heating in it".* Another engineer talked of the conflict between the desire to 'do the right thing', a marketing opportunity and risk:*"we are* *really struggling because our own internal sustainability groups, they want to demonstrate in our annual sustainability report how our intelligent and efficient design has saved our clients carbon emissions… it's kind of a double edged sword, it could brilliant or the client could turn round and say well hang on you haven't given us the flipping building we paid for!"*

6 CONCLUSION

This paper has described a mixed methods investigation of the relationship between energy data, construction industry actors and the legislative framework. The legislative framework describes a set of regulations, incentives and reporting mechanisms aimed at engaging industry with energy feedback and reducing energy consumption of new and existing buildings. The framework uses a variety of metrics to evaluate building energy performance and there is no obligation for designers to evaluate finished buildings. Incentives and certification schemes target different people and there is no explicit connection between mechanisms and therefore between the actors.

This lack of connection between data collection and designers was illustrated in Figure 1. The design versus actual figures show the disparity between predictions and recorded consumption in the data base. These represented a mix of building types and showed a trend for an increase from predicted to actual recorded consumption. The inaccuracy of predictions is illustrated in Figure 2; even when the total consumption figures are close, the proportional breakdown of consumption is often quite different. Figure 3 shows more accurate predictions in user controlled uses like hot water and plug loads than in fixed services.

While these differences can be explained in part by calculation methodologies used in the legislative framework, interviewees described other reasons why design predictions were often not accurate; they were based on assumption and defaults rather than precedent or evidence. Creating a stronger incentive to incorporate energy data feedback into the design process could help generate more accurate predictions and lower energy consumption

The current barriers to collecting and using energy feedback are complex. Interviewees indicated a desire to 'do the right thing' but are often hampered by costs, inability to access buildings, a perceived risk of litigation, loss of money or reputational damage. Currently the perceived disincentives outweigh the perceived benefits. The framework of legislation in the future must therefore increase the benefits available to actors of creating low energy buildings whilst simultaneously overcoming the existing barriers. This will require the removal of some existing barriers, and the simultaneous creation of new incentive measures. Further work is needed to develop a full set of recommendations.

Further work needs to examine the motivations of individual actor types and identify which particular barriers or opportunities are important to them; similarly different building types and calculation methods may represent different perceived conditions. Also, different procurement routes, client organisations and funding streams may offer different opportunities and present varying barriers, this should be examined in greater detail.

7 REFERENCES

B. Bordass, R. Cohen and J. Field, "Energy performance of non-domestic buildings: closing the credibility cap", *Building Performance Congress* (2010).

B. Bordass and A. Leaman, "Making feedback and post-occupancy evaluation routine 1: A portfolio of feedback techniques", *Building Research & Information*, 33 (4), S. 347–352, (2005), doi: 10.1080/09613210500162016 .

BRESCU, *Energy Consumption Guide 19 ("ECON 19"), Energy Use in Offices*, Watford (2003).

BSRIA, *Soft Landings Framework*, BSRIA, Bracknell (2009).

Building Research Establishment, *BREEAM: Code for Sustainable Homes* (n. d.). Available at http://www.breeam.org/page.jsp?id=86 , Accessed on 24.02.2013.

Building Research Establishment, "*BREEAM: What is BREEAM?*" (n. d.). Available at http://www.breeam.org/page.jsp?id=66 , Accessed on 24.02.2013

CIBSE, *TM 46 Energy Benchmarks*, (Nr. CIBSE TM46: 2008), CIBSE, London (2008).

CIBSE , *TM22 Energy assessment and reporting method*, (Nr. CIBSE TM22: 2006) ,CIBSE, London (2006).

Climate Change Act, *Climate Change Act*, HMSO (2008).

Department for Communities and Local Government, *A Guide to Display Energy Certificates* (2008).

The Department for Communities and Local Government, *Explanatory Memorandum To The Energy Performance Of Buildings (Certificates And Inspections),Amendment Regulations* The Department for Communities and Local Government, *England And Wales*, (2009).

Creswell and W. John, *Research design: qualitative, quantitative, and mixed methods approaches*. 3rd ed, SAGE, Los Angeles: (2009)

T. Day, P. Jones and, P. Ogumka, *Review of the impact of the energy policies in the London Plan on applications referred to the Mayor (Phase 2) Final Report* , South Bank University, London (2007).

Department for Energy and Climate Change, "CRC Energy Efficiency Scheme - Reducing demand for energy from industry, businesses and the public sector - Policies - Inside Government - GOV.UK", (2012). Abgerufen am 24.02.2013 von https://www.gov.uk/government/policies/reducing-demand-for-energy-from-industry-businesses-and-the-public-sector--2/supporting-pages/crc-energy-efficiency-scheme.

Department for Energy and Climate Change, *Enhanced capital allowances (ECAs) - reducing demand for energy from industry, businesses and the public sector - Policies - Inside Government - GOV.UK* (2012). Available at https://www.gov.uk/government/policies/reducing-demand-for-energy-from-industry-businesses-and-the-public-sector--2/supporting-pages/enhanced-capital-allowances-ecas , accessed on 24.02.2013.

Department for Energy and Climate Change, *Feed-in Tariffs: get money for generating your own electricity - GOV.UK* (2013). Available at https://www.gov.uk/feed-in-tariffs, accessed on 24.02.2013.

Department for Energy and Climate Change, *Green deal: energy saving for your home or business - GOV.UK* (2013). Available at https://www.gov.uk/green-deal-energy-saving-measures, accessed on 24.02.2013.

Department of Trade and Industry (DTI), *Meeting the energy challenge. a white paper on energy*, The Stationery Office, London (2007).

D. Furniss, A. Blandford and P. Curzon, "Confessions from a grounded theory PhD: experiences and lessons learnt", *Proceedings of the 2011 annual conference on Human* *factors in computing systems,*: ACM (CHI ’11), S. 113–122, New York, NY, USA (2011). doi: 10.1145/1978942.1978960.

D. Jaunzens,; P. Grigg and R. Cohen, *Building Performance Feedback: getting Started*. (Digest Nr. 478), BRE Bookshop, London (2003).

A. Leaman, B. Bordass, "An intellegant approach to occupant satisfaction using feedback", *Building Services Journal* (2004).

L. Lutzenhiser, "Innovation and organizational networks barriers to energy efficiency in the US housing industry", *Energy Policy*. 22 (10), S. 867–876, (1994). doi: 10.1016/0301-4215(94)90146-5.

Merton Council, "The Merton Rule", *The Merton Rule* (2013). Available at www.merton.gov.uk/environment/planning/planningpolicy/mertonrule.htm. Accessed on 21.02.2013.

Office of the Deputy Prime Minister, *Conservation of fuel and power approved document L2A new buildings other than dwellings*, Office of the Deputy Prime Minister, London (2006).

Rosenow, "Energy savings obligations in the UK—a history of change", *Energy Policy*, 49 , S. 373–382 Jan (2012). doi: 10.1016/j.enpol.2012.06.052.

Strauss, L . Anselm, J. Corbin, "Basics of qualitative research: grounded theory procedures and research". *Sage*, *New-bury Park (CA)* (1990).

The European Parliament, The Council of the European Union "Directive 2010/31/EU of the European Parliament and of the Council of Europe 19 May 2010on the energy performance of buildings (recast)", *Official Journal of the European Union*. L (153), S. 13–35 (2010).

H. Torrance, "Triangulation, respondent validation, and democratic participation in mixed methods research", *Journal of Mixed Methods Research*, 6 (2), S. 111–123 (2012). doi: 10.1177/1558689812437185.

J.C.Vischer, "Applying knowledge on building performance: from evidence to intelligence.", *Intelligent Buildings International*, 1 (4), S. 239 (2009).

Sustainable Building Conference 2013

UNRAVELLING THE UNINTENDED CONSEQUENCES OF HOME ENERGY IMPROVEMENTS

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Abstract. *Household energy use accounts for more than one-quarter of all energy use in the UK. However reducing energy demand in this sector is a 'wicked' problem characterized by radically different views from stakeholders, changing resources and a range of variables such as climate, built form, socio-economic factors, efficiency of heating systems and occupant behaviour; resulting in lower energy savings than expected. This may undermine the national Green Deal programme which aims to improve existing housing by offering up-front loans to be repaid by energy savings. To address this issue, we have developed and applied a robust measurement, monitoring and evaluation (MME) framework to gather quantitative and qualitative data on energy use and energy behaviours for 90 households across UK, as part of an on-going action research project evaluating household energy use in low carbon communities. A third of the houses have not had any technical or behaviour change interventions, and act as 'control'. Our MME framework adopts a mixed methods approach, including occupant feedback interviews, questionnaire surveys, activity log sheets as well as continuous physical monitoring of low-carbon technologies, environmental conditions and energy use, to provide valuable insights into individual and household level energy behaviours. The first round of MME has uncovered a number of unintended consequences associated with energy behaviours, such as inappropriate operation of low carbon systems due to lack of understanding, incorrect and inadequate use of heating system controls due to their complexity, excessive use of electric immersion heaters in homes with heat pumps, along with common energy habits such as opening windows during heating, leading to increased energy use and a widening gap between predicted and actual savings. Ultimately, the research seeks to create a body of evidence to help inform future policy formulation and strategy implementation for meeting national* CO_2 *targets.*

1 INTRODUCTION

Household energy use accounts for more than one-quarter of all energy use in the UK (National statistics 2012). Whilst new homes can achieve greater savings in relation to existing buildings due to better building construction and more efficient technologies, the rate of growth in the domestic sector in Great Britain is only 0.85% (Palmer & Cooper 2012). The need for policy to encourage low-energy retrofitting of existing homes is immediate and urgent. This is why the national Green Deal programme, launched in October 2012, aims to improve the take-up of energy efficient measures by offering up-front loans to be repaid by energy savings. Yet without understanding the impacts of the many and varied factors at play in domestic energy demand, this national programme may be undermined.

Reducing energy demand in homes is a 'wicked' problem characterised by radically different views from stakeholders (Gupta and Gregg 2012), changing resources and a range of variables such as climate, built form and physical construction, efficiency of technologies and heating systems, socio-economic factors and the behaviour of the occupants in their homes. All of these have an impact on actual energy savings, which are often lower than expected (Gupta and Chandiwala 2010). Davies and Oreszczyn (2012) note that refurbishment programmes to reduce energy demand in homes have the potential for unintended consequences; unanticipated 'side effects' that mean today's solutions become tomorrow's problems. They state that possible impacts can relate to many areas including population health, deterioration of the building fabric and contents, as well as economic, social and cultural viability.

There is a multitude of known side effects including indoor air quality (IAQ) problems, higher fuel prices, overheating, changes to the hygrothermal properties of the building fabric and health and safety issues such as increased fire risks (Davies and Oreszczyn 2012). In addition to these, energy efficient improvements have been found to result in increased energy use and carbon emissions due to the 'rebound effect'. The 'rebound effect' works on the premise that if the energy efficiency of a service is increased, the consumption of those services also increases. An example of this is as energy efficient lights use less energy, and therefore cost less to run, the occupant may be less inclined to switch them off, thereby offsetting some of the energy savings potentially achieved. Whilst the evidence available for establishing the rebound effect is far from comprehensive often varying hugely depending on many other factors, there is enough to suggest that the direct rebound effect in relation to home heating for example can be as much as 30% (Sorrell 2007). Further research studies also reveal the performance gap between modeled or designed performance and actual (in-use) performance of low carbon technologies (LCTs) (Bell et al 2010).

The impact of the behaviour of occupants and their interaction with their home cannot be ignored in the expected energy savings of energy efficient measures and is widely documented (Revell & Allen 2012; Palmer et al 2012). Whilst many models and theories aim to establish the influences upon energy behaviours, quite often it comes down to individual context and specific behaviour. Moreover, recent research has found that often, there is no set pattern to the type and number of energy behaviours relating to high household energy use, rather each household has a unique set of behaviours which therefore cannot be grouped or characterised as 'high energy use' behaviours (Fell and King 2012). Thus the contextual data surrounding energy behaviours is critical to understanding a household's overall energy use.

This paper seeks to outline the measuring, monitoring and evaluation approach used in a current research project that focuses on establishing the impact and unintended consequences of localised energy behaviours on domestic energy use in existing and retrofitted homes, with the ultimate aim of suggesting change strategies for reducing energy use in homes.

2 EVALOC LOW CARBON COMMUNITIES PROJECT

Research presented in this paper is part of the ongoing EVALOC low carbon communities project, which is a RCUK funded research programme with the key aims of assessing and evaluating the impacts of low carbon communities (LCCs) on individual and community behaviours and energy use, and the communities' success in achieving sustained and systemic change. It brings together an interdisciplinary team of researchers from Oxford Brookes University and the University of Oxford to undertake an action research-based approach within six communities across the UK.

Within the EVALOC project itself, the activities are split into community-level and household-level. At household level, the impacts and effectiveness of community-led energy renovations and behaviour initiatives are evaluated through a measuring, monitoring and evaluation (MME) study of 30 houses (Group A) using a whole-house monitoring system and across six Government-funded low carbon communities (LCCs) in the UK. The results are cross-compared with post-occupancy evaluations of 33 houses which have received LCC-led behaviour change interventions (to initiate low carbon living) and another 25 'control' houses located in the LCCs which have not had any intervention (technical or behavioural). This helps in understanding the differences in household behaviours and their motivations for consuming less energy across the three distinct groups, as well as the appetite for community-led low-energy renovations. The main aims of this research strand are as follows:

- Measure, monitor and map the impacts (on localised energy behaviours of inhabitants) and effectiveness (on achieving real-savings in energy use and CO2 emissions) of the low-carbon interventions both on a short and long term, from a technical and occupants' perspectives
- Assess the interaction between user behaviour and physical aspects of housing performance in relation to energy use.
- Establish the actual energy savings achieved from low carbon interventions in households to inform future policy formulation and strategy implementation, for meeting national CO_2 targets

The household level research is designed to provide holistic understanding of energy use and energy behaviours at an individual household level by covering the three fundamental aspects of energy use in the home, the physical environment, the technical context and the occupant, and the interactions and relationships between these. By both measuring and monitoring existing homes, evidence relating to actual energy use and environmental conditions can be provided, as well as into the perceptions and actual behaviours and interactions of the occupants; the 'sayings' versus the 'doings' of the occupants. By analysing both in relation to one another, patterns and correlations can be seen (or not) between technical and physical improvements to homes and the behaviours of the occupants. This is critical to understanding the impact of behaviour on energy use not only in the short term but also the longer term relating to sustained systemic change, as well as evaluating the impact of physical and technical improvement measures and assessing any differences between what was expected, what is actual, and any unintended consequences.

3 EVALOC HOUSEHOLD SAMPLE PROFILE

The aim was to recruit approximately 90 households across the six communities, split into three groups. In total 95 households were recruited through various means; through the LCC group (newsletters, events, face-to-face meetings, LCC lists of participants), recommendations of existing EVALOC participants and visits to local community buildings and events unrelated to the LCC. Each participant was offered a small financial incentive to aid retention. Despite this, there were a number of drop-outs during the first wave (due mainly to personal issues and time constraints) thus the total number of households currently participating is 88.

Households were allocated to one of three groups, identified as A, B or C, based on a number of selective criteria;

- **Group A:** households that have received some kind of physical treatment (demand or supply side) from the LCC, as a result of DECC funding

- **Group B:** households that have received some support from the LCC which could be an energy display monitor or behavioural intervention.
- **Group C:** households that have had no intervention or support from the low carbon community and will act as 'control'.

In reality, it was often difficult to recruit 'pure' samples within these groups, as a vast majority of households had 'standard' technical interventions such as double glazing and energy efficient appliances/lighting within their homes. As such, a distinction was made between 'typical' technical improvements e.g. double glazing, energy rated appliances and reflective radiator panels and 'intensive' technical improvements e.g. solid wall insulation and low-carbon technologies.

3.1 Dwelling and occupancy profiles

The households were also selected to represent, as best possible, the housing stock of the UK in terms of house type, age as well as a good spread of occupancy type, in terms of age, gender etc. (Figure 1). The focus tenure of the study is owner-occupied but a sample of social housing has also been included, where the occupants have been resident for over 10 years in the communities with a high proportion of social housing. This enables the research to be viewed in the wider context, but obviously the sample number is too small to provide extrapolation of results to the larger scale and should instead be seen as evidence-based case studies.

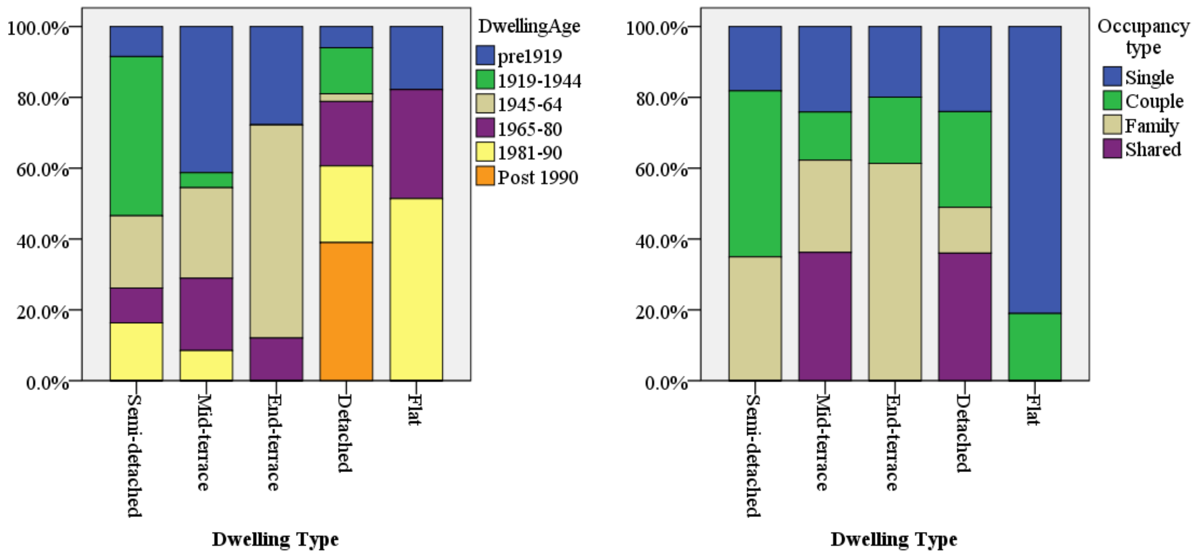

Figure 1: Dwelling and occupancy profiles of EVALOC households showing spread of household profiles within the study

3.2 Technical improvements and building systems

Out of the 88 households for which data is readily available, 74 have double glazing, 6 have secondary glazing and 8 have single glazing. 54 are cavity wall properties (48 of which have full or partial insulation), with the remaining 34 of solid wall construction (only 3 of which have partial insulation). In terms of low carbon technologies in the Group A households, 19 solar PV systems, 6 solar thermal systems and 5 air source heat pump systems are being monitored.

All households have central heating systems, with the fuel typically being gas (other fuels including coal and electricity) despite two out of the six communities not being on mains gas supply. The vast majority of the households are naturally ventilated (but with intermittent extract fans or mobile fans) but two Group A households have MVHR systems installed as part of their retrofit strategy.

4 DEVELOPING A MEASURING, MONITORING AND EVALUATION (MME) APPROACH

To add to the growing body of evidence relating to the impacts and understanding of household energy use and energy behaviours, the EVALOC team has developed and applied a robust measurement, monitoring and evaluation (MME) framework to gather quantitative and qualitative data on energy use and energy behaviours within the 88 EVALOC households.

4.1 Our overall approach

The mixed method approach adopted enables data to be gathered and cross-tabulated to provide invaluable insights into individual and household level energy behaviours. Whilst the quantitative (numeric) data provides detailed information on the actual energy use, behaviours/interaction as well as performance of the built environment, the qualitative (narrative and images) allows further probing into the reasons, understanding and motivations behind household energy use and behaviours. It was felt important to combine both building and social science methodological approaches to ensure the socio-technical aspects of household energy use were covered in depth. As such, the survey tools and techniques include building performance evaluation and audits, semi-structured interviews (occupancy feedback) and social network analysis. The data collection takes the form of both spot (one-off) measurements and continuous monitoring (Figure 2).

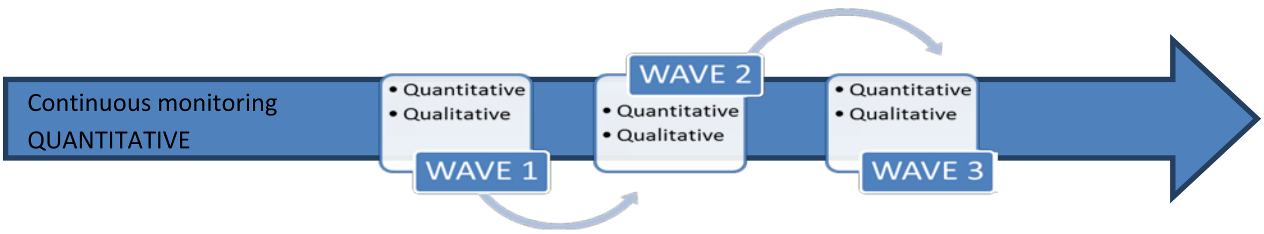

Figure 2: Data collection approach

By adopting this approach, self-reporting bias can be minimized through triangulation of data, but as previously noted, the households should be viewed as in-depth case studies rather than statistical generalisations.

4.2 Elements of study

The MME framework developed is based on the three core areas of a household energy use; a) the technical and physical aspects, b) the occupant, and c) the interaction (between occupant and technical). Within these three core areas, six elements of study comprise the measurement, monitoring and evaluation of:

- Energy (gas and electricity) consumption

- Internal and external environmental conditions
- User interaction with physical environment (opening-closing of doors, windows)
- Occupancy
- Performance of building fabric through thermal imaging surveys
- Long-term performance of low-carbon technologies and on-site renewables

A graduated MME approach has been taken within the study, based on the grouping of the households. As Figure 3 shows, Group Cs have least involvement; whilst Group As have whole-house monitoring systems installed in their homes, to monitor energy, environmental and interaction data every 5 minutes.

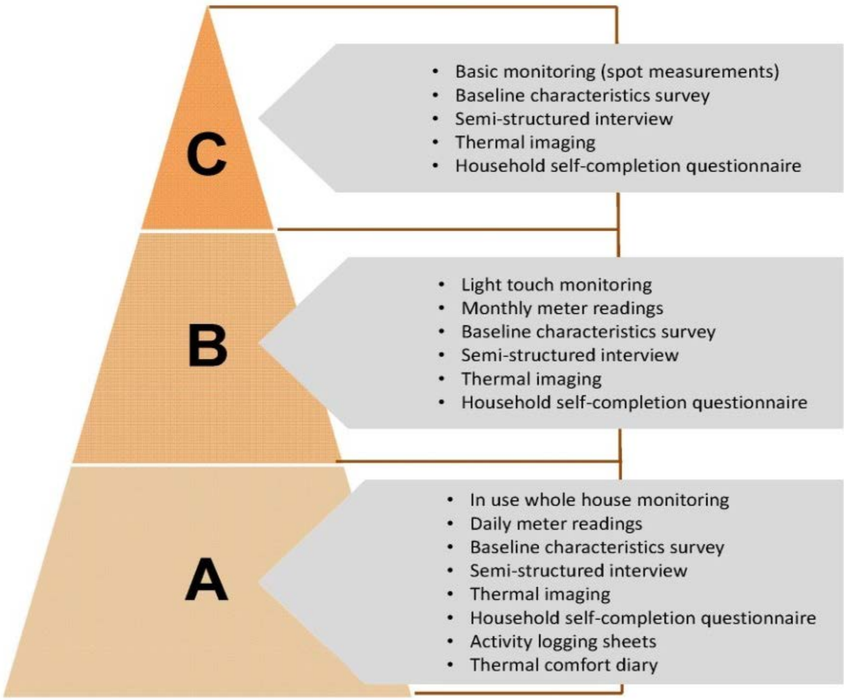

Figure 3: Graduated MME approach used

4.3 Application of MME to 88 households

The first round of MME was undertaken between May and August 2012, and involved a baseline characteristics survey of the technical and occupancy characteristics of the recruited households, a semi-structured interview that included themes such as a) heating and hot water systems, b) home improvements, c) lighting and appliances, d) general views of the home, e) thermal comfort, f) energy behaviours, g) energy displays (if applicable), h) community involvement and i) social network analysis. Spot measurements of external and internal environmental conditions and meter readings were also undertaken whilst light touch monitoring (temperature and humidity data loggers) was installed in Group B households.

Following on from the first round surveys, the whole house monitoring equipment was installed into 30 Group A households during September and December 2012, providing a minimum of 12 months data, including two heating seasons. The installation of this equipment itself has afforded the researchers interesting insights into the use of low carbon technologies, and the awareness and understanding of the occupants within homes that have such technologies installed.

5 ANALYSIS OF QUANTITATIVE AND QUALITATIVE DATA

5.1 Internal environmental conditions

Spot measurements of all households found that the internal mean temperature between the three groups ranged by only 1°C (21-22°C), and there was also very little difference between humidity levels across the three groups. However, the range of CO_2 results (indicative of indoor air quality) across the groups suggests that Group Cs, followed by Group As have the worst internal CO_2 levels in both mean and variance. In Group A households this may be as a consequence of certain physical interventions such as improved air tightness and insulation, and point to inadequate ventilation in certain households.

Among respondents who answered that they 'always close windows before turning up the heating', it has been discovered in the homes that are being continuously monitored that CO_2 levels of over 2,000ppm (Figure 4) are being achieved and the fact that they do not open windows is also corroborated through the monitoring. Increased levels of CO_2 can lead to sickness and ill health and it is a concern to find such levels in existing homes, even with little to no building fabric improvements, and thus supposedly 'naturally leaky'. It highlights the need for further study into this area.

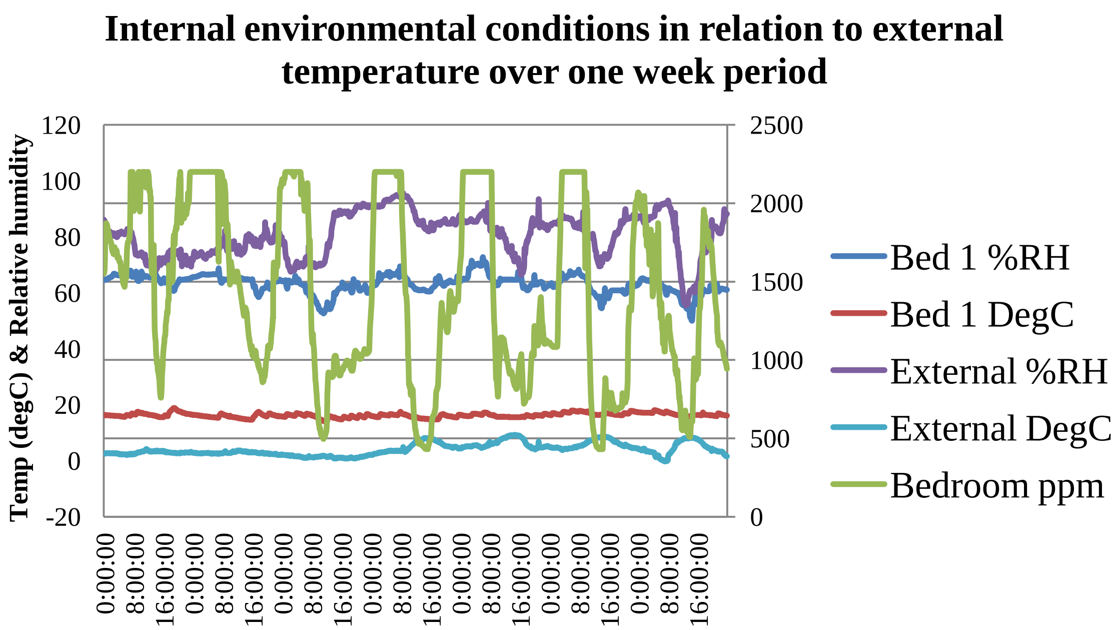

Figure 4: CO_2 levels, internal and external temperature in main bedroom in typical 1970s mid-terrace 3bed home with new double glazing, tricklevents and cavity wall insulation. 2,000ppm is upper limit to 'comfortable levels'

5.2 Energy use and performance of low carbon technologies (LCTs)

Initial analysis of daily and weekly gas and electricity consumption in relation to internal and external environmental conditions and monitoring of LCTs such as solar PV generation and export (Figure 5) and efficiency of air source heat pumps is highlighting discrepancies between peak usage times by occupant and peak generation/performance times as well as potential inefficiencies of LCTs due to inappropriate use or incorrect installation.

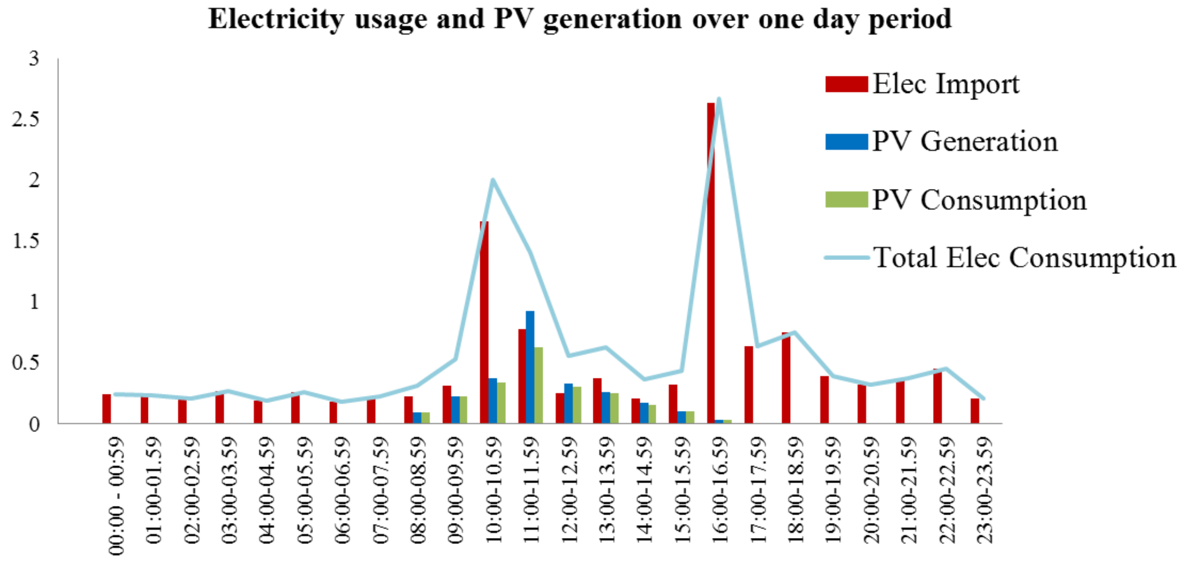

Figure 5: Chart showing PV generation in relation to electricity import from grid in household with high daily occupancy levels – note peaks of import electricity in relation to peaks of solar generation.

5.3 Occupant feedback on energy behaviours

Using comparative data from DECCs Low Carbon Communities Challenge (LCCC) evaluation report (DECC, 2012), analysis reveals that although there is an increase in all communities in their concern for global warming, there appears to be a drop-off in energy behaviours over the last 2 years (please note, statistical differences between LCCC evaluation and the EVALOC households).

The reasons why concern has risen but potentially not translated into behaviour, are varied. However evidence suggests that although households felt they were capable of reducing their energy use and were aware of the issues of global warming, they had either done all they could (without substantial retrofitting and use of low carbon technologies which they could/would not do for mainly financial or aesthetic reasons) or all that they would be willing to do, without compromising their comfort levels and/or interfering with their daily routines:

"…being an electrician I know where the money goes but you get to the point where you start penny-pinching…the effort overcomes the gains."

"…And I just couldn't do that, I would not feel comfortable in my own home if I tried to do something like that."

Within the first round surveys, the qualitative semi-structured interviews also offered insight into the impact of technical improvements, from LCTs such as air source heat pumps to building fabric improvements such as cavity and loft insulation and the potential positive and negative consequences of such interventions on the awareness, behaviours and comfort levels of the occupants;

Household with air source heat pump:

"…But now with this air pump I leave all the doors in the house open..."

Household with cavity wall insulation:

"…that little front bedroom was very cold and… it was getting mould on the walls… and so yes…I think the house is generally much warmer."

Household with loft insulation:

'…free insulation but since they did that I've started [to notice] mould on my ceiling.'

5.4 Emerging unintended consequences and impacts

By studying the actual performance of LCTs, energy use, internal and external environmental conditions as well as the interactions of occupants (such as opening/closing windows and doors), these can be cross-analysed with awareness and understanding as well as comfort levels thus exposing unintended consequences in relation to energy behaviours and technical interventions.

The first round of MME has uncovered further evidence on unintended consequences and impacts of technical interventions and behaviours – both positive and negative in relation to energy use, health, comfort, control and performance of both building fabric improvements and LCTs as outlined in Table 1 below. The assumption is that the main intended outcome from both the physical and behavioural interventions by the LCCs was to reduce localized carbon emissions and increase positive energy behaviours within their communities.

Positive consequences	Negative consequences
Improved comfort levels in homes with double glazing and wall/loft insulation	Low carbon technologies using more energy than energy output
Increased awareness of energy saving measures (through both behavioural and technical interventions)	Occupants 'guilt-free' to leave lights on and/or turn heating up, use more fuel as technical interventions improve efficiency of building
Increased concern for global warming and climate change (through both behavioural and technical interventions)	Occupants not adapting habitual behaviours to suit low-carbon technologies e.g. washing during the day if solar PVs present
Reduction in fuel bills following installation of PV panels	Lack of understanding of heating controls, reducing ability to control comfort levels
Impact of technical interventions on behaviours: change in energy behaviour profile to suit 'free' electricity use	Adaptation of low carbon technologies to suit habitual behaviours instead of vice versa leading to reduced comfort levels and potentially unnecessary energy use
Installation of low carbon technologies such as ASHP, solar PV providing kick-start to energy behaviour changes	Purchasing of energy efficiency appliances, but unaware of actual energy consumption of appliances, leading to increased energy use
Increased awareness and concern leading to installation of energy saving and energy efficient systems and appliances	Lack of knowledge into maintenance of low carbon technologies leading to early degradation of systems and/or systems not being installed correctly
Increased sharing of energy saving information between friends	Increase in damp and mould following installation of insulation (wall/loft)
NB. Due to the early stages of the analysis these findings are yet to be corroborated with actual data and so must be considered as perceived positive and negative impacts	Lack of understanding of low-carbon technologies, reducing ability to control comfort levels and energy use
	Over-exposure of energy-saving related advice resulting in energy lethargy?

Table 1: Positive and negative consequences of technical and behavioural interventions within EVALOC households

6 CONCLUSIONS

The MME framework produced as part of the EVALOC project is enabling detailed analysis of behaviours and practices within existing homes in relation to their impacts on localized energy use. Alongside this, the measuring and monitoring strategy provides actual data relating to energy use, interactions between occupant and building, internal and environmental conditions and the performance and use of LCTs. With predicted energy savings informing the economic sustainability of current funding schemes such as the Green Deal, a greater understanding of factors mediating the gap between predicted and actual outcomes is vital. By critically analysing both qualitative and quantitative data through the mixed methods approach of the framework, the researchers are able to create a robust database that will further add to the body of evidence relating to energy behaviours and technical interventions and their impact on household energy use.

Whilst further analysis of the data available is required, factors impacting both negatively and positively on the sustained and systemic reduction in household energy use are being identified. Such key areas of concern to date are indicative of known, but little researched unintended consequences of technical interventions on health, internal environmental conditions and energy use. In addition, the preliminary findings substantiate the need for increased knowledge and understanding of the installed technologies and behaviour change in line with technical interventions in order to maximize energy use reductions but also reveal the difficulties in achieving long-term changes to energy behaviours in the face of many other socio-cultural, environmental, and economical factors. Ultimately, the research seeks to create a body of evidence to help inform future policy formulation and strategy implementation for meeting national CO_2 targets.

REFERENCES

M. Bell, J. Wingfield, D. Miles-Shenton and J. Seavers, *Low carbon housing, lessons from Elm Tree Mews*, Joseph Rowntree Association (2010).

M. Davies and T. Oreszczyn, “The unintended consequences of decarbonising the built environment: A UK case study”, *Energy and Buildings*, 46 80-85 (2012).

DECC, *Low Carbon Communities Challenge evaluation report* (2012).

D. Fell and G. King, *Domestic energy use study: to understand why comparable households use different amounts of energy*, DECC (2012).

R. Gupta and S. Chandiwala, "Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments", *Building Research and Information*, 38:5, 530-548 (2010).

R. Gupta and M. Gregg, "Appraisal of UK funding frameworks for energy research in housing", *Building Research and Information*, 40:4, 446-460 (2012).

J. Palmer and I. Cooper, *United Kingdom housing energy fact file 2012*, DECC (2012).

J. Palmer, N.Terry and P. Pope, *How much energy could be saved by making small changes to everyday household behaviours*? DECC (2012).

K. Revell and S. Allen, *Energy use behaviour change*, 417, POST (2012).

S. Sorrell, *The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency*, UKERC (2007).

National Statistics, *A factsheet on domestic energy consumption in the UK since 1970, Energy consumption in the United Kingdom*, Chapter 3, DECC (2012).

Sustainable Building Conference 2013

A USER-FOCUSED INTEGRATED SYSTEM FOR SUSTAINABLE REFURBISHMENT

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Abstract. *Nowadays, it is urgent to renovate a great number of residential buildings. The necessity of improving energy efficiency must also be considered as an opportunity to improve indoor comfort. To achieve this goal, it is essential to develop tools to be used in the decision-making process, aiming to refurbish buildings in an integrated, efficient and sustainable way.The integrated system developed is based on a set of indicators. Sustainability indicators are useful to synthesize and organize complex information. They can provide data to evaluate a process in different stages: evaluation, diagnosis, comparison and tracing. The set of proposed indicators aims to accomplish the holistic approach pursued by sustainable development. So, these indicators are divided into three groups: environmental, social and economic. However, the main innovation of the system of indicators is the social ones. The sustainable refurbishment system aims to be a user-focused one. Therefore, the starting point is the needs of the user and social indicators are developed around this.The system tackles the sustainable refurbishment of buildings beyond energy problems. It proposes incorporating users in the decision-making process involving them in the refurbishment and so, contributing to the success of the renovation. In order to achieve this target, three social indicators are used, divided into 10 sub-indicators, and a "Questionnaire about Sustainable Refurbishment" is drawn up.This research has been carried out in the framework of "Sustainable Refurbishment" Research and Development Project, an integrated project under the supervision of the Centro para el Desarrollo Tecnológico e Industrial (CDTI) from the Spanish Government, in which University and the Construction Industry collaborate. This research project aims to develop an integrated system for the retrofitting of existing buildings to improve their energy efficiency. Accordingly, an additional objective of the project is to improve quality of life of residents.*

1 INTRODUCTION

Recent research projects on energy renovation highlight that incorporating users in the decision-making process facilitates a successful renovation (DEMOHOUSE 2008). In order to address the task of reducing energy use in buildings architects need to seek ways of integrating user involvement in building performance (Janda 2011). "Sustainable Refurbishment" R&D Project [http://rs.fi.upm.es/] tackles the sustainable refurbishment of residential buildings beyond energy problems. At the same time that energy efficiency is improved is essential to enhance the quality of life of residents in other aspects to involve them in the process. In order to achieve this target, three social indicators are used, divided into 10 sub-indicators, and a "Questionnaire about Sustainable Refurbishment" is drawn up. One global social indicator is calculated from this system of indicators. This social indicator quantifies the social performance of the building. The questionnaire is an important part of the set of indicators to engage the residents in the process. First, asking them about their needs and next, equally important, educating them on sustainability issues.

2 BACKGROUND

Indicators are quantitative, qualitative or descriptive measures, helpful to simplify the information available about an item and/or quality of a process (including development, planning, preparation and operation), in a relatively simple way to use and understand (García Navarro 2009). Indicators have three main functions: to measure, simplify and communicate. They are useful to manage information about complex issues such as sustainability because they try to prioritize in an issue with multiple perspectives. Sustainability must deal with environmental, economic and social indicators.

2.1 Sustainability indicators in European and International standards

The International Standard Organization (ISO) in Technical Specification ISO/TS 21929-1:2006 "Sustainability in building construction –sustainability indicators. Part 1: Framework for the development of indicators for buildings" defines a framework for establishing sustainability indicators for buildings. It provides a guide for developing and selecting sustainability indicators. The norm explains that many aspects of building performance are related at the same time with environmental, economic and social impacts, such as: building location, spatial solutions, services, client needs, technical solutions, service life or functional performance of the building, including indoor conditions that affect the health and the well-being of the users.

The European Norm EN 15643-3:2012 "Sustainability of construction works — Sustainability assessment of buildings — Part 3: Framework for the assessment of social performance", in accordance with ISO, defines social aspect as: "aspect of construction works, assembled system (part of works), processes or services related to their life cycle that can cause change to society or quality of life". This norm concentrates social dimension of sustainability on the assessment of aspects and impacts of a building expressed with quantifiable indicators. Social performance measures will be represented through indicators for the following social performance categories:

- Accessibility
- Health and Comfort
- Loadings on the neighborhood
- Maintenance
- Safety / Security
- Sourcing of Materials and Services
- Stakeholder Involvement

The objectives of the assessment are to determine the social impacts and aspects of the building and its site; and to enable the client, user and designer to make decisions that will help address the need for sustainability of buildings. The whole life cycle of the building must be considered: design, construction, use and end of life.

2.2 Social indicators in environmental evaluation tools

Nowadays, the most thorough methodologies to face the sustainability of new or existent buildings are the methods and environmental evaluation tools based in Life Cycle Assessment. Originally, these methods focused on reducing environmental impacts. Gradually, the social and economic commitment that sustainability requires has broadened indicators and methods to these areas too. Since the late 90, the publications of institutions such as International Initiative for a Sustainable Environment (IISBE), World Green Building Council (WGBC) and Sustainable Building Alliance (SBA) show that these methods are in constant evolution.

Despite the general consensus about the need to deal with social, environmental and economic aspects at the same time, in many of these tools, social aspects require further research (Simón-Rojo and Hernández-Aja 2011). The categories and criteria that include "social aspects" are not clearly defined in some of the methods and tools reviewed such as the *British Building Research Establishment Environmental Assessment Method* (BREEAM), the American GREENGLOBE, the Australian GREENSTAR, the Japanese *Comprehensive Assessment System for Built Environment Efficiency* (CASBEE), the Green Building Tool (GBTOOL) or the Australian *National Australian Built Environment Rating System* (NABERS). Whereas, for example the American *Leadership in Energy & Environmental Design* (LEED) and the Spanish *Valor de Eficiencia de Referencia de Edificios* (VERDE), *Hexálogo ASA* (Asociación sostenibilidad y Arquitectura) or *Guía de edificación sostenible para la vivienda en la Comunidad Autónoma del País Vasco* are more explicit collecting social aspects.

3 METHODOLOGY

The research studies, analyzes and considers the social indicators of international, European and national sustainability evaluation methods, in addition to other investigations summarized in the following list:

- DEMOHOUSE Project: "Design and Management Options for improving the energy performance of Housing", *Eco-buildings. European Commission. Sixth Framework Programme*, 2008.
- SECURE Project. Barriers and possibilities for a more energy efficient construction sector, *Intelligent Energy Europe*, 2009.
- Plan Estratégico 2010. Barrio de San Cristóbal de los Ángeles. Distrito de Villaverde. Madrid, *Empresa Municipal de Vivienda y Suelo (EMVS) y Universidad Carlos III*
- ISO/TS 21929-1:2006 "Sustainability in building construction –sustainability indicators. Part 1: Framework for the development of indicators for buildings".
- EN 15643-3:2012 "Sustainability of construction works. Sustainable assessment of buildings. Part 3: Framework for the assessment of social performance".
- Environmental evaluation tools: BREEAM, LEED, CASBEE, GBTOOL and VERDE.
- "Guía de la edificación sostenible para la vivienda en la Comunidad Autónoma del País Vasco", *Departamento de vivienda, obras públicas y transporte. Gobierno Vasco*.
- Hexálogo ASA (*Asociación Sostenibilidad y Arquitectura*).
- Internationally-recognized experts on sustainability in construction such as Sangter, Newsham, Larsson or the WBCSD (*World Business Council for Sustainable Development*).
- Agenda 21 de Málaga.

3.1 Selection of a set of indicators

There is a need for sustainability indicators in order to assess a progress towards a goal. However, the simplification of complicated issues can be misleading (S. Ghosh et al. 2006). If they are too complex or numerous they will not be understood by the non-expert population.

It is also important to consider how far they are applicable to the process of change. Furthermore, it is important to take into account the context in which they are going to be used. Following these indications, from the review of the criteria considered as “social” aspects, we chose some of them for the system of indicators established in this research and other new criteria were developed. The general aspects that International and European standards reflect are more developed in national regulations. Some of them were used to elaborate our social indicators, such as:

- Core Documents of Spanish Building Regulations (Código Técnico de la Edificación)
- RD 47/2007 sobre Certificación de Eficiencia Energética de Edificios.
- “Orden sobre la modificación del Plan General de Ordenación Urbana de Valladolid para su adaptación la Ley 5/1999 de Urbanismo de Castilla y León”
- “Ordenanza de Torrejón de Ardoz (Madrid)” and “Ordenanza Bioclimática de Tres Cantos (Madrid)”.
- “Decreto de Ecoeficiencia 21/2006 de Cataluña”.
- UNE 170001-1: 2007 “Accesibilidad universal. Parte 1: Criterios DALCO para facilitar la accesibilidad al entorno” and UNE 170001-2: 2007 “Accesibilidad universal. Parte 2: Sistema de gestión de la accesibilidad”.
- “Orden 1369/2006, de 21 de abril, de la Consejería de Medio Ambiente y Ordenación del Territorio de la Comunidad de Madrid, por la que se aprueban los criterios para obtener la consideración de Vivienda con Protección Pública de carácter sostenible”.

Every social indicator proposed is divided in sub-indicators that deal with more specific aspects in order to facilitate its quantification. This research is developed under the framework of “Sustainable Refurbishment (SR)” Research and Development Project that is an integrated project under the supervision of the *Centro para el Desarrollo Tecnológico e Industrial* (CDTI) from the Spanish Government, in which University and the Construction Industry collaborate. The development of a system of indicators is part of Work Package 8 “Integrated model development”. The Construction Company FCC CO is the leader of the project and the coordinator of this task. Another participant in this task is *Grupo de Termotecnia,* a research group from *Escuela de Ingenieros de Universidad de Sevilla*. The final system of indicators agreed between the participants is shown in Table 1. Our research group *giSCI* was responsible of social indicators. This paper focuses on the development of the set of social indicators.

3.2 Benchmarking for social indicators

Considering the reference methods, standards, regulations and literature, we established an objective, a calculation method and the evaluation parameters for each sub-indicator that comprises every social indicator. In paragraph 4.1 it is shown the final system of social indicators (Table 3).

Environmental Indicators	**EN1**	**Building Use. CO2 emissions**	**EN1.1**	Global emissions	**EN1.1.1**	Global Energy Efficiency Indicator (EEI)
					EN1.1.2	Class of Energy Efficiency (CEE) A-G
			EN1.2	Heating	**EN1.2.1**	Heating EEI
					EN1.2.2	CEE (A-G). Heating
			EN1.3	Cooling	**EN1.3.1**	Cooling EEI
					EN1.3.2	CEE (A-G). Cooling
			EN1.4	Domestic hot water	**EN1.4.1**	Domestic hot water EEI
					EN1.4.2	CEE (A-G). Domestic hot water
			EN1.5	Lighting and equipment	**EN1.5.1**	Lighting VEEI
	EN2	**Building Use. Final energy**	**EN2.1**	Heating EEI	**EN2.1.1**	EEI for net energy heating demand
					EN2.1.2	EEI for heating system
					EN2.1.3	Use of renewable energy
			EN2.2	Cooling EEI	**EN2.2.1**	EEI for net energy cooling demand
					EN2.2.2	EEI for cooling system
					EN2.2.3	Use of renewable energy
			EN2.3	Domestic hot water EEI	**EN2.3.1**	EEI for domestic hot water system
					EN2.3.2	Use of renewable energy
			EN2.4	Lighting and equipment	**EN2.4.1**	Lighting VEEI
	EN3	**Building Use. Delivered energy (kwh)**	**EN3.1**	Natural gas		
			EN3.2	LPG		
			EN3.3	Diesel fuel		
			EN3.4	Solid mineral fuels		
			EN3.5	Electric power		
			EN3.6	Solar energy		
			EN3.7	Biomass		
			EN3.8	Geothermal		
			EN3.9	Others		
	EN4	**Use of water**	**EN4.1**	Supply		
			EN4.2	Evacuation		
			EN4.3	Reuse	**EN4.3.1**	Rainwater
					EN4.3.2	Greywater
Social Indicators	**S1**	**Users satisfaction**	**S1.1**	Users satisfaction		
	S2	**Quality of life**	**S2.1**	Health and comfort	**S2.1.1**	Hygrothermal comfort
					S2.1.2	Indoor air quality
					S2.1.3	Acoustic comfort
					S2.1.4	Visual comfort and Natural ventilation (*)
					S2.1.5	Cross-ventilation possibilities
					S2.1.6	Use of vegetation
			S2.2	Universal Accesibility and Design for All	**S2.2.1**	Ambulation
			S2.3	Community services	**S2.3.1**	Users services
	S3	**Participation agreement**	**S3.1**	Information to the users of the building		
Economic Indicators	**EC1**	**Energy and community services costs (Use)**	**EC1.1**	Heating and Hot water		
			EC1.2	Water supply		
			EC1.3	Electric power		
			EC1.4	Community services		
	EC2	**Refurbishment costs (Project and Construction)**	**EC2.1**	Pre-Design Stage		
			EC2.2	Design Stage		
			EC2.3	Construction Stage		
			EC2.4	Use Stage		
	EC3	**Amortization period**	**EC3.1**	Amortization period		

Table 1 : Integrated model system of indicators. Breakdown of indicators and sub-indicators

The underlying difficulty of quantifying qualitative rather than quantitative aspects such as social aspects leads to establish a common reference pattern for comparing all the indicators on the same terms. That is, even though the units are in some cases percentages, in others a specific quantity with a magnitude and in others a positive/negative response or a description of a situation, we proceed to assign all these values a number that belongs to a common reference pattern. This way, everything can be compared on the same terms. This normalization process is referred to in Carraro's paper "Aggregation and projection of sustainability indicators" (Carraro et al. 2009). They introduced a new sustainability index: FEEM SI (Fondazione Eni Enrico Mattei Sustainability Index). Normally, the benchmarking procedure assigns only two values, 1 and 0, according to the correspondence to a chosen reference level. In the case of the FEEM SI the purpose was not only to identify best and worst practices, but also to provide a measure of a distance from a given target. This is why five different benchmark levels were identified, and used to attribute different levels of sustainability in FEEM SI.

The research started attributing five levels to every sub-indicator. Finally, because of the difficulty to attribute a value for each level in every social indicator we decided to simplify it to three levels. More research is needed in many of the areas related with social aspects of built environment to identify levels that provide more steps to go from an unsustainable situation to a fully sustainable one. The common reference pattern used for this research is:

0.00	Unsustainable
0.50	Admissible. A discreet level of sustainability, but still far from target
1.00	Appropriate. Target level, fully sustainable

Table 2: Normalization benchmark levels

3.3 Establishing rules for calculating and weighting social indicators

Weighting rules of social indicators meet the following criteria:

- The relative weight of the indicators *S1 User Satisfaction* and *S3 Participation Agreement* is lower than *S2 Quality of Life* because *S2* indicator reflects the matters directly related to the physical characteristics of the building. (See equation (1))
- The relative weight of the sub-indicator *S2.1 Health and Comfort* is higher than *S2.2 Universal Accessibility and Design for All* and *S2.3 Community Services* because it captures those features of the building more directly related to improving energy efficiency, the main priority of "*Sustainable Refurbishment*" project. (See equation (2))
- The relative weight of sub-indicator *S2.1.2 Visual Comfort and Natural Ventilation* is higher than the rest of sub-indicators of the *S2.1 Health and Comfort* sub-indicator because it is considered a *sine qua non* requirement, a prerequisite. It is an essential requirement to ensure the health and hygiene of housing and so, to improve the living conditions in the case of non-compliant. Therefore, the breach of this condition implies that the overall social indicator (*SI*) is 0.00 (Unsustainable). The others sub-indicators of *S2.1* have been considered with equal importance and their relative weight have been distributed among them. (See equation (3))

$$SI = (0.05 \times S1) + (0.85 \times S2) + (0.10 \times S3) \quad (1)$$

$$S1 = S1$$
$$S2 = (0.90 \times S2.1) + (0.06 \times S2.2) + (0.04 \times S2.3) \quad (2)$$
$$S2.1 = (0.7 \times S2.1.2) + [0.06 \times (S2.1.1 + S2.1.3 + S2.1.4 + S2.1.5 + S2.1.6)] \quad (3)$$
$$S2.2 = S2.2$$
$$S2.3 = S2.3$$
$$S3 = S3$$

Concisely, in a single equation, would be as follows:

$$SI = (0.05 \times S1) + (0.0459 \times S2.1.1) + (0.5355 \times S2.1.2) + (0.0459 \times S2.1.3) + (0.0459 \times S2.1.4) + (0.0459 \times S2.1.5) + (0.0459 \times S2.1.6) + (0.051 \times S2.2) + (0.034 \times S2.3) + (0.10 \times S3) \quad (4)$$

The global social indicator SI that is obtained is interpreted as follows:

SI = 0.00 Unsustainable

The refurbishment process has not considered the basic social aspects.

SI = 0.50 Admissible

The refurbishment process has considered the basic social aspects and puts the building in a better position to deal with other improvements in the future.

SI = 1.00 Appropriate

The refurbishment process has managed to fully incorporate into the building basic social aspects. It has also allowed to establish criteria for tracking them over time and to compare it with other buildings.

3.4 Case Study: residential building in Jacinto Benavente Av, Málaga (Spain)

The theoretical application of these indicators on a pilot building of “Sustainable Refurbishment” R&D project enabled to analyze them in order to reduce the group of indicators. This way, the set of social indicators is adapted to the specific needs of the project: to obtain a system for a fast and convenient evaluation to be used by the Construction Company FCC CO. The pilot building is a residential building of 140 public housing units for rent for people with low income and educational level in Málaga (Andalucía).

In particular, the theoretical application of *S2 Quality of Life* was helpful to guide the direction of the refurbishment beyond energy efficiency problems. Selected social indicators facilitate prioritizing between different requirements in the building. Therefore, they allow planning the refurbishment in progressive stages over time.

4 RESULTS

The most significant results of the research are two tools: a list of social indicators for a quick evaluation and a questionnaire about sustainable refurbishment. The first one synthesizes basic social aspects of a sustainable refurbishment. Meanwhile, the second one facilitates a participative decision-making process and it is part of the system of indicators as its use is obligatory to obtain the maximum punctuation.

4.1 List of social indicators for a quick evaluation

Initially, 4 social indicators were proposed. They were composed of 50 sub-indicators. Finally, they were reduced to 3 composed of 10 sub-indicators to adjust the system to the targets of the project, as it is shown in Table 3.

Two criteria of the system of indicators are considered essential. Both criteria are grouped in the social sub-indicator *S2.1.4 Visual comfort and Natural ventilation.* This sub-indicator deals with two basic conditions for the habitability of dwellings. Those criteria are ratio of glazing and ratio of operable window to room area, in order to achieve enough day lighting and to provide adequate natural ventilation. This requirement is considered *sine qua non*, and it is marked with an asterisk (*) to emphasize its importance. As it was explained in paragraph 3.3, if the building gets 0.00 point at this sub-indicator, then the global punctuation would be

0.00 Unsustainable for the whole building. In the residential building in Málaga, analyzed as Case Study, this sub-indicator enabled detecting that the standard flat (Type A) suffers a lack of healthiness because of the enclosure of the flat open terrace by the residents. So, the global punctuation of this building at its current state is *0.00 Unsustainable*.

S1 Users satisfaction					5%
Did you fulfill the questionnaire about sustainable refurbishment?					
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
No		Yes, at pre-design stage		Yes, at pre-design and use stages	
S2 Quality of life					85%
S2.1 Health and comfort					90%
S2.1.1 Hygrothermal comfort Has the building the energy efficiency certificate?					6%
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
No		Yes, the rating of the building is worst than C and users are informed about it		Yes, the rating is better than C and users are informed about it	
S2.1.2 Indoor air quality Has the building the ventilation system required to provide the necessary indoor air quality?					6%
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
No		Yes, the dwellings have the required admission and extraction openings		Yes, the dwelllings fulfilled CTE DB HS3	
S2.1.3 Acoustic comfort Has the building any indoor or outdoor acoustic problems?					6%
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
Yes, there is acoustic discomfort but the reason of the problem is not identified		Yes, the satisfaction questionnaire has been fulfilled and the reason of the acoustic problem is identified		No, there is no acoustic discomfort in the building	
S2.1.4 Visual comfort and natural ventilation (*) Is there daylighting and natural ventilation in 100% of bedrooms, living rooms, dining rooms and kitchens? (*) *Sine qua non* requirement					70%
0.00	Unsustainable			1.00	Appropriate
No				Yes, the glazing area is bigger than 1/10 of room area and the operable part of the window is bigger than 1/20 of room area in every bedroom, living room, dining room and kitchen	
S2.1.5 Cross-ventilation possibilities Is there cross-ventilation in the dwellings to improve indoor air quality and thermal comfort?					6%
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
No		Yes, at least 50% of dwellings had that possibility		Yes, more than 75% of dwellings had that possibility	

Table 3: List of social indicators for a quick evaluation - Summary of calculation method, evaluation parameters and weighting of social indicators

S2.1.6 Use of vegetation Has the building and its plot any possibilities to be used as CO_2 sink?					6%
0.00	Unsustainable	0.50	Admissible	1.00	Appropiate
No		Yes, there is some vegetation but not enough		Yes, the vegetation has been improved adding new elements	
S2.2 Universal Accesibility and Design for All					6%
Are the common areas of the building and the plot accessible?					
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
No		Yes, at least one way is accessible		Yes, indoor and outdoor common areas of the building are fully accessible	
S2.3 Community services					4%
Has the building instructions of use, a management plan or any common service for the users?					
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
No		Yes, there is a cleaning and maintenance service in the building		Yes, there are cleaning and maintenance service, instructions of use and at least another common service	
S3 Participation Agreement					10%
Are the users of the building well-informed about the construction work that is going to be carried out?					
0.00	Unsustainable	0.50	Admissible	1.00	Appropriate
No		Yes, the constructor has convened briefings series with the neighborhood to inform them about the work in progress		Yes, the “Participation Agreement” has been written and all the stakeholders has signed it to establish a participating decision-making process	

Table 3: List of social indicators for a quick evaluation - Summary of calculation method, evaluation parameters and weighting of social indicators (continue)

4.2 Questionnaire about sustainable refurbishment

The questionnaire is organized in five areas: Energy, Water, Waste, Building Conservation, and Level of Satisfaction and Comfort. The main objectives are collecting information, as well as, informing the residents about different issues related to sustainable refurbishment of the building. The questionnaire must be used before and after the refurbishment process to obtain the maximum punctuation in indicator *S1 Users satisfaction*. It also contains useful information to calculate *S2 Quality of life* and *S3 Participation agreement*.

Questions are formulated in such a way that the affirmative answer is also the better in terms of sustainability. So, somehow, the user is being educated at the same time that is being informed and that information is being collected. Furthermore, all the affirmative answers are in the same column therefore, the questionnaire quickly provides a global vision of the building current condition before the refurbishment or later, after it has been undertaken.

Replying the questionnaire promotes a participating decision-making process. The information obtained would be useful for a preliminary evaluation of the condition of the building and to detect action priorities. Additionally, the delivery of the surveys and the questionnaire itself would be helpful to inform about the refurbishment and about essential aspects of sustainability. It would contribute to reduce social barriers of the refurbishment process because it would promote residents participation, it would be helpful to explain the refurbishment to them and it would facilitate the higher degree of social implication that is necessary to achieve a successful refurbishment.

5 CONCLUSIONS

- The questionnaire together with the group of social indicators provides a user-friendly tool to quantify if the refurbishment process has managed to incorporate basic social aspects in the building. They also allow to track the intervention and to compare with other buildings.
- The questionnaire on sustainable rehabilitation promotes a controlled participatory decision-making process, in order to reduce the inherent difficulties of this short of processes.
- The simplification effort undertaken to address social issues without requiring excessively laborious calculations allowed synthesizing a group of indicators for obtaining and managing crucial social aspects in the building.

REFERENCES

C. Carraro et al., “Aggregation and projection of sustainability indicators: a new approach”, *The 3rd OECD World Forum on Statistics, Knowledge and Policy Charting Progress, Building Visions, Improving Life*, Busan, Korea, October (2009).

DEMOHOUSE Project, “Design and management options for improving the energy performance of housing”, *Eco-buildings, European Comission. Sixth Framework Programme* (2008). Available online: http://www.demohouse.net

EN 15643-3, *Sustainability of construction works — Sustainability assessment of buildings — Part 3: Framework for the assessment of social performance* (2012).

ISO/TS 21929-1, *Sustainability in building construction –sustainability indicators. Part 1: Framework for the development of indicators for buildings* (2006).

J. García Navarro et al., “Settings for sustainability indicators in mining landscapes: the mining Valley of Laciana (León, Spain), *Revista Informes de la Construcción*, 61(514), 51-70, Instituto de Ciencias de la Construcción Eduardo Torroja CSIC, Madrid, April-June (2009).

S. Ghosh, R. Vale and D. Vale, “Indications from sustainability indicators”, *Journal of Urban Design*, 11(2), 263–275 (2006).

K.B. Janda, “Buildings don’t use energy: people do”, *Architectural Science Review*, 54, 15-22 (2011).

M. Simón-Rojo and A. Hernández-Aja, “Sustainability assessment tools for urban design at neighbourhood scale”, *Revista Informes de la Construcción*, 63(EXTRA), 41-49, October (2011).

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EXPLORING THE WHOLE LIFE CARBON BENEFITS OF INSULATION MATERIALS IN HOUSING REFURBISHMENT

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Abstract. *Embodied carbon can be an important part of a building's whole life carbon cost and as such offers potential possibilities to reduce carbon emissions. To date the majority of research in this area has focused on new buildings and overlooked the existing housing stock much of which is in urgent need of upgrading if emissions reduction targets set out by the Government are to be achieved. This paper briefly explores the whole life benefits of including embodied carbon in the specification of insulation materials in UK retrofits. Insulation has the potential to both reduce in-use CO2 emissions of a building as well as lead to further emissions during its manufacture and transport, and in the case of bio-insulations to even sequester CO2. Dynamic thermal simulation was used to predict CO2 savings over 25 to 50 year periods resulting from heating reductions of retrofitting, and the embodied carbon values of the materials used was calculated using two freely available databases. Three insulation materials were used for comparison; Polyurethane foam, Mineral wool and Wood fibre. The results suggest that the reduction of embodied carbon in retrofitting has the potential to reduce a buildings whole life carbon, with the extent of this reduction dependent on whether sequestered carbon is included in the figures for bio based insulation. Although the accepted orthodoxy recommends the use of the most efficient insulation available, this study shows that the inclusion of embodied carbon values into the equation brings this approach into question.*

Keywords: low carbon refurbishment, embodied carbon, whole life carbon

1 INTRODUCTION

Rising fuel prices and the spectre of climate change are driving moves to improve the thermal efficiency of our homes. The UK's existing housing stock is in particular need of attention with many requiring extensive retrofits to achieve emission reductions on the scale needed. Household energy use is responsible for 27% of the total UK Carbon dioxide emissions (Boardman 2007). Of this, space heating accounts for some 53% (SDC 2006). Increasingly stringent building regulations are resulting in new homes with much improved operational emissions but the majority of the UK population live in older, less efficient homes. Estimates suggest around 86% of the UK's houses will be made up of existing stock by 2050 (SDC 2006). Almost 40% of these were built before 1945 (EHCS 2009) to standards far below those needed to reach emission reduction targets set by government.

Applying insulation to the building envelope is core to any retrofit project and typically employs petrochemical based foams or mineral wools. Although these materials can substantially reduce the carbon emission resulting from space heating, their manufacture and disposal has an embodied carbon (EC) cost. The current doctrine suggests that the resulting energy savings more than compensate for this initial carbon debt.

In contrast, a number of insulation materials such as Wood fibre and cellulose offer a low embodied carbon alternative. Such materials can possess negative EC values, due to carbon sequestered as the plants grow. Accepting the urgent need to reduce CO2 emissions, this paper explores the potential net carbon savings offered by the use of these materials in a low EC approach to retrofitting. A number of refurbishment scenarios are modelled in order to determine the scale of potential carbon savings over time.

2 CONTEXT

As greater quantities of natural materials appear on the market, consumers can now choose between the typically cheap, highly efficient man-made materials with a high embodied carbon, and the less efficient, more expensive plant derived materials with a low or even negative embodied carbon. Negative values result from the sequestration of carbon through photosynthesis, as the plant grows. Although dependent on a number of variables, these negative values have the potential to exaggerate differences in EC costs.

This paper examines through a number of simulations the initial EC difference and the trade-off between embodied energy and energy saving potential, and therefore the potential of sustainable material specification to maximise the whole life carbon savings resulting from thermal improvements to typical UK housing stock. High EC approaches to refurbishment using conventional man made building materials are compared to Low EC approaches using natural materials and the resulting net carbon savings calculated. The high EC approach reflects very closely standard practice today.

2.1 Embodied carbon

Embodied Carbon (EC) extends the concept of Embodied Energy (EE) which itself can be described as the "*the sum of the energy requirements associated, directly or indirectly, with the delivery of a good or service*" (Cleveland & Morris 2009). Calculation of EC follows energy flows back to the carbon emissions resulting from their generation and supply. Although carbon emissions are responsible for the majority of global warming other atmospheric gases also contribute. The embodied carbon equivalent (ECe) is a more comprehensive quantification of a material's emissions expressed in Kg CO2 but including other greenhouse gases (if emitted). Table 1 shows embodied energy, embodied carbon and embodied carbon equivalent values for a selection of materials from the ICE database (Hammond & Jones 2011) that were used in this study. Although ECe values are not always very different from EC values, certain materials of which the plastic foams listed are a good example show marked increases. The ICE database uses a 'cradle to gate' measurement due to it being the most commonly seen in the data sources reviewed (ibid).

2.2 Sequestered carbon

The embodied carbon in a material remains stored for an assumed life period. While carbon can be sequestered for any amount of time, the longer it is removed from the atmosphere the more pronounced its effect on reducing global warming. However, while carbon stored in wood is unlikely to be stored indefinitely, if it is held for a period comparable with those used to assess GWP it is considered sequestered. Indeed, attributing a negative EC value must assume a reasonable time frame. The IBO (Waltjen, 2009) database ascribes GWP over a 100 year period and assumes ideal future scenarios. The uncertainty surrounding the realisation of such assumptions is a reason sequestered carbon is omitted from the ICE database. The large number of unknowns in timber products (e.g. how much of the cut timber is used, transport, machining) mean that EC figures could become meaningless or even misleading. However, the manufacturers of the Wood fibre insulation modelled in this study claim that 99% of the wood it uses are off cuts from local saw mills. The use of what would otherwise be a waste product from monitored, managed forests gives a level of confidence to attributing a figure for sequestered carbon. Of course, suitable operational and end of life scenarios must be assured. Recycling, wastage during building and transport of materials can all alter the EC value.

Material	Embodied Energy (MJ/kg)	Embodied Carbon (KgCO2/Kg)	Embodied Carbon eq. (KgCO2e/kg)
Mineral wool	16.6	1.2	1.28
Expanded polystyrene	88.6	2.55	3.29
Polyurethane	101.5	3.48	4.26

Table 1: Embodied energy and carbon of insulation materials (source: ICE database)

2.3 EC in buildings

To date, consideration of the embodied carbon has focussed on embodied carbon in new buildings. EC values vary with building size, construction type, building use and the study parameters, but approximate figures can be drawn. Monahan and Powell (2011) calculate emissions at 34.6 tonnes CO_2 for a 3 bedroom semi-detached house constructed with modularised timber panels, and 52 tonnes when constructed with traditional masonry cavity walls. In another study, three new builds showed comparable values of 50 TCO2 each (EHA 2008).

EC values are often described as a proportion of the total carbon cost. Ramesh et al. (2010) in an overview of LCA of buildings concludes that EE accounts for around 10-20% of the lifetime energy. These values depend largely on the operational energy of building which can vary greatly. Sturgis & Roberts (2010) estimate EC to account for 30% in houses, 45% in offices and 60% for warehouses. A report (Wray & Atkinson, 2011) on the cradle to grave footprint of offices showed EC to make up approximately one third the total life carbon.

As new buildings become ever more energy efficient the EC proportion, of the whole life carbon cost, will increase. Hammond & Jones (2009) estimated EC of domestic new builds (built to 2006 regulations) to be between 12-19 years of their operational energy related emissions and it can be assumed that this value will increase in a building constructed to 2010 regulations. A report by Jones (2011) proposes that EC has been further underestimated due to an overestimation of operational electricity emissions of the future. They argue that previous studies have not considered the future decarbonisation of electricity generation and as a result overestimate operational energy by 50% for a typical domestic new build.

These operational and embodied values cannot always be considered distinctly separately and can be interrelated. Hacker et al (2008) studied the relationship between thermal mass and

EC over the next hundred years in southern England and concluded that, although the buildings with higher thermal mass had higher EC values (due to the large amount of cement etc.) the resulting energy savings from avoiding cooling loads offset the higher EC values relatively quickly. By contrast, the Bed-zed development (Lazarus, 2002) focused on the potential to reduce EC. The use of recycled materials and local procurement was prioritised. Recycled materials made up 15 % of the total materials used and reduced the embodied impact by some 20-30 % whilst maintaining building performance. As regards sequestration, a modelling study (McInerney and Tucker, 2012) on small houses built to the Passivhaus standard found that constructing them of low EC materials could result in sequestration of 26 $TC0_2e$ whereas a non-renewable fabric led to emissions of +31 $TC0_2e$.

2.4 EC in Retrofit

Little research has focused on the EC of refurbishment. One report (EHA, 2008) showed that renovations produced some 15 tonnes of CO2 compared to new build values of around 50 tonnes and the renovated houses reached a thermal efficiency comparable to that of the new builds. The conclusion highlighted the increased period needed by the new builds to offset their larger EC cost. Although using it as a comparative measure to show the benefit of refurbishment, the report did not examine reductions of EC.

Many of the materials commonly employed when retrofitting, such as foam insulation, plasterboard and mineral wool insulation have high embodied carbon values but are commonly specified for a number of reasons. Firstly the current orthodoxy focuses heavily on the reduction of operational emissions through the specification of high performance insulating materials; typically these possess higher EC values. This initial outlay of carbon is justified by the insulations potential to save many times the value of its EC over its lifetime through heating energy savings. One report (XCO2, 2009) concludes that *"the choice of insulation material is not important"*.

Secondly the insulation market is dominated by a small number of large companies who produce very cheap, very efficient insulation. The large scale manufacture and relatively cheap raw materials enable these companies to produce their products very competitively. Comparison of two fibrous insulations, mineral wool and sheep's wool, showed sheep's wool to be over four times the price (Spittle, 2012). Both materials have similar conductivity values and possible applications but the price difference is substantial. With cost always an important driver the cheaper and more efficient a product is, the shorter its pay-back period. From a consumers perspective a financial view may take priority over levels of EC.

3 METHODOLOGY AND RESULTS

Dynamic thermal simulation (IES, 2012) was used to predict saving in space heating energy use over a base line model. This figure was then converted to ECe for the fuel type used (gas). The volumes of materials used for each study were calculated and corresponding ECe figures were obtained using the ICE (2011) and IBO (Waltjen, 2009) databases. The thermal properties of the insulation materials were based on specific commonly available brands of insulation (table 2).

3.1 Retrofitting three house types to three levels of insulation

A semi-detached house, a bungalow and a terraced house were modeled (table 3 and figure 1) and their heating energy use assessed. The buildings were all uninsulated. Low (L1), medium (L2) and high (L3) levels of retrofitted insulation were applied to each base model (table 4). The wall insulation was applied in line with a realistic practice, by filling cavity first then adding internal insulation followed finally by external insulation. The ECe and emissions from space heating energy were added to give the whole life net savings.

Insulation	Element	Conductivity (W/mK)	Density (Kg/m3)	ECe (Kg CO2/Kg)
Polyurethane (PU)	All elements	0.022	32	4.26
Mineral wool (MW)	External Wall / floor	0.04	140	
	Cavity	0.04	30	
	Roof	0.038	36:0-120mm, 45: >120	1.33 (mean)
Wood fibre (WF)	Internal/external wall	0.044	190	-0.18
	Cavity	0.038	24	-0.907
	Floor and roof	0.038	140	-0.18

Table 2: Properties of insulation materials modeled

Wall	Brick – cavity - Brick
Floor	Suspended Timber floor, un-insulated
Roof	Felt – batten – Slate
Glazing	4 mm single glazing
Ventilation	1 air change/hour
Weather file	Kew
Heating profile	Oct 1 – May 31 (0600 – 1000 & 1600 – 2200)
Glazed area	10% External Wall

Table 3: Base model parameters

	Insulation added					(Kg CO2/Kg)		
Retrofit measures	External Wall (mm)	Internal Wall (mm)	Cavity Wall (mm)	Floor (mm)	Roof (mm)	PU	MW	WF
Control	0	0	0	0	0	0	0	0
Low (L1)	0	0	50	50	50	1735	548	-309
Medium (L2)	0	50	50	100	100	3471	2216	-705
High (L3)	100	0	50	150	150	5206	3884	-1101

Table 4: Insulation levels applied

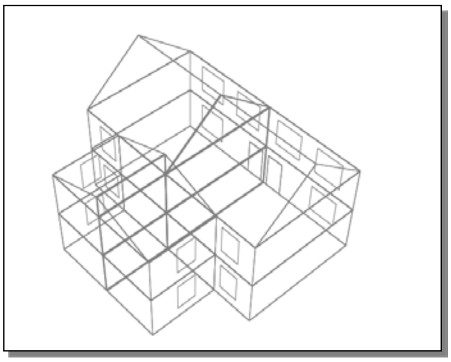

Figure 1: Semi-detached model

Figures 2-4 show the results for the semi-detached house which follow a similar pattern to the other two house types. For the L1 level of retrofit (figure 2) the net saving for the Polyurethane is the greatest of all three insulations at over 20 tonnes ECe, due to its effective thermal performance giving greater energy savings than Mineral Wool or Wood fibre. However, for L2 and L3 levels of retrofit the Wood fibre shows the largest net saving due to the combined factors of increased levels of sequestered carbon and the diminishing returns of heat energy saved with greater depths of insulation. At high levels of insulation there is not so great a difference in heat losses between the Polyurethane and the Wood fibre despite the difference in values of conductivity.

For all buildings (terraced, detached and semi-detached) for the L1 level of refurbishment scenario, Polyurethane achieves the largest net savings (figure 5). Although it has a high ECe value per Kg, its superior thermal efficiency out performs the other materials. On the other hand, L2 and L3 level refurbishment results in Wood fibre insulation giving the higher net savings in the majority of cases. This is due to the larger quantities of sequestered carbon in the Wood fibre outweighing the better thermal performance over time of the Polyurethane. Mineral wool performs poorest throughout yet does show a closer equivalence with Polyurethane as insulation levels increase.

The figures are significant when compared with the 25 year totals of annual heating emissions which for the semi-detached house after insulating were between 42 and 52 tonnes depending on the refurbishment scenario and the insulation type. For the L3 retrofit the difference in ECe of Polyurethane and Wood fibre is about 5 tonnes which is equivalent to around 2-3 years of heating energy emissions.

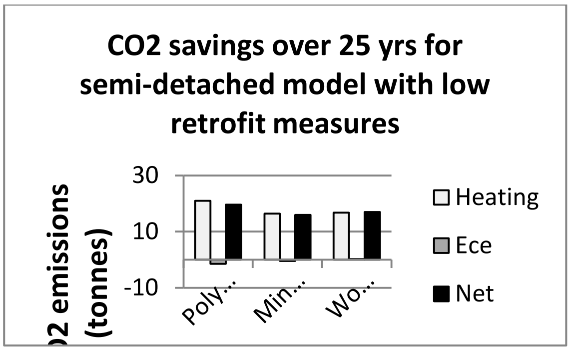

Figure 2: Semi-detached model (L1)

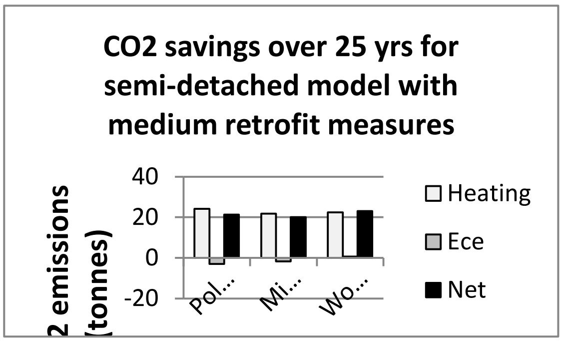

Figure 3: Semi-detached model (L2)

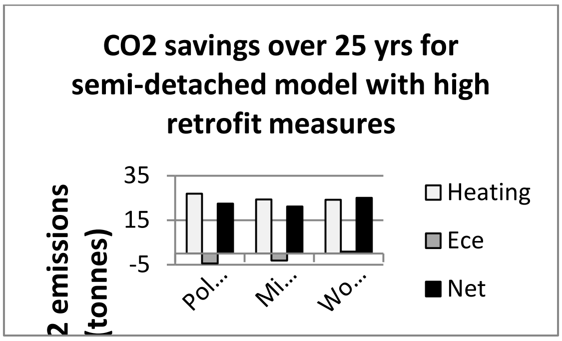

Figure 4: Semi-detached model (L3)

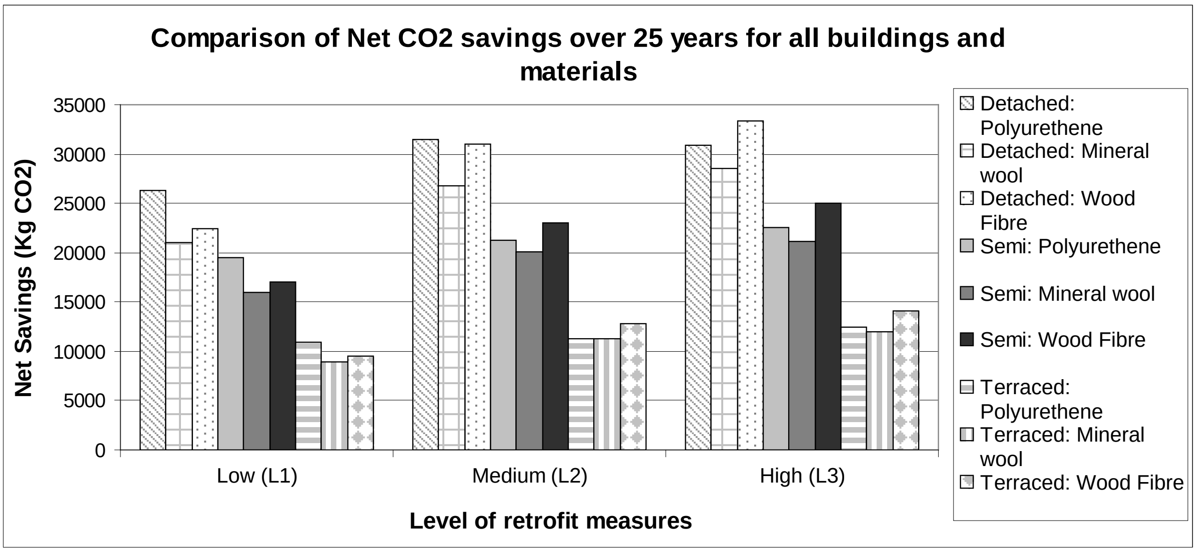

Figure 5: Net CO2 savings for terraced, detached and semi-detached under three levels of retrofit

3.2 Retrofitting bungalow with wall insulation only

A bungalow with a floor area of 96m^2 was modelled (based on an existing building) and external wall insulation added in increments. Internal and external finishes such as render and plaster were included in the ECe calculations (full details not given here due to space restrictions). The construction was of brick/block cavity with an initial 50mm of cavity insulation, and a concrete floor with 25mm Polystyrene insulation. The results show that as external wall insulation is added, up to a thickness of approximately 60mm Polyurethane gives the highest net CO2 savings over 25 years due to a better thermal performance (figure 6). At 60mm both Polyurethane and Wood fibre save equivalents amounts of CO2, and above 60mm the Wood fibre saves the most. The curves of both lines reflect the diminishing returns of adding further insulation, and the more pronounced curve for Polyurethane is a result of its increase in positive ECe value with increased thickness.

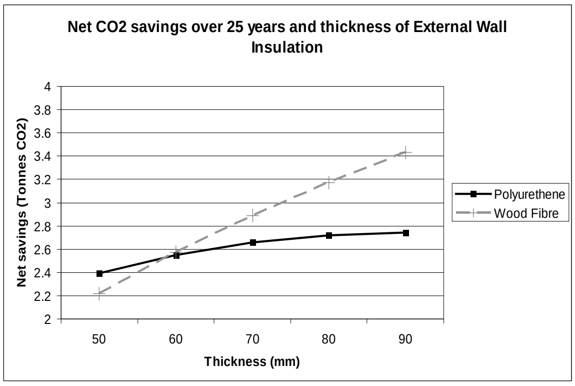

Figure 6: Insulation thickness and CO2 savings

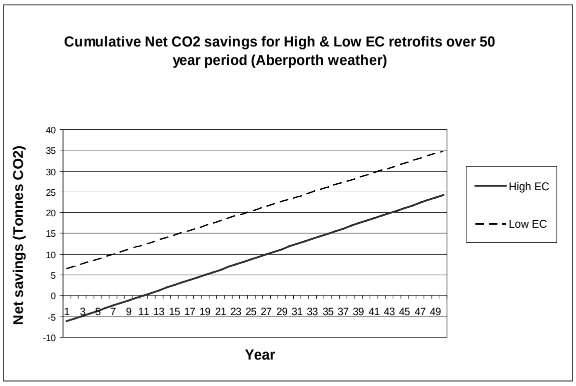

Figure 7: ECe type and CO2 savings

The high and low ECe approach was further developed to include the materials and methods of adding insulation. The insulation was increased in thickness to give a U-value in each envelope element of 0.2 W/m2K, and double glazing was added. The high ECe materials used such as plasterboard and screed are not exceptional but are commonly employed. The low ECe approach saves more CO2 until the 302nd year (figure 7).

The quantities of wall and roof insulation in the low ECe model were then reduced to determine how much Wood fibre would be required such that the point at which both high and low ECe models saved equal amounts of CO2 at the 50 year point. Only 35mm of Wood fibre on the walls was needed which is only a quarter of its initial thickness of 140mm, and half the thickness of the required Polyurethane. At the same time roof insulation was reduced to 100 mm compared to the 200mm of Polyurethane needed. This level of Wood fibre insulation resulted in U-values below those required by Building Regulations. The results indicate that if a specific length of building life was to be assumed, then buildings would need less insulation if sequestering insulations were used, and such saving in volume of insulation could reduce the cost differential between the manmade and natural insulations.

3.3 Sensitivity tests

Finally, some sensitivity tests were done to quantify the effects on net ECe savings that other building parameters would have. Figure 8 shows the effect on 25 net year saving of improving airtightness (or reducing ventilation) of the building from 1ac/hour to 0.5 ac/hour. The figures indicate that the effect of this parameter change is of the same order as that obtained by switching from a high to a low ECe approach. Figure 9 shows the effect of climate on net savings, and the order of difference in net saving between the high to a low ECe approach is similar to that resulting from the difference between London and Aberdeen climates. These two results provide further evidence that levels of ECe should be taken seriously and that potential effects on net savings are significant.

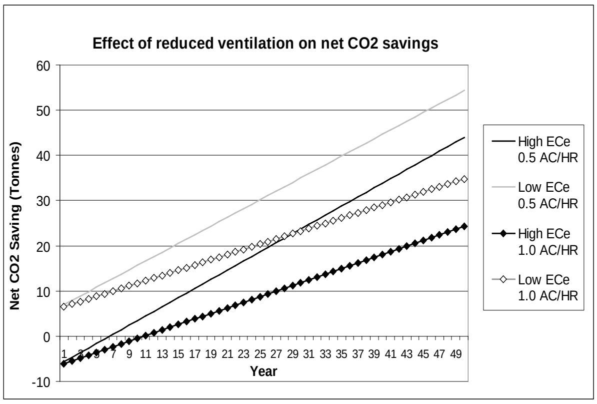

Figure 8: Ventilation rate and CO2 savings

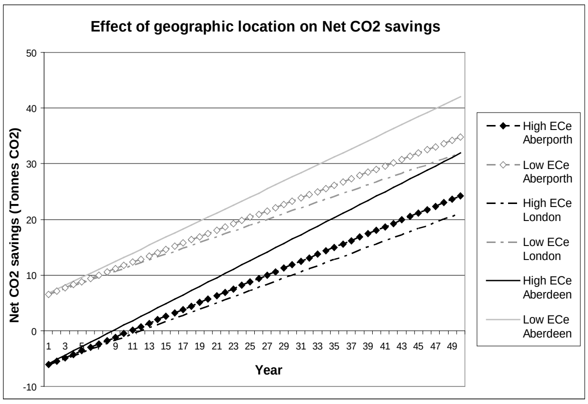

Figure 9: Climate and CO2 savings

4 DISCUSSION

The Embodied Carbon of the materials used to thermally retrofit existing buildings has been shown to have a noticeable effect on the building whole life carbon cost. While the specification of low ECe materials over high ECe materials will directly reduce the carbon debt of a building, a further less obvious relationship is seen with insulation. Here the net carbon savings are a function of the ECe value of the material, its achieved U-value and the law of diminishing returns obtained from incremental increases of insulation thickness. Over a 25 year period Polyurethane shows superior net savings when small amounts of insulation are used, but for higher levels of insulation Wood fibre insulation saves greater quantities of CO2 over time. Including secondary materials and methods of application further exaggerates the relationship.

Any alteration of time parameters would affect the specific results shown here. Increasing the time period over which net savings are considered would benefit the higher ECe approaches, giving them a longer saving period over which to repay their ECe debt. However, an argument also exists for the increased value of carbon saved today over that saved ten years from now [Harvey & Aggerwal, 2011]. The Low ECe approaches in this study save carbon sooner rather than later. Although Polyurethane insulations outperform Wood fibre at lower thicknesses, the move toward more advanced insulation standards such as Passivhaus and the higher levels of Code for Sustainable Homes and AECB standards, mean that bio-based insulations may have a more important role to play than has been previously thought.

Government schemes intended to promote energy saving such as ‘Warm Front’ have tended to insist that the cheapest materials are used for insulation, and bio based insulations such as Wood fibre, Hemp and Sheep’s Wool have been excluded from such schemes. It is interesting that the net CO2 emissions over periods of time that relate to building life cycles can be reduced by using bio based insulations suggesting that a different metric could be chosen for assessing effectiveness of insulation other than cost or conductivity.

If the potential benefits of embodied carbon to reduce whole life carbon are to be capitalised upon, it must become included in government policy. Although this study and others would support such a move, analysis of the implications of embodied carbon is still a relatively new field and the weight of evidence supporting its inclusion is relatively small. Any further research in this field would serve to strengthen its case. Crucially, any development in the area of embodied carbon would benefit from larger, more accurate, primary databases. The accurate consideration of carbon requires the ability to accurately measure it.

5 CONCLUSIONS

Modeling has indicated that the net emissions of a bungalow refurbished with high ECe materials are about 11 tonnes greater than the same building refurbished with Low ECe materials over a 35 year period, when the elements of both buildings were given similar U-values. Ignoring the sequestration of carbon in the Wood fibre would reduce but not remove this difference. The important effect of minimising ECe in the retrofitting approach was highlighted when High ECe refurbishment with advanced U-values was compared against the Low ECe refurbishment with reduced thicknesses of insulation resulting in U-values below current building regulations. Contrary to what might be expected the Low ECe approach had a higher net saving until the 50th year. A further finding was that the relative importance of ECe can be influenced by geographic location and indirect benefits of retrofitting such as improved air tightness.

The benefits of Low ECe insulation become apparent when considering whole life carbon emissions of a building. Focussing only on operational emissions and or cost (of insulation or heating bills) favours High ECe insulation. While the cost of the various approaches was considered here only briefly, it is clear that in today's market the Polyurethane is both cheaper and more thermally efficient per unit volume. Considered from a home owner's point of view the Polyurethane will typically provide lower fuel bills each year while Wood fibre will paradoxically result in higher fuel bills but yet have the potential to save more carbon over a given period.

The accuracy of ECe data, along with the assumptions inherent in attributing sequestered carbon, has the potential to significantly change the results given here.

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REFERENCES

B. Boardman, *Home Truths: A low carbon strategy to reduce UK housing emissions by 80% by 2050*, University of Oxford Environmental Change Institute, A report for the Co-operative bank and Friends of the Earth (2007).

C.J. Cleveland and C.G. Morris, *Dictionary of energy, expanded edition*, Elsevier Science (2009).

EHA, *New Tricks with Old Bricks*, The Empty Homes Agency Ltd, London (2009).

EHCS, *Decent homes and Decent places*, English House Condition Survey 2007, Department for Communities and Local Government (2009).

J. Hacker, T. De Saulles, A. Minson and M.Holmes, "Embodied and operational carbon dioxide emissions from housing: a case study on the effects of thermal mass and climate change", *Energy and Buildings*, 40, 375–384 (2008).

G. Hammond and C. Jones, *Inventory of carbon and energy* (*ICE)*, BSRIA (2011).

G. Hammond and C. Jones, "Embodied carbon: the concealed impact of residential construction", *Global warming engineering solutions*, chapter 23, Springer (2009).

H. Harvey and S. Aggarwal, “The costs of delay”, *Climate Works Foundation* (2011). Available at http://www.climateworks.org/ , accessed on 2/11/11 .
C. Jones, “Embodied Carbon: A look forward”, *Sustain insight article: Volume 1*, Sustain (2011). Available at http://www.sustain.co.uk/articles-presentations/3/embodied-carbon-report/ .
I.E.S.(Integrated Environmental Solutions) (2012). Available at www.iesve.com (2012).
N. Lazarus, *BedZED: Toolkit part 1.A guide to construction materials for carbon neutral development.* Bioregional 2002 (2009)
M. McInerney and S. Tucker, “Renewable versus Non-Renewable Building Fabric: A comparative study of the effect of material choice on the embodied energy and global warming potential of low energy dwellings”, *Proceedings of Advances in Computing and Technology: 7th Annual Conference*, University of East London, London (2002).
J. Monahan and J.C. Powell, “An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework”, *Energy and buildings*, 43(1), 179–188 (2011).
T. Ramesh, R. Prakash and K.K. Shukla, “Life cycle energy analysis of buildings: an overview”, *Energy and Buildings*, 42(10), 1592-1600 (2010).
B. Spittle, *Minimising the embodied carbon of retro-fitting materials for existing homes: what is the whole life carbon benefit?*, Unpublished MSc thesis, University of East London, London (2012).
S. Sturgis and G. Roberts, *Redefining Zero: Carbon profiling as a solution to the whole life carbon emission measurement in buildings*, RICS Research (2010).
SDC, *Stock Take: Delivering improvements in existing housing stock*, Sustainable Development Commission (2006).
T. Waltjen, *Details for Passiv houses: A catalogue of ecologically rated constructions*, IBO Austrian institute for healthy and ecological building, 3rd edition. Springerwein, New York (2009).
M. Wray and J. Atkinson, *Whole life cost and carbon: sustainable offices*, South west regional development agency (2011).
XCO2 Conisbee Ltd , *Insulation for Sustainability: A Guide*, A study undertaken by XCO2 for BING Federation of European Rigid Polyurethane Foam Associations (2009).

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ENERGY CONSUMPTION REDUCTION STRATEGIES THROUGH INTEGRATED SYSTEM DECISIONS IN DEEP RETROFIT PROJECT DELIVERY

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Abstract. *Buildings consist of different system designs working towards the unified goal of providing the needed conditions and improving the comfort level of occupants. Even though there is vast potential in the integration of building systems, there is a need to increase the transparency of the decision making process by improving the resolution of multi-dimensional design attributes. It is achieved by considering all decision-makers' priorities with respect to decision attributes as well as the inter-personal inputs based on information and knowledge. In this context, a deep retrofit process is more inclusive yet more complex to achieve higher energy efficiency targets with the inherited characteristics of a building such as historic considerations and building orientation. The case study building presented in this paper is the Connelly School Retrofit Project, a showcase building in Pittsburgh, Pennsylvania with cutting edge technologies and techniques used as well as a collaborative design process. The project team follows a whole building design process via multiple system integration. This paper presents the findings of a case study deep retrofit project that seeks to reduce energy consumption through integrated system decisions with several system combinations that is shaped by the time of day and occupancy needs.*

Keywords: *energy efficiency, retrofits, integrated process maps, system integration, case studies, sustainable design*

1 INTRODUCTION

It is well known that with existing buildings constituting most of the building stock, the greatest impact on reducing building energy consumption in most developed countries (such as the US) will result from retrofitting existing buildings. This needs to be based on radically improving their energy efficiency and overall performance. However, the complexity of the integrated design process that helps to improve the building performance needs to be more clearly defined. Developing reliable criteria set is an important step to evaluate building performance or design process efficiency. It should be developed after defining the problem statement for setting basis for identification of the optimum decision compared to other design decision options (Dan 2004).

Retrofit projects require more integration of design activities with existing conditions due to the need for resolution of the inherent characteristics and designing best fit project status for these specific characteristics. It is critical to design for the most appropriate technologies for the building characteristics that are enlightened as a consequence of audits. So that, integration of related parties and design activities come to the attention of team earlier. Hence, the complexity of the process can be improved by providing a sound technical framework for decision making early in the retrofit process. Even though we are also evaluating thermal, visual, indoor air quality measures, in this paper, the analysis is limited to energy efficiency and cost measures in investigating the performance outcomes.

Another analysis criterion is the management strategies developed by the project team. These measures are used to highlight the project values and goals in order to achieve targeted performance. So, in this case study analysis, the critical mechanical, electrical, and plumbing (MEP) design decisions that are taken using specific criteria based on the team priorities were tracked. While comparing design options, this study is also showing how the building has performed on simulation analysis according to selected evaluation criteria.

2 METHODOLOGY

A case study methodology has been chosen for this empirical study since it investigates a contemporary phenomenon (building energy efficiency) within its real life context (deep retrofit process); since the boundaries between phenomenon and context are not clearly evident; and in which sources of evidence are used (Yin,1984). This specific project was chosen for analysis, since it is a business incubator with green technology demonstration showcase. As the showcase aspect of the building, the process was more transparent to observe and follow the design documents; such as specifications and basis of design; compared to traditional building processes. Semi-structured interviews, personal meetings, group meetings, and follow-up meetings (using open-ended questionnaires) were conducted with the project participants who were part of the design decision making process. We specifically conducted the interview to the design team including MEP engineers since we are tracking retrofit decisions. The key issues being investigated are: what are the critical decisions, how and why were these decisions taken instead of other options, and at what time, and by whom were the decisions taken (Gultekin et al. 2012). The adopted interview framework for a design decision example is shown below:

<table>
<tr><th></th><th>Design Decision</th><th>Other Design Options</th><th>Selection Criteria</th></tr>
<tr><td rowspan="2">E.g.</td><td rowspan="2">Window Upgrade: Double-hung windows with coated film and gas fill</td><td>Double-hung windows</td><td rowspan="2">R- value
Cost
Payback</td></tr>
<tr><td>Triple clear windows</td></tr>
<tr><th></th><th>Change of</th><th colspan="2">Impact of the decision</th></tr>
<tr><td rowspan="2">E.g.</td><td>Controls Systems</td><td colspan="2" rowspan="2">Change in size of chillers/ HVAC Systems
(Less chillers due to decrease of cooling load)</td></tr>
<tr><td>Replacing CV units with VAV units</td></tr>
</table>

Table 1: Critical decision example

3 CASE STUDY: CONNELLY SCHOOL RETROFIT PROJECT

The case study presented in this paper is the Connelly School Retrofit Project in Pittsburgh USA. This is a 300,000sqf (27,870sqm) green technology demonstration showcase building owned by Pittsburgh Green Innovators Inc. This deep retrofit project is intended to achieve almost 49% reduction in energy consumption of the building through the integrated MEP system design decisions. The decision making environment was collaborative due to the selection of the design-build delivery method. Based on the interview conducted with the mechanical designer of the project, the general process characteristics are mapped out as in Figure 1:

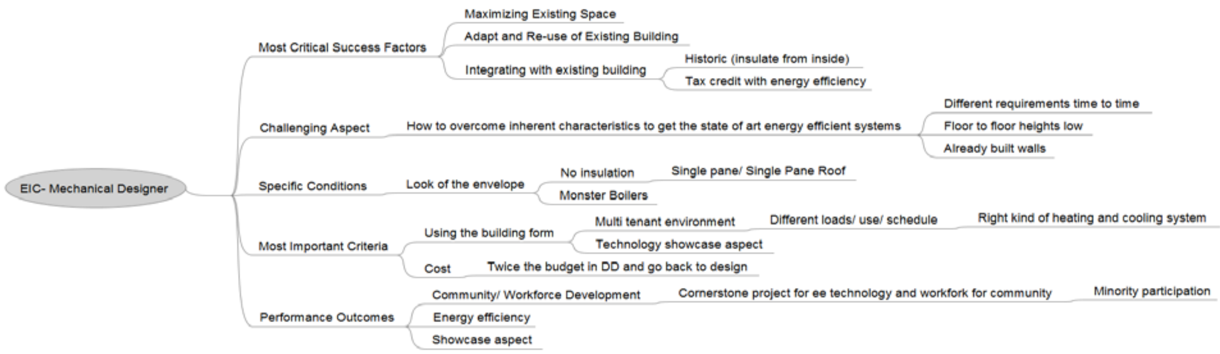

Figure 1: EIC, Mechanical Designer general condition interview content

Energy optimization of the project is expected to achieve 49% efficiency/reduction compared to ASHRAE 90.1-2007 (ASHRAE, 2007). The role of the MEP systems within the Connelly School (newly renamed Energy Innovation Center, EIC), in addition to the more common aspects, will be to showcase innovative energy technologies, to provide demonstration and training on sustainable building systems, and to provide flexibility for future energy efficient technologies. The MEP concepts have been developed to meet the goals of the project while maintaining the historical aspects of the former Connelly Vocational School. The building typology is in two forms and functions: Saw-tooth roofed section serves as a light industrial/manufacturing area while the tower portion serves as offices and training facilities for tenants associated with green technology suppliers. These sections will be equipped with different technologies so as to observe their performance levels for learning purposes (Figure 2).

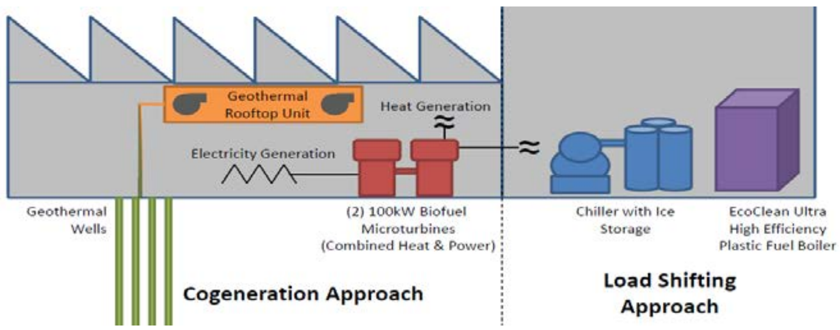

Figure 2: Energy generation technologies at EIC

Energy efficiency aspects of the project include natural day light and lighting controls, insulation of the existing building envelope, replacement of existing curtain wall window systems, a super-critical carbon dioxide-based geothermal ground source heat pump system, active chilled beams and radiant panels, Dedicated Outdoor Air Systems (DOAS) with MERV-13 filters, passive desiccant wheels for moisture control, energy recovery and Demand Controlled Ventilation (DCV). The building systems are also being designed to demonstrate demand side energy management control strategies through the use of ice storage, and the future implementation of a Combined Heat and Power (CHP) system with an absorption chiller that utilizes waste heat from the CHP plant. The proposed systems are *energy efficient, provide improved indoor air quality, reduce the amount of mechanical space, minimize the historic impact to the exterior and maximize the use of rentable floor space.* These are the general decision making criteria that shaped the final MEP system selection within the observable mechanical room (Figure 3); and through the building with smaller ducts and shorter pipes.

4 FINDINGS

4.1 Evaluation criteria priorities for system selection

Concurrently with the performance analysis, different priorities also present considerable variations in decision options regarding aesthetics, historical value and showcase nature of the building. Even in the selection of HVAC systems, not only energy efficiency but also indoor air quality, demonstration of technologies, demand reduction, flexibility, historical and spatial reasons came into consideration to meet the owner’s needs and provide the best value to the project. Here are the criteria that shaped the building system selections during the design.

1. **Energy Efficiency:** The main goal of the building, improving the energy efficiency of the systems holistically which triggered iterations in energy modelling during the design progressed. By the help of ten energy models in process, the project exceeded 45% compared to ASHRAE 90.1-2007 and achieved all 21 points under LEED Core and Shell, Energy & Atmosphere Credit 1. Starting from including insulation to the existing building envelope; replacement of existing curtain wall and clerestory window systems, natural day light and lighting controls, a carbon dioxide based ground source heat pump system, dedicated outdoor air systems with energy recovery, decoupled sensible and latent loads, ice storage, hot water storage and combined heat and power are energy efficient systems used in building design.
2. **Indoor Air Quality:** The DOAS approach, which is also supported by VAV systems to each zone, provides higher level of ventilation rates than code requirements. This rate was considered sufficient to handle latent load of the space by decoupling the latent load strategy based on CJL Engineering integrated system design.
3. **Demonstration and Training in Sustainable Design:** The next criterion is relying on demonstration of the state of art technologies’ working principles individually and performance impact holistically. The training potential of these technologies combined

Figure 3: Observable mechanical room drawing (Courtesy of CJL Engineering)

with the collaboration of the International Union of Operating Engineers ( ) was designed to meet the owner's goal of promoting the green economy throug ctured education and training programs for public (CJL Engineering, 2012). Observ decks were located at the mechanical room to overlook the systems during the tour h

4. **Demand Side Management:** Demand reduction criteria shaped the very fir cisions on building design to reduce heating and cooling loads through the insul of the existing building envelope and utilizing natural light. The existing conditions e roof and fenestration were extracting energy from the building, and propose terials provided significant lower U-Factors as in Table 3 and 4.

Component	Baseline / Existing	Proposed
Roof - Saw tooth	Metal	Metal
Insulation Type	None	Spray Ins below deck
R-Value	R-0	R-30 ci
U-Factor	U-0.519	U-0.046

Table 3: Roof construction retrofit comparison (CJL Engineering, 2012)

Component	Baseline / Existing	Proposed

Vertical Glazing – Saw tooth	Fixed	Curtain Wall
U-factor	1.20	0.43
Solar Heat Gain Coefficient	0.70	0.35
Shading Coefficient	0.81	0.41
Clerestory – Saw tooth	Fixed	Fixed
U-factor	1.20	0.43
Solar Heat Gain Coefficient	0.70	0.35
Shading Coefficient	0.81	0.41
Skylights – Saw tooth	Metal w/o Thermal Break	Metal w/ Thermal Break
U-factor	2.0	0.43
Solar Heat Gain Coefficient	0.70	0.35
Shading Coefficient	0.81	0.41
Shading Devices	None	Vertical & Horizontal

Table 4: Fenestration retrofit comparison (CJL Engineering, 2012)

Additionally, peak demand has been further reduced by load shifting strategies such as ice and hot water storage, and peak trimming strategies which were demonstrated through the future implementation of the CHP system (CJL Engineering, 2012). The facility is also designed to able to trim and shift demand load based on resources and peak pricing.

5. **Historic Preservation:** Apart from the energy performance related criteria that shaped the design of the HVAC systems, historical preservation was also decisive on the selection of systems by appearance. It was important to preserve the typology of the building from outside and inside by choosing unobtrusive installation and minimal equipment that do not change the appearance of the building. For CJL Engineering's design, the use of water cooled terminal units allowed for smaller ductwork and less vertical shaft space, and no large unsightly roof mounted equipment was necessary (CJL Engineering, 2012). Also, with the help of the waterside economizer, the number of louvers was minimized at the historic exterior of the building (compared to conventional system with an airside economizer).
6. **Maximize Rentable Floor Space:** This criterion is applicable to all renovations, and even all new constructions to maximize the revenue of the owner from the floor space. However, this could be more challenging to achieve by also considering the historic traces inside and outside of the buildings. In this project, the compactness of the HVAC system benefitted the floor space with less mechanical floor area and less vertical shaft space.
7. **Moisture Management:** This was considered hand in hand with energy efficiency and indoor air quality during the HVAC design. The main ventilation system was selected as DOAS which provides humidity control by delivering the air with low dew point temperatures. That is used for tempering of the outside air with lower humidity levels. This helps to eliminate wet coils and drain pans at the space level (CJL Engineering, 2012). In addition to DOAS, VAV was supporting the tenant space to provide individual comfort levels.
8. **Flexibility:** This criterion is an umbrella value to all decisions to get benefit of the systems used with future technologies added to the building and provide a certain level of

comfort level in such a multi-tenant building. In the light of these goals, the mechanical room was designed to maximize letting space and facilitate the integration of future energy systems that do not currently exist. Also, on site electricity generation provided occupants to go for an alternative source especially during the peak hours.

4.2 Deep retrofit strategies and decisions for Connelly School Retrofit Project

Energy efficient systems were selected based on the criteria that the team prioritized. Not only the system efficiency, but also the holistic performance was considered. Additionally, room for future technologies was left to promote the search of improving energy efficiency of all systems.

1. **Envelope Design:** The main reason for choosing a retrofit project over a new construction is to utilize the infrastructure and shell already there. However, it is challenging to integrate the state of art technologies into an existing building. Before designing for energy supply, it is important to reduce the demand side starting from the envelope at the very first step. In this project, the most significant amount of energy saving (49%) was achieved by upgrading the insulation. Insulating the building from the inside was the final design decision based on the priorities of the team (Table 5):

Insulate from Inside	Insulate from Outside
Historic View of envelope	Floor Area
	Thermal Storage Usage

Table 5: Comparison of decision analysis for insulation application based on benefits

2. **Ventilation Systems:** Various dedicated outdoor air systems (DOAS) were chosen for the Connelly School Project. A large DOAS (30,000 CFM-849m^3/min) serves the first floor of the building, along with all lower levels. Smaller DOAS units (2,500-1,800 CFM- 70.8-51 m^3/min) were provided at each level of the academic tower (CJL Engineering, 2012).
   DOAS was chosen as the ventilation system without heating and cooling features. The main concern in going for this design option was to reduce energy consumption on moisture control. This selection helped dehumidification under the specific weather conditions of Pittsburgh. So, ventilation was provided at very low dew points to remove latent load of space. CJL engineering's integrated system solution provided decoupling the sensible and latent loads of the facility, allows for numerous sensible cooling devices to be utilized at the zone level such as radiant cooling panel technology, chilled beam technology, or more common fan coil or terminal heat pump technology (CJL Engineering, 2012). This design decision was based on the following criteria: prioritizing energy efficiency, indoor air quality, moisture control, and flexibility to satisfy the required comfort level.
   Additionally, DOAS was also supported by a dual energy recovery system that reduces the heating and cooling load on central plant which serves to both minimize the demand and improve energy efficiency. From the indoor air quality point of view, VAV units provide the control air supply. The CO2 and humidity sensors sustain the comfort level through occupancy and latent loads. Controllability also provided the utilization of demand control ventilation, zone pressurization, occupied/unoccupied mode scheduling, and energy savings on the central dedicated outdoor air system based on design (CJL Engineering, 2012). As a consequence, the main ventilation system is selected as DOAS

due to the benefits (Table 6) on space, humidity control, and energy consumption and supported by VAV for flexible heating and air conditioning purposes at each occupied space.

DOAS	VAV
Low Dew Point Temperature	Heating and AC in addition to Ventilation
More Humidity Control	
Less Space: Smaller AHUs and Ducts	
One Location	

Table 6: Comparison of ventilation decision analysis for ventilation system selection

3. **Cooling System:** Since moisture control was the biggest priority, the cooling system load had handled after the latent load had reduced. This prioritization led the team to control the cooling load more efficiently. The interdependency of these systems was not limited to a single system selection, since various system combinations that are designed integrated were serving better at performance. Even in single cooling system, the energy was served by both a central chilled water plant (525 ton) and a ground source heat pump system (30 ton).
   Another criterion, demonstration and training in sustainable design, was always taken into consideration through the system selection process. This goal led the team to utilize cutting edge technologies for serving different spaces. Also, this differentiation was aimed to help trainees to observe energy performances of new technologies. For example, the entrance unit was designed to be served by a super-critical carbon dioxide-based, geothermal ground source heat pump system. The heat pump system, which utilizes CO_2 as its refrigerant, is a cutting edge technology that utilizes high-pressure CO_2 in a phase change process to cool or heat the building air and extract or reject heat to the ground (CJL Engineering, 2012). This system works with smaller pumps and provides less costly installations. Additionally, partial ice storage, which is also cooled three water-cooled chillers, helped to reduce the peak time electric utility demand by keeping the flexibility of different system use approach in mind. These chillers were configured in a primary-secondary distribution system that helps to operate independently based on load required by VAV systems. The interdependency of the system had ended up with a more energy efficient holistic solution which required integration of systems in design.
4. **Heating System:** Same with the cooling design, heating system selections were done integrative to ventilation design selection. Also, the selection was not limited a single system for the energy efficiency, demonstration purposes, and flexibility criteria. The heating system design consisted of three high efficiency condensing boilers and a hot water storage system. A combined heat and power (CHP) system with gas fired micro turbine was utilized in conjunction with the heating plant for the future demand side management and energy efficiency criteria (CJL Engineering, 2012). As a result of integrated design approach, waste heat from CHP and hot water storage tanks was designed to feed domestic hot water. Additionally, as same in the cooling design, CHP was configured in a primary-secondary distribution system that helps to operate independently based on load required by VAV systems. Even integration of systems required more time including the iterations in energy models, ended up with a more energy efficient solution.

5. **Building Automation System (BAS):** BAS is an important step to take in regard to observe how the building was performing. Demonstration and training values are lying in the transparency of the systems' performances. BAS was supported by a high-speed, peer-to-peer network of DDC controllers and a web-based operator interface (CJL Engineering, 2012). It was designed to utilize systems' performances on each region for occupants to see their trends and educational purposes.

5 CONCLUSION

Connelly School Retrofit Project is a high level and comprehensive example in green retrofit building projects. Not only building performance levels but also process improvements are upgrading the practices regarding efficiency. In this study, the focus is on building systems criteria followed through the design process. The performance indicators for systems and process are listed below (Gultekin, 2012).

The distinction on primary performance outcomes are shaped by the criteria set at earlier phases. For example, the EIC team used cutting edge technologies that will also be tried and tested (state-of-the-art) considering the upfront costs and accessibility to technology. The team set their different values and goals at the earliest phase available.

It is established from interviews with project team members that it is more important to use multiple system integration strategies appropriate to the inherent characteristics of a retrofit project rather than independent high performance technologies. Whole building design techniques provide architectural, mechanical, and electrical designers to integrate systems and make the operation as efficient as the designed performance. In order to improve the indoor environmental quality, the designer lets the systems work in different combinations according to different needs and seasonal conditions.

Not only in retrofit projects but also in energy-efficient building design, the integration of various systems is very important. It serves to reduce energy demand and helps to achieve better efficiency rates. Also, flexibility is important in that systems can operate in different combinations during the different time frames and occupancy rates. The Connelly school project handled the process successfully by considering as many system combinations as technology allowed.

Performance Indicators	Connelly School Retrofit Project
Energy Efficiency	
LEED Scorecard	Platinum
Energy Saving by Retrofitting	49%
Annual Energy Consumption*	45%
Cost Efficiency	
First cost of technologies	✓
Payback period analysis	✓
Process Services and Management	
Delivery Method	Design Build
Project Priority	System Performance Demonstration
Technology Selection Criteria	State of Art

*Relative to ASHRAE 90.1-2007

Table 7: Performance indicators that are tracked in design

REFERENCES

M.D. Bostenaru Dan, "Multi-criteria decision model for retrofitting existing buildings", *Natural Hazards and Earth System Sciences*, 485-499 (2004).

C.L. Conroy, J.R. Gaus and D.J. Kopko, *Personal Interviews*, September 12th (2012).

CJL Engineering, *Energy Inovation Center: The Basis of Design*, Pittsburgh, PA (2012).

P. Gultekin, C.J. Anumba and R.M. Leicht, "Towards an integrated process model and decision support system for high performance green retrofits", Architectural Engineering Institute Conference (2013).

P. Gultekin, S. Mollaoglu-Korkmaz, D.R. Riley and R.M. Leicht, "Process indicators to track high performance green building project performance", ASCE Journal of Management in Engineering, Management for Considerations on Sustainability (under review) (2013).

M. Santamouris, *Advances in Building Energy Research*, Earthscan, Sterling, VA (2008).

R. Yin, *Case study research: Design and methods* (1st ed.), Sage Publishing, Beverly Hills, CA (1984).

WIRELESS SENSING TO IMPROVE DECISION MAKING FOR ASSET MANAGERS IN RETROFIT PROJECTS

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Abstract. *This paper looks at the issues currently faced by asset managers in making decisions as to how to improve the energy efficiency of buildings under their stewardship. The performance gap between the designed and occupied energy efficient retrofit can make it difficult to make the best choice of intervention. One potential solution to close this performance gap is through the use of Wireless Sensor Networks (WSNs) to record dwelling environmental conditions pre and post retrofit measures. A case study has been portrayed identifying the use of WSN to assist asset managers to make strategic decisions.*

1 INTRODUCTION

Housing Associations manage a large proportion of the UK housing stock. But with large numbers of properties and varying archetypes, how do social housing providers decide which investment works should be undertaken to improve the energy efficiency of their housing stock?

Social housing provider Orbit Heart of England is currently looking at various avenues to inform decision making when faced with energy efficiency improvements. One such project is a three year Knowledge Transfer Partnership (KTP) in conjunction with Coventry University. This project aims to equip Orbit with the knowledge to understand the technologies, techniques and tools to make strategic decisions on how best to address energy consumption and carbon emissions within its stock portfolio.

Orbit is committed to reducing the CO_2 emissions from its housing stock and mitigating the impact of fuel poverty on their customers. Orbit has taken the initiative in developing pilot projects in the past 5 years to assess the performance of retrofit energy saving technologies into the housing stock. The results of the pilots will then inform and influence their asset management strategy.

This paper will look at the use of Wireless Sensors as a means of assessing the performance of energy saving technologies and how the data collected can improve decision making for asset managers in energy efficient retrofit projects.

2 MOTIVATION

Housing is responsible for roughly 27% of the UKs carbon emissions, thus improvements must be made in order to meet the Governments 2050 Carbon Reduction Targets. Given that 80% of 2050’s houses have already been built (Pelsmakers, 2012), retrofit works to improve existing properties is a key part of any solution to the problem. However, given the large number of energy saving technologies and design principles available, as well as strong budget constraints, how can asset managers make the best decisions in terms of cost and performance, choosing the most appropriate technology rather than the latest "eco-bling"?

The green technology and retrofit industry is growing rapidly with new products, materials and claims entering the market all of the time. Asset managers must have confidence in the energy saving solutions that are to be applied to their housing stock. These technologies must improve, protect and ensure the long term viability of the asset. However, given the wide range of possible technologies, the question of which interventions will provide the greatest energy efficiency improvement to the stock portfolio, whilst providing value for money remains.

In terms of quantifying energy savings, simulation tools for measuring energy performance (such as SAP – Standard Assessment Procedure) give varying results, any figures for energy savings given by simulation tools are only as accurate as the underlying algorithm, and may not be accurate. According to Sustainable Traditional Building Alliance (STBA) "for the building materials found in the traditional buildings of the UK and Ireland, there is almost no well-defined traditional or vernacular material properties data for use in modelling and calculation programmes". Therefore if there is insufficient data available to the designer there is obviously going to be a large performance gap in energy efficient retrofit buildings (May *et al*. 2012, p. 22). Design packages do not take full account of occupant behavioral factors which can also have a major bearing on energy performance of a building. This means that while a particular technology may look good on paper, its in-situ performance may be significantly different.

Monitoring can be used to gain insight into the actual performance of a given technology. By measuring energy use and environmental parameters before and after any works are undertaken, it is possible to quantify the improvement any intervention has made. Monitoring can also assist in troubleshooting problems, as the performance of an existing system can be measured and compared to its expected performance, allowing the asset management and design teams insight into where the performance deficit may lie. The monitoring process can be used to aid asset management good practice, in a more reliable way than SAP estimates, since such monitoring takes into account the as-installed performance. Monitoring can be used to provide detailed and accurate information on the improvements any retrofit works have made, rather than relying on resident feedback.

Capital expenditure in assets must also be carefully considered to ensure it remains in the best interests of all parties involved to invest in the asset. Therefore strategic development tools must be put in place not only to recommend which technologies work in specific scenarios but also identify the process, logistic and anticipated CO_2 reductions and the capital outlay required, to meet the Governments CO_2 reduction targets. When the benefit (in terms of energy use or resident comfort) of a particular intervention is known, not only can the asset management team be sure of using an appropriate technology, but the business case for such an intervention can be better made.

3 RELATED WORK

It has been recognised that there is a performance gap between the designed and the actual energy consumption of buildings. This can be attributed to several reasons some of which being:

- Changes to the initial brief,

- Change in the client and the building requirements,
- Cost cutting, and
- Once occupied the building is not used as predicted (Bill Bordas, 2004).

Modeling software used during the design process, is useful in appraising design options “but poor at predicting absolute energy consumption” (CIBSE, 2012). Software tools which generate EPC’s (Energy Performance Certificates) and SBEM (Simplified Building Energy Model) ratings fall under the NCM (National Calculation Methodology) standard which is used to illustrate compliance with building regulations. It is important to note that these energy assessment tools only model elements of a building a designer has influence over i.e. any unregulated energy use such as appliances are excluded (CIBSE, 2012). This means there can be a large difference between the designed energy performance and the actual performance. The industry has recognised that unregulated energy must be taken into account in the design process to close the performance gap. The RIBA (Royal Institute of British Architects) and CIBSE (Chartered Institute of Building Service Engineers) are undertaking research and developing a tool called CarbonBuzz to ensure this performance gap is closed. CarbonBuzz will allow designer access to energy performance data from buildings on an anonymous basis, research is progressing and over time it will provide evidence of energy performance of low carbon building designs (RIBA & CIBSE collaboration, 2012).

In many cases buildings have not met the needs of the end user, leading to some distrust in the efficacy of green technologies. To close this *credibility gap*, the building industry must demonstrate a building’s energy efficiency by monitoring its performance. Wireless sensors can be used to monitor a buildings performance and the data gathered can be used to educate the industry to avoid making the same mistakes. This point is highlighted in The Retrofit Challenge: Delivering Low Carbon Buildings (Leeds Metropolitan University, 2012) where it is recommended that ICT and real energy monitoring must be used to increase the understanding of industry in the actual energy performance of our buildings. Leeds Metropolitan University have embraced ICT and monitoring to perform critical analysis of building performance. In one such project extensive research was undertaken into thermal bypass in party walls. During this research a significant amount of monitoring was undertaken and reasons for heat loss from party wall identified. Assessing the energy performance of this element of the building has helped designers to close the performance gap (Lowe et al, 2006). Assessment of a building energy performance and closing the gap between design and actual energy consumption is a relatively new phenomenon. It has been observed that the construction industry focuses on short term goals, with different professions within the same team focused solely on the completion of their element of the works to deliver the project and hand the keys over to the client. To close the performance gap professionals may need to take a holistic view rather than the current fragmented approach. In “A new Professionalism: remedy or fantasy” (Bill Bordass, 2013) suggests developing a professional identity, where the feedback loop is closed in the built environment sector. This is where energy performance monitoring can assist the asset management process, as it will provide the practitioners with the information necessary to deliver buildings with high energy efficient design targets into the real world.

4 MONITORING TO PROVIDE FEEDBACK INTO THE DESIGN PROCESS

This section describes the decision support methodology. First, the asset management process is described, followed by a description of the WSN equipment, and monitoring methodology.

Orbit's asset management team need to make informed decisions as to how best to manage the stock portfolio. Decisions must be made on the key principles of asset management such as:

- Planning,
- Budgeting,
- Pricing,
- Economic appraisal,
- Acquisition and disposal,
- Recording, valuation and reporting,
- Management in use, and
- Needs analysis (Department of Treasury and Finance, 2010).

Computer science technology has developed to a stage where it can be used in the built environment, in real life conditions. This can be achieved through the use of Wireless Sensor Networks, miniature computing devices capable of sensing their environment and collecting environmental data in real time. The data collected by WSN can be used to determine the actual performance of a material or technologies and the impacts the occupants living habits have on the energy consumption and on the building.

Wireless sensors provide information that fall under headings of Recording, valuation and reporting and Management in use. Asset managers must then assess the data and make a decision based upon the information provided from all categories represented above. However, with pressing issues such as fuel poverty, climate change and the Government CO_2 targets, data collected from wireless sensors and the forthcoming recommendation may take the driving seat over the traditional drivers such as cost. Where in the past an asset maybe disposed off due to the level of capital required to bring it to the required standard, asset managers may have to elect to retrofit the asset and incur higher initial capital costs to bring the asset to an energy efficient standard. In 2016 tenants will be able to ask for landlord consent to make energy efficient improvement to their home, which can not be unreasonably refused. By April 2018 it will be "unlawful to rent out a residential or business premise that does not reach a minimum energy efficiency standard" (the intention is for this to be set at EPC rating E) (DECC, 2011). Therefore disposal of units which do not currently meet this standard could pass responsibility to others in the public or private sector - depending on the purchaser. This is not socially acceptable for the vast majority in the social housing sector, due to the role housing associations play in the community.

Therefore asset managers must make informed decisions to ensure appropriate, cost effective energy saving solutions are applied to their assets and wireless sensor systems can help achieve this.

The monitoring equipment used in this study, has been developed in conjunction with Cogent Computing Applied Research Centre at Coventry University. Several types of Wireless sensor *nodes*, have been developed. Each node is capable of measuring temperature, humidity, and light levels. Specialist mains powered nodes add the ability to measure CO_2, and VOC, additionally electricity consumption (or generation in the case of solar PV) can be measured. A detailed description of the sensing system is out of the scope of this paper, further details can be found in (Gaura, et al, 2012).

The current monitoring regime consists of a two week monitoring period, complete with resident questionnaire. For retrofit properties, this regime is performed both before and after the retrofit takes place, to allow the energy and comfort performance improvements to be assessed. Every five minutes each node takes a reading from its attached sensors, and transmits it wirelessly to a central *sink* for storage and processing. This sink is also equipped with a web based data visualization software, allowing the readings gathered by the sensors, as well as other performance metrics (such as comfort levels) derived from the data to be viewed in real time. At the end of each deployment, the gathered data is automatically transferred to a central data store, to allow archiving and comparison between deployments.

5 CASE STUDY

One issue Orbit have questioned is whether to take a fabric improvement or renewable technology approach to reducing fuel poverty and CO_2 emissions in the housing stock. The case study in this section outlines the results from one particular study where a renewable technology was installed into an existing property. The property itself is a 3 bedroom property in rural Warwickshire, off the main gas grid. The family demographic consisted of 2 adults and 3 children. The property had high energy consumption with the customer complaining to the association about their fuel bills.

Though the use of monitoring, an initial investigation into the properties energy use highlighted that the residents did have exceptionally high energy consumption. However, Orbit was able to establish that, in the most part, this consumption was not due to the heating system (both space and hot water) itself, but the residents living style. Following the monitoring process, some changes were made to the heating program with the aim of reducing the energy demand. Additionally a 1.88kWp Photo Voltaic (PV) array was installed, Orbit decided to install PV to assess the impacts and potential saving this form of technology can have on high energy homes, including understanding occupier behavioral influence and engagement levels in reducing their energy consumption. The monitoring of the PV system took place in the summer of 2012, consequently the energy consumption figures did not include space heating demand.

The property was monitored prior to the installation of PV and the average electrical consumption of the property stood at 25kWh per day. This is extremely high considering the national average is 15kWh per day DECC (2012)

Post installation the property was monitored to determine the impacts. Figure 5.1 shows the daily generation of the PV system.

The design output for the PV system was 1.88kWp, from the monitoring data the system is producing 1.47kWp. Taking into account cloud cover and shading this generation is in line with the anticipated design. While the overall energy use for the property still stands at 24kWh per day. This is offset by the PV system, meaning that the resident is paying for on average 18kWh per day. Thus, despite the PV installation reducing the metered energy by 1/3rd this is still above the national average and the PV system has not resolved all the residents issues with high fuel bills. Additionally, the interventions to the heating system settings made after the first monitoring cycle, were reversed, as the resident felt that the PV system would “solve all their problems”. This has meant that the initial energy savings though correct use of the heating system have been lost.

Orbit has decided going forward to pursue a fabric first approach and reduce the energy consumption of a property before installing renewables combined with occupier education programme. The monitoring deployment and analysis helped to inform this decision as it was found that a reduction in energy consumption through the use of renewables is highly dependent on user behavior. Whereas installing measures which reduce the heating load in a building is not so dependent on occupant behavior and likely to have a better impact in improving the energy efficiency of a particular building. Additionally, Orbit will undertake a tenant education program, in properties with a high occupant based energy use. This educational initiative is expected to help further reduce energy consumption in addition to savings made through the application of technology.

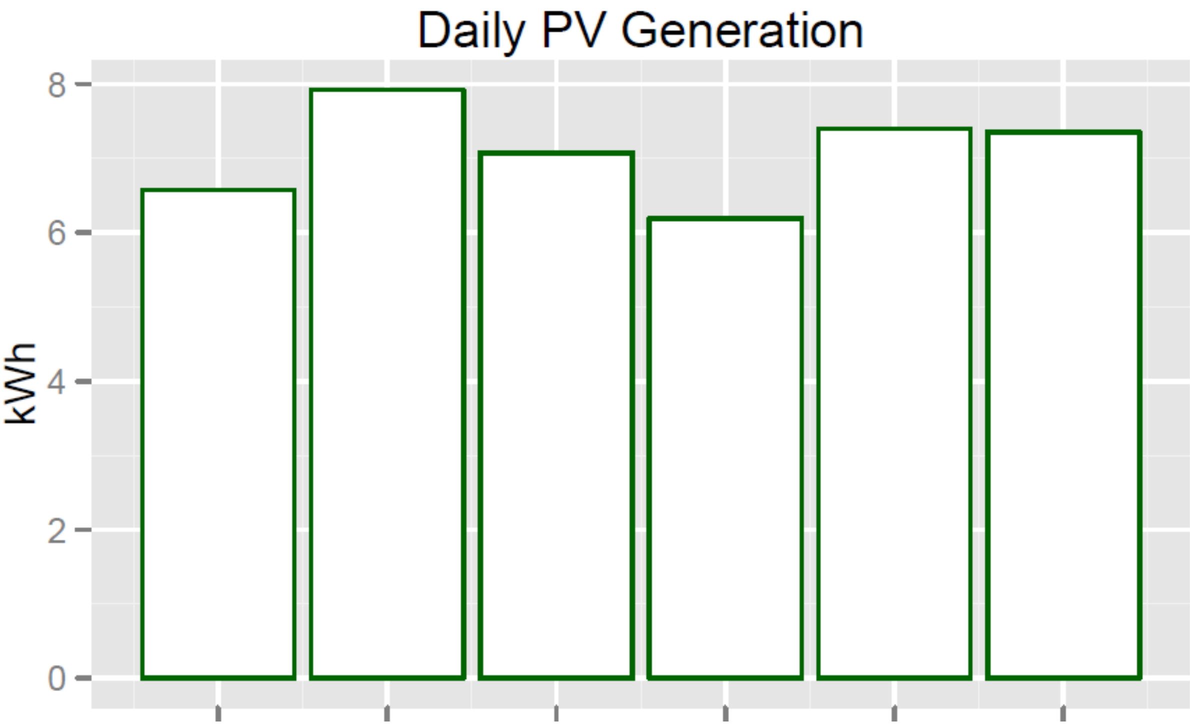

Figure 1: Example of sensor data showing PV generation.

6 CONCLUSIONS AND FUTURE WORK

With regard to monitoring, future work will be undertaken to develop a detailed monitoring strategy. This will take the lessons learnt from the work undertaken in this project and develop a set of guidelines for assessing the success of retrofit pilot projects. For example, topics covered by the strategy will include how and when to monitor, and training (non specialist) Orbit's staff to make use of the monitoring equipment. This will aid Orbit in its future decision making process, after the KTP research project has finished. It is expected that the strategy would be relevant to the wider construction industry.

The retrofit industry is going to grow a considerable rate (with initiative such as the Green Deal) and building new energy efficient forms of construction will become main stream. Before this sector of the construction industry starts to further expand it is important the performance gap between design and actual energy consumptions is closed. WSN systems can help to close this gap and provide asset managers, architects and specifies with the necessary information to make informed decisions in relation to the best methods to employ when improving the energy efficiency of existing buildings.

REFERENCES

B. Bordas, ed., *Energy performance of non-domestic buildings: Closing the credibility gap*, Building Performance Congress, Frankfurt (2004).

B. Bordass, ed., *A new professionalism: remedy or fantasy,* Building Research & Information, London (2013).

CIBSE, *Guide F: Energy efficient buildings.* CIBSE, London (2012).

Department of Energy and Climate Change, *Energy Act*, Department of Energy and Climate Change, London (2011).

Department of Energy and Climate Change, *Energy consumption in the UK*, (2012). Retrieved November 2012, from https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/energy-consumption-in-the-uk

Department of Treasury and Finance, *Asset management principles*, Department of Treasury and Finance, London (2010).

E. Gaura, ed., *Sustainable future? Building and life-style assessment*. International conference on Intelligent Advanced Systems, Malaysia (2012).

Leeds Metropolitan University, *The retrofit challenge: Delivering low carbon buildings.* The Centre for Low Carbon Futures, Leeds (2012).

R. Lowe et al., *Evidence for significant heat loss through party wall cavities in load bearing masonry construction*, Leeds Metropolitian University, Leeds (2006).

N. May et al., *Responsible retrofit of traditional building,* Sustainable traditional building alliance, London (2012).

S. Plesmaker, The environmental design pocket book, RIBA, London (2012).

RIBA & CIBSE collaboration, *CarbonBuzz,* (2012). Retrieved February 18, 2013, from http://www.carbonbuzz.org/about.jsp

A MULTILEVEL AND MULTI-SCALE METHOD TO OPTIMISE THE SUSTAINABLE CONSTRUCTION WORKS

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Abstract. *The nature of the sustainable approach in the construction management is complex, because of large number of involved components and relationships between disciplines, objects, phases of the life cycle, aspects and variables of any actual project or construction works process. Complexity is one of the major assumptions of the conceptual model on which the new, still in progress, European assessment standard family of CEN TC 350 is based, adopting a multidisciplinary approach. However, the future developments are expected to go more and more into the direction of the integration of the three major components in the life cycle: environmental, social, economic, as well as at the international level the discussion on wider system boundaries, beyond the building, is going on. These are sufficient grounds to start managing any case of construction works as an interdisciplinary and multi-layer issue, evaluating and planning any action as the integration of a certain number of actions involving many variables and producing cross effects. At this point a multiscale and multilevel approach becomes indispensable. The paper actually contributes to start up a new generation of sustainable approaches at construction problems, reporting on the research focused on the development of inductive, logical/operational guidelines, aiming at optimising the sustainable management of construction works. The identification of a multiscale and multilevel method supporting the decision-making process, focused on key objectives/ criteria/ indicators with respect to the energy, environmental, social and economic performances, is applied to "Città Studi Campus Sostenibile". The project, member of the ISCN network and inserted in the European Peripheria framework, is promoted by the Politecnico and the University of Milan to transform the university district into a model part of the city in terms of quality of life and environmental sustainability.*

Keywords: *sustainable construction works, European standards, Multilevel, Multi-scale, Integrated approach*

1 INTRODUCTION

After years of development and application of methods for *assessing* the sustainability of buildings in various parts of the world, and the related "labeling" of the buildings, the European Union has felt the need to adopt an "umbrella" policy, developing and sharing common framework methodologies and indicators between the Member States. The Standards, set out by CEN TC 350 "Sustainability of construction works", are supposed to be voluntary and are still under development, also considered the huge need of time required by a similar route, including the exchange of proposals and approvals of complex documents at both central and peripheral / national working groups and levels of the European Union (Ilomäki et al. 2008).

In the meantime all the Standards are going to be adopted, it is necessary that a *virtuous process of implementation and monitoring* applied to real cases starts, so to *test the effectiveness* of the available *standards*, and identifying the gaps in the perspective of the future revisions of the first standards to be published. The research presented is still in progress, aiming to provide a contribution in this direction.

Actually, in the real cases of application, *the traditional tools and strategies* of project management show their own *limits* when the decision-maker seeks sustainable goals.

The paper aims at giving a contribution to fill this gap, paving the way to develop *appropriate methods / guidelines* for the management of sustainability in constructions, in order to *support a decision-making process* (by public and private managers, planners, developers, policy makers) from a *sustainable point of view*.

The main goal is the identification of a *multi-scale* operative method applied to the different phases of the construction process, aimed at improving energy (Masera 2004) (Palazzo et al. 2011), environmental and social performances, with respect to the building, the urban and the neighborhood context, helped by the setting of *key indicators* (environmental, economic, social).

2 CONTEXT

2.1 State of art

With no doubts one of the major merits of the *environmental labels and rating systems* for the *assessment of sustainability in construction works* is the start of a widespread process of awareness about the importance of the resource use and related limits.

On the other hand, it is widely recognized by the international community not only the researchers but also the operators of the construction supply chain that the worldwide proliferation in recent years has also produced several problems, first of all a sense of disorientation by the stakeholders (designers, contractors, public authorities).

The diffused application of the different rating systems has also showed, in addition to the difficult manageability of an even large number of indicators, the limits of such assessment methodologies with respect to aspects and impacts not expressly quantifiable.

2.2 Developments

For the above reasons, the European scientific community, under the pressure of the European Commission, is involved in several research programs supporting the harmonization process of the existing standards (Ilomäki et al. 2008), in particular attempting to:

- The definition of a *single tool* to assess the sustainability (and improve performance) (Gargiulo 2012) for all stages of the process, including CED (Cumulative Energy Demand), LCA (Life Cycle Assessment) of products and processes with reliability of performance and assumed actual measured values TQA (Total Quality Assessment), LCC (Life Cycle Cost) for the evaluation of economic indicators such as economic risk investments, profitability, etc. (Daniotti et al. 2010).
- The *simplification*, drastic reduction in the number and in the application of indicators

- The transition from a *first generation of indicators* (only environmental pressure-state-impact) to a *second* one (environmental, economic, social), easier to use.

The method adopted by CEN TC 350 for managing the sustainability of buildings is essentially based on the following categories subject to analysis and evaluation: *Aspects, Impacts, Performances, Indicators*. Each category is applied to each *stage* of the building *life cycle* (Daniotti 2012) and is so defined:

- *Aspect:* aspect of the construction of an assembly (of the building), processes or services related to their life cycle (Lavagna 2008) that can cause changes in environmental, social/ quality of life, economy;
- *Impact*: any change to the environment, society/ quality of life, economy (the users of the building, or the owner, operator and occupants, and neighbors), positive or negative, in whole or in part resulting from environmental/ social/ economic;
- *Performance*: relative performance (Gargiulo 2008) impacts and environmental aspects/ social/ economic (Stoy et al. 2011).

The suggested methodology of performance evaluation will take into account aspects and impacts / performances that can be expressed in *quantitative indicators*, measured without value judgments.

2.3 Conceptual framework

A method of managing complexity, especially taking into account sustainability, needs to be planned and developed using logic and graphic techniques and tools that bring together different and interacting categories (variables), taking care to search for cause-effect linkages, convergences, divergences, and any reasonable relationship between one and the others.

Even the methods that CEN TC / 350 is developing to manage the environmental/ social/ economic interactions between the *internal and external variables*, playing in the construction process along the whole life cycle, are based on this assumption.

Actually, the common introduction to the European standards reports: "In the future, the assessment methodologies within this standard framework may be part of an overall assessment of *integrated building performance*. The assessment methodologies may also be extended to an assessment of the neighborhoods and wider built environment".

And yet, in the definitions, sustainability assessment of buildings is described as a "*combination of the assessments of environmental performance, social performance and economic performance* taking into account the technical requirements and functional requirements of a building or an assembled system (part of works), expressed at the building level".

In other words, since the first draft writing, was already covered that future reviews will be set in a perspective, but also practically organized, based, not just on the analysis and assessment of the variables taking place, but on the integration of three (environmental / social / economic) components. And it means that *as much as we are able to manage integration as an aspect of complexity, the more we will be successful to achieve the sustainability goals*.

3 METHODOLOGY

3.1 Case study

"Città Studi Campus Sostenibile" is an international multi / inter - disciplinary project, focused on the energy / environmental / social up-grading of the Italian University Campus Leonardo (Politecnico di Milano and Università degli Studi di Milano) and its neighborhood (www.campus-sostenibile.polimi.it) (Bruglieri et al. 2011).

The Politecnico di Milano plays a significant international role in the field of engineering and technology as well as in architecture and design. Established in 1863, the school moved to the current site of Città Studi in 1927. Buildings are owned, managed and maintained by the institution. The campus is composed of old buildings (most of them are from the 20ies of the last century, some of the 60ies and only few were constructed in recent years). Some buildings represent significant samples of the Italian modern architecture, designed by well-known architects. The sustainable campus project concerns the “Leonardo Campus”, which is the main one of the seven campus of Politecnico di Milano distributed around the Lombardia region. Today, the “Leonardo Campus” occupies a surface of 186.613 m^2 and 17.484 students are enrolled in the different programs. In addition, 1.748 staff members (professors and personnel) work every day on the campus.

The first challenge is a strong commitment to reduce the energy consumption of buildings. The initial stage of the work, conducted in 2007, was mostly dedicated to create a baseline for measurements and the quantification of indicators, describing main characteristics (orientation, lighting layout and activation, heating and cooling devices, windows, shading devices, etc.) of the 3.700 building spaces and more than 100 fields for each zone. At the current and the further stages the aim is creating a *virtuous system of management*, related to the maintenance work plan and potentially redirecting and improving design choices. This strategy is expected to ensure at present and in the future the valuing and integration of new sustainable projects and initiatives at the *building and campus levels and connected with the urban context*.

3.2 Reference models

The International Council on *Systems Engineering* (INCOSE) defines systems engineering as "an *interdisciplinary approach* and *method to enable the realization of successful systems*. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with the design of architecture and system validation, always taking into account the totality of the problem. The discipline of Systems Engineering integrates all the disciplines and specialties of various working groups forming a *structured development process that proceeds from concept to realization and commissioning of the system*. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets *the needs of users*".

Another factor is related to the ability to identify and manage the *network of relationships, dependencies and dynamics between different components of a complex system*. The goal is to "guide them" into an overall behavior resulting from the *harmonization* of those parts, it would not be possible to obtain simply by putting them together. The skill lies in being able to predict the interactions between the different elements that contribute to the overall behavior and control them.

To avoid overlooking relevant aspects of the problem, or to minimize this risk, the system administrator typically adopts a "*top-down*" and proceed in a structured manner, often repeatedly *through the different levels and different dimensions in which the problem can be splitted*.

3.3 Method and application to the case study

The conceptual model elaborated in the research is *multidimensional*, because, as anticipated, there are many variables involved. The *critical issues* are highlighted by the intersections between the different set of variables involved in the case study.
In synthesis, the *method and supporting models* are featured as:

- *Multi-dimensional,*
- *Multi-criteria,*
- *Multi-layer*.

The aim is visualizing the complexity, reducing the initial model in simple partial models and therefore manageable, then recomposing the results in order to find the output corresponding to the given input, as reported in the logic chain: *Complex Input - Simple Issues - Recomposition - Interpretation / Correction – Output.*

In order to better manage the *multi-criteria* analysis, in line with modern theories and techniques of statistics, economics, and engineering involved in decision-making, the under development method is based mainly on the use of *matrices*, crossing one by one criteria and alternatives or set of variables to each other, and *multi-layer* tools, linking more than one set of variables to each other simultaneously. The aim is to obtain, crossing logically variables between them, much information as possible about the different *combinations*, to discover the *effects of possible actions* with a view of *integration* and *synergy*. The target of the analytical work in support of the decision-maker is to identify a panel of indicators suitable for subsequent stages of decision-making processes, to submit to the stakeholder groups. The following set of variables (and related *key factors*) have been identified as characterizing the different attributes of the case study:

- *Multi-role (A)* Responsibility
- *Multiactivity (multi-function) (B)* Functional requirements
- *Multi-scale (C)* Spatial interconnections
- *Multi-sector (D)* Integration with the city
- *Multi-objective (E)* Decisional roles
- *Multi-stage (F)* Life Cycle
- *Multi-stakeholder / multi-interest (G)* Corporate Responsibility
- *Multi-impact (H)* Cause-effect relationships
- *Multi-performance (I)* Efficiency
- *Multi-indicator (L)* Evaluation.

For each one of the above sets are identified a certain number the actual *variables* and the profile as involved in the project. By way of example, following are presented the profiles of the Multi-impact (H) and the Multi-performance (I) sets of variables.

- *Multi-impact (H) profile*:

Each action by the D.M. (Decision-Maker) determines such impacts. With a view to sustainable development, the impacts are broadly grouped into three categories:

- environmental
- social
- economic.

Actually, any action, such as deciding whether to use a particular component / product / material in a building or to build using a given structural material (eg wood, or reinforced concrete) causes an impact or generates a number of impacts that may also not be inscribed in one of three main categories. For example, a certain material, permanently inlaid in a room, eg. a classroom, produces a measurable impact on the environment in CO2 equiv., but it is also due to effects on the health of the occupants. Therefore, it impacts on the environment and society. And if the same material is put in place in an office room, it generates a third impact: economic, since the effect on the health of the employee is reflected in his work productivity.

Taking as reference the relevant indicators, as identified by CEN / TC 350 and in related European projects (SuPerBuildings, Open-House), the impacts can be substantially the following way.

Direct:

- environment (land use, water, energy, resources, placing of waste)
- on the health of the occupants

Indirect:

- fallout on the global environment and ecosystems at different scales (photochemical pollution, global warming, carbon footprint, etc.)
- level of user satisfaction and consequent productivity / social diseases, etc. (society - economy)
  effects on the quality of life of external social groups (eg residents of adjacent neighborhoods)
- effects on the macro economy (employment in industry and manufacturing, purchasing raw materials, contribution to recycling, imports, etc)
- effects on the micro economy (LCC, in particular energy consumption during the various stages and especially that of use) (Stoy et al. 2011)
- reflections on the local economy (value or devaluation of the site).

The impact on the outside, the so-called “externalities”, especially in a context such as the particularly dense urban environment, are too often neglected in practice, more or less consciously by decision-makers, and difficult to control in a step subsequent to that decision. As we know, too much often, they might end up to fall in the sphere of health and well-being (environmental and social), and a little later also economical for the high costs associated with health.

- *Multi-indicator (I) profile*:

If performances are normally in relation to the impacts (negative effects), the other category of the results of actions and therefore the choices (technical solutions, design, use of materials and components) to be taken into account in an assessment of the sustainability of a intervention, in certain contexts, such as structures of excellence, are a key factor.

This is due to their direct reflection on the "total quality" of the object of evaluation, as well as to a number of indirect effects on the user. The performance is expressed by the indicator, which measures the "behavior", that translates into how far away the object number of

performance-evaluation with respect to a reference value (benchmark). Obviously the goal is to minimize or maximize the impact and effect depending on the specific case where the impact is positive or negative, so that the construction / operation will respond in the best way possible with the established requirements (functional / technical, environmental, economic, social / cultural).
The expected performances in the case study concern to:

- the Reputation of the University (parameters used in the common methodologies for evaluating the level of quality of the University - international benchmarking)
- the Reputation of the Stakeholders (good performances can be certified as much qualified are the construction actors, eg. investors, designers, contractors, suppliers, etc.)
- the Environment (efficiency of design and technical solutions for saving water, energy, resources and waste minimization)
- the Users (level of functionality: accessibility, space and functional efficiency)
- the Owner / the tenant (fexibility, adaptability).

The second step of the method development has been the creation of a navigational matrix ("framework", Figure 1), which identifies the objective relations (constraints in either direction, interferences) with a view of sustainability, in particular related to the construction process / transformation of the city, present / not present between the set of variables, taken two by two. They also indicate the "relevant aspects" of these reports, to focus the thematic areas of *sensitive relationships* to have an overall idea of the problems and areas where the search for solutions. But they can also be considered as the *strategic aspects* on which to intervene on the basis of *environmental / social / economic criteria*, activating solutions today considered *sustainable*.

Below is the *Legend of Figure 1:*
■ existence of relevant relationships
□ absence of relevant relationships / existence of not relevant relationships
R - real estate
P - public procurement
A - environmental (impacts, performances)
S - social (impacts, performances)
E - economic (impacts, performances)

Variables Set / Variables Set	A	B	C	D	E	F	G	H	I	L
A – Multi-role	-	■	■	■	■	■	■	■	■	□
		R/ S/ E	A / S / E	R / P / A / S	P / R	P / R / S / E	S	A / S / E	R / A / S / E	
B - Multiactivity (multi-function)	■	-	■	□	■	■	■	■	■	■
	R/ S/ E		S		P / R / A / S / E	R / A / S / E	S	A / S	S / E	S / E
C - Multi-scale	■	■	-	■	■	■	■	■	■	■
	A / S / E	S		A / S / E	A / S / E	A / S / E	A / S / E	A / S / E	A / S / E	A / S / E
D - Multi-sector	■	□	■	-	■	□	■	■	■	□
	R / P / A / S		A / S / E		P / A / S / E		R / A / S / E	A / S / E	R / A / S / E	
E - Multi-objective		■	■	■	-	□	■	□	□	■
		P / R / A / S / E	A / S / E	P / A / S / E			R / S			P / R
F - Multi-stage	■	■	■	□	□	-	■	■	■	■
	P / R / S / E	R / A / S / E	A / S / E				P / R / S	P / R / A / S / E	A / S / E	A / S / E
G - Multi-stakeholder / multi-interest	■	■	■	■	■	■	-	■	■	■
	S	S	A / S / E	R / A / S / E	R / S	P / R / S		R / S	A / S / E	P / R / A / S / E
H - Multi-impact	■	■	■	■	□	■	■	-	■	■
	A / S / E	A / S / E	A / S / E	A / S / E		P / R / A / S / E	R / S		A / S / E	A / S / E
I - Multi-performance	■	■	■	■	□	■	■	■	-	■
	R / A / S / E	A / S / E	A / S / E	R / A / S / E		A / S / E	A / S / E	A / S / E		A / S / E
L - Multi-indicator	□	■	■	□	■	■	■	■	■	-
		A / S / E	A / S / E		P / R	A / S / E	P / R / A / S / E	A / S / E	A / S / E	

Figure 1: The navigational matrix to manage the complexity of the relationships between the sets of variables involved, highlighting the crucial issues

4 RESULTS AND DISCUSSION

Observing the navigational matrix (Figure 1), some early considerations can be done. The *social aspects* are very present both at the levels linked to a geographic / spatial / function (together with those related to the building project management), as well as to those more closely related to the themes “green” (sustainable development). They can therefore be considered “cross” to all the sets and substantially on 3 areas:

- territory / population
- building
- social groups (stakeholders).

They can also be divided in social aspects:

- relating to the *physical* characteristics (accessibility of the site and building, technical accidents on health and welfare, etc.)
- relating to the *sociological* sphere (consequences of behavior, relationships among stakeholders, etc.)

Because of their sheer number, heterogeneity and often difficult to focus, however, as deemed by the scientific community that is helping with the most advanced studies in European standardization work, their development certainly deserve a lot of effort and attention. From this point of view, also the DM (decision-maker) covered with a “social responsibility”, an obligation which requires him to include actors and social groups (stakeholders) affected by its choices in the decision-making process both as the advisory and proponent actors.

The *environmental* aspects (use of resources and energy, emissions and waste), properly studied in the context of ecology or starting point of the work of setting standards CEN TC 350, are *transverse to the scales* and abide by the direct responsibility of the DM and those who work with him in the process of implementation of the decisions as in the building.

These must bear in mind that the setting of each goal among the possible alternatives (build a new building rather than rent or renovate another, for example) inevitably generates effects (impacts) on the shared environment. The involvement on the part of D.M. stakeholders in the choices means not only have a voice to protect the interests of the represented part, but, as is clear in this case, to become co-responsible, as in the positive so in the negative reversible / not reversible impacts due to the choices on the environment.

The *economic* aspects have the characteristic of being present in many areas and relationships, and of being different depending on the scale. They range from those related to micro-economics and real estate procurement (more easily controlled and controllable) to the macro-economic effects of the choices that the DM does within a plurality of variables most elusive in its control and very even to his knowledge. The latter are only partly controllable and require extensive knowledge of the subject. Social responsibility in this area is actually a field rather "mined" for the DM. The close connection with the cycle of life, both at the macro level (involving different spatial scales) and micro (building or part of it, the whole Campus) requires the DM to consider all items of LCC (Life Cycle Cost) and examine their correlations with all possible aspects. Ensure that the LCC, which is actually a methodology widely known and applied, becomes in effect a strategic support for decision-making.

5 CONCLUSIONS

The research is still under development. However, some early conclusions from the first step and related application of the method have been drawn and are below reported:

1. The decision-making process in construction works belongs in itself to the *general area of complexity*.
2. Sustainability is a wide concept and even *dividing the aspects, performances and impacts of any process by components* (environmental, social, economic), this is only a start point, because of the *high level of the variables and the relationships* engaged.
3. Disciplines and andvanced knowledge areas as i.e. SE (Systems Engineering) or MCDM (Multicriteria models and methods for decision-making) are able to offer models and methods to help the management supporting the decision-making.
4. Any multi-dimensional/criteria problem in construction works can be managed using a *Top-down and Multilevel approach*, dividing the complex input into simple parts, described by *sets of variables* and analysing the relationships between the sets.
5. The identification of mentioned sets of variables involved in the problem and the *visualization* by matrices can be useful to the project manager and the decision-maker to detect the relationships and chains of causes-effects taken in by any option of choice, to *identify, keep under control* along the whole decision-making process and hereafter *monitor* during the *life cycle, the crucial issues*.
6. Further developments in this field are expected, in order to offer to the construction actors, particularly managers and decision-makers, *appropriate methods / guidelines* for the *optimization* of construction works from a sustainable *point of view*.

REFERENCES

M. Bruglieri, D. Schiaparelli, A. Colorni and A. Luè, *PoliUniPool: a carpooling system for universities*, 14th Meeting of the Euro Working Group on Transportation, Poznan, Poland (2011).

B. Daniotti, *Durabilità e manutenzione edilizia*, Torino, Italy, UTET (2012).

B. Daniotti and F. Re Cecconi, *Test methods for service life prediction*, CIB (2010).

C. Gargiulo, "Performance oriented building assessment: time and space the two dimensions of sustainability", *CIB W115 Green Design Conference Proceedings* ISBN: 978-90-365-3451-2, 27-30 September 2012, Sarajevo, Bosnia and Herzegovina, 2012(366):146-149.

A. Ilomäki, T. Lűtzkendorf and W. Trinius, "Sustainability Assessment of Buildings in CEN/TC350 Sustainability of Construction Works", *Proceedings of the World Conference SB08* (ISBN 978-0-646-50372-1), Melbourne, Australia (2008).

M. Lavagna, *Life cicle assessment in edilizia. Progettare e costruire in una prospettiva di sostenibilità ambientale*, Milano, Italy, Hoepli (2008).

G. Masera, *Residenze e risparmio energetico - Tecnologie applicative e linee guida progettuali per la costruzione di abitazioni sostenibili*, Milano, Italy, Il Sole24Ore (2004).

D. Palazzo, G. Masera, M. Grecchi et al., *International Journal for Housing Science and its Applications* (ISSN: 0146-6518), 35(1):11-21 (2011).

C. Stoy and E. Beusker, *BKI Objectdaten: NK1 Nutzungkosten* (ISBN 978-3-94167-914-6), Stuttgart, Germany, Baukosteninformationszentrum Deutscher Architektenkammern (BKI) (2010).

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ENERGY PERFORMANCE ASSESSMENT AND DECISION SUPPORT TOOL FOR DWELLINGS

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Abstract. *The UK has set itself a target to reduce its carbon dioxide (CO_2) by 20% by 2020 and 80% by 2050. The UK housing stock is one of the least energy efficient in Europe and accounts for more than a quarter of the total energy use and related carbon dioxide emissions. More than 75% of the existing dwelling stock will still be present in 2050. For UK to meet the ambitious CO_2 reduction targets, it is necessary that the energy performance of the existing dwelling is taken into account and improved. The UK government has several policies and initiatives to improve the energy performance of the housing stock. Several tools have been developed particularly in the last decade for energy assessment of dwellings, largely to inform policy development. However, when it comes to policy implementation stages, stakeholders such as local councils, energy suppliers, social housing providers and planners lack a tool, which assists them in estimating the potential for energy performance improvement through implementation of energy efficiency and renewable energy interventions. This paper discusses the framework of a tool to meet this need. The approach is based on developing dwelling objects using aerial and terrestrial imagery, digital maps and national databases and statistics providing housing data on a GIS platform. These are then used to estimate the baseline energy performance and quantify energy consumption and carbon emission reduction potential. Analytical hierarchy process then enables evaluation of various energy efficiency and renewable energy interventions based on environmental, technical, financial and social criteria determined by the stakeholders. The methodology is prototyped in a proof-of-concept tool. The testing of the tool using empirical case studies with the involvement of local authorities and social housing providers illustrates that the tool can support town stakeholders in making informed decisions with regard to the implementation of energy policies and initiatives and contribute to meeting CO_2 emission reduction targets.*

1 INTRODUCTION

The UK government in its Climate Change Bill is committed to reduce its CO_2 emissions by 80% by 2050 over its 1990 baseline (H.M. Government 2008). The government is also committed to meet the EU target to obtain 15% of energy from renewable sources by 2020 (House of Lords 2008). Buildings contribute almost a half of all CO_2 emissions in the UK. Of those emissions 27% come from approximately 26 million residential dwellings (All Party Urban Development Group 2008). It is expected that about 75% of the existing domestic stock will be still present in 2050 (Wright 2008). The UK housing stock is one of the oldest and the least efficient in Europe. The reduction of CO_2 emissions from the existing built environment is thus a key component of meeting the overall CO_2 emissions reduction target (Jones et al. 2007).

Range of improvements through energy efficiency and renewable energy measures is promoted through Government policies and initiatives including Carbon Emissions Reduction Targets (CERT), Community Energy Savings Programme (CESP), Energy Company Obligation (ECO) and the Green Deal (DECC 2009). The initiatives not only target reduction in energy consumption but also improve the standard of living and eliminate fuel poverty (DECC 2011a, b). The local development framework requires local governments to involve the local community, utility providers, environmental groups and housing corporations amongst others in their appraisal and management process of the framework (OPDM 2010). Therefore, energy and carbon models which can undertake predictions and evaluate the potential of different energy efficiency and renewable energy interventions for the housing stock are essential for implementation of these policies and initiatives (Cheng et.al. 2011).

The paper presents a methodology and a proof-of-concept tool that integrates energy databases with visualization systems and decision support technique in Geographic Information System (GIS) to enable the evaluation of the environmental and financial implications of various energy efficiency and renewable energy interventions at dwelling and neighbourhood levels.

2 ENERGY MODELLING APPROACHES

Several building physics based bottom-up models have been developed in the UK over a number of years to estimate the current and future residential demand. Some of the notable models include Building Research Establishment's Housing Model for Energy Studies (Shorrock et al. 1997); Johnston Energy and CO_2 Emission Model (Johnston 2003); UK Domestic Carbon Model (Boardman et al. 2005); DECarb Model (Natarajan et al. 2007); Energy and Environmental Prediction (EEP) Tool (Jones et al. 2007); and Community Domestic Energy Model (Firth et al. 2010)

All these models have the same energy calculation engine which is the BREDEM (Building Research Establishment Domestic Energy Model). The transparency of models in terms of data sources and model structures is crucial issue and no access is available to the raw input data and core calculation algorithms of almost all the models (Kavgic et al. 2010; Natarajan et al. 2007). These models assist in informing policy development, none of them assist stakeholders involved in implementing these policies. All models above except for EEP rely on standard archetype models of dwellings which are limited in number. EEP relies on drive-through surveys to gather information which is hugely time consuming (Jones et al. 2007).

This research intends to address these gaps through developing a methodology and proof-of-concept tool that integrates energy databases with visualisation systems and multi-criteria analyses. For this purpose, the Standard Assessment Procedure (SAP) was selected as a main element of the proof-of-concept tool. SAP is underpinned by BREDEM is now the UK's National Calculation Methodology, meeting one of the requirements of the Energy Performance of Buildings Directive (DECC/BRE 2010).

The methodology and the proof-of-concept tool aim to enable stakeholders assess the baseline energy performance of dwellings on a neighbourhood level. The tool permits stakeholders to develop tailor-made scenarios of energy efficiency and renewable energy interventions for individual or multiple dwellings. The tool informs the stakeholders of the environmental benefits in terms of indicative increase in SAP rating of the dwelling, energy saved in kWh and amount of CO_2 reduced in kg for tailor-made energy performance improvement scenarios. Most importantly, the tool incorporates the use of multi-criteria decision analysis technique which assists stakeholders in meeting the requirements of the local development framework through incorporation environmental, technical, economic and social parameters as selection criteria.

3 MODEL DESCRIPTION AND PROTOTYPE DEVELOPMENT

Various energy balance equations within SAP require an input of over 80 different parameters. This data is typically readily available for new developments; however, for existing dwellings, most of this data has to be gathered through site surveys. This research however makes use of aerial and terrestrial imagery, published databases such as Homes Energy Efficiency Database (HEED), household surveys such as English House Condition Survey (EHCS), census and the Office of National Statistics (ONS). The data from these sources form input for the core energy balance calculation engine. The framework of this concept is presented in Figure 1 which forms the basis of development of the prototype.

The prototype tool is built on a GIS platform as it helps in integrating and managing vast and various formats of data and can connect various data sets together by common locational data e.g. address (Goodchild 2009). The database created can be shared for various purposes including modelling and simulating scenarios. For this research, ArcGIS 10 was used as it provides a geoprocessing functionality which allows personalising tasks through inherent programming capabilities (Environmental Systems Research Institute 2010).

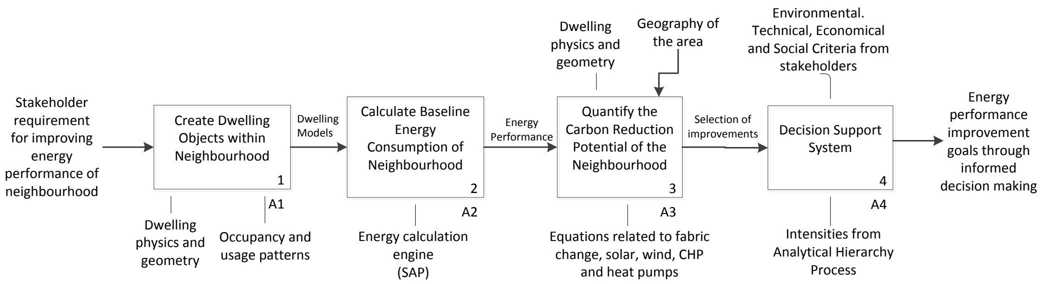

Figure 1: Framework of the energy performance assessment and decision support tool

Each dwelling is considered an object consisting of attributes holding parameter related information. These attributes are derived from imagery, maps and databases which then act as input for energy balance equations. The energy balance equations estimate the baseline energy performance. Based on the existing characteristics of the stock, the potential for improvement to building fabric is identified and installation of renewable energy resources is quantified. Finally, an analytical hierarchy based decision support tool assists in selecting the most appropriate interventions based on environmental, technical, economic and social criteria.

3.1 Creating Dwelling Objects

The principal stage in this framework is developing domestic dwelling objects. These objects act as a source for all calculations related to baseline energy performance and quantification of carbon reduction potential. Investigations of the energy balance equations reveal that the input data can be classified into three major categories as presented in Figure 2 and described below:

- Geometric sub-model consisting of details on foot-print, floor height, exposed perimeter and wall area and roof-area;
- Physics sub-model consisting of details on ventilation and u-values of walls, windows, roof and floors;
- Usage sub-model consisting of details on the type and use of heating system, heating controls and electrical appliances.

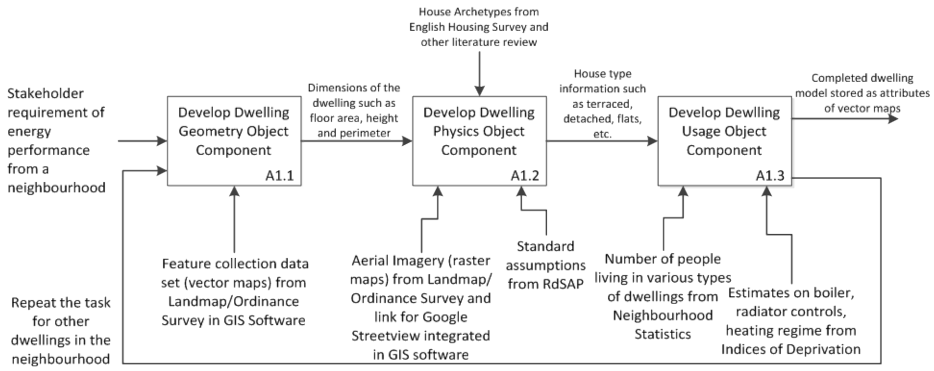

Figure 2: Framework for creating dwelling objects

The geometry object component defines the dimensions which are typically unique to each dwelling. The OS MasterMap Topography Layer and Landmap Building Blocks layer contain the features represented by points, lines and polygons (vector maps) that can provide the information for generating a geometry object component (Ordnance Survey 2010; MIMAS, 2012).

The physics object component defines the thermal characteristics of the material used for construction of dwelling. Dwellings of similar age typically have similar construction characteristics (Dowson et al. 2012; Killp 2005). The age band is identified using aerial and terrestrial imagery from Ordnance Survey and Google Maps. The construction characteristics for these archetypes are obtained or inferred from the English Housing Survey and the Homes Energy Efficiency Database (Communities and Local Government 2012). The climate of the locality also affects the energy performance, the information for which is sourced from the MetOffice and Department of Environment and Climate Change. The dwelling usage component defines the amenities present within the dwellings and the way they are used by the occupants. Traditionally assumptions made regarding occupancy patterns and usage has been regarded as a drawback in the bottom-up building physics based techniques. Recently (Shipworth 2011; Kelly et al. 2013) have investigated relationships between internal space heating and socio-demographics. The usage component identifies the socio-demographic profile of the area from the census and neighbourhood statistics data maintained by the ONS to determine the usage profile of the dwellings (Office of National Statistics 2012).

The data related to dwelling geometry component is already included as attributes when sourced from Ordnance Survey and Landmap. Hence this data is not required to be input by the user. One of the significant advantages of using GIS based software is that the data entry process can be replicated for several dwellings that have similar characteristics. This is particularly useful when replicating similar data across the archetypes.

3.2 Estimate Baseline Energy Performance

The attributes of the dwelling objects created form the input to the energy balance equations based on SAP and underpinned by BREDEM (BRE 2011). Using the programming capabilities of ArcGIS and MS-Excel, empirical and analytical equations for heat balance are modelled. The attributes from the object database and the equations calculate the following energy performance characteristics identified from SAP/BREDEM (BRE 2011):

- Heat losses due to ventilation from the type and number of floors, number of chimneys, flues, fans, passive vents and floors and average wind speed in the area.
- Heat losses from building fabric such as doors, windows, roof, floor and walls taking into consideration their area and U value.
- Energy demand for water heating depending on the number of occupants, temperature rise for hot water and losses due to presence of storage cylinder and distribution of hot water through pipes.
- Internal gains from occupant metabolism, lighting and electrical appliances, cooking, water heating and boiler pumps for space and water heating and losses from evaporation; and external gains due to solar radiation through windows.
- Space heating demand depending on the building geometry, heat losses, difference between internal temperature demand and external temperature and fraction of living space to total dwelling area.
- Energy required by the heating system to meet the total (water and space) heat demand depending on the efficiency of the system.
- Electricity required for pumps, lighting and electrical appliances.
- Energy cost depending on amount of electricity required from the grid and type and amount of fuel required for space and water heating.
- SAP rating based on the total cost of energy use (for space heating and lighting) normalised to the floor area of the dwelling;
- CO_2 emissions based on amount of electricity and total amount of fuel for space heating and water and their emission factors.

The performance evaluation can be undertaken for several dwellings depending on the user requirements. Based on the level of energy performance, ArcGIS allows developing thematic maps and areas with higher energy consumption can be identified as hotspots.

3.3 Quantification of Energy Consumption and Carbon Emission Reduction Potential

The existing characteristics of the dwellings determine the energy consumption and carbon reduction potential. The lower the baseline energy performance, the higher is the potential for reducing energy consumption and carbon emissions. Studies by (Peacock et al. 2007; Jenkins 2010; Boardman 2007) and the discussions with the stakeholders undertaken as a part of this research has revealed the following as the most widely applicable energy performance improvement measures:

- Changes to building fabric such as insulation of roof, walls, floor and installation of low-e double glazed windows.
- Replacing the low efficiency boilers with ‘A’ rated condensing boilers.
- Installation of solar photovoltaic panels for electricity generation and solar thermal for hot water generation.
- Installation of micro wind-turbines for electricity generation.

- Installation of micro-combined heat and power (μ-CHP) unit to meet space heating demand and generate electricity as a by-product of heat generation.
- Installation of air source heat pumps (ASHP) and ground source heat pumps (GSHP) to meet space heating demand.

Changes to building fabric essentially involve decreasing the thermal conductivity (U value) of the existing fabric to reduce heat loss. With more heat retained within the dwelling, space heating demand is reduced. For calculation purposes, it is assumed that the new fabric quality at least complies with the Part L of Building Regulations (HM Government 2010). Apart from the electrical storage heaters, all other space heating systems will involve use of a boiler. Condensing boilers (regular or combination) typically have efficiency higher than most other boilers (BRE 2011).

The solar potential of a dwelling depends on the available roof area, the orientation of the roof and its angle of inclination. All this information can be sourced from the geometry component of the dwellings. Solar thermal panels further require a cylinder for storage and distribution of hot water. This this option is usually only feasible for dwellings having storage cylinders, the information which can be sourced from the building physics component of the dwellings. Installation of micro-wind turbines is independent of buildings of the dwelling models however depends on local wind speed. However, the Planning Permission requires any building mounted or standalone micro-wind turbines to be installed only on detached dwellings. Further, the DECC recommends micro-wind turbines for areas having annual average wind speed of more than 5 m/s.

The primary benefit of μ-CHP is that the fuel used to generate heat is also used to generate electricity at the point of use. The typical ratio of heat to electricity generation is about 6:1 in a domestic μ-CHP unit and may be fuelled by gas or biomass (Hayton et al. 2008). The electricity generated is driven by heat demand of the dwelling. Hence, μ-CHP is an attractive option where the dwellings where heat demand is large and can replace oil or solid fuel. Heat pumps, both air and ground source, operate on the same principle as refrigeration, however, in reverse. This means the heat pumps extract ambient heat from the environment and increases its temperature to heat space or water (Staffell et al., 2010). GSHP require heating coils to be laid in the ground. Thus only dwellings having sufficiently large and accessible back yards can be considered for GSHP. ASHP is considered for dwellings where GSHP is not an option.

Using the querying capabilities of ArcGIS, dwellings satisfying the conditions for installation of these energy performance improvement measures are identified. Similar to the energy balance equations, the equations are modelled to estimate the new levels of energy consumption from application of interventions and comparing them with existing to quantify savings. Equations are also modelled for estimating annual savings in energy bills which includes the feed-in-tariff for electricity generation and renewable heat incentive for heat generation using renewable sources of energy. Reduction in energy bills also reflects an increase of SAP rating of the dwellings, which is also calculated.

3.4 Decision Support System

Energy planning decisions are complex as several parameters are involved in the process thus necessitating a decision support system. Furthermore, as the case with most energy-related decisions, various groups of decision makers are involved. Multi-criteria decision analysis (MCDA) deals with making decisions in presence of multiple stakeholders, criteria and alternatives (Wang et al. 2009). Pohekar et.al. (2004) have discussed several MCDA techniques and argue that Analytical Hierarchy Process (AHP) developed by (Saaty 1980) is one such technique most applicable for making sustainable energy planning decisions which is incorporated in this research. Based on the studies by (Akash et al. 1999; Gamboa et.al. 2007; Georgopoulu et al. 2003) and the discussions with stakeholders during this study, the following were identified as important criteria based on which the selection of abovementioned interventions depends:

- Annual reduction in CO_2 levels
- Initial investment (capital cost and grants received though government policies)
- Return on investment (annual running cost to user and savings made through feed-in-tariff and renewable heat incentive)
- Social Acceptability (personal likeliness towards intervention)
- Ease of implementation (access to resources and timeline)

Pairwise comparison is undertaken for each of the alternatives for each criterion. A scale of 1-9 is used to assess the intensity with 1 indicating equal importance and 9 extremely high importance (Saaty 1980). Based on the intensities assigned, a matrix is created. The matrix is then normalised and iterations are undertaken to identify the resultant eigen-vectors. The eigen-vectors established are the rankings that determine the preference for the alternatives based on the criteria.

4 VALIDATION AND CASE STUDY

To validate the framework, baseline energy calculations were undertaken on the developed proof-of-concept prototype, on a set of dwellings owned by a social housing provider in Middlesbrough. Thus the energy performance of the dwellings estimated by the method in this research is compared with the energy performance from actual survey of the property. 34 properties of various age and detachment were selected to ensure adequate representation of different archetypes.

The results from the analyses indicate that the estimated energy performance is within a maximum range of ±8% of the actual energy performance provided by the social housing provider. The average error over the 34 properties is just about 1% and the standard deviation of the error is 0.03. The results are clearly within a close proximity of the actual energy performance and hence the approach is reliable.

Subsequent to the validation, a case study was undertaken for 756 dwellings in a Lower Level Super Output Area (LLSOA) in Middlesbrough. The dwellings consisted of a majority of terraced houses followed by a small number of semidetached and detached dwellings of different age groups. The annual energy consumption details for these house types estimated using the approach developed in this research is presented in Table 1.

No.	Dwelling Type	Number	Energy Consumption (kWh/Annum)
1	Terraced	719	15,948,608
2	Semi-detached	23	357,700
3	Detached	14	265,387
	Total	756	16,571,695

Table 1 : Summary of Energy Consumption in LLSOA

The results show an annual energy consumption of just over 16.5 GWh. This computes to an average energy consumption of 21.85 MWh per dwelling per year within the LLSOA. The national average energy consumption estimated for domestic dwellings is 19.8 MWh (OFGEM 2011). The estimated energy performance is approximately 10% higher than the national average. The results can however be considered consistent as most of the dwellings in this LLSOA are pre-world war properties and have low insulation standards (HEED 2012).

The prototype was further used to estimate the energy saving potential of the same dwellings. The average wind speed in this area of Middlesbrough was less than the required 5 m/s and hence was not considered suitable. Table 2 shows the results from the analysis of various interventions including changes to building fabric and installation of Solar PV, µ-CHP, condensing boiler and ASHP. Since most dwellings in this area are terraced houses, space is a constraint for ground source heat pumps, hence only air source heat pumps (ASHP) are considered.

Intervention	**Fixed Cost**	**Energy Saved (MWh/Year)**	**CO_2 Saved (Tons/Year)**	**Annual Savings**	**Lifetime Savings**
Fabric Change	£5,973,156	9,084	1,795	£281,090	£8,432,708
Solar PV	£4,309,200	631	127	£19,327	£5,428,080
µ-CHP	£1,814,400	1,311	678	£271,404	£5,186,160
Condensing Boiler	£1,209,600	585	115	£259,308	£483,179
ASHP (underfloor	£6,804,000	4,005	793	£123,984	£3,719,520
ASHP (Radiator)	£4,536,000	-1,037	-205	-£32,130	-£963,900

Table 2 : Quantification of energy saving potential in LLSOA

The results indicate that for this LLSOA, fabric insulation and use of µ-CHP offer the most CO_2 reduction potential for investment made. While the use of ASHP using radiators currently offer no savings in energy used due to their low efficiencies. The ASHP using under-floor heating appear to have good impact on CO_2 reduction however is currently cost intensive. Further analyses of the results show that, just by improving the fabric of the building through insulation of solid walls and roof and installation of low emissivity double glazed windows can reduce the energy demand by 9,084 MW or just over 41.5%. Installation µ-CHP and solar PV can further contribute 15% of total energy thus reducing the demand from the national grid.

This information was then presented to stakeholders in a focussed group to determine the ranking of the improvement measures based on their criteria for selection. The intensity values from pairwise comparison of the criteria and the alternatives were evaluated using AHP described earlier. The results from this process are presented in Table 3.

Alternative	**CO_2 Reduced**	**Initial Invest.**	**Return on Invest.**	**Social Accept.**	**Ease of Implemen.**	**Goal**
Fabric Change	0.1403	0.0550	0.0674	0.0359	0.0219	32.05%
µ-CHP	0.1103	0.0801	0.0517	0.0282	0.0125	28.29%
Solar PV	0.0663	0.0582	0.0349	0.0170	0.0086	18.50%
Condensing Boiler	0.0359	0.0561	0.0136	0.0092	0.0048	11.95%
ASHP	0.0218	0.0451	0.0093	0.0056	0.0104	9.21%

Table 3 : Rankings for improvement alternatives using decision support

The results indicate that improving building fabric is the most popular choice. This is consistent with the current poor quality of the dwelling stock in the area and the amount of energy savings it has to offer. µ-CHP is more popular than the boiler as the former is not only high in efficiency but also generates electricity. ASHP are the least popular most likely reasons being low efficiencies and high installation costs.

5 CONCLUSIONS

- This paper presented a framework that integrates visual systems, databases and decision support system to rapidly evaluate energy performance of the dwellings.
- The validation using the prototype has showed that the framework provides reliable estimates of energy consumption and enables a systematic analysis of various energy efficiency and renewable energy interventions and eliminating the drive-by surveys.
- The equations modelled to quantify the energy savings give stakeholders a clear idea on which interventions are more applicable for particular characteristics. For e.g. the tool predicts that for a dwelling having good fabric insulation, the heat demand is low and hence µ-CHP is not an ideal choice. Because, µ-CHP is heat driven and lesser the heat, lesser is the electricity generation, affecting feed-in-tariff and lifetime returns.
- The decision support system takes into consideration the opinion of the stakeholders which will help in identifying and eliminating the barriers of implementing energy improvement measures, particularly in the privately owned and privately rented housing sector.
- The developed framework and the prototype make an attempt to address the requirement of a tool for stakeholders to make informed decisions regarding implementation of energy policy.

REFERENCES

All Party Urban Development Group, *Greening UK cities' buildings*, All Party Urban Development Group (2008)

B.A. Akash, R. Mamlook, and M.S. Mohsen, "Multicriteria selection of electric power plants using analytical hierarchy process", *Electric Power Systems Research*, **52**, 29-35 (1999).

B. Boardman, *Home Truths: A low carbon strategy to reduce UK housing emissions by 80% by 2050*, University of Oxford's Environmental Change Institute (2007).

BRE, *The Government's standard assessment procedure for energy rating of dwellings*, BRE on behalf of DECC (2011).

V. Cheng and K. Steemers, "Modelling domestic energy consumption at district scale: A tool to support national and local energy policies" *Environmental Modelling & Software*, **26**, 1186-1198 (2011)

Communities and Local Government, *English Housing Survey 2010-11*, Department of Communities and Local Government (2012).

M. Dowson, A. Poole, D. Harrison and G. Susman, "Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal", *Energy Policy*, **50**, 294-305 (2012).

DECC, *Community energy saving programme*, Department of Environment and Climate Change Consultation (2009).

DECC, *Evaluation synthesis of energy supplier obligation policies*, Department of Energy & Climate Change (2011a).

DECC, *The Green Deal and energy company obligation*, Department of Energy & Climate Change (2011b).
DECC/BRE, *The Government's standard assessment procedure for energy rating of dwellings,* Building Research Establishment (2010).
Environmental Systems Research Institute, *A quick tour of what's new in ArcGIS 10*, (2010). *Available at: http://help.arcgis.com/EN/ArcGISDesktop/10.0/help/index.html#//00qp0000000p000000.htm.* Accessed December 19, 2011
S. K. Firth, K.J. Lomas, A.J. Wright, "Targeting household energy-efficiency measures using sensitivity analysis", *Building Research and Information,* **38**, 24-41 (2010).
G. Gamboa and G. Munda, "The problem of windfarm location: a social multi-criteria evaluation framework", *Energy Policy,* 35, 1564–1583 (2007).
E. Georgopoulu, Y. Sarafidis, S. Mirasgedis, S. Zaimi, D.P. Lalas, "A multiple-criteria decision-aid approach in defining national priorities for greenhouse gases emissions reduction in the energy sector", *Europen Journal of Operational Research,* **146**, 199-215 (2003).
M.F. Goodchild, "Geographic information systems and science: Today and tomorrow", *Procedia Earth and Planetary Science,* 1037-1043 (2009).
J. Hayton, and B. Young, *Method to evaluate annual energy performance of micro-cogeneration heating systems in dwellings*, BRE on behalf of DEFRA (2008).
HEED, *Area summary report (Middlesbrough, Middlesbrough South and East Cleveland),* Energy Savings Trust (2012).
H.M. Government, *Climate Change Act*, The Stationery Office Limited (2008)
HM Government, *The Building Regulations 2010 Conservation of Fuel and Power in Existing Dwellings,* NBS Part of RIBA Enterprises Ltd (2010).
House of Lords, *The EU's Target for Renewable Energy: 20% by 2020,* The Stationery Office Limited (2008).
D. P. Jenkins, "The value of retrofitting carbon-saving measures into fuel poor social housing", *Energy Policy*, **38**, 832–839 (2010).
D. Johnston, *A physically based energy and carbon dioxide emission model of the UK housing stock*, Leeds Metropolitan University (2003).
P. Jones, J. Patterson and S. Lannon, "Modelling the built environment at an urban scale-energy and health impacts in relation to housing", *Landscape and Urban Planning,* **83**, 39-49 (2007).
M. Kassem, N. N. Dawood and N. Mitchell, "A decision support system for the selection of curtain wall systems at the design development stage", *Construction Management and Economics*, **30**, 1039-1053 (2012).
M. Kavgic, A. Mavrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic and M. Djurovic-Petrovic, "A review of bottom-up building stock models for energy consumption in the residential sector", *Building and Environment,* **45**, 1683-1697 (2010).
S. Kelly, M. Shipworth, D. Shipworth, M. Gentry, A. Wright, M. Pollitt, D. Crawford-Brown and K. Lomas, "Predicting the diversity of internal temperatures from the English residential sector using panel methods", *Applied Energy*, **102**, 601-621 (2013).
G. Killp, *Built fabric & Building Regulations, Background Material F: 40% House Project,* University of Oxford's Environmental Change Institute, Oxford (2005).
MIMAS, *Building Blocks* (2012). *Available at:*

http://landmap.ac.uk/index.php/Datasets/Building-Blocks/Building-Blocks, Accessed 2 Jan 2013
S. Natarajan and G.J. Levermore, “Domestic futures-Which way to a low-carbon housing stock?”, *Energy Policy*, **35**, 5728-5736 (2007).
Office of the Deputy Prime Minister, *Planning Policy Statement 12: Local Development Frameworks*, The Stationary Office (2010).
Office of National Statistics, *Super Output Areas (SOAs)* (2012). *Available at: http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/super-output-areas--soas-/index.html*, Accessed 2 Feb 2013
OFGEM, *Typical domestic energy consumption figures*, OFGEM (2011).
OS MasterMap Address Layer, *Coverage: Middlesbrough, Updated June 2012*, Ordinance Survey, *GB* (2012).
OS MasterMapTopography Layer, *Coverage: Middlesbrough, Updated June 2012*, Ordinance Survey, GB (2012).
Ordnance Survey, *OS MasterMap and Topography Layer User Guide and Technical Specifications*, Ordnance Survey (2010).
A. D. Peacock, S. Turan, D. Jenkins, M. Ahadzi, G. Bowles, D. Kane, M. Newborough, P. C. Eames, H. Singh, T. Jackson and A. Berry, *Reducing CO_2 emissions through refurbishment of UK housing*, European Council for an Energy Efficient Economy (2007).
S. D. Pohekar and M. Ramachandran, “Application of multi-criteria decision making to sustainable energy planning - A review,” *Renewable & Sustainable Energy Reviews*, **8**, 365-381 (2004).
T. L. Saaty, *The analytic hierarchy process*, Macgraw-Hill (1980).
M. Shipworth, “Thermostat settings in English houses: No evidence of change between 1984 and 2007,” *Building and Environment*, **46**, 635-642 (2011).
L.D. Shorrock and J.E. Dunster, “The physically-based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioxide emissions of the UK housing stock”, *Energy Policy*, **25**, 1027-1037 (1997).
I. Staffell, P. Baker, J. P. Bartoj, N. Bergman, R. Blanchard, N. P. Brandon, D. J. L. Brett, A. Hawkes, D. Infield, C. N. Jardine, N. Kelly, M. Leach, M. Matian, A. D. Peacock, S. Sudtharalingam and B. Woodman, “UK microgeneration. Part II: Technology overviews,” *Proceedings of Institution of Civil Engineers: Energy*, **163**, 143-165 (2010).
J.J. Wang, Y.Y. Jing, C.F. Zhang and J.H. Zhao, “Review on multi-criteria decision analysis aid in sustainable energy decision-making”, *Renewable and Sustainable Energy Reviews*, **13**, 2263-2278 (2009)
A. Wright, “What is the relationship between built form and energy use in dwellings?” *Energy Policy*, ***36***, 4544-4547 (2008).

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REDUCING CARBON EMISSIONS BY USING DESIGN QUALITY INDICATORS (DQI) IN UNITED KINGDOM ARCHITECTURE AND CONSTRUCTION COMPANIES

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Abstract. *Global warming has changed the views and attitudes of people all around the world towards lifestyle, transport and construction. The UK government has set a zero carbon target for the construction industry to meet by 2050. Effective procedures and tools must be used in order to meet this zero carbon target. This paper studies the impact of architectural and construction companies using Design Quality Indicators (DQI) as a tool to reduce carbon emissions. A quantitative approach was adopted for this study; where 180 questionnaires were distributed to professional architects employed by 15 SME's, in West Midlands. 130 questionnaires were returned and formed the main source of data. Based on the questionnaire's findings, the main challenges concerning the zero carbon targets have been highlighted; a set of solutions to overcome these challenges has also been recommended in this study.*

1 INTRODUCTION

Approximately, 50% of UK's total carbon emissions arise from the Construction industry, including designing the building, construction, the materials used as well as the building itself (*Construction and Sustainable Development, 2008).* In 2008, in response to the risks associated with climate change, the UK legally committed to the Climate Change Act, which aims to cut carbon emission levels produced since the 1990's by 80% by the year 2050. In order to meet the carbon emission targets, carbon budgets were also set in the years leading up to 2050, the following aims were set: by 2012 the budget aimed to reduce carbon emissions by 22%, by 2016 all new homes must be constructed to zero carbon standards, by 2019 all new domestic homes built must be in accordance to zero carbon standards, 28% carbon reduction should be reached by 2017, by 2022 a 34% reduction is set and finally, by 2027 there should be 50% reduction in carbon emissions (CIOB, 2010). It has been reported that the UK construction industry is aiming to have all designs tested and assessed via a third party design review tool, it has been recommended that Design Quality Indicators (DQI) should be the main assessment tools used for all designs (CIC, 2009). One way carbon emission can be reduced is by controlling the design quality and improving communication between parties. This study will evaluate the importance of using Design Quality Indicators (DQI) in reducing Carbon emission in the UK construction industry in order to meet the zero carbon targets.

Based on the purpose of the study, the following research objectives have been set: Do Design Quality Indicators (DQI) have a direct impact on reducing carbon emissions in construction?

2 OVERVIEW OF ZERO CARBON WITHIN THE CONSTRUCTION SECTOR

Construction is one of the biggest factors affecting climate change. The UK Government wants the construction industry to adapt to climate change and the risks associated with it, new technologies must be found to make the construction process more sustainable, construction should also be managed more appropriately with improving climate change being on top of the agenda (Crown, 2009). The construction industry accounts for 70% of UK manufacturing capital. Therefore, the successful delivery of construction projects in terms of cost, design and time have a substantial impact on the UK's economical status (Construction Matters, 2008). The term zero carbon was created by the government, it refers to their goal that over a year the net carbon emissions produced from using energy in homes should be zero. This definition is related to residential buildings only (Communities and local government, 2009). The construction industry's carbon footprint must also be reduced in order to reduce carbon emissions. Minx and Wiedmann defined carbon footprint as " a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" (Minx and Wiedmann, 2008, pp.1-11). Phillips explained that there are five elements to carbon footprints, they are; project management carbon; this refers to "the off-site carbon cost of designing and managing a project, embodied carbon, construction carbon, running carbon and deconstruction carbon. (Phillips, 2008, p.15)

A Low Carbon Transition Plan was implemented by the UK Government (IGT, 2010). The main plan for carbon transition for domestic use was; to reduce carbon emission by 29% by 2020 compared to carbon levels in 2008 by increasing energy efficiency in homes and to construct new homes with zero carbon from 2016. The carbon transition plan for non-domestic use is to reduce non-domestic building emission by 13% (as this currently accounts for 18% of all UK carbon emissions) by 2020 as compared to levels reached in 2008 and for all new public sector buildings to achieve zero carbon from 2018, and all new private sector buildings to achieve this goal from 2019.

In order to reduce carbon emissions all construction industry workers, as well as construction clients must be aware of exactly how the zero carbon process works and what everyone's role is in achieving this goal (King, 2010). In order to be effective, the Low carbon design must be well understood and appropriate strategies must be developed and applied. One example this is efficient communication between all managers, clients and users regarding the buildings operations as well as ways of increasing energy efficiency; as this will result in low carbon management, which will eventually lead to low carbon design (CIOB, 2011).

Another way of reducing carbon is to choose local materials or materials from around the UK; imported materials have a higher carbon footprint than local materials as transporting materials is also considered in the calculation of carbon emissions (Barrett & Wiedmann, 2007). The life cycle assessment approach (LCA) implies that all building should be assessed according to their life cycle; this refers to the starting materials used to construct the building to the materials used to demolish the building at the end, the materials used throughout the buildings life cycle should be reused and recycled effectively (Brochers, 2010). By using this approach the designer can produce cost-effective, sustainable building with efficient natural materials and reduce carbon emissions by designing simple, flexible and passive designs according to the location and orientation of the building and maintain and recycle all materials used (Halliday, 2008).

3 DESIGN QUALITY INDICATORS (DQI)

In 2006, the Construction Industry Council (CIC) proposed a process for designing buildings. The process composes of four stages; briefing, design, construction and in-use. These four stages are used to gather data from the DQI questionnaires. The questionnaire is the main tool used to gather data, it converts the stakeholders perception of design quality into measurable and quantifiable results by asking a set of simple questions. The questionnaire will also investigate stakeholder's opinions on the three main factors of building design, which are functionality, building quality and impact (CABE, 2006). It has been found that the effectiveness of Design Quality Indicators is highest in the offsite stages of briefing and design, "the million-pound mistake is made on day one, in poor briefing and design thinking" (OGC, 2007). The briefing stage is a creative stage, where all the client's needs and ideas are investigated, communicated, shared and developed (Excellence, 2004). The main purpose of the design team during the briefing process is to clearly define the desired outcomes rather than trying to discover design solutions that will reach the outcomes (DFES, 2004). During the briefing stage, clients can reject or modify the design as they so wish, as changes are easier to adapt to and accommodate during the early stages compared to later stages. It is the client's duty to accept design proposals that are functional, feasible, technically and financially suitable for them (CABE, 2010). The design stage is the most time consuming and thought consuming stage. At this stage, the optimum design is pursued where the end result will be efficient, not expensive to maintain and environmentally friendly (OGC, 2007).

The managerial aspect plays a very important role in successful completion of a construction project. Furthermore, according to DQI USA there is growing demand for high performance buildings that are innovative, sustainable and fit for purpose. Egan was keen to find new ways of recreating the construction industry in the UK; he found that the construction industry is lacking certain key qualities. He believes that the construction industry does not give enough time and effort to the quality subject and how to achieve it, he found that during the construction process many mistakes are being made due to lack of communication (Egan, 2002).

With assistance from CABE, the strategic forum for construction, and OGC the Construction Industry Council (CIC) developed a tool for measuring quality; known as Design Quality Indicators (DQI) (Ashworth & Hogg, 2007). Although many methods and tools are used to improve quality, most of these tools do not take into consideration the clients and users' needs. Whereas, DQI measures construction performance by providing feedback and capturing perceptions of design quality embodied in buildings (Gann et al., 2003) and involves all stakeholders in the assessment of design quality (Thomson et al., 2003). This study will explore the impact of DQI on reducing carbon emissions in the UK construction industry. The benefits of measuring DQI was highlighted by Marc A. Sallette (2009) and the CIC (USA, 2011) (Faroogui & Ahmed, 2009), some benefits are listed below; reduction in overall cost of project, improved capital planning, increased accuracy, improved decision making, effective communication, reduction in operating costs, decrease in capital expenditures and energy costs, increased asset value and a reduction in user complaints.

4 METHODOLOGY

For this study, a quantitative approach is chosen so that the main objective of the study can be investigated as well as uncovering general facts and causes of carbon emissions in the UK construction industry. All data will be collected from a large sample rather than using a qualitative method to gather results from the opinions of a small sample of interviewee's. The questionnaire will investigate the impact of the independent variable; which is DQI, in reducing the dependent variable, which is carbon emission. The relationship between DQI and carbon emissions in architectural and construction companies in the United Kingdom will also be examined.

4.1 The study model

The model below shows the independent variable of this study (Design Quality Indicators - DQI) divided into three sections which are functionality, build Quality and impact. The diagram shows the direct impact these variables have on carbon emissions, therefore in order to reduce carbon emissions these three factors must be addressed accordingly.

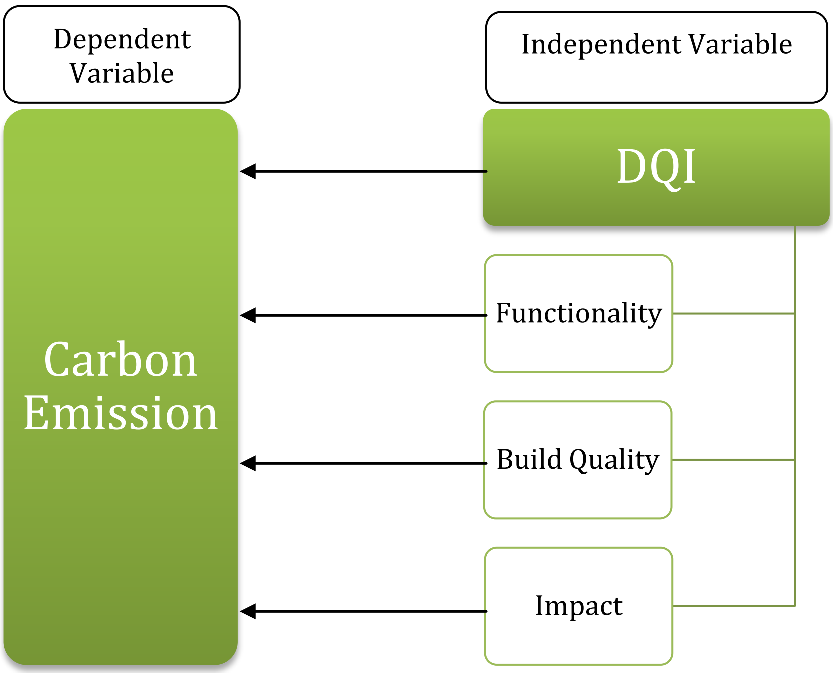

Figure 1: Study Model

4.2 The research population

Most charted architectural companies have a branch in the West Midlands; this is because according to RIBA (2011): "the West Midlands have a diverse, professional population of around 1,400 architects in 400 practices that provide a rich and dynamic resource for the community." During the selection process, each architectural companies approach on sustainability and their knowledge regarding carbon emissions were considered so that only appropriate companies were chosen for the study. The research population chosen is divided into two categories: Consultancies using Design Quality Indicators (DQI) and Consultancies that do not use DQI.

4.3 The Sampling Procedure

180 professionals that are employed by 40 different RIBA accredited architectural companies were chosen. Individuals that were chosen had relevant design experience and were knowledgeable on sustainability and carbon emissions. Their responses to the carbon targets were recorded.

4.4 The research sample

Out of the 180 questionnaires distributed there were 132 respondents, the respondents were professional workers employed by 30 RIBA accredited architectural companies. The demographics of the sample were; 14% were partners of the companies, 12% were business associates, 19% were senior architects and 39% were qualified architects. All participants were chosen as they were well informed of the research subject and were capable of expressing their opinions based on the experiences they have had. Respondents had a variety of education and different qualifications, such as; 8% of participants had a diploma, 48% had a BSc degree, whilst 32% completed their masters and only 2% had a PhD or other qualifications.

4.5 Instrumentation

The questionnaire was developed after critically evaluating the main factors affecting carbon emissions in the UK construction industry as well as having an in-depth analysis of Design Quality Indicators (DQI) as this is the main focus of this study... As mentioned previously whilst the low or zero carbon emission depends on three main factors which are: materials, design and the client's perception.

4.6 Testing methodology

In order to describe the demographics of the sample, a number of statistical analysis methods were used to analyse the data, descriptive statistical tools were used, such as means, percentages, frequencies and other methods including measures of central tendency. The respondents' perception regarding the research variables is described using percentage and frequency, significant items are identified using the average and standard deviation is used to show the variability from the average. Also, coefficient of determination, R^2 is used in the statistical model, its main purpose is to predict future outcomes based on other related information. Simple linear regression will also be used to show the impact of the independent variable (DQI) on the dependent variable (Carbon Emissions). The relationship between two or more variables is expressed using this statistical method.

5 SURVEY ANALYSIS

Means of the data obtained from the questionnaire shows that the average Design Quality Indicators' items range from 3.00- 4.35 where the test value = 3.5. From the high average scores, it can be seen that the most common DQI items that impact carbon reduction are: caring about the thermal comfort inside the designed buildings, the delivery of functional and efficient buildings which fulfil the client's needs and taking into consideration the durability of the finishes. Whereas, the low average scores show that more attention should be given to: the companies' design of easy access and storage for waste during construction of the project and the companies should encourage the use of spaces standard design. As for of the problems facing companies that cause high carbon emissions in construction projects the average ranges from 2.80-3.70 where the test value = 3.5, the highest average scores in this analysis show that the most common reasons for high carbon emissions are: the clients are more interested in lower initial cost than long term cost, energy requirements can't be met by renewable energy resources alone and user comfort is given priority over environmental impact. These outcomes show that carbon emissions can be reduced offsite by having briefing forms at the start of the project that include zero carbon sections.

Design Quality Indicators' items							
Item	Strongly agree	Agree	Neither	Disagree	Strongly disagree	Means	Std
	%	%	%	%	%		
The company cares about the thermal comfort inside their designed buildings.	43.1	50	6.2	0.8	-	4.35	0.97
The company delivers functional and efficient buildings which fulfil the client's needs	39.2	54.6	3.8	2.3	-	4.30	0.65
The buildings designed by the company are efficient and fit for purpose.	25.4	63.1	10	1.5	-	4.1	0.63
In our designed buildings we take into consideration the durability of the finishes.	42.3	38.5	10	6.9	2.3	4.1	1
The company plans an easy access and storage for waste during construction.	14.6	33.8	33.1	15.4	3.1	3.40	1.01
The company encourages the use of spaces standard design.	4.6	25.4	43.1	22.3	4.6	3.00	0.92

Table 1: Analysis of Design Quality Indicators' items

In addition to overall mean and standard deviation of DQI were; M= 3.75, Std = 0.79. This shows that architectural and construction companies in the West Midlands that responded to the questionnaire have a tendency to practice thorough briefing at the beginning of a project to understand the client's needs and requirements.

Overall mean of Carbon (M=3.2427, Std= 0.643), which show tendency among architecture and construction industry clients to put more importance on initial cost and user comfort rather than long term cost and environmental impact.

According to this research survey, the result of the Linear Regression test shows that R (.713) and R Square (.508) which means the dependent variable (carbon emissions) is significantly correlated to the independent variable (Design Quality Indicators-DQI). This achieves the objective of this research, which is the Design Quality Indicators (DQI) has a direct impact on reducing carbon emissions in construction.

Carbon items							
Item	Strongly agree %	Agree %	Neither %	Disagree %	Strongly Disagree %	Means	Std
The clients put more importance in the initial cost over the long term cost.	23.8	41.5	18.5	16.2	-	3.70	1.00
Energy requirements can't be met by renewable energy resources alone.	12.3	51.5	21.5	13.8	0.8	3.60	0.90
User comfort is given priority over environmental impact.	15.4	30.8	35.4	16.9	1.5	3.40	0.99

Table 2: Analysis of Carbon items

6 CONCLUSION

Climate change forced the whole world to change and modify methods used in construction. In 2008 the UK planned carbon reduction targets, which aim to reduce carbon emissions by 80% by 2050 (IGT, 2010). The challenge for architectural and construction firms is to reduce carbon emissions by improving communication and building quality and meeting government targets without solely depending on new mechanical technologies. It was found that the main problems facing companies who felt they still produce high carbon emissions are:

- Clients prefer lowering the initial cost rather than the long term cost efficiency and reducing energy.
- Clients give priority to user comfort over environmental impact.
- Many consultancies prefer the use of mechanical systems over passive design.
- Communication between parties is either weak or starts at a later stage.
- Briefing forms do not include a zero carbon emissions section, which is a vital factor to inform the client about the importance of reducing carbon emissions and the opportunities of designing a sustainable building.
- Lack of construction skills; many companies believe that it is difficult to reuse many materials and it is easier to use traditional methods of construction rather than incorporating new technologies. However, based on the questionnaires findings, it is possible for companies to use Design Quality Indicators (DQI) as DQI's will prevent companies facing many of the problems stated above.

The findings of the study also show that carbon emission is significantly correlated with Design Quality Indicators (DQI). Therefore, this indicates that this study achieved the main research objective, which was to investigate whether DQI's have a direct impact on reducing carbon emissions in construction.

Moreover, the questionnaire also revealed that carbon emissions are correlated with functionality and impact, as well as being significantly correlated to building quality. These findings also achieve the sub-objectives of the study model.

BIBLIOGRAPHY

M. Arvola, *Interaction designers' conceptions of design quality for interactive artifacts*, DRS, Montreal (2010).
T. Bogers, J. J. van Meel and T. J. van der Voordt, *Architects about briefing*, Emerald, 26(3/4), 109-116 (2008).
R. Brindley, *RIBA Journal* (2011). Available at: http://www.ribajournal.com/index.php/feature/article/overcast_with_sunny_spells/ accessed on 13 July 2011.
CABE, *Better public building*, The Commission for Architecture and the Built Environment and the Department for Culture, London (2006).
CABE, *CABE* (2010). Available at: www.cabe.org.uk/buildings accessed on 9 July 2011.
CABE, *Learning through buildings and places*, CABE, London (2010).
CabinetOffice, *Government Construction Strategy*, Cabinet Office, London (2011).
CERNUNNOS, *CERNUNNOS* (2009). Available at: http://www.cernunnos-consulting.co.uk/ accessed on 28 July 2011.
CIC, *Reflection on 20 years of CIC*, Construction Industry Council, London (2008).
CIOB, *The definition of zero carbon*, The Chartered Institute of Building, Berkshire (2008).
CIOB, *Facts and Figures*, The Charted Institute Of Building, London (2010).
CIOB, *Buildings in Design*, CIOB, London (2011).
T. B. & E. Committee, *Construction matters*, The Stationery Office Limited, London (2008).
F. Costello, *Newgovernment organisation is supporting research to achieve zero carbon homes by 2016* (2010). [Online] Available at: http://www.publicarchitecture.co.uk/knowledge-base/files/zero_carbon_homes_by_2016.pdf [Accessed 5 July 2011].
Crown, *The UK low carbon transition plan*, TSO, London.
DQI (2009) Retrieved May 20, 2011, from http://www.dqi.org.uk
Edward Cullinan Architects (2008) Accessed on July 29, 2011, from http://www.edwardcullinanarchitects.com/projects/he_wdl.html
EQUATE, *The Green Carbon Project* (2010). Available at: http://www.equate.com/upload/Green_Carbon_Project_141.pdf accessed on 24 June 2011.
Construction Excellence, *To the construction commotments and get in training for 2012* (2011). Available at: http://www.constructingexcellence.org.uk/, accessed on 27 May 2011.
B.Gething, *Design for future climate*, British Association for Print and Communication, Swindon (2010).
Government, *Low carbon and construction*, Department for Business, Innovation and Skills, London (2010).
Government, *Code for sustainable homes*, Communities and Local Government, London (2006).
S.Halliday, *Sustainable Construction*, 1st ed., Butterworth Heinemann, Oxford (2008).

HMRC (2011). Available at: http://www.hmrc.gov.uk
HM-Treasury (2010). Available at: http://www.hm-treasury.gov.uk [Accessed 2011].
IGT, *Low carbon construction*, Crown, London (2010).
J. Kelly and K. Hunter, *Life cycle costing of sustainable design*, RICS, London (2009).
I.M. Kirkeby, Said Business school (2011). Available at: http://www.sbs.ox.ac.uk/centres/bt/Documents/KirkebyInterviewMedBF4%200PRINT.pdf , accessed on 10 July 2011.
J.Ko, *Carbon: Reducing the footprint of the construction process*, Construction Products Association, London (2010).
Lathams, Council, W. & 4Thought, *The streetly Scool, DQI briefing report*, Walsall Council, Walsall (2010).
T. A. Markus, "Lessons from the design quality indicator", *Building research and information*, 31(5), 399-405 (2003).
MADE, *International Digital Laboratory*, MADE, Birmingham (2008).
M. L. Mitchell and J. M. Jolley, *Research design explaned*, 7th ed., Belmont, Wadsworth (2010).
I.Moran, H.Stephens and R. S. John, *Housing matters*, Cobbetts, London (2011).
P. Morrell, "New challenges to which Construction must respond" *The Structural Engineer*, 88(15/16), 5 (2010).
NHBC, *Who's doing what in housing worldwide*, NHBC Foundation, Amersham (2009).
OGC, *Achieving excellence in construction procurement guide*, OGC, London (2011).
B. Phillips, "Whole-life carbon footprinting", *The Structural Engineer*, 86(6), 15-16 (2008).
RIBA, *Skills for low carbon buildings*, Royal Institute of British Architects, London (2009).
RIBA, *Architecture* (2011). Available at: http://www.architecture.com/RegionsAndInternational/UKNationsAndRegions/England/RIBAWestMidlands/AboutTheRegion.aspx , accessed on 30 July 2011.
M. A. Sallette, *Design quality indicator: top 10 benefits for building owners* (2009). Available at: http://hq.construction.com/advice_opinions/0911_Design_Quality_Indicator.asp accessed on 10 June 2011.
R. Simmons, *CABE* (2010). Available at: http://webarchive.nationalarchives.gov.uk/20110118095356/http://www.cabe.org.uk/articles/good-design-in-a-changing-world , accessed on 29 June 2011.
F. Strategic, *Strategy for sustainable construction*, HM Government, London (2009).
Strategic forum for construction (2011). Available at: http://www.strategicforum.org.uk , accessed on 6 July 2011.
S. Stretton, *How to get to zero carbon*, Cambridge Zero Carbon Society, Cambridge (2010).
Sustainable Construction Group, *Sustainable design in the built environment*, Sustainable Construction Group , London (2011).
K. Symons and D. Symons, "Embodied energy and carbon– what structural engineers need to know", *The Structural Engineer*, 87(9), 19-23 (2009).
The Construction Index (2011). Available at http://www.theconstructionindex.co.uk , accessed in 2011.
UKGBC, *Low carbon existing homes*, Green building council, London (2008).
UK, W., *Sewers for adoption: a design and construction guide for developers*. s.l.:s.n. USA, D. (2011).

DQI USA (2011). Available at: www.dqionline.com , accessed on 20 May 2011.

THE RELATIONSHIP BETWEEN PEOPLES' SATISFACTION AND LEED BUILDING RATING IN JORDANIAN OFFICE BUILDINGS

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Abstract: *The study investigates differences in occupants' satisfaction in three office buildings meeting different levels of LEED certification in Jordan during the summer of 2012. This study is carried out based on post occupancy evaluation to measure occupants' perceptions of the internal environment, control over internal environment and also its impact on their performance. The result is evaluated using further analysis of the building micro-climate, active and passive design features. The study shows significant difference in occupants' satisfaction relating to air, quality, visual and acoustic comfort, however this difference does not always match the overall rating of the building especially in the area of acoustic comfort and lighting quality. This may be partly due to the fact that LEED focuses on reducing energy consumption rather than provide a high-level of occupants' satisfaction.*

1 INTRODUCTION

Buildings designed in different locations around the world have different characteristics related to their energy and environmental performance. Most people spend fifty percent of their lives within indoor environments and there is evidence that the quality of internal environment greatly influence occupants health, mental state, and performance (Sundstrom, 1994). Better physical environment of offices will boost the employees and ultimately improve their productivity (Carnevale 1992, Clements-Croome 1997). Physical environment can be explained around thermal, lighting, acoustic and air quality. Green building has now become a flagship of sustainable development in this century that takes the responsibility for balancing long-term economic, environmental and social health. Various concepts of assessing Green buildings have been proposed around the world. Leadership in Energy and Environmental Design (LEED) is an Environmental Assessment Methodology developed by the US Green Building Council launched since 1998.

LEED is a voluntary scheme that helps buildings owners to demonstrate leadership, innovation and social responsibility. LEED certification provides independent verification of building projects' sustainability credentials. There are four levels of LEED certification: Certified, Silver, Gold and Platinum. LEED certification can start from individual buildings and homes, to entire neighborhoods and communities addressing the entire lifecycle of a project. LEED projects have been successfully established in 135 countries. International projects outside the United States, make up more than 50% of the total LEED registered square footage. (USGBC, 2013). Figure 1 shows the six key LEED criteria. The focus of this paper is on the Indoor Environmental Quality criteria, which includes thermal comfort, air quality, natural light and occupant control over indoor environment.

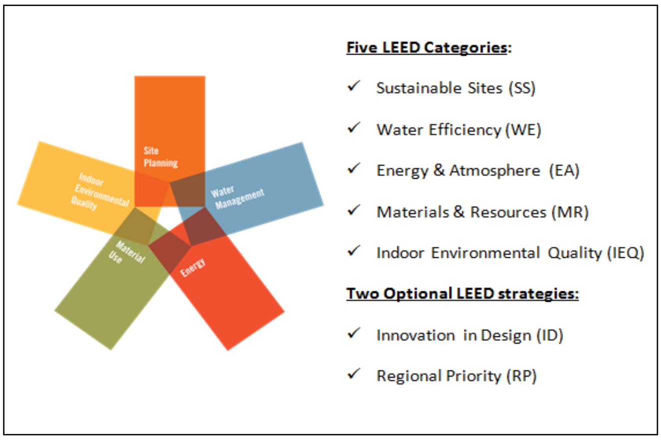

Figure 1: LEED Criteria

The aim of this study is to evaluate the peoples' perception regarding the internal environment, their performance/health and level of control in three office buildings in Amman Jordan meeting different levels of LEED certification. The results of occupant perception regarding internal environment in different buildings are compared against the LEED rating of the buildings. The results are used to evaluate the robustness of the LEED criteria in meeting people's satisfaction in these buildings.

2 METHODOLOGY

This study is conducted using case study approach and post occupancy evaluation POE using quantitative research methodology. Information about the case study building have been collated and used as the basis for interpretation of user responses from the questionnaires. The type of questionnaire used in the research project is a closed questionnaire, since the choice of response was already set by the questionnaire; furthermore, it included questions concerned about specific facts of the issue being reached (Naoum, 2010). The questionnaires focussed on collecting data on peoples' perception regarding internal environment, their heath and performance and also their level of control over the internal environment. The six main aspects are: Demographics, Thermal and air quality comfort, Acoustic comfort, Lighting comfort, Productivity, Health and Personal control. The questionnaires were distributed to the occupant of the 3 buildings each meeting different LEED criteria and a total of 63 responses were returned and analysed.

2.1 Location and climate: Aman - Jordan climate

Jordan is a small country, but it has four different bio-climatic regions, which includes; The mountain areas cover about 10% of the total land area of the country and classified under the Mediterranean bio-climatic region. The country is also surrounded by steppe area known as Irano-Turanian bio-climatic region. The majority of Jordan from the eastern sides, is considered as dessert, which is about 80% of the total land area of Jordan and belongs to the Saharo-Arabian bio-climatic region. The Rift Valley bio-climatic region starts from the northern parts of the Dead Sea and extends to the south of the Gulf of Aqaba at the Red Sea: furthermore, the inland sand dune areas and sandy mountains of Wadi Rum belong to the 'Tropical Penetration' also known as Sudanian or Subtropical bio-climatic region (Al-Eisawi, 1996). The case study buildings in this paper are located in Amman. Since approximately 80% of Jordan is considered as desert areas, it explains why 95% of the total population occupies only 5% of the country (Al-Eisawi, 1994) leading to highly densely populated cities such as Amman.

2.2 LEED buildings

The three LEED buildings that are discussed in this study are rated as 'Gold', 'Silver' and 'Certified'. The design technologies that are applied in these buildings and also the location of these building are discussed as follows:

Gold certified: WHO Headquarter Building

The WHO Headquarter Building is rated as Gold. This building is located in Al Abdali Dakhiliyeh Circle, Amman, Jordan (on a land of 2,500 m2 area). This building is a 4 story office building which includes a basement floor for parking and services. The GF is for the common facilities between WRO and CEHA, such as a reception hall, meeting rooms, library and video conference room. Figure 2 shows the external view and location of the WHO building. This office is located within one block from the main road with a high level of background noise.

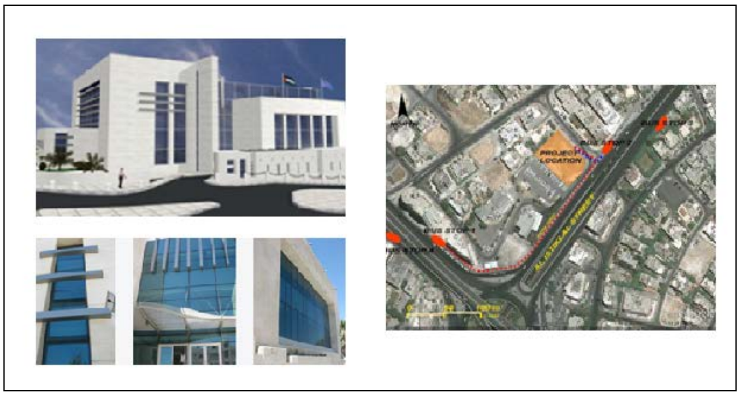

Figure 2: WHO building Gold Certified - External view and location (Source: Engicon report)

The WHO building has sustainable systems incorporated to improve the operation as well as minimise the impact of the building on its environment. The building has Sustainable Drainage Systems that collect about 90% of rainfall which is treated stored and used for non-portable uses. The building also uses water efficient appliances such as automatic sensor fixtures and flow restricting devices to improve water efficiency. Solar thermal systems have been installed to provide hot water supply for the building. The building has full air-conditioning with high COP and air heat recovery system. The building spaces have individual lighting control in addition to using remote switching for general lighting areas (parking, corridors), individual control is very important in ensuring effective management of electrical lighting systems especially when there is adequate day lighting available to maintain interior lighting levels.

Silver certified: The Embassy of the Kingdom of the Netherlands

The Embassy building consists of offices, meeting and storage facilities with total floor areas 1253 m². The building consists of solar PV and Solar thermal renewable systems. The building has also been designed and constructed to reduce solar heat gain and reduce building heat island using sun shading devices integrated into the building's south facade. Figure 3 shows the design philosophy of the building. The HVAC strategy includes heat pump and thermal storage load and dry cooler and air handling unit. This building is located in a quiet location within three blocks away from the main road with a low background noise level. The assessment of background noise was done based on prior experience of the location and the relative closeness of the building to sources of noise such as roads etc.

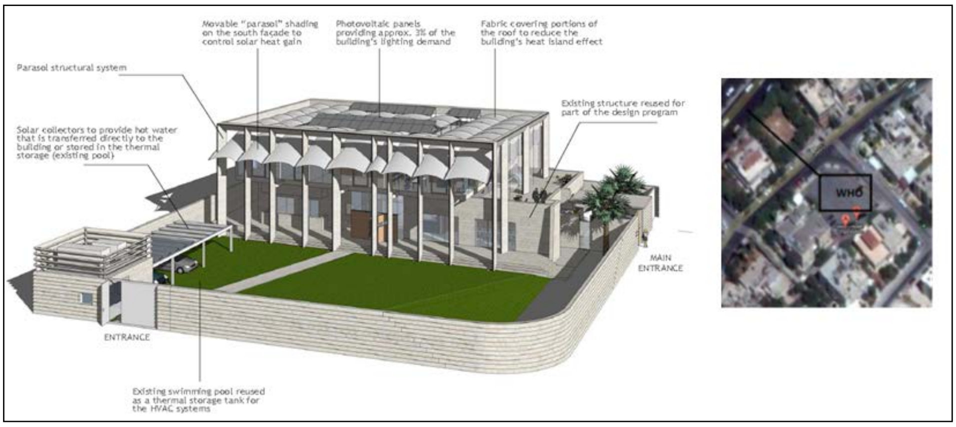

Figure 3: Silver Certified Netherlands Embassy (Source: Al Nasa'a 2009) and location map

Certified: Engicon office building

The Engicon is an office building that works on unique projects of different scales and complexities. This building is located in Amman- Jordan. This office building has a central heating system with individual control, double glazing with individual control and mechanical system. Figure 4 show the external view and location of this office building. This office is located a block away from the main road with the moderate background noise level.

Figure 4: Certified building – Engicon office building and location map (Source: Engicon website)

2.3 Peoples' perception

The people's perceptions are gathered about the internal environment, andtheir health and performance by distributing 25 questionnaires to each of the three case study buildings. In the silver building all the responders filled the questionnaires while in Gold and Certified the number of responders were 21 and 18 respectively.

The focus of the questionnaire is on the occupants' perception regarding their internal environment, its impact on their health and performance and their control over the internal environment. The internal environmental issues are focused around four categories of thermal comfort (summer/winter), air quality (summer/winter), lighting comfort (quality and quantity) and acoustic comfort. There are also questions on people's productivity and their health based internal environment and the peoples' control over the internal environment.

3 DISCUSSION AND ANALYSIS

The people's perception regarding internal environment, their health and performance and also their level of control are questioned.

3.1 Internal environment

Internal environment are questioned around four factors of thermal comfort, air quality, acoustic comfort and a lighting comfort.

Thermal comfort: Peoples' perception regarding thermal comfort in winter and summer are explored. The occupants were asked to rate thermal comfort conditions in their offices based on likert scale (1= Uncomfortable and 7=Comfortable). ANOVA T test has been carried out to analyses the data and compare the thermal comfort responses in the three buildings for both summer and winter conditions. The results show that there is no significant differences between thermal comfort responses in summer (n=64, P>0.05) while there is a significant differences between thermal comfort in winter (n=64, P<0.05).

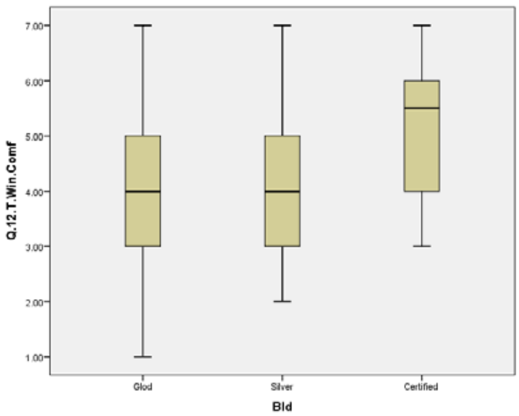

Figure 5: Average of occupants perception regarding thermal comfort in winter in three LEED Building (1= Uncomfortable…….7= Comfortable)

Figure 5 shows the average occupants vote in the certified building is around 6 (which is close to comfortable) while the occupants votes in the Silver and Gold building is around 4. According this piece of analysis, it can be concluded that thermal comfort in the Certified rated building is better than the Gold and Silver buildings, despite it receiving the lower LEED accreditation in comparison to the other two buildings.

Air quality: Occupants' perception regarding air quality in winter and summer was established. The survey question was asked; 'How would you describe air quality in your office in summer and winter' based on likert scale (1= Fresh / Odourless and 7= Humid / Smelly). ANOVA T test is carried out between the air quality in these three buildings in both summer and winter. The results shows that there is not any significant differences between air quality during winter (n=36, P>0.05) but there is a significant differences between air quality during summer (n=36, P<0.05). The BOX plot in Figure 6 shows the level of air quality (Freshness and ardour level) in the Gold, Silver and Certified rated buildings. This analysis shows that air quality in the silver building is better than the Gold and Certified buildings.

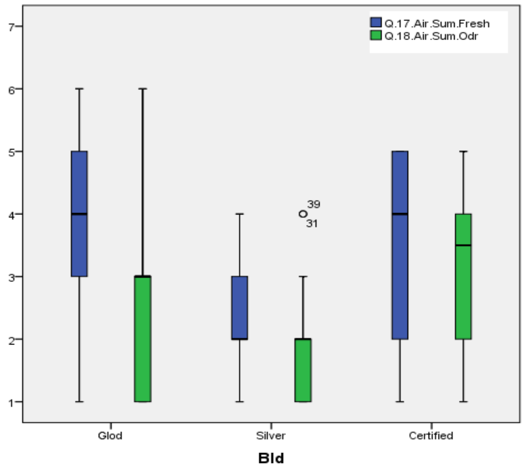

Figure 6: Average of occupants perception regarding air quality in summer in three LEED Building (1= Fresh / Odourless ……5= Stuffy/Smelly)

Acoustic comfort: The acoustic factors which affect speech intelligibility are background noise level and reverberation time (Shield et al, 2003a). Background noise commonly refers to any undesired sounds that impedes what a person wants or needs to hear (Knecht et al 2002). The source of background noise level in offices can be divided into the following three sources.

1. Noise from inside the office. Noise sources inside an office are workers and the office's equipments.
2. Noise from outside the office (within the buildings). This noise source usually refers to the noises that are transferred from different parts of the building such as corridors, meeting areas and other offices.
3. Noise from outside the organisation (building). These noise sources usually refer to the environmental noises such as those from transportation systems, industrial, plant and also rain fall on lightweight roofs which are transmitted through the building envelop.

In order to have an idea of the main internal sources that may impair the speech intelligibility and may not allow colleagues to hear each other properly, the relationship between overall noise and the sources of noise are investigated with a regression analysis. The results show that there is a significant relationship between the 'Overall noise inside the office' and 'Noise from outside office (but within the department) (n=36, P<0.05)' and 'Noise from workers' (n=36, P<0.05). Table 1 shows the result of this regression analysis.

As the main requirement of acoustic comfort is a sufficiently 'quiet' environment which enables communication tasks to be carried out comfortably and without distraction, i.e. with no unwanted sounds or vibration. Poor acoustic factors affect speech intelligibility inside offices meaning that colleagues would be unable to hear each other and hence transfer of information between them would be impaired. As it is discussed the overall noise inside the office is related to the noise from colleagues as well as the noise from other departments. Therefore, there is a risk of lack of speech intangibility in these offices. For these reasons occupant' perceptions of how well hear their colleagues and how well their colleagues hear them are questioned based on the scale shown in Table 2.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.143	.443		.324	.747
	Q.26.N.Inside.Workers	.395	.104	.442	3.780	.000
	Q.27.N.Inside.Others	.226	.145	.182	1.556	.125
	Q.28.Noise.Outside.Office	.312	.133	.327	2.346	.022
	Q.29.Noise.Outside. building	.020	.125	.022	.161	.872

a. Dependent Variable: Q.25.N.overall

Table 1: Results of regression analysis between noise and different noise sources

Very well	**Quite well**	**Okay**	**Not very well**	**Not at all**

Table 2: Questionnaires administered to occupants of three LEED buildings regarding speech intelligibility

The ANOVA T test was carried out between the responses from occupants from different offices. The result shows that there is a significant difference between responses in different buildings (n=63, P<0.05). Figure 9 shows the average of speech intelligibility in the three offices.

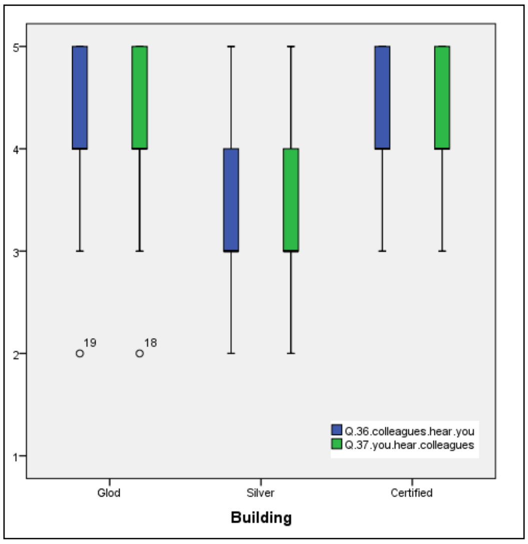

Figure 7: Average of occupant's perception regarding speech intelligibility in three LEED Building (1= Very well ……5= Not at all)

Figure 7 shows that on average in the 'Gold' and 'Certified' rated buildings the level of colleagues hearing each other was 4 which means 'not very well', however in the 'Silver' building the level of colleagues hearing each other was 3 which is 'ok'. This means the Silver rated building has better speech intelligibility compared to the 'Gold' and 'Certified' rated buildings. This difference warrants further investigation but may relate to the following;

- Office layouts: The Silver and Gold buildings are cellular while the 'Certified' office is open plan. This may be the reason why speech intelligibility in the Silver rated building is better than Certified.

- Office envelops: The envelop of Silver rated building is concrete which is a better sound insulator which can have a significant impact in preventing noise travel from other parts of organisation inside the offices.
- Office location: The noise from outside the building does not have an impact on speech intelligibility; this may be related to the use of an air-conditioning system that results in a reduction in the need to open windows. This means that the buildings envelop is completely sealed. According to the regression analysis the dominant noise level which people hear is noise from the cars. The noise level which is heard from cars in the Gold and Certified rated buildings is higher than the Silver rated building and may related to the location of the Silver building as it is located in a quieter region compared to the other two case study buildings. According this piece of analysis, it can be concluded that the level of acoustic comfort in the Silver rated building is better than the Gold and Certified buildings. The reasons for these differences should be investigated in detail in further study.

Lighting comfort: Lighting comfort can be discussed relative to quantity and quality of light with the source of natural and artificial light. The quantity of light is related to the amount of required light level on working surfaces and the quality of light is related to glare and uniformity etc. According to the ANOVA T test there was not any significant difference between quantity of light from both natural and artificial light in three LEED buildings. The only differences between the three LEED buildings are about the quality of light (Glare) with the source of Artificial light ($n=63$, $P>0.05$). As shown in Figure 10 the level of glare in the Gold and Certified buildings is close to unsatisfactory while in the Silver building it is close to satisfactory.

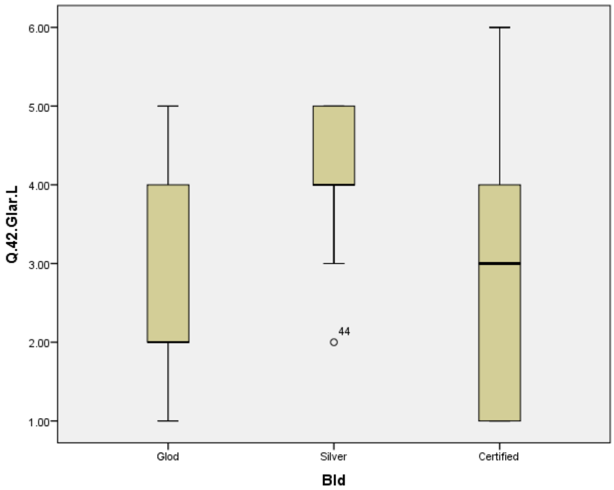

Figure 10: Average of occupants' perception regarding Glare from artificial light LEED Building (1= Unsatisfactory ……7= Satisfactory)

Results of assessing internal environment

Table 3 summarises the internal environment in the Gold, Silver and Certified buildings, which shows that the buildings have different 'Thermal comfort in winter', 'Air quality in summer', 'Acoustic comfort – speech intelligibility' and 'Lighting comfort'. Table 3 rates each internal environmental factor ('1'= best internal environment and '2' = poor internal environment). As can be seen the sum of the Silver building in three out of four conditions has better internal environment while in the Certified building one out of four conditions stated better internal environment and in the Gold building none of the conditions resulted in best condition marks. It can be concluded that the occupants in the Silver building are more comfortable compared to the Gold and Certified buildings, in addition occupants in the Certified building are more comfortable than the Gold. Overall it can be concluded that there is not any significant relation between LEED accreditation and peoples' satisfaction about internal environment. This may be related to the fact that LEED guidelines do not consider the Acoustic comfort, and artificial light in its criteria.

Name of Building	*WHO*	*Embassy*	*Other*
LEED Credit	**GOLD (G)**	**Silevr (S)**	**Certified (Ce)**
Thermal comfort in winter	2	2	1= Certified is the best
Air quality in summer	2	1= Silever is the best	2
Acoustic comfort Speech intelligibility	2	1= Silever is the best	2
Lighting comfort Glare from artificial light	2	1= Silever is the best	2
Total Grade	**None / Four**	**Three / Four**	**One / Four**

Table 3: Summary of internal environment

3.2 Occupants' Health and performance

According to the extensive research there is a significant relationship between 'peoples' performance and health' and internal environment (CIBSE, 1999).

Health: Peoples' perceptions regarding their health when they are inside these buildings are questioned. The survey question asks; 'How would you describe your health when you are inside this building?' through the lickert scale (1=Less healthy, 7= More healthy). The results are compared between the three buildings. The results show that the people's perception regarding the occupants' health are not significantly different according to the ANOVA T test, ($n=63$, $p> 0.05$).

Performance: Peoples' perception regarding their performance when they are inside these buildings is questioned. The survey question asks; 'How would you describe your productivity when you are inside this building?'

Productivity decreased by				**Neutral**	**Productivity increased by**			
-40% or less	-30%	-20%	-10%	0	10%	20%	30%	+40% or more

Table 4: Questionnaires administered to occupants of three LEED buildings regarding performance

The levels of performance are compared between the three buildings according to the ANOVA T test. The results show that the people's performance in these three buildings are significantly different ($n=63$, $P<0.05$). The results show that the occupants productivity in the 'Gold' and Certified building increases by 20% while the productivity of people in the 'Silver' building only increased by 10%. As it is discussed in the previous sections the internal environment in the 'Silver building is better than the other two buildings and it was expected that the peoples' productivity would be higher in this building as well, but the responses suggest that it is not. The reason for this difference may be related to the level of occupants control over the internal environment which is assessed in the next part.

3.3 Control over internal environment

Bauman (1999) argues that giving people individual control over the environmental conditions in their workplaces, designers and facility managers can help increase worker satisfaction and productivity. The occupants' perception about the control levels over the various internal environments which are Heating, Cooling, Ventilation, Lighting and Noise are questioned through the likert scale (1= No control and 7= Full control). The ANOVA T test is carried out between the participants perceptions on the levels of control. There is a significant difference between the peoples' perception over the control of internal environment (n=63, p <0.05). Table 6 shows the average of control over the various internal environments.

Internal environmnet control	*WHO*	*Embassy*	*Other*
	GOLD (G)	Silevr (S)	Certified (Ce)
Heating control	5.66	2.16	4.44
Cooling control	6.61	2	4.4
Ventilation control	4.19	1.6	4
Lighting control	2.61	1.88	3.27
Noise	6.09	5.28	2.72
Average control	**5**	**3**	**4**

Table 6: The average of control over the various internal environments

As it can be seen the control over the various internal environments in the Silver building is less than the Gold and Certified. This can be one of the main reasons for the lack of consistency between performance and the level of internal environment. In addition, one of the other reasons may due to the acclimatisation as the occupants of the Silver building are from Netherlands, which it can be assumed are more used to a colder climate in comparison to Jordan.

5 Conclusion

This study uses post occupancy evaluation to investigate the occupant's satisfaction with the internal environmental condition of three LEED certified office buildings in Amman Jordon. The study shows the importance of the level of control over the comfort factors and its relation with occupant performance. In addition, according to this study, it can be concluded that there is inconsistency between the level of comfort inside the building and LEED accreditation. This may be related to the fact that the LEED criteria are heavily weighted towards energy reduction and less weighted towards occupants' satisfaction within the internal environment. It can be argued that that internal environment has a significant impact on people's performance and by developing the LEED criteria not only is it possible to save fuel energy; but also possible to improve occupants performance and reduce the cost of running businesses through increased productivity. It appears that if LEED criteria consider improvements in these two key areas of acoustic comfort and lighting quality, in particular source of artificial light under the 'Indoor Environmental Quality Criteria' as well as control over these factors, the higher LEED criteria buildings not only can perform better in terms of energy use but also occupants can have a higher performance.

REFERENCES

D.M. AL-Eisawi, "Forests and man impact in Jordan", *Proceedings of "MAN AND MOUNTAIN' 94". Primo Convegno Internazionale la Protezione e lo Sviluppo dell'* Ambiente Montano. Ponte di legno (BS), Grafiche Galeati, Via Selica 189, 40026, Italy (1994).

D. M. AL-Eisawi, *'Vegetation of Jordan'*, UNESCO (ROSTAS), pp. 284, Cairo (1996).

Bauman and S. Fred , " Giving occupants what they want: guidelines for implementing personal environmental control in your building", *World Workplace Conference*, Los Angeles, CA (1999).

H. Bougdah and S. Sharples. Environment, technology and sustainability, Taylor and Francis, London (2001).

D.G. Carnevale, "Physical settings of work", *Public productivity and management review*, 15, 4,423-436 (1992).

CIBSE, *Environmental factors affecting officer worker performance:a review of evidence TM24*, CIBSE, London (1999).

Clements and D.J. Croome, " Specifying indoor climate", *Naturally ventilated buildings*, Spon (1997).

H.N. Knecht, P.B. Nelson and G.M. Whitelaw, "Background noise levels and reverberation time in unoccupied classrooms: predictions and measurements", *American Journal of Audiology*, 11, 65-71 (2002).

S.Naoum, "*Dissertation research and writing for construction students*", Taylor & Francis (2010). Available at :< http://lib.myilibrary.com?ID=72960> accessed on 24 August 2012.

B.M. Shield and J.E. Dockrell, "The effects on noise on children at school: A review", *Journal of Building Acoustics*, 10(2), 97-116 (2003).

E. Sundstrom, J.P. Town, R.W. Rice, D.P. Osborn and M. Brill, *Office noise, satisfaction, and performance, environment and behavior*, 26(2), 195-222 (1994).

USGBC, *What is LEED?* (2013). Available online: http://www.usgbc.org/leed. Accessed on 15th/05/2013.

CFD SIMULATION FOR WIND COMFORT AND SAFETY IN URBAN AREA: A CASE STUDY OF COVENTRY UNIVERSITY CENTRAL CAMPUS

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Abstract: *This study is based on a series of computational fluid dynamics (CFD) simulations to evaluate wind conditions at pedestrian level around the Hub, a newly built structure, part of Coventry University campus. The aim was to provide more insight in the pedestrian living conditions around the Hub and at the same time, study the influence of the building shapes on wind distribution. Detailed aerodynamic information can be obtained using CFD, which offers considerable advantages compared to wind tunnel testing. It was also meant to advice the University's Estates Department of the possibility of wind nuisance around the central campus area. The simulation was performed for different wind speeds and directions. The velocity field was computed using the finite volume method. Wind comfort and wind safety are assessed and potential design improvements are evaluated. The predicted results showed that the distribution of the velocity field varied and had different characteristics with different wind directions. The results showed that the wind speed amplification factors in diverging passages were generally larger than in converging passages. By using CFD in this manner it is anticipated that these types of advanced performance-based studies will be a useful tool and an essential aid for urban designers and environmental planners.*

Keywords: CFD, pedestrian wind comfort, built environment, modelling

1 INTRODUCTION

Pedestrian-level wind (micro)-conditions is one of the first microclimatic issues to be considered in modern city planning and building design (Wu and Kriksic 2012). The construction of a new building alters the microclimate in its vicinity; hence wind comfort and safety for pedestrians become important requirements in urban planning and design. Today, some city authorities request studies of pedestrian wind comfort and safety for new buildings and new urban developments.

High-rise buildings are particularly influential to wind effects. Therefore, information about wind flow patterns around buildings can be important to architects and urban planners. As a result of the public's growing awareness of the latest scientific and engineering achievements, contemporary architects, designers and engineers should pay more attention in creating more comfortable and functional buildings and their surroundings.

In particular, near and around high-rise buildings, high wind velocities are often introduced at pedestrian level that can be experienced as uncomfortable, or sometimes even dangerous. Traditionally, wind flow at pedestrian level can be simulated in boundary-layer wind tunnels. However, with the advent of computational power and the introduction of numerical methods like the

Finite Element Analysis, it is possible to accurately simulate the same conditions in a virtual environment using advanced modelling techniques like the Computational Fluid Dynamics (CFD). The latter can provide significant cost benefits for assessing and optimising engineering design solutions related to environmental concerns.

CFD allows the investigator to analyze the full domain of the model, provides a complete picture of the problem and presents the results in an easy-to-understand graphical way, as opposed to relying on expensive and time consuming collection of several dozens of discrete points, as it is usually the case with physical wind tunnel modelling. CFD modelling has been used by enviro-metrics to assess comfort levels with respect to wind climate, based on evaluating the wind flow fields around buildings, as well as the associated outdoor thermal comfort, air ventilation, snow accumulation, rain infiltration and other microclimatic conditions (Stathopoulos and Baskaran 1996).

Over the last two decades, along with the perfection of the CFD method, many researchers have concentrated on the numerical simulations of air flow past a single building. Their studies revealed some complicated flow phenomena, such as separation, vortex shedding, recirculation and reattachment and predicted some accurate numerical results (Paterson et al 1986, Murakmi 1998, Bosch and Rodi 1998).

Pedestrian-level winds can be described quite adequately in terms of mean velocities in the presence and absence of a new building within a specific urban environment. Although it can be argued that pedestrians are mostly affected by gust effects and mean wind speeds may not be sufficient to cause results for concern, the fact remains that several major cities planners require only the fulfilment of certain mean (sustainable) speeds with a specified probability of exceedance (Stathopoulos 2006). The process of comparison between computational and experimental results has already been challenged and appears problematic on its own. For instance, is it more meaningful to carry out point-by-point comparisons or does it make more sense to examine pedestrian-level wind speeds affecting a particular zone or area of influence for a specific activity within the urban environment?

2 CLIMATE-RESPONSIVE DESIGN STRATEGIES

Outdoor human comfort in an urban climate may be affected by a wide range of parameters, including wind speed, air temperature, relative humidity, solar radiation, air quality, human activity, clothing level, age, etc. Several criteria have been developed by the wind engineering community for evaluating only the wind-induced mechanical forces on the human body and the resulting pedestrian comfort and safety. There are significant differences among the criteria used by various countries and research institutions to establish threshold values for tolerable and unacceptable wind conditions even if a single parameter, such as the wind speed, is used as a criterion. These differences range from the speed averaging period (mean or gust) and its probability of exceedance (frequency of occurrence) to the evaluation of its magnitude (experimental or computational) (Blocken et al 2012, Chronis et al 2012, Mochida and Lun 2008, Blocken and Persoon 2009, Tominaga et al 2008, Yoshie et al 2007).

The presence of tall buildings influences wind speeds at low level in their immediate surroundings. The effects on the local microclimate may be favourable or unfavourable depending on the building shape, size, orientation and interaction with neighbouring buildings or obstacles. The faster winds at high level may be deflected down to ground level by tall buildings causing unpleasant and even dangerous conditions for pedestrians. Wind may be channelled around buildings, between buildings or along avenues causing accelerated wind speeds at pedestrian level and giving rise to pedestrian discomfort. On the opposite end, suitably arranged tall buildings may provide sheltered areas for pedestrians, although this can lead to accumulation of traffic fumes and/or other pollutants, if there is insufficient air circulation (wind speeds) (Tan et al 2007, Stathopulos et al 2004, Mohamed 2009).

2.1 Typical Locations of Strong Wind in Built up Areas

When a gust of wind strikes a tall building surface it tends to deflect towards the ground causing high speed winds on the windward side, as well as near the corners of the buildings at street/ pedestrian level. Based on strong wind, occurrences at pedestrian areas often occur at the three regions shown in Figure 1 and are associated with the three types of flow (Emil et al 1996): Type I : Vortex flow between buildings, near ground level (region A), Type II: Descending air flows passing around leeward building corners (region B), Type III: Air flows passing through openings (passages) at ground level connecting the windward and leeward sides of buildings (region C).

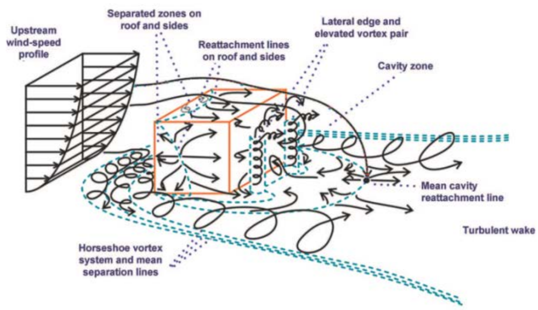

Figure 1: Regions of high surface wind speeds around a tall building

2.2 Pedestrian Comfort

Pedestrian comfort criteria are based on mechanical wind effects without consideration of other meteorological conditions (temperature, relative humidity). These criteria provide an assessment of comfort, assuming that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes and their corresponding gust wind and speed ranges are used to assess pedestrian comfort. More specifically, the comfort classes, associated wind speed ranges and limiting criteria are summarized in Table 1 based on information from Shane (2011).

Comfort Classes	Description	Location types (Examples)
Sitting	Occurrence: > 70% of the time. Acceptable for sedentary activities, including sitting.	Outdoor Cafés, Patios, Terraces Benches, Gardens, Fountains, Monuments.
Standing	. Occurrence: > 80% of the time. Acceptable for standing, strolling, etc.	Building Entrances, Exits Children's Play Areas
Walking	. Occurrence: > 80% of the time. Acceptable for walking, or rigorous activities	Public/private Sidewalks Pathways. Public / Private Vehicular Drop-Off Zones
Uncomfortable	Occurrence: > 20% of the time. Unacceptable for walking	
Dangerous	Occurrence: > 0.01% of the time. Dangerous to walk	

Table 1: Desirable pedestrian wind comfort classes for various location types

2.4 Aim and main objectives of the current study

The aim of this study is to provide a qualitative assessment of the student and pedestrian comfort and safety due to the likely wind conditions formulating around the main Coventry University campus and especially around the newly constructed Hub. The main objectives were set as follows:

- To investigate the typical wind patterns around the Hub and the resulting wind environment at pedestrian level and to detect the so called ‘critical areas’ and classify them according to Table 1.
- To identify the origin (source) of possible causes of undesirable wind conditions.
- In essence, to assess and quantify the wind generated around the campus and specifically near and around the Hub and to advice on the effect this predicted wind may have on the neighbourhood.
- To generalise the findings by analysing, commenting and, if appropriate, revise certain wind comfort criteria to suit the requirements for busy city life and business usage.

3 MODEL DEVELOPMENT

Coventry University has changed dramatically in the last few years. Among several new buildings, The Hub distinguishes as it creates an architectural as well as an environmental impact to the City of Coventry. The particular building claims very high standards such as low carbon footprint, low energy consumption (first class insulation), flexibility in its use, functionality (minimum number of columns), etc. However, none has considered the effect this building has or has-not on their occupants, such, as students and other pedestrians outside and around it. Hence, the relation between wind effects, wind comfort, wind danger and wind (local) climate may be of interest.

Using the Fluent Code (FLUENT 2007), the wind generated around the campus and specifically near and around The Hub will be assessed and quantified. The typical wind flow pattern around the aforementioned building and the related wind environment at pedestrian level will be investigated and discussed. Useful comments will be drawn on the effect this predicted wind may have on the neighbourhood.

The CFD simulations were performed using the commercial CFD code Fluent and the 3D steady RANS equations. Closure was provided by the realisable (k-ε) turbulence model (Shin et al 1995) The choice of this turbulence model was based on recommendations by (Franke et al 2004) and on earlier successful validation studies for pedestrian-level wind conditions(Blocken and Persoon 2009) and (Blocken et al 2004). Pressure velocity coupling was taken care off by the SIMPLE algorithm (Lanunder and Spalding 1974). Second order discretisation schemes were used for both the convection terms and viscous terms of the governing equations. Simulations were performed for four wind directions (0^o, 90^o, 180^o, and 270^o). The latter were deemed to be sufficient to cover the most onerous conditions. The iterations were terminated when the scaled residuals showed very little further reduction with increasing number of iterations. The following minimum values were reached: For x, y, z-velocity components: 10^{-8}. For (k –ε): 10^{-7}. For continuity: 10^{-6}

Various articles recommend the following generalised boundary conditions for the simulation limits (Franke et al 2004) and (Blocken et al 2004):

- Symmetries on the edges and the upper surface of the volume.
- Pressure-outlet for the boundary leaving the simulation volume.
- Variation of the wind speed profile with height, at the air entrance of the simulation field.
- Adoption of the wall function model for the treatment of cells near solid walls.

For treatment of areas close to “wall” surfaces such as ground or building facades, there are two calculation models in FLUENT. Considering the complexity of our simulations, the criterion for the choice of the "wall function" model was based on the coarse mesh implementation, as opposed to that of the "two-layer approach", hence, economising on the resources available in Fluent. Essentially, for studies related to wind comfort at pedestrian level, it is appropriate to use smooth surfaces for ground and buildings (zero height of roughness). the total number of grid elements used in simulation 355187.

3.1 Boundary Conditions

The approaching wind was created from a power-law model to approximate the mean velocity profile:

— (1)

Where; U= mean wind speed, U_g= gradient wind speed, Z= high above ground, Z_g= depth of the boundary layer (gradient height, Z_g = 40 m), and α (alpha)= power law exponent. The exponent α varies according to the type of terrain; α= 0.14, 0.25 and 0.33 for open country, suburban and urban exposures respectively. All calculations in this article were based on the value of α= 0.14. (Aynsley et al 2002) and (Jianming et al 1999). The variation of the inlet velocity at inlet is shown in Figure 2.

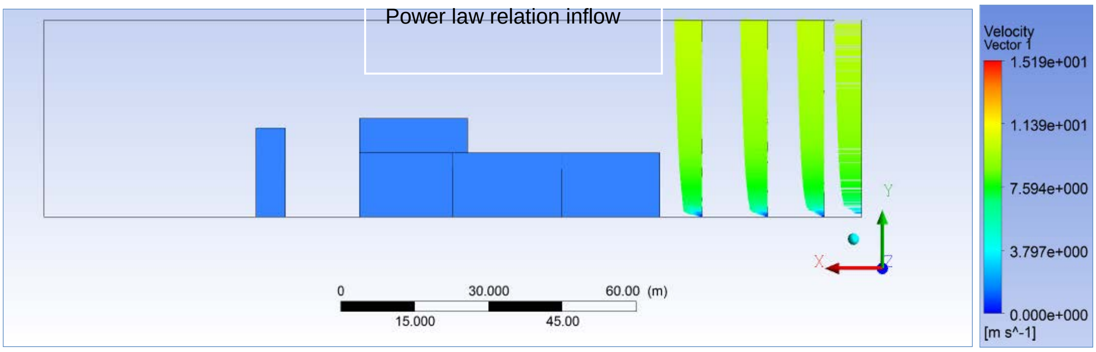

Figure 2: Inlet mean wind speed profiles in the CFD simulation

Since the *k-ε* model was used, the values of *k-ε* were required to account for the turbulence in the approaching wind. The turbulent kinetic energy k can be calculated if the turbulence intensity at a given height is known, , the turbulence intensity of the inlet velocity profile is assumed to follow the Gaussian distribution with a standard deviation of 0.15.

- (2)

The other important value required is the dissipation rate ε; which can be obtained from the assumption that the wind is neutrally stratified and homogeneous in the surface layer, where the rate of energy production is approximately equal to its dissipation rate, therefore

— (3)

Where *k* is the von Kaman constant (*k* =0.41) and u_* is the friction velocity. The u_* was calculated from

— (4)

Since *k* had been obtained from Eq. (2). The value of *u** determined by (4).
The boundary conditions applied in the computing domain are summarized as Table 2.

3.2 Local meteorological data for Coventry

The average annual local atmospheric wind conditions for Coventry are shown in the *wind-rose* plotted in Figure 3, This is based on historical Meteorological Office data taken from Coventry (Coleshill) and measured over a 7 years period. It is obvious that southerly winds dominate throughout the year, with easterly winds being particularly infrequent (Cameron 2005).

Turbulence model	Standard k– ε model
Inlet	— , — , , — , k =0.41
Outlet	Gauge pressure=0
Bottom	Smooth wall, using the log-law wall function, (Wall function)
Top	Free slip, flux normal to the boundary is zero, symmetric boundary conditions is applied
Sides	Free slip, flux normal to the boundary is zero; symmetric boundary conditions is applied

Table 2: The boundary conditions for the computing domain

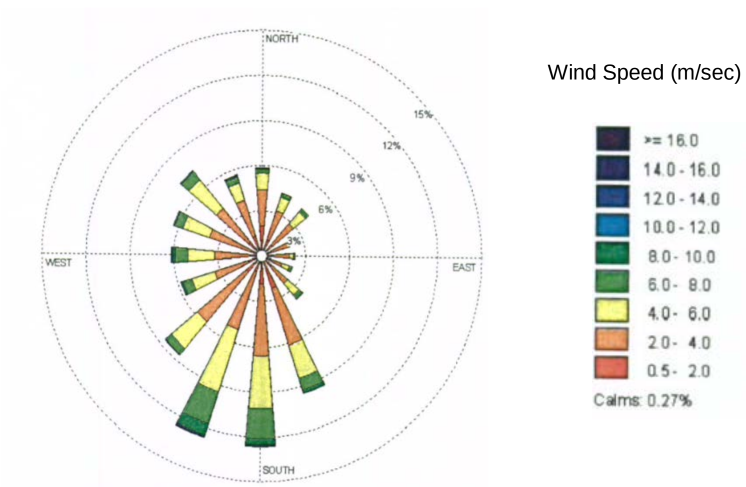

Figure 3: Historical wind –rose for Coventry (Coleshill)

4 CASE STUDY

The area under study is shown on the Coventry University campus. Figure 4(a and b), depicts the top and iso-views with overall dimensions of the main building (Hub B1, B2) and the building height of 20 m.

5. VELOCITY DISTRIBUTION FOR WIND FLOW AROUND BUILDINGS

The velocity stream lines around the building were studied using the CFD method. The results were presented for the mean wind speed, V_{mean}, at a pedestrian height of 1.5 m from ground level. The basic results from the CFD simulations for the proposed new building are presented in Figures 5(A, B, C and D). These figures show plan views of head level velocity streamlines for prevailing wind speed 6 m/s.

5.1 North direction

Figure (5A), northerly wind direction, shows wind velocity above the prevailing wind speed especially between the two main blocks. This creates an extended shelter zone behind the buildings but also creates problems because pedestrian wind discomfort arises underneath the main building (Hub). The wind flow pattern at pedestrian level between the two buildings is shown quite complex with recirculation areas behind the buildings and large velocity gradients near the main building, B1 (see Figure 4d). In addition, the leeward side of the building, shows the formation of eddy flow (eddy currents developing), at the point where the two air streams meet, following earlier splitting at the windward side. This eddy flow is closer to the short side of the building.

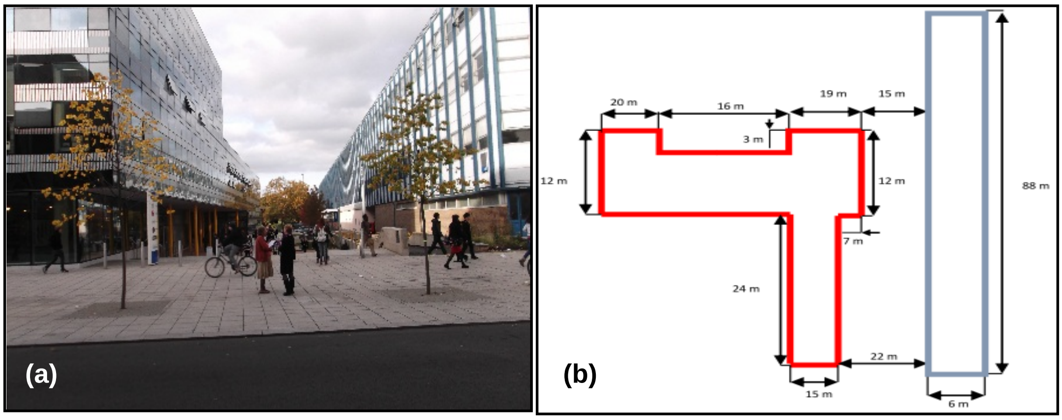

Figure 4 (a): A view of the pedestrian area between the Hub and James Starley building
(b): Main dimensions of the buildings considered

5.2 East direction

In the case of East wind direction Figure (5B), near the entrances to the buildings, the wind speed increases owing to the narrow pass between buildings B1 & B3 (Bernoulli's Principle). The most notable point to observe is the presence of local wind velocity above the prevailing wind speeds (indicated by the yellow lines) near all corners and between building blocks. The distribution of velocity around the building proves that the air also splits at the windward side and meets at the leeward side of building B3. The maximum velocity is present at the front corner of building B3 and at pedestrian level.

5.3 West direction

When the wind is blowing from West Figure (5C), the velocity streamlines build up in the area surrounded by buildings B1 & B2 and the most affected zones are the corners of the upstream in building B1. at the student pedestrian, the wind speed accelerate by 40% higher than wind velocity can occur compared to the reference wind speed at the pedestrian height.

5.4 South direction

For Southerly winds Figure (5D), the most affected zones are the area surrounding buildings B1 and B2 due to the Venturi effect leading to wind speed accelerated by 40%. Also, at the building coroners, the wind speed exceed by 50-60% those at reference wind speed.

6 ASSESSMENT OF WIND COMFORT AND SAFETY

In order to evaluate the wind comfort in pedestrian, Figure 6 shows CFD results at selected points between buildings B1 and B3 (labelled as: 1, 2 and 3), at pedestrian level. It demonstrates that the peak 'pedestrian' wind speeds are higher when the wind direction is from North, South and East, rather than West. This is because building B3 acts as an obstacle to westerly currents.

Also, when the wind direction is from the North or South, it is clear that wind speeds at point 2, in the middle and near the end of pedestrian path, are greater than that at point 1, for all wind speed values.

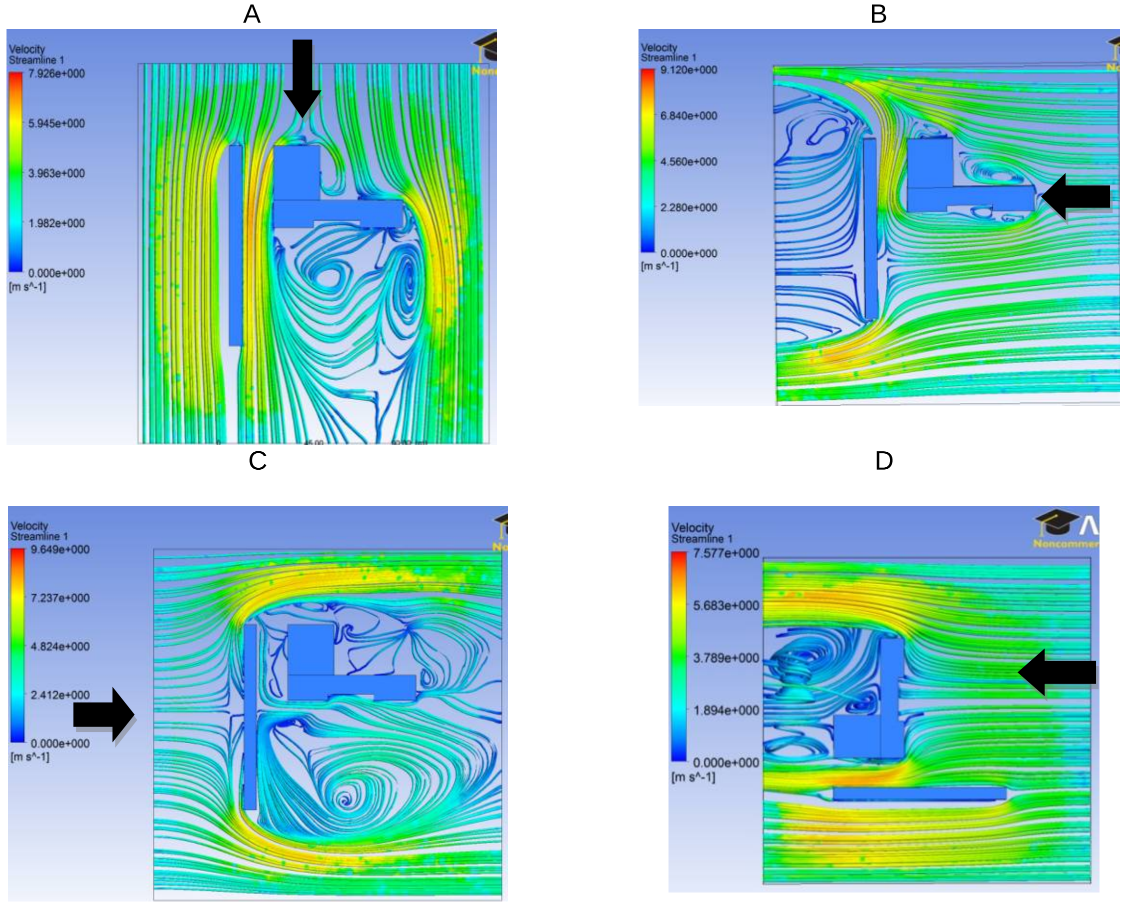

Figure 5: Wind stream-line at pedestrian level (1.5 m above the ground) of the area surrounding the Hub, (A) North direction, (B) East direction, (C) West direction and (D) South direction

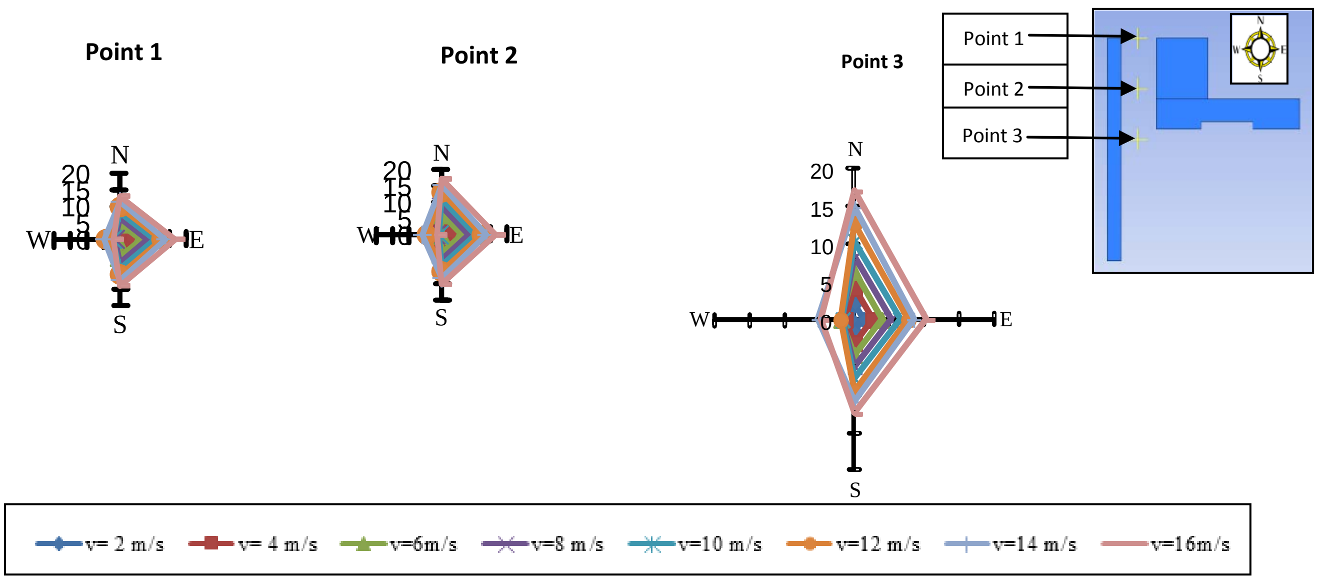

Figure 6: Wind rose diagram for mean wind speed at pedestrian level; points 1,2 and 3

Yet, when the wind blows from East, point 3 has the lower peak value because of the location of building 2.

It is apparent that the identification of origin causing undesirable wind comfort depends on the building design. So, optimisation of wind comfort to suit the requirements for city life and commercial usage can be important.

In general, solving a wind nuisance problem after the design has been finalized can be difficult, expensive and not very effective. Hence, wind environmental conditions should be taken into account during the design stage. Combining architectural design with considerations for acceptable wind climate is often difficult. After reading the report produced from this study the University's Estates Department took the results under consideration. It was decided to introduce vegetation with plants and trees in an effort to '*break*' the wind and decrease the velocity at key areas specified in the study (Figure 7).

Figure 7: Area between the Hub and James Starley (building B3) before and during vegetation works

7 CONCLUSION

In general, when two or more buildings are constructed in proximity, the fluid flow surrounding the buildings may be significantly deformed and of a much complex nature than usually acknowledged. Knowing the strong dependence of comfort on velocity and turbulence it is of practical interest to study these flow features associated with certain building arrangements, typical of urban areas and hence to assess the comfort conditions on the neighbour pedestrian circulations.

This paper has presented a CFD simulation for the evaluation of pedestrian wind comfort and safety in urban areas, the use of CFD in assessing and optimising engineering design solutions related to environmental concerns has been demonstrated through several case studies.

Results from the simulations presented in this paper show that FLUENT is a good tool for evaluating critical effects of wind around buildings from the viewpoint of pedestrians comfort. In addition, helping us to quantify wind discomfort levels.

The idea of studying wind comfort and safety in urban area incorporate the aim of raising attention to available methods and tools that facilitate planning with health and comfort in mind. Urban planning decisions including landscape transformation, rejuvenation—all determine the thermal and aerodynamic conditions, the bioclimatic load users will be exposed to. Therefore the involvement of all relevant disciplines in the design process, cooperation and communication between various professionals (architecture, planning, climatology and biometeorology) is therefore of paramount importance.

REFERENCES

R.M. Aynsley, W. Melbourne and B.J. Vickery, *Architectural aerodynamics,* Applied Science Publishers, London (1977).

B. Blocken, W.D. Janssen and T. van Hooff, “CFD simulation for pedestrian wind comfort and wind safety in urban areas: general decision framework and case study for the Eindhoven University campus”, *Environmental Modelling & Software*, 30(0), 15-34 (2012).

B. Blocken and J. Persoon, “Pedestrian wind comfort around a large football stadium in an urban environment: CFD simulation, validation and application of the New Dutch wind nuisance standard”, *Journal of Wind Engineering and Industrial Aerodynamics*, 97 (5–6), 255-270 (2009).

B. Blocken, S. Roels and J. Carmeliet, “Modification of pedestrian wind comfort in the Silvertop Tower passages by an automatic control system”, *Journal of Wind Engineering and Industrial Aerodynamics*, 92 (10), 849-873 (2004).

G. Bosch and W. Rodi, “Simulation of vortex shedding past a square cylinder with different turbulence models”, *International Journal for Numerical Methods in Fluids*, 28 (4), 601-616 (1998)

A. Chronis, K.A. Liapi and I. Sibetheros, “A parametric approach to the bioclimatic design of large scale projects: the case of a student housing complex”, *Automation in Construction*, 22(0), 24-35 (2012).

Cameron Taylor Bradford Inc., *Pedestrian wind comfort study* (2005)

S. Emil and S. Robert, *Wind effects on structures*, third edition, John Wiley and Sons (1996).

Fluent Inc., *FLUENT 6.3.26 User Manual* (2007).

J. Franke, C. Hirsch, A.G. Jensen, H.W. Krus, M. Schatzmann, P.S. Westbury, S.D. Miles, J.A., Wisse and N.G. Wright, “Recommendations on the use of CFD in wind engineering”, In: *Proceedings of the International Conference Urban Wind Engineering and Building Aerodynamics*, J.P.A.J. van Beeck (ed.), von Karman Institute (2004).

J. He and C.C.S. Song, “Evaluation of pedestrian winds in urban area by numerical approach”, *Journal of Wind Engineering and Industrial Aerodynamics*, 81(1–3), 295-309 (1999).

B.E. Launder and D.B. Spalding, “The numerical computation of turbulent flows”, *Computer Methods in Applied Mechanics and Engineering*, 3(2), 269-289 (1974).

T.V. Lawson, *The Determination of the wind environment of a building complex before construction*, Department of Aerospace Engineering, University of Bristol, Report Number TVL 9025(1990).

A. Mochida and I. Y. F. Lun, “Prediction of wind environment and thermal comfort at pedestrian level in urban area”, *Journal of Wind Engineering and Industrial Aerodynamics*, 96(10–11), 1498-1527 (2008).

A. H. Mohammadipour and S.H. Alavi, “The optimization of the geometric cross-section dimensions of raised pedestrian crosswalks: a case study in Qazvin”, *Accident Analysis & Prevention*, 41 (2), 314-326 (2009)

S. Murakami, “Overview of turbulence models applied in CWE–1997”, *Journal of Wind Engineering and Industrial Aerodynamics*, 74–76(0), 1-24(1998)

D.A. Paterson and C.J. Apelt, “Computation of wind flows over three-dimensional buildings”, *Journal of Wind Engineering and Industrial Aerodynamics*, 24(3), 193-213 (1986).

F. Shane, *Pedestrian level wind study,* 1451 Bathurst Street. GmE 11-008-PLW, September 16 (2011).

T. Shih, W.W. Liou, A. Shabbir, Z. Yang and J. Zhu, "A new k-□ Eddy viscosity model for high Reynolds number turbulent flows", *Computers & Fluids*, 24(3), 227-238 (1995).

T. Stathopoulos and B.A. Baskaran, "Computer simulation of wind environmental conditions around buildings", *Engineering Structures*, 18(11), 876-885 (1996).

T. Stathopoulos, "Pedestrian level winds and outdoor human comfort", *Journal of Wind Engineering and Industrial Aerodynamics*, 94(11), 769-780 (2006).

T. Stathopoulos, H. Wu and J. Zacharias, "Outdoor human comfort in an urban climate", *Building and Environment*, 39(3), 297-305 (2004).

D. Tan, W. Wang, J. Lu and Y. Bian, "Research on methods of assessing pedestrian level of service for sidewalk", *Journal of Transportation Systems Engineering and Information Technology*, 7(5), 74-79 (2007).

Y. Tominaga, A. Mochida, R. Yoshie, H. Kataoka, T. Nozu, M. Yoshikawa and T. Shirasawa, "AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings", *Journal of Wind Engineering and Industrial Aerodynamics*, 96(10–11), 1749-1761 (2008).

H. Wu and F. Kriksic, "Designing for pedestrian comfort in response to local climate", Journal of Wind Engineering and Industrial Aerodynamics, 104–106(0), 397-407 (2012).

R. Yoshie, A. Mochida, Y. Tominaga, H. Kataoka, K. Harimoto, T. Nozu and T. Shirasawa, "Cooperative project for CFD prediction of pedestrian wind environment in the Architectural Institute of Japan", *Journal of Wind Engineering and Industrial Aerodynamics*, 95 (9–11), 1551-1578(2007)

A STUDY ON EDUCATION OF SUSTAINABLE DEVELOPMENT IN TAIWAN– USING ENERGY RESOURCE CENTRES IN PUBLIC MIDDLE AND ELEMENTARY SCHOOLS AS AN EXAMPLE

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Abstract. *In order to respond to idle school space caused by a lower birth rate, Taiwan has sought to enhance schools' building lifecycles and transform them into bases for environmental education. This study uses 32 Taiwanese middle and elementary schools, to assist in transforming idle space into energy-resource learning centres and implementing energy-resource teaching. According to each school's needs, idle space was transformed into "Energy-Resource Education Centres" with a focus on energy-saving. This provided schools with locations for achievement displays, and an expert consultation team was established to assist them in drafting, implementation, and performance review and achievements sharing of a resource transformation plan. The increase in students' energy-resource education cognition and attainment levels was understood through questionnaires. Renovation categories included renewable resource applications, energy-saving designs, improvement of the indoor environment, healthy and natural construction materials and reclaimed rainwater re-usage. The renovations provided a 13.4% energy use decrease and many schools' water and electricity use also exhibited a decline. Schools had a yearly increase in their building life-cycle maintenance and management evaluation, and enhanced the effectiveness of teaching by allowing students to participate in operation of the facilities. During renovation, schools were able to choose the best plan for their particular geographic, climatic and human characteristics. This allowed renovation to have concrete results and educational significance, and also to be able to be incorporated into daily life and teaching, which will enable students to cultivate a philosophy of "energy-saving and carbon reduction" from early on. Energy-resource education can also be promoted to the community, effectively creating links in the energy-resource education network, and striving towards a low-carbon school goal.*

1 INTRODUCTION

In order to respond to idle school space caused by a lower birth rate, Taiwan has sought to enhance schools' building lifecycles and transform them into bases for environmental education that accord with sustainable development. The above is in accordance with the viewpoints of Chen N.T., Liu K.S., Chiang C.M., Tsai Y.H., and Hsieh M.C. (2010). This study uses 32 Taiwanese middle and elementary schools as research subjects, to assist in transforming idle space into energy-resource learning centres and implementing energy-resource teaching.

The target structure of the energy-resource educational centre plan is shown in Figure 1 below:

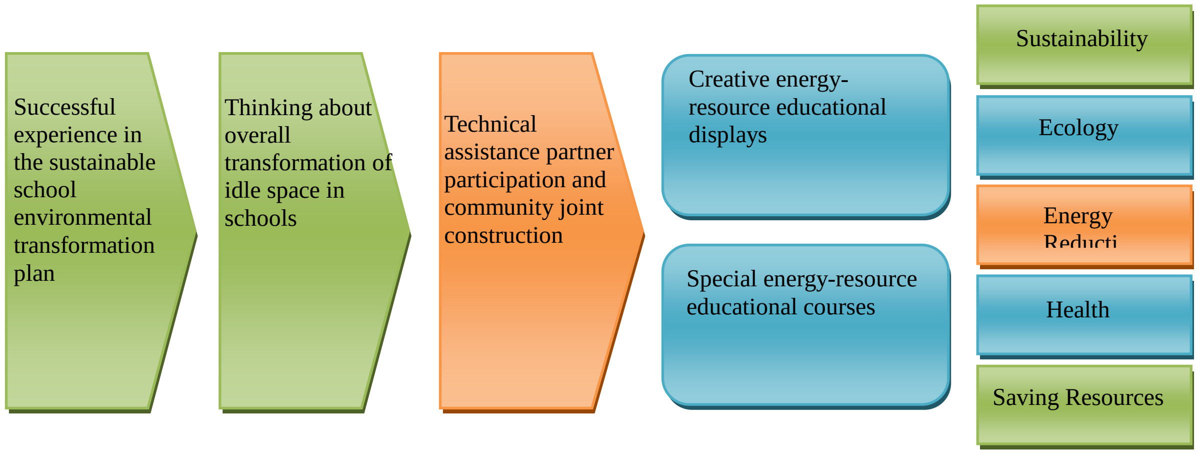

Figure 1. Plan target structure

2 METHODS

According to each school's needs, idle space was transformed into "Energy-Resource Education Centres" with a focus on energy-saving. This provided schools with locations for achievement displays in resource and eco-education, and an expert consultation team was established to assist them in drafting, implementation, and performance review and achievements sharing of a resource transformation plan. The increase in students' energy-resource education cognition and attainment levels was understood through questionnaires.

2.1 Expert consulting team

According to research by Chen N.T., Liu K.S., and Chiang C.M. (2011), the following steps can be used in the creation of an expert consulting team: establish a consulting team mechanism; work with administrative implementation and professional technical guidance from the MOE (Ministry of Education); assist schools with design and implementation, as well as carrying out examination of results and benefit analysis etc.; conform to plan implementation. This can achieve superior results in the consulting process.

2.2 Physical hardware

(1) "Energy-resource educational centre construction and renovation project": indicates that when idle school space is being renovated into an energy-resource centre, the facilities must act as a normal physical building construction project.

(2) "Energy-resource display equipment and educational tools": indicates the development of building facilities and educational equipment that possess educational display capacity, with sustainable education as a goal. The proposals for energy-resource educational centres are shown in Figure 2.

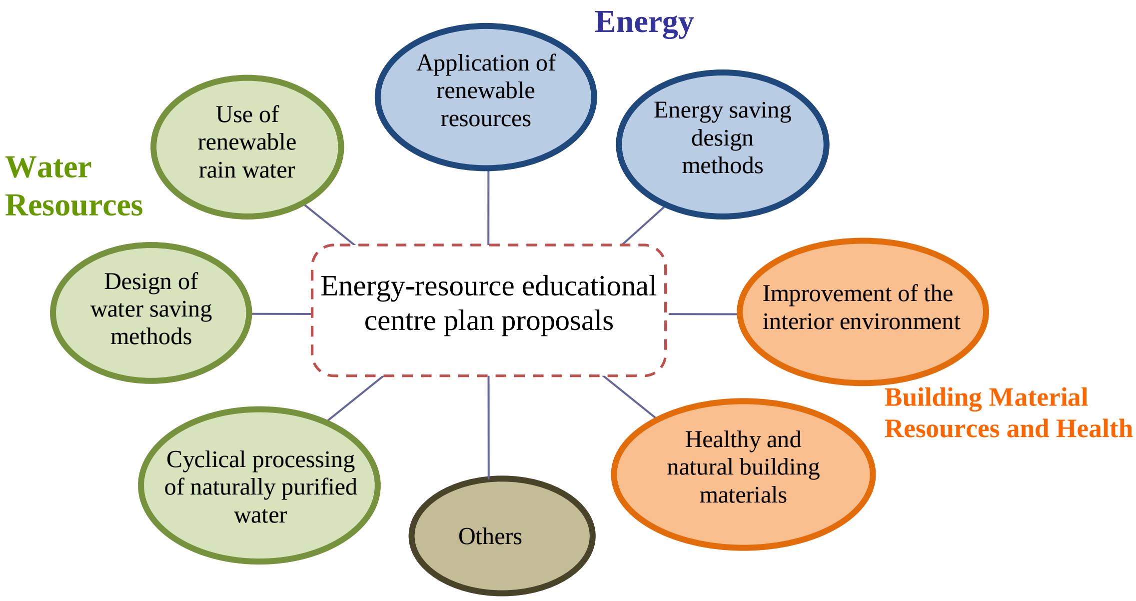

Figure 2. Energy-resource educational centre proposals

2.3 Software component

The software component must be able to conform to the development of sustainable education with local characteristics. Every school should develop special energy-resource classes and energy-resource creative educational activities according to the "Energy-resource educational centre" plan targets.

Ex.:

(1) Classes on energy-resource characteristics

Goals should be planned according to the "Energy-resource educational centre", with each school's unique characteristics as a prerequisite. This can lead to the development of thematic energy-resource educational courses such as: partnering the fields of nature and life technologies (Physics, chemistry, biology or earth science), social education fields (geography, history or civics), and important topics in environmental education etc., to implement issues-immersion teaching.

(2) Energy-resource creative teaching activities

Should suit the energy-resource characteristics classes, and with each school's unique characteristics as a prerequisite, energy-resource educational activities should be held, such as: jointly organising school water quality monitoring activities with post-secondary institutions in neighbouring regions, and holding energy-resource promotion experience camps etc.

In the future it will be able to conform even better to different neighbourhood special educational institutions and be more able to develop into a close-knit sustainable-development education contact network.

3 RESULTS

Renovation categories included renewable resource applications, energy-saving designs, improvement of the indoor environment, healthy and natural construction materials and reclaimed rainwater re-usage. The renovations provided a 13.4% energy consumption decrease and many schools' water and electricity usage also exhibited a general decline. Schools had a year-on-year increase in their building life-cycle maintenance and management evaluation, and as indicated by Shih Y.L. (2010), this also can enhance the effectiveness of teaching by allowing students to participate in actual operation of the facilities.

3.1 Recycling of reclaimed rain water

In 2008, there were 10 schools that applied for this category. The project contents mostly involved recycled rain water educational display equipment. In 2010, the rain water reclamation equipment usage continued to expand, with a portion of the schools applying for newly added educational equipment. From the completion of installing at the end of 2009 until the end of November 2011, statistics show that the southern region reclaimed 607 tonnes of rain water while the northern region reclaimed 8 808 tonnes, for a total of 9 415 tonnes of rain water (see Table 1). If converted into carbon reduction amounts, approximately 1 949 kilograms of carbon dioxide emissions were saved. The northern region's reclaimed amount was significantly higher than the southern region which indicates differences due to location and climate. Due to reasons of actual environmental conditions and choice of project, the difference between the southern and northern regions was quite substantial.

Item	2009 (tonnes)	2010 (tonnes)	Total (tonnes)	CO_2 emission reduction (kg)
Northern Taiwan	3,571	5,238	8,809	1,823
Southern Taiwan	91	516	607	126
Total	3,662	5,754	9,416	1,949
Date of calculation	Jan.-Dec. 2009	Jan.-Oct. 2010	--	--

Table 1. 2008-2010 Rainwater collection amounts and CO_2 emission reduction equivalents

3.2 Application of renewable resources

This item was the one that the largest number of schools applied for in both 2008 and 2010. Compiling results from the completion of the project plan in 2008 up until November 2010, the total reclaimed amount (power generated) was 23 484 kWh in the southern region and 13 460 kWh in the northern region, for a total of 36 944 kWh (see Figure 3). If converted into carbon dioxide emissions saved (1 kWh equal to 0.625 kilograms of carbon emitted), this is equivalent to a reduction of 23 090 kilograms of carbon dioxide emissions. This works out to a saving of between $77 582 Taiwan Yuan (approximately £1700) at a non-summer electricity rate of 2.1 Yuan per kWh below 110 kWh, to $188 413 (approx. £4140) Taiwan Yuan at a summer rate of 5.1 Yuan per kWh above 710 kWh.

Similar to "Recycling of reclaimed rain water", this category showed large differences between the northern and southern regions. The main reason for this is the effects of geography and climate that influenced the implementation of the project in each locality. According to Chiang C.M., Chen H.H., and Huang C.Y. (2004), it can be understood how important "building locally" is. That is to say, the local environment and climate must be taken into account when designing project contents. Only then can the goal and meaning of energy-resource education be effectively achieved.

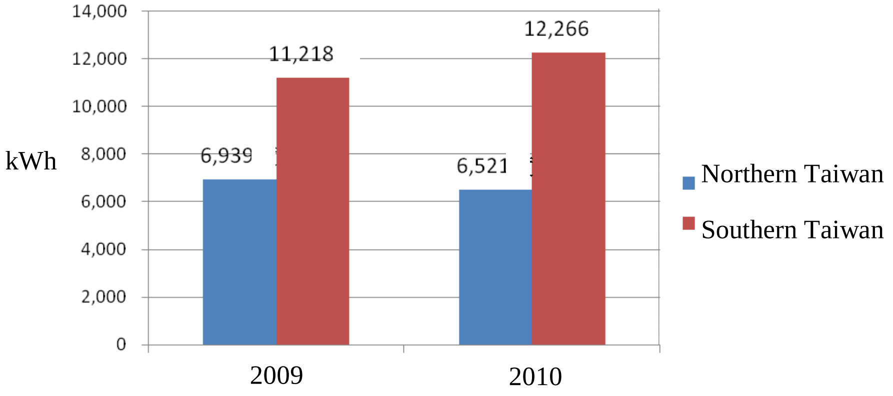

Figure 3. 2009-2010 Renewable energy production amounts

3.3 Benefits of water and energy savings

Calculating statistics for 2 years of average per-person school water and electricity usage, while excluding new building construction and renovation, the majority of schools showed a downward trend in water and electricity usage. In 2008, this amounted to 89,882 kWh, 2009 was 85,178 kWh, and 2010 was 77,870 kWh. Comparing 2010 and 2008, there was a total saving of 13.36% of electricity (see Figure 4)。

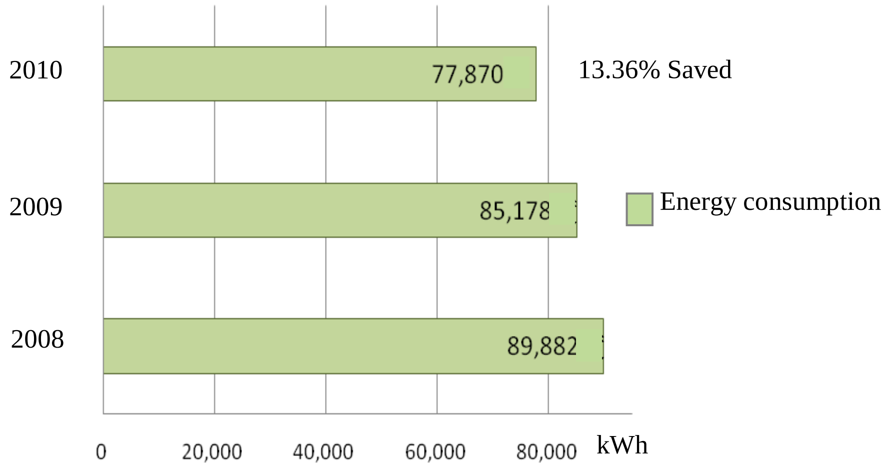

Figure 4. 2009-2010 Energy saving design features post-installation efficiency

As the European Commission indicates (http://ec.europa.eu/environment/eussd/ retrieved May 10, 2013), through the creation of sustainable communities it is possible to manage and use resources efficiently, tap the ecological and social innovation potential of the economy and in the end ensure prosperity, environmental protection and social cohesion.

Each school considered differences in local climatic and environmental conditions to allow construction items and their contents to conform with particular local characteristics. Below is an introduction of this study's more unique cases, with the hope that case sharing can be provided to other schools and groups with interest in energy-resource education, and also to be able to produce innovation in developing energy-resource transformation according to local characteristics such as different environmental and climatic regions:

Northern Region: In Yilan County's Yueming Elementary School complied by setting up an environmental and energy-resource monitoring system which can be used to carry out teaching about greenhouse gas inventory and reduction. This allows students to learn how to use numbers for analysis from a scientific perspective. Students also were able to grow and take care of climbing plants, thereby giving further thought to how to reduce behaviour that leaves a burden on the environment (Figure 5).

(1) Greenhouse gas inventory and reduction education

(2) Students growing plants and taking care of climbing vines

Figure 5. Yilan County Yueming Elementary School

Southern Region: Yong'an Elementary School in Houpi District, Tainan City started implementation of a three-year "Yong'an Green Villa – Global Children's Centre" plan in 2007. This plan's goal was to take space designated as "unusable" and transform it into "usable" and then again into "useful" space. This was by using a "point, line, area" model to create this school's very unique energy-resource education centre, as well as effectively integrating educational classes and promoting this idea to community residents allowing a basic local energy-resource education centre to start to take shape (Figure 6).

(1) Wind and solar power generation system

(2) Using recycled building materials to construct ample shading systems

Figure 6. Tainan City Yong'an Elementary School

After the invigoration of environment and space, not only did they have energy-resource efficiency and educational capability, but also showed vitality and helped to stimulate students' learning. From teaching materials and class design aspects, each school worked hard in planning and diligently designing, which inspired quite a lot of creativity, such as: Tianzi Elementary School in Gaoshu Township, Pingdong County used naturally-cleaned water circulation educational display facilities and interpretive signs combined with a concept towards healthy and natural building materials to transform and beautify the original ugly water tower. This has now become an optimal location for student learning (Figure 7).

(1) Improving the original water tower surrounding landscape environment

(2) Painted rainwater recycling "piggy bank"

Figure7. Pingdong County Tianzi Elementary School

4. CONCLUSIONS

During renovation, schools were able to choose the best plan for their particular geographic, climatic and human characteristics. This allowed renovation to have concrete results and educational significance, and also to be able to be incorporated into daily life and teaching (Pictures 8). Each school used its capital account for hardware transformation, and as indicated in Shih Y.L. (2004) used its current account for planning corresponding teaching activities or relevant educational literature. This allowed the meaning of energy-resource education to be more easily promoted through incorporation in routine classes, holding relevant practice activities, educational visits, workshops and experience camps, etc.

As well, the model through which each school actively trained "Young Commentators" is very much worth other schools to refer to and learn from (Picture 9). For the children, this is not only a nice teaching method, but also allows children to use their own creative explanations to allow energy-resource education to become even more diversified and interesting.

As for schools receiving subsidies for planning activities with their current account, educational literature was the main item of focus, followed by educational visits and then holding training camps. Through multi-faceted implementation of current account planning, the schools' students and teachers were able to have more opportunities to learn about energy-resources. As well, as Chen Z. D. and Tzeng C. T. (2011) pointed out, schools can reach out to neighbourhood residents and technical support teams to effectively create links to the energy-resource education network, to work towards the low-carbon school plan assisted by innovative energy-resource education methods, to effectively implement the mission of sustainable development.

Figure 8: Energy-Saving Lamp Observation and Comparison

Figure 9: Results of the Young Commentators Programme

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REFERENCES

Conference papers

Chiang C.M., Chen H.H., and Huang C.Y. 2004. Preliminary discussion on the results of sustainable school renovation – using Taipei County Shenkeng Elementary School, Nantou County Sheliao Elementary School, Kaohsiung City Zuoying Elementary School, and Taidong County Xinxing Elementary School as an example. In: *The Proceeding of Second Roun*d o*f the Sixteenth Session of Architectural Research Conference*, Taipei, Taiwan.

Shih Y.L. 2010. The new trend towards low carbon schools – energy-resource educational centre 3 years achievement exhibition. *Ministry of Education electronic newsletter*.

Other publications

Shih Y.L. 2004. *Exploring techniques in the development process of elementary school students' environmental education experience, feeling towards the environment and environmental awareness – using upper grades in Taipei County and City as an example.* Master's Thesis, National Taiwan Normal University Institute of Environmental Education.

Research Projects

Tzeng C. T., Lin Z. Y., and Liao M. Z. "Research on the Implementation of Green Building Code Quality Control Results - Chiayi County Junior High School and Elementary School as an example". The 24th Architecture Research Results Conference of the Architectural Society. Taiwan Architectural Society. September 22nd, 2012. Taizhong, Taiwan.

Chen Z. D. and Tzeng C. T. An analysis of solar hot water heaters applied to swimming pools – "Using Tainan City Public Elementary and Middle Schools as an example". The 23rd Architecture Research Results Conference of the Architectural Society. Taiwan Architectural Society. November 11th, 2011. Tainan, Taiwan.

Chen N.T., Liu K.S., Chiang C.M., Tsai Y.H., and Hsieh M.C. 2010. Case study research on sustainable renovation and reuse of idle space in schools. *Tung Fang Institute of Technology Faculty of Interior Design*.

Chen N.T., Liu K.S., and Chiang C.M. 2011. *2010 Schoolyard activation consulting team plan report.* Ministry of Education.

Internet Resources

European Commission (2013, May 10). Retrieved from http://ec.europa.eu/environment/eussd/

Sustainable Building Conference 2013

TOWARDS A FRAMEWORK FOR INVESTIGATING SOCIO-CULTURAL BARRIERS TO CRADLE-TO-CRADLE PRINCIPLES IN BUSINESS PARK DEVELOPMENT

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Abstract. *The cradle-to-cradle (C2C) philosophy has been described as a paradigm changing innovative platform for achieving ecologically intelligent and environmentally restorative buildings. Whereas conventional sustainability efforts focus on doing "less harm" to the environment, C2C proposes a radically new way of thinking about waste, renewable energy and promotion of diversity. Industry specific barriers to change however hinder adoption of C2C in the built environment. In this study, it is argued from a synthesis of extant literature that many of these barriers are rooted in socio-cultural factors, a better understanding of which could help accelerate adoption of C2C principles in the built environment. Using business park developments as a backdrop, a framework for interrogating the socio-cultural context within which development projects take place and barriers to C2C adoption is proposed. The framework incorporates the competing values framework which is adapted to facilitate diagnosis and matching of different organisational value profiles to the choices that development stakeholders are likely to make in relation to C2C implementation. A key theoretical proposition which derives from this framework is that stakeholder organisations that subscribe to open system values are more likely to overcome socio-cultural barriers and implement C2C principles as a design model compared to stakeholder organisations that orient towards internal process values. It is anticipated that culture profiles of key stakeholder organisations and the nature of their alignment towards C2C oriented changes will be identified through empirical testing of this framework.*

Keywords: *business parks, cradle-to-cradle, competing values framework, socio-cultural barriers.*

1 INTRODUCTION

The cradle-to-cradle (C2C) philosophy has been described as a paradigm changing innovative platform for achieving ecologically intelligent and environmentally restorative buildings (Mulhall and Braungart, 2010). Whereas conventional sustainability efforts focus on doing "less harm" to the environment, C2C proposes a radically new way of thinking about waste, renewable energy and promotion of diversity such that human systems can mimic the functioning of natural ecosystems where there is no waste generation and the primary source of energy is the sun. Despite the growing technological, social and economic prospects of C2C implementation in the built environment, its adoption as a design strategy for achieving a positive synergy with the environment has been rather slow. Hoffman and Henn (2008) have argued that in spite of overcoming formidable technological and economic hurdles in recent years, environmental progress in the building design and construction industry would continue to stall if social and psychological barriers are not addressed. This argument clearly establishes the fact that a significant barrier to C2C adoption is the socio-cultural context within which development projects take place. There is the need therefore to fully interrogate potential socio-cultural barriers to the implementation of C2C in the built environment so as to aid the formulation of appropriate strategies for overcoming such barriers.

The aim of this paper is to identify the various socio-cultural barriers to C2C implementation in the built environment, using business park developments as a context. Based on this, a framework is proposed for pilot testing to guide further empirical studies on the extent to which such barriers inhibit the adoption of C2C principles amongst key stakeholders involved in business park developments. Business parks as used in this study consist of a clustered agglomeration of businesses involved in different functions which can range from manufacturing production, retail, and export processing, to technology or research parks (Memedovic, 2012). Such clustered developments are very ideal for C2C implementation.

The next section discusses the C2C concept followed by a review of the relevance of business parks as hubs for economic development with negative environmental implications. The relevance of C2C in this context as a long-term strategy towards the achievement of a truly positive synergetic relationship with the environment is presented before discussing potential socio-cultural barriers to the implementation of C2C principles. Based on these discussions, a socio-cultural study framework which is underpinned by the competing values framework is proposed as a guide to further interrogate the socio-cultural barriers to C2C implementation.

2 CRADLE-TO-CRADLE PHILOSOPHY

The C2C philosophy provides a platform for a conceptual shift in thinking from the linear cradle-to-grave model of development where waste is accepted as a by-product, sometimes recycled but then eventually ends up in landfill and where energy is predominantly from fossil fuels. Even with recent sustainable development efforts which have sought to alter this linear end-of-pipe development models such as circular economy and industrial ecology, a reductionist approach which does not create a true spiral loop/circular flow of materials and energy has often been the outcome. Sustainability in itself is viewed by most organisations as the simultaneous improvement in social and human welfare whilst reducing any ecological impact in the quest to effectively achieve the organisations objectives (Sharma and Starik, 2002). But the overarching question is why the target should be a reduction in negative ecological impact when a truly positive impact can be realised by re-configuring the current and pre-dominant model of development–zero carbon, zero emissions, and zero waste. This is the question that underpins the C2C design and development philosophy.

With inspiration from the earth’s natural ecosystem where biogeochemical processes which are powered by the sun’s energy sustain all biological systems without any waste generation, the C2C philosophy aims for designs that function in the same manner as naturally occurring and regenerative processes (McDonough and Braungart, 2003; Debacker et al., 2011). Thus rather than managing waste, the C2C goal is to design products and systems that are ecologically intelligent so that materials from products and systems eventually serve as “nutrient” feeds for other biological or technical systems after their service life. This approach envisions a total eradication of waste as these become beneficial nutrients that support/feed into other useful processes (McDonough et al., 2003). McDonough et al.

(2003) proposed three tenets of C2C as:
- Waste is equal to food: waste either serves as a technical or biological nutrient
- Use of current solar income: dependence on solar sources of energy
- Celebrate diversity: promoting biodiversity, cultural and conceptual diversity.

3 CRADLE-TO-CRADLE IMPLEMENTATION IN BUSINESS PARKS

Business parks provide the institutional framework, modern services, physical infrastructure and assistance for local companies through forward and backward linkages that can support new enterprise incubation, start up's and knowledge sharing for the mutual benefit of all businesses and are often conceived as hubs for economic development (Ratinho and Henriques, 2010; Memedovic, 2012). The planning and development process of business parks is somewhat underpinned by the concept of cluster development in regional planning which is an umbrella concept for the agglomeration of interlinked businesses. Business parks can vary based on their core function and are either categorised as science/technology parks, research parks, light industrial parks, heavy industrial parks, export processing zones/parks, retail parks or even mixed use parks. A key strength of cluster developments is the provision of common services to businesses that might otherwise be too costly for any single business to invest in (Memedovic, 2012).

Business parks have in the past been associated with poor environmental management, pollution, traffic congestion and reduced quality of life (Memedovic, 2012) even though it is a good model for economic development. High energy consumption as well as waste from industrial production can contribute to negative environmental and social impacts. Despite well-intended efforts from industrial ecology and circular economy studies which have sought to create a closed-loop of material and energy flows through symbiotic sharing of materials and utilities (Gibbs, 2003), a true closed loop system has not been achieved. Eco-industrial parks (EIPs) for instance have often focused on a vision of reduction in negative environmental impacts by creating inter-linkages between businesses to ensure that energy, water, and materials are managed sustainably (Lowe et al., 1998). Consequently there is scope to explore opportunities for realising a truly positive ecological impact of business parks whilst at the same time promoting economic and social benefits. Tudor et al. (2007) have even suggested that there should be more emphasis on thinking beyond "sustainability" in the development of EIPs. This dovetails neatly into the C2C agenda for business park developments.

The C2C vision proposes to integrate features into the spatial development of business parks that would facilitate true recycling of technical and biological nutrients, promote cultural, intellectual and bio-diversity and derive energy from solar or other renewable energy sources. These features could be bio-digester, constructed wetlands, waste water treatment ponds, and rainwater recycling installations all of which can aid the extraction of biological nutrients in wastewater from the business park. The business park can also be designed with recyclable building components, interiors and materials as well as planning to support a symbiotic sharing/circulation of technical nutrients that would otherwise have become waste. Positive emissions could also be promoted through use of self-cleansing and self-purifying façades (Hüsken et al., 2009), roof gardens and vertical gardens throughout the park.

Biodiversity can be promoted through incorporation of features such as gardens, fish ponds, green roofs and aquaponic ponds that provide space for flora and fauna to flourish. Cultural diversity can be promoted through joint sharing of infrastructure, incorporation of local materials and features in designs as well as incorporating features that support livelihoods of local communities around the business park. Conceptual diversity can be promoted through aesthetically pleasing features, design innovation and flexible, adaptable mixed use park designs. The energy vision is to promote direct utilization of solar energy through the incorporation of photovoltaic roofs and skylights, solar roof and wall panels or stand-alone solar photovoltaic or solar thermal installations. Indirect utilization of solar energy can also be promoted in the business park through features such as bio-gas plants, geo-thermal plants, wind turbines or small-scale hydro plants depending on local conditions. The C2C objectives as well as how these can be achieved in business park developments have been summarized in Table 1.

C2C objectives	C2C implementation strategies
Environmental objectives To ensure that waste generated is equal to food for other processes To ensure that energy is wholly derived from solar and other renewable energy sources To ensure that biodiversity is promoted	Design business park to be wholly dependent on renewable energy sources Design individual units that can clean the surrounding air, generate energy, recycle water and serve as habitat for flora and fauna. Design individual building units so that they can easily be dis-assembled and recycled without reducing material value. Avoid the use of toxic and hazardous materials both in development and operation of business parks Design flexible and mix-use building units that can easily be adapted for different functions Cluster businesses/companies to support industrial symbiosis Create habitats for flora and fauna in the business park.
Economic objectives To ensure that businesses are more profitable To engender local and regional economic development Increased commercial attractiveness of business park	Operate the facility on solar and renewable energy sources to alleviate cost of energy Treat and reuse wastewater to alleviate cost of water. Exchange materials as nutrients across businesses to alleviate cost of waste disposal.
Social objectives To improve the quality of life of local community To conserve local culture and heritage by promoting cultural diversity To provide facilities and services to serve development needs of local community	Use locally available materials for development as well as design to reflect local heritage Provide opportunity for training and development of workers and community Integrate features that create a comfortable and healthy working environment and community. Integrate features that create livelihoods for local community

Table 1: Cradle-to-cradle objectives and implementation strategies in business parks

4 SOCIO-CULTURAL BARRIERS TO C2C IMPLEMENTATION IN BUSINESS PARKS

Hoffman and Henn (2008) have argued that overcoming technological and economic hurdles alone are not sufficient for making environmental progress in the building, design and construction industry unless social and psychological barriers are overcome. The development of business parks involves a wide range of stakeholders. These range from planning and regulatory authorities to private developers, regional development agencies, engineers, architects, contractors as well as preservation groups and local community groups. Socio-cultural barriers could therefore manifest to varying degrees amongst these development stakeholders and thus inhibit C2C adoption irrespective of the potential social, economic and environmental prospects. Petersen and Andersen (2009) and Hoffman and Henn (2008) provide some insight into such socio-cultural barriers to change. Barriers identified in these studies and other supporting literature is discussed under five main themes.

4.1 Self- interest versus collaboration

Hoffman and Henn (2008) revealed that some stakeholders could resist a more integrative approach to green construction as they may feel threatened that this would disrupt already existing structured role systems of designs flowing from the architect to engineers and then to contractors. The same argument could apply to C2C implementation where new structures that can promote collaborative joining of forces to stimulate and promote “new thinking” during design development could be resisted by some stakeholders. This lack of collaboration can also be fuelled by competing interests amongst stakeholders leading to sub-optimal decisions (Bechky, 2006). For instance developers may only be concerned with initial capital costs, whereas users may be more concerned about long-term cost savings (Van Bueren and Priemus, 2002). This situation creates a lack of leadership or power vacuum for implementing C2C in business parks. A high level of early collaboration involving non-traditional design development stakeholders such as environmental experts, chemists or even energy experts is needed to achieve C2C designs. At the operational stage of the business park, a high level of collaboration amongst users is also needed to facilitate the symbiotic sharing/exchange of technical nutrients and sharing of common utilities and infrastructure. Petersen and Andersen (2009) have however argued that the modern society favours individualism at the expense of collaboration which then inhibits communal use of technologies.

4.2 Short-term versus long-term focus

It has been argued that developers and consumers alike are more concerned with immediate returns irrespective of the longer term benefits that can be reaped from lower operating costs of facilities (Hoffman and Henn, 2008). Chalifoux (2006) also revealed that construction professionals tend to eliminate green building features during value engineering exercises without taking life cycle cost assessments into consideration even though this raises the operational costs of buildings. Similar findings have been echoed by Grosskopf and Kibert (2006) who revealed that consumers are more willing to buy into features with shorter capital cost recovery periods. This short-term focus could be a potential barrier to C2C implementation in business parks given that C2C is a life-cycle phenomenon that can be facilitated by a longer-term focus.

4.3 Risk Aversion versus Risk Affinity

Given that building projects and more so spatial developments like business parks cannot be prototyped and tested like manufactured products, design and construction stakeholders are more apprehensive about adopting new technologies and processes due to the fear of unknown risks (Hoffman and Henn, 2008). Cousins (2011) for instance have highlighted several problems in buildings that were designed to test emerging renewable energy technologies. These ranged from external rainwater harvesting systems that burst in cold weather due to lack of insulation, ventilation and condensation build up problems with heat recovery systems, high energy for running communal biomass and green water recycling systems to other maintenance problems of installed renewable energy technologies. A key stakeholder involved in these projects even raised questions about the true maintenance requirements of renewable energy technologies and subsequently claimed that had these requirements been clearly known initially, they would have been more circumspect in adopting such technologies for their projects. Adopting new processes could giving rise to new routines (Petersen and Andersen, 2009), which would require staff re-training and establishment of new structures without full knowledge of the potential future risks (Hoffman and Henn, 2008). Even financial institutions are known to be hesitant in financing unproven environmental technologies and the same applies to building inspectors who are known to reject environmentally sound technologies because they are new and unproven (Hoffman and Henn, 2008).

4.4 Knowledge rejection versus knowledge seeking

Project delivery professionals are most likely to disregard unfamiliar emerging technologies and even the acquisition of knowledge on unfamiliar terminologies irrespective environmental implications because these challenge conventional terminologies (Kempton et al., 1996; Hoffman and Henn, 2008). For instance, the vinyl chloride monomer in poly vinyl chloride (PVC) products has been criticized for its highly carcinogenic and toxic effects but terminologies such as polyolefin-based products which are proven to be safe throughout their lifecycle as well as provide the performance benefits of PVC (McDonough et al., 2003) is likely to be unpopular amongst construction professionals nor even arouse their interests because of the unconventional nature of the terminology. This could be more so the case in the presence of pluralistic terminologies and competing ideas relating to sustainable development. This attitude towards unconventional knowledge and terminologies amongst some stakeholders is likely to pose a barrier to the adoption of C2C in business parks.

4.5 Projection of positive illusions versus improvements in actual practices

Research has revealed that people, businesses and society often tend to project an aspiration of their virtues rather than the reality of their behaviours when it comes to environmental responsibility (Hoffman and Henn, 2008). Thus, most developers are more likely to claim that their properties are environmentally friendly (Bazerman et al., 1999) especially when they have implemented some energy saving, waste cutting or emissions cutting strategies. Hoffman and Henn (2008) argue that such projections could however be far from the reality of negative impacts of their activities on the environment. Businesses and society at large are therefore “locked-in” (Petersen and Andersen, 2009) to their current practices and would easily find reasons to supplant and justify their current practices than make changes to actual behaviours/practices irrespective of the positive prospects of change.

4.6 Bureaucracy/Rigidity versus flexibility

Hoffman and Henn (2008) have argued that many regional building codes do not support the installation of composting toilet or greywater systems, suggesting that there is the tendency for the standards and regulations to draw attention to the law rather than the purpose behind the law. Tenbrunsel et al. (1997) for instance have revealed that sub-optimal decisions can be reached by decision makers due to strict adherence to standards. Similarly, Williams and Dair (2007) have also revealed that in many instances, stakeholders were unable to implement sustainability measures in their designs because they were not allowed by regulators. They suggested that perhaps, policies and regulations were lagging behind best practices. Debacker et al. (2011) have also revealed that inflexible laws and regulations were a major barrier to C2C implementation as this was usually cited by stakeholders as a major hindrance in C2C inspired developments.

5 FRAMEWORK FOR UNDERSTANDING SOCIO-CULTURAL BARRIERS

5.1 Competing values framework (CVF)

The competing values framework (CVF) is an appropriate framework for understanding the extent to which socio-cultural barriers amongst different development stakeholders inhibit C2C implementation in business parks. The CVF, which is empirically derived and validated and has been applied to several studies on cultural change especially in relation to sustainability (Linnenluecke et al., 2009). The CVF can be used to diagnose different stakeholder organisational cultures which could then be mapped onto the socio-cultural barriers that are revealed to be prevalent in these organisations. Organisational culture here is defined as a pattern of basic assumptions – invented, discovered, or developed by a group as it learns to cope with its problems – that has worked well to be considered valid and, thus to be taught to new members as the correct way to perceive, think, and feel in relation to such problems (Schein, 1992). The CVF consists of four competing values in organisations that can influence the priorities they place on change implementation (Figure 1). The internal process quadrant of the CVF represents organisations that focus on the use of formal structures to achieve organisational efficiency with an ultimate aim of economic profitability. Such organisations are dominated by a hierarchal culture (Zammuto et al., 2000) where decision making is data driven and any innovations that are promoted within the organisation are aimed at increasing productivity and maximizing profits and economic gains. The focus on conformity to roles which constrains employee choices and actions (Scott, 2003) as well as existence of formalized structures and emphasis on profitability suggests that such organisations are less likely to be open to collaboration and pursuance of long-term goals.

The human relations quadrant represents organisations that focus on employee development and the creation of a stimulating work environment that facilitates social interaction and high interpersonal relations. Such organisations are dominated by a group culture and there is a focus on upgrading the skill and knowledge base of their employees as this is considered a core business strategy (Zammuto et al., 2000). The rational goal quadrant represents organisations that focus on rational goal setting and planning based on the demands from their wider external environment (Zammuto et al., 2000). Thus, the structure and decision making process of the organisation is designed to facilitate planning; forecasting and control so as to achieve efficiency in relation to their competitors. Unlike the internal process quadrant which focuses purely on economic profitability to the detriment of the wider external environment, organisations in the rational goal quadrant consider the impact their operations have on their external environment and society at large in their quest to achieve efficiency (Zammuto et al., 2000). The fourth quadrant which is the open systems quadrant represents organisations that focus on adaptability and readiness in their quest to achieve growth and place a lot of emphasis on the external environment. Such organisations are dominated by a development culture and are flexible enough to adapt to changes that take place in the external environment. They also place emphasis on innovation, promote risk-taking and setting of new challenges.

The different quadrants of the CVF arguably reflect different organisational characteristics that could either be compatible or incompatible with the socio-cultural barriers discussed. The CVF can thus be used to gain a more detailed understanding of how socio-cultural barriers manifest and inhibit C2C implementation in business parks. The entire study framework presented in Figure 1 relates stakeholder organisational characteristics - as defined by the CVF - to the extent to which these socio-cultural barriers/drivers would influence the implementation of C2C actions and achievement of C2C outcomes. The C2C actions and outcomes in the framework are derived from Table 1.

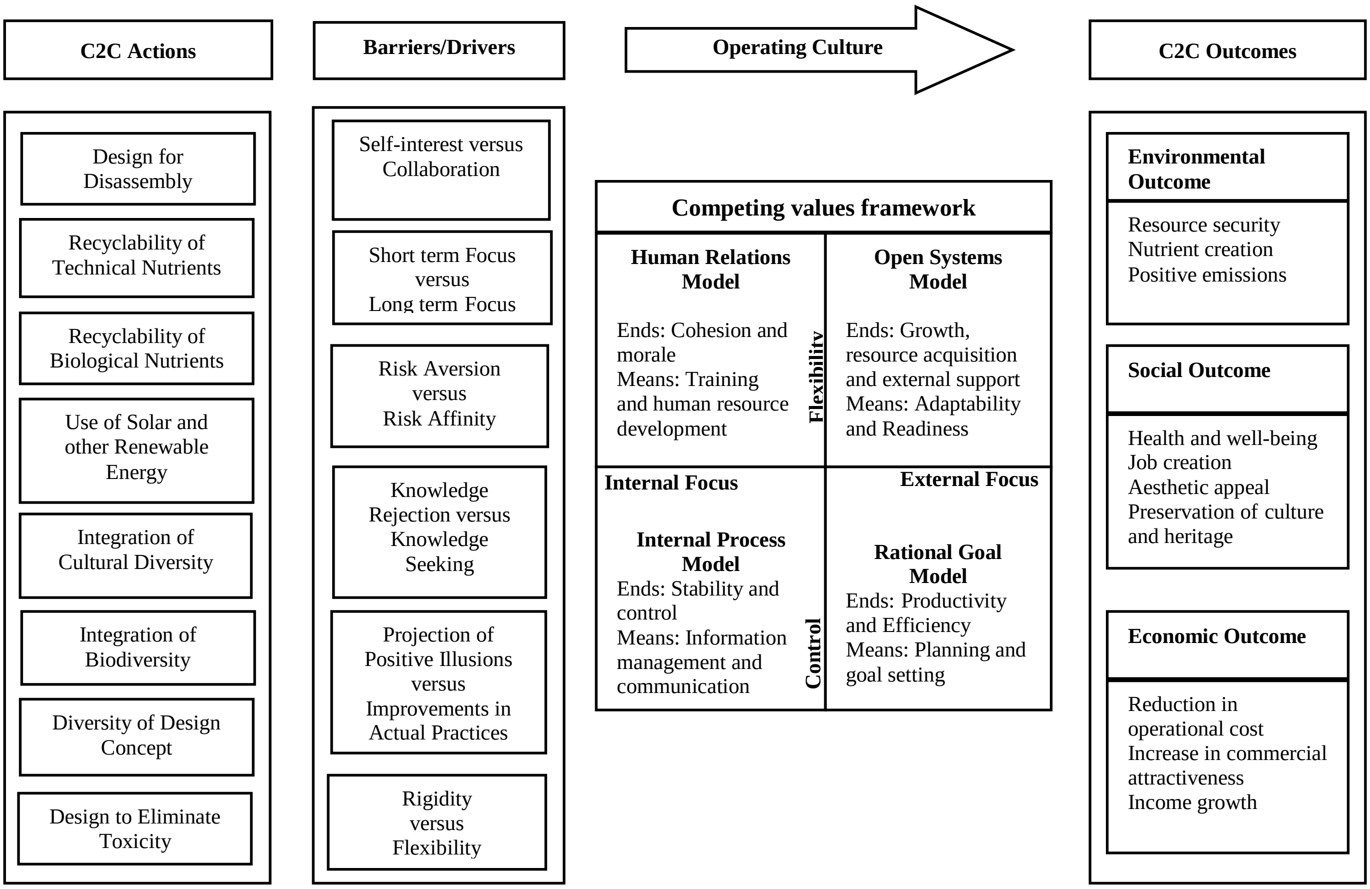

Figure 1: Proposed framework for assessing the socio-cultural influence of C2C implementation

It is proposed that stakeholder organisations that are more oriented towards the internal process culture will emphaise control through risk minimization and conformity. Barriers such as risk aversion, bureaucracy and self-interest are likely to be more pronounced although they may seek knowledge towards incremental improvements in relation to C2C especially when viewed as a means to achieve conformance with existing regulations. Conversely, stakeholder organisations that are more oriented towards the open systems culture create by promoting innovation, vision and constant change. They are most likely to overcome all barriers as they focus on the long-term, encourage risk taking, seek knowledge and are very flexible especially when C2C is conceived as a means to achieve innovation. It is also proposed that stakeholder organisations that are more oriented towards the human relations culture would promote human resource development and seek long-term C2C outcomes that are predominantly social in nature. Barriers such as short-term focus and knowledge rejection are thus likely to be overcome except their internal focus may still present barriers to external collaboration. Stakeholder organisations that are more oriented towards the rational goal culture compete and focus on achieving immediate gains. Barriers such as knowledge rejection are likely to be overcome whereas bureaucracy, short-term focus and self-interest may still be well pronounced. There is also the tendency that such stakeholder organisations would be mostly driven by C2C outcomes that are predominantly economic in nature.

Though the framework in Figure 1 can be applied to different developments, it is been applied in this study to business park developments. The validation of this framework as a tool to interrogate the socio-cultural barriers to C2C implementation in the context of business parks is however yet to be undertaken as part of an on-going study.

6 CONCLUSIONS

The C2C philosophy has been discussed as a paradigm changing innovative platform for creating a positive ecological footprint in the built environment. C2C has been argued as a development model that can transform business parks to economic growth hubs that provide truly positive social and ecological benefits. Though several strategies have already emerged from circular economy and industrial ecology studies on how to realise “closed loop” systems in business parks, it has been argued that such efforts have not been entirely successful as they often focus on reduction of negative impacts rather than the promotion of positive gains. The three C2C principles are advocated for as strategies for realising positive impacts in the business park context. However, implementation of C2C principles is likely to be hindered by socio-cultural barriers prevalent amongst development stakeholders. There is the need to further interrogate the extent to which such socio-cultural barriers influence C2C implementation. To guide further empirical investigation, the CVF has been proposed as an ideal framework for understanding the extent to which socio-cultural barriers manifest amongst development stakeholders and inhibit C2C implementation. The resulting study framework has led to some theoretical propositions that would subsequently be tested with field data using business parks as a backdrop. A key proposition is that stakeholder organisations that are more oriented towards the open systems culture would be the most likely to overcome all socio-cultural barriers and implement C2C actions as a means to promote innovation. The proposed socio-cultural study framework, which can also be applied to other developments, is however yet to be validated through a pilot study involving business park stakeholders.

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REFERENCES

M.H. Bazerman, D.A. Moore and J.J. Gillespie, "The human mind as a barrier to wiser environmental agreements", *American behavioral scientist*, 42(8), 1277-1300 (1999).

B.A. Bechky, "Gaffers, gofers, and grips: Role-based coordination in temporary organizations", *Organization Science*, 17(1), 3-21 (2006).

A. Chalifoux, "Using life cycle costing and sensitivity analysis to "sell" green building features", *Journal of Green Building*, 1(2), 39-48 (2006).

W. Debacker, T. Geerken, P. Stouthuysen, V.M. Holm, K. Vrancken and S. Willems, *Sustainable building, material use and cradle to cradle: A survey of current project practices*, OVAM, Mechelem, Belgium (2011).

D. Gibbs, "Trust and networking in inter-firm relations: the case of eco-industrial development", *Local economy*, 18(3), 222-236 (2003).

K. Grosskopf and C. Kibert, "Developing market-based incentives for green building alternatives", *Journal of Green Building*, 1(1), 141-147 (2006).

A.J. Hoffman and R. Henn, "Overcoming the social and psychological barriers to green building", *Organization & Environment*, 21(4), 390-419 (2008).

G. Hüsken, M. Hunger and H. Brouwers, "Experimental study of photocatalytic concrete products for air purification", *Building and Environment*, 44(12), 2463-2474 (2009).

W.M. Kempton, J.S. Boster and J.A. Hartley, *Environmental values in American culture*, MIT Press (1996).

M.K. Linnenluecke, S.V. Russell and A. Griffiths, "Subcultures and sustainability practices: the impact on understanding corporate sustainability", *Business Strategy and the Environment*, 18(7), 432-452 (2009).

E.A. Lowe, S.R. Moran and D.B. Holmes, *Eco-Industrial parks: a handbook for local development teams*, Indigo Development (1998).

W. McDonough and M. Braungart, "Towards a sustaining architecture for the 21st century: the promise of cradle-to-cradle design", *Industry & Environment*, 26(2), 13-16 (2003).

W. McDonough, M. Braungart, P.T. Anastas, and J.B. Zimmerman, "Applying the principles of green engineering to cradle-to-cradle design", *Environmental Science & Technology*, 37(23), 434-441 (2003).

O. Memedovic, *Europe and central Asia conference on industrial parks as a tool to foster local industrial development* (2012).

D. Mulhall and M. Braungart, *Cradle to cradle criteria for the built environment*, Duurzaam Gebouwd, Netherlands (2010).

L.K. Petersen and A.H. Andersen, *Socio-cultural barriers to the development of a sustainable energy system-the case of hydrogen National Environmental Research Institute*, Aarhus University (2009).

T. Ratinho and E. Henriques, "The role of science parks and business incubators in converging countries: Evidence from Portugal", *Technovation*, 30(4), 278-290 (2010).

E.H. Schein, *Organisational culture and leadership*, Jossey-Bass Pub,San Francisco (1992).

W.R. Scott, Organisations: Rational, natural and open systems. Prentice-Hall, NJ (2003).

E.M. Van Bueren and H. Priemus," Institutional barriers to sustainable construction", *Environment and Planning* B, 29(1), 75-86 (2002).

K. Williams and C. Dair, "What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments", *Sustainable Development*, 15(3), 135-147 (2007).

R.F. Zammuto, B. Gifford and E.A. Goodman, “Managerial ideologies, organisational culture and outcomes of innovation: a competing values perspective”, *Handbook of organisational culture and climate*, Ashkanasy et al. (eds.), Sage Pub. Inc., 261-278, Thousand Oaks, California (2000).

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INTEGRATION OF BIM IN HIGHER EDUCATION: CASE STUDY OF THE ADOPTION OF BIM INTO COVENTRY UNIVERSITY'S DEPARTMENT OF CIVIL ENGINEERING, ARCHITECTURE AND BUILDING

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Abstract. *In the context of Architecture, Building Information Modelling (BIM) is a design methodology which enables all of the design details, decisions and characteristics to be held within a collaborative digital representation and information package. The design and project information can then be shared, accessed and altered live, facilitating an efficient and fluid collaborative design and asset management process across the whole life cycle of a building. It is argued that BIM has many benefits for projects such as reducing waste, improving the efficiency and enhancing collaboration between different parties to a project which can lead to improved quality and also cost and time reductions. Government drive indicates that BIM skills and information sharing, protocols and processes are essential for improving efficiency of design and operational performance of buildings. It is therefore important that the principle of BIM is integrated into the training of future construction professionals. The aim of this paper is to outline the process that has been undertaken to integrate BIM within the undergraduate curriculum at Coventry University's Civil Engineering, Architecture and Building (CAB) department. A critical analysis of a case study construction engineering department has been carried out to inform the development of the strategy for integration of BIM within existing course structure. The case study offers a lesson on the adoption of BIM to enhance the student skills and understanding relevant to their professional disciplines.*

Keyword: *Building Information Modelling (BIM), collaboration, higher education, low impact buildings, sustainability, integrated design*

1 INTRODUCTION

The Department of Civil Engineering, Architecture and Building (CAB) at Coventry University recently embarked on the task of integrating BIM theory and practices across its undergraduate and postgraduate degree courses. The department has a clear objective that it wants all students on graduation to leave, with a greater awareness of 'BIM' and the practices involved through both theoretical and practical skills. Smith et al (2009 p.xxvii) argues that “Building information modelling is nothing more and nothing less than a systems approach to the design, construction, ownership, management, operation, maintenance, use, and demolition or reuse of buildings. A building information model is any compilation of reliable data in single or multiple electronic data formats, however complete or incomplete that supports a systems approach in any stage in the lifecycle of a building”. This may be seen by some as an over simplification but in essence if all members of a project team collaborate together, through the entire project life cycle with BIM theory at the core of the design process the benefits that can be achieved are vast.

A core feature of working within a BIM environment is the drive towards encouraging multi-disciplinary collaboration from the very outset of a project. The benefits of all disciplines working together within one core BIM environment are multiple. A major issue that is experienced within non BIM design processes is the matter of conflict in different design outputs. The ethos of having a core central BIM model is to facilitate a smooth transition through these issues by identifying conflicts earlier on in the design and construction process thus reducing the negative effects on time and costs. Projects can be visualised and evaluated early in the design process allowing the client and designer alike to optimise the design with regards to special and environmental performance.

Angela Brady (2012) states in the RIBA BIM overlay plan of work, "the aim (of the BIM overlay) is to assist design and construction teams in using BIM to provide a more efficient, intelligent and cost effective design process and to offer enhanced services to clients, particularly in relation to the whole life of buildings".

2 METHODOLOGY

The research has been carried out using critical evaluation of content of undergraduate courses within CAB department in Coventry University as a case study for integration of BIM into Higher education. The research also relied on the critical review of current knowledge in the areas of government policy, application of BIM in the construction industry and the integration of BIM into higher education courses. The evaluation uses a descriptive case study approach where a critical evaluation has been carried out of the current state of courses relative to the opportunities for collaborative working practices with a view to integrate BIM throughout the undergraduate degree and improve the ability of students to develop critical skills required in the construction sector. Coventry University has been using Project Based Learning (PBL) to provide an opportunity for students to work in groups and therefore have the opportunity to practice aspects of collaborative working practices expected in the construction industry. The case study approach used in this paper also looked at this collaborative working platform and reviewed its effectiveness relative to the application of BIM through the PBL. Stage 1 of the study will evaluate department’s current initiatives to integrate BIM into the various aspects the courses. Stage 2 of the study will evaluate the departments’ future development plans to further implement the BIM integration strategy.

3 DRIVERS FOR BIM IN HIGHER EDUCATION

Over the last few years the UK Government has made significant moves outlining where they expect the construction industry to be over the coming years in regards to BIM. The UK Government has mandated that all public building projects will have to be using BIM design processes at level 2, fully collaborative 3D BIM, or higher by 2016. As Francis Maude (2012), Minister for the Cabinet Office states, “The Governments four year strategy for BIM implementation will change the dynamics and behaviours of the construction supply chain, unlocking new, more efficient and collaborative ways of working. This whole sector adoption of BIM will put us at the vanguard of a new digital construction era and position the UK to become the world leaders in BIM”. The Cabinet Office states in the Government Construction Strategy (2011) “there is a detailed programme of measures Government will take that will reduce costs by up to 20% by the end of this parliament”; it is believed that BIM will be one of the key factors in achieving this target.

As discussed in the BIS BIM strategy Report carried out by the BIM Industry Working Group (2011, p6) “key to any successful change programme is communication of the change and adequate support during the process”, part of the responsibility to provide that support will fall on Academic Institutions. The BIS BIM strategy Report (2011, p6) goes on to state that in regards to how training is provided the “recommended solution is a strongly led hybrid provider drawing on the educational and research expertise of universities, the robust experience of accrediting bodies and the engagement of credible industry led best practice, as well as vocational training delivered by CPD or the training supply chain.”.

Barison and Santos (2009) found the application of BIM in HE to be focussed predominantly on single course integration rather inter-disciplinary. However, the application of BIM in the industry is an integrated practice that allows for effective collaboration between different professionals. It is with these facts in mind the CAB Department has started to incorporate BIM across its degree programmes, with the aim of improving the BIM awareness and skills necessary for which will be necessary for effective cross or inter-disciplinary collaboration. Another key driver in the push for wider adoption of BIM across the industry is the positive effects that BIM working practices will have in regards to delivering low impact sustainable buildings for the future, in an increasingly energy conscious time. The target is that by increasing the BIM awareness and skills of students, whilst at the same time parallel to these increasing students’ abilities to analyse and design low impact buildings, graduates will be in the best placed position to contribute positively to the future of the construction sector.

The National BIM Report 2012 canvassed the opinions of over 1000 participants with differing levels of awareness and understanding of BIM for 2011. The results show that 73% of participants agree that the industry is simply not yet clear enough on what BIM actually is. Following on from this, NBS repeated the survey in 2012-13 titled the NBS National BIM Survey 2013, canvasing the opinions of the industry for the year 2012. The same question was asked and this time around 74% now felt that ‘the industry isn’t yet clear enough on what BIM is yet, clearly there is still further work to be done in regards to preparing the industry. Also highlighted within the findings is the lack of awareness amongst all participants. The National BIM Report 2012 established, “that awareness of BIM is (was) not universal, with 21% of participants stating that they were not aware of BIM (in 2011)”. In the repeated study, NBS National BIM Survey 2013 the same question was asked again, this time around however the number of participants ‘neither aware nor using BIM’ fell to 6%. This result is a marked improvement on previous years amongst the industry participants. As good as an improvement as this last result is it would be somewhat counterproductive if Higher Education institutions allowed graduates to leave university without any awareness of BIM themselves. This could hinder the Government and industry in their push for greater adoption of BIM, whilst at the same time hindering graduates chances of gaining the opportunities they strive for. It is one of the responsibilities of Higher Education institutes to provide graduates with the necessary skills to succeed with an increasingly competitive industry, with an awareness and ability to work within a BIM working environment being one of those skills.

The extent to which BIM is adopted across the construction industry depends on whether industry leaders buy into the Governments sentiments. Currently major players within the industry are making strong drives towards the adoption of BIM, with some already delivering projects at maturity level 2. Balfour Beatty has recently invested a considerable amount of funds into the adoption of BIM across their company. In 2012 Balfour Beatty "signed a three year, $12 million agreement that will help Balfour Beatty expand its adoption of Building Information Modelling (BIM)" balfourbeatty (2012). Capita Symonds have also been investing heavily in the adoption of BIM they announced that from "July 2012 all its new design projects will use BIM Level 2 as standard" capitasymonds. (2013). The Royal BAM Group also recently signed a three year contract worth "(£2.8m) with software firm Autodesk to provide Building Information Modelling (BIM) technology across its global operations, including all BAM projects in the UK" building (2013). Speaking about the deal in October 2012, BAM Construct Design & Marketing director Chris Gilmour stated that BIM would be used across all projects, "Not just special projects – no matter how big or small the project, we will be fully embedding BIM" www.building.co.uk (February 2013). This review of the construction industry is by no means exhaustive; it is however a small indication of the commitment that industry is making towards adopting BIM.

4 STRATEGY FOR INTEGRATION OF BIM IN THE CAB DEPARTMENT

4.1 Stage 1 – Current Initiative

The first stage in enhancing students awareness of BIM was taken through the introduction of a 'Project Implementation Plan (PIP) coursework' (which can otherwise be known as a BIM execution plan) for a second year inter-disciplinary group project involving 230 students working in groups. This particular idea concentrates on the 'Information' aspect of BIM. There is no design aspect to the projects, just a clear focus on the PIP document to effectively plan the projects, emphasising collaborative and integrated working practices. The next step is to improve students awareness of BIM through lectures on theory and context. This is driven by the findings of NBS National BIM Survey (2012), which finds 74% of participants agreed that the industry was simply not yet clear enough on what BIM actually is. The expectation is that these BIM awareness lectures will help to address this issue.

4.2 Stage 2 - The Future Initiatives

The second stage aims to further incorporate BIM across the undergraduate courses. The aim is to give first year students a taste of the collaboration skills required for group work at the very start of their studies at Coventry, without explicit reference to 'BIM'. The early exposure of students of the principles of BIM will ultimately smooth the learning curve as they encounter these issues through their course. In addition technical tutorial support will be provided to second year students from all construction and engineering courses through BIM software workshops.

In addition, the department is reorganising its third year multi-disciplinary collaborative integrated project module with the aim of getting the best BIM integration as possible. The final year project runs with around 250 students, working in groups from multidisciplinary backgrounds within the CAB Department. The ethos of the module is to replicate collaborative construction industry processes, as reasonably close as possible, within an academic setting. The module aims to develop knowledge and skills that will help the student's capacity for group integration, across various construction professions, by undertaking a major construction scenario-based project. Students are expected to synthesize the knowledge gained in taught modules and apply these skills and abilities to the development of a project from inception through to tender. Of equal importance to these technical skills is the personal and professional skills that the students are expected to further develop through participation in the Integrated Project. These include the development of critical, analytical and transferable study skills, which are of practical benefit in the workplace and key to continued professional development. The module has been running for a number of years and therefore the infrastructure that is currently in place for this module opens up a valuable opportunity to integrate live BIM practices. The aim is to realign the module to suit the departments BIM learning requirements.

The first steps that have been embarked on are to establish exactly what level of BIM competency the students need to achieve. Establishing the level of BIM that is feasible to integrate within undergraduate students is an ongoing point of discussion that will need to be continually evaluated and developed. The expectation is to improve the student awareness in the practices and processes involved in working on a BIM collaborative and integrated project. The module team is building on this platform and in essence is repackaging the module with a greater emphasis placed on the BIM collaborative processes and the sustainability of the project. For the wider range of parties involved in the project the concentration may be more on the 'Information' sharing aspects of BIM. Working within a BIM environment, adopting BIM information sharing protocols, collating the data in an interoperable format, and utilising documents such as the 'Project Implementation Plan' aims to improve how information is shared amongst all the varying parties involved.

There are two major aspects to the project, the first will be the low carbon refurbishment and redevelopment of the case study building and secondly to design new extension directly attached to the case study building. The refurbishment task requires initial benchmarking of the current building performance against similar buildings in the sector. Effective collaborative effort between teams will have to be demonstrated in the proposed improvement strategy with respect to functionality and energy performance criteria. The team will be required to predict the effectiveness of design choices and going through reiterative process to optimise the design. The second part of the project will be to create a new modern extension to the case study building. The teams will be required to create an optimised architectural design and focal point.

The overriding core directive for the project will be the BIM coordination and collaboration. Teams will be directed to ensure that they adhere to a BIM ethos and collate the team's project information into an interoperable design package. Running under this core directive will be three key main threads; the architectural design, the structural design and the sustainability strategy. The aim will be for the three key main threads to integrate seamlessly with each other. Sustainability has existed in previous entities of the module so is not something completely new, however, a greater emphasise will now be placed on this area ensuring that the project replicates the industry's desire and need for low impact design and sustainable buildings for the future, allowing students to graduate with a greater understanding of BIM working practices and low impact design strategies.

To immediately immerse the teams into a BIM working environment, the teams, once formed, will be presented with the task of formalising the groups 'Project Implementation Plan (PIP)'. The PIP plan will set out the working and information sharing protocols for the teams from the outset. The PIP plan will be a follow on from the PIP plan all students completed in year 2. The idea is that by having completed a smaller PIP plan, the learning curve progressing on to the year 3 PIP will be reduced. The result being that when students embark on the final year Integrated Project they will already be familiar with the PIP plan and therefore BIM working and information sharing processes and protocols, enabling them to adopt a greater understanding and emersion of BIM within the final year Integrated Project. The emphasise at this initial stage will be for students to firm up their information sharing protocols to ensure that the full team is aware of the agreed processes and directives.

A predominant element of the new Integrated Project format will be the designation of a BIM coordinator role as well as the creation of a BIM coordination task (BIMC). It will be the job of the BIM coordinator to ensure that the BIM content and coordination is developed and maintained, to ensure that all the team members collate and present all information in one cohesive document, printed and electronic. The separate task will set out directives to assist the BIM coordinator in understanding their role. By creating a separate task and a titled team member's role the aim is for the BIM coordinator to lighten the workload of all the other members in regards to information processing and exchange, crucially reducing the workload of the lead designer who in our case will be acting as the model manager in the later stages of the project.

As well as the BIMC task, each group will be provided with a base 3D model of an existing university building. The base model that the students will receive as a 'starting block' will be provided in two different formats, REVIT and SketchUp. Students who progress through the different degree courses will gain a differing set of software skills depending on the requirements of each specific course, hence the variation in the format of the base model provided. This therefore represents a micro representation of one of the main issues that the industry is facing in regards to a lack of the required skills amongst staff. Therefore, Coventry will be adopting an 'OpenBIM' approach to the module, where all groups will have to ensure that file sharing and interoperability are carefully considered.

Groups will need to produce plans of their design and amend the existing 3D model; the software adopted will depend largely on the previous experience of the team members. The groups will then be tasked with creating a new extension to the existing building in response to the scenario brief requirements whilst also considering and developing ideas on how they can upgrade the existing structure on site. The idea of using both of these approaches, existing building interrogation and new build extension is significant. Industry consultation has shown that through using an existing building, which would be surveyed, evaluated and then upgraded to improve the energy performance, the students experience a potentially valuable side of BIM, 'BIM used as a tool for the energy improvement of existing buildings'. At the same time having each team design an extension to the existing building opens up the door for groups to be able to gain skills in areas of new design processes. The aim is that by having these two different approaches to the scenario brief students will be able to access the most rounded BIM experience.

Each group will have to consider how they can upgrade the existing building with the aim of improving the energy performance. The sustainability strategy will be an extremely important aspect which teams will have to consider carefully, a minimum BREEAM rating of 'very good' will be requested for the existing structure with a rating of 'excellent' for the new extension. Existing building stock presents an important area of opportunity and challenge for reducing carbon emission in Europe. It is believed that BIM information processes and modelling will be an important tool in the future, utilised to analyse and upgrade existing buildings, improving the facilities management and energy performance of current building stock. The task will be set up to involve multi-disciplines in the process of energy survey and low carbon redesign. This project will focus on an energy survey of the existing building and benchmarking that against similar types of buildings within the sectors, this energy survey will allow the students to identify areas of improvement. The students will be expected to develop a strategy for low carbon refurbishment and predict the benefits of such interventions using thermal modelling software. The collaboration in this instance will be achieved through understanding of inter-operability of different software environments such as sharing files between 2D CAD, BIM software (3D modelling and BIM platforms), and thermal modelling software such as IES Virtual Environment and Ecotect. It is expected that this aspect of the work will lean heavily on all professional disciplines. The target is that by ensuring that all team members are involved in the sustainability strategy all of the team will need to be aware of the consequences that their decisions have on the environmental impact of a design. The integration of the sustainability strategy findings with the architectural/structural design will be closely reviewed with the aim of creating a distinct sustainable strategy which needs to be seamlessly integrated with the design teams processes and therefore increase the low impact design awareness of all graduates.

The Civil Engineering teams of each group will be tasked with creating a structure for the new extension; students will be given free rein to design the initial structure on any CAD design platform. The next key step will be to get each Civil Engineering team to then transfer this data into a 3D BIM platform, if they haven't already used one in the first place. This is one of many processes in which interoperability of students working environment is crucial. To successfully complete the task students will have to demonstrate an understanding of the interoperability of software. To assist in this crucial step of the design process all groups will be offered support and tutorials to assist them, likewise to other processes that may be unfamiliar to students. The major benefit in having a 3D model of the structure will be that it can be analysed and interrogated within the BIM and structural analysis software. Each Civil Engineering team will be allocated certain tasks requiring them to integrate their structural designs further, giving them a greater understanding of the capabilities and benefits of using 3D parametric software. The ability for Civil engineers to be able to demonstrate an understanding of how to interrogate 3D structural design software aims to lead to improvements in the programming, cost and the integrity of structural designs.

Throughout the integrated project there will be a number of aspects to ensure that groups develop and demonstrate an understanding of interoperability. Teams will be tasked to merge their differing models (structural design model and Architectural design model). At this point groups will receive learning on how to model share regardless of format. During the model merging process teams will have to utilise IFC data standard import and exports. The aim of the task is to ensure that students become aware of the interoperability of data sharing and the demands and consequences that it has on the design process. Each model will be evaluated, manipulated and analysed as the group's progress through the module. As previously discussed teams will continue to investigate the effectiveness of design choices adopting a reiterative design process. The target is to move individual team members away from 'silo'd' design processes towards collaborative and integrated working practices. The aim is that through replicating some of the challenges which industry will need to overcome to achieve BIM maturity level 2 and level 3 and by moving away from isolated design practices, graduates will develop the skills required to successfully work within a BIM collaborative and integrated working environment.

The teaching processes of BIM will be supported by a range of 3D BIM models. The emphasis for first year students learning is on domestic buildings, as such a BIM domestic house design is being created. The model will be completed to such a level that it can be interrogated, analysed and navigated, including multiple points of interest such as MEP detailing, cost/quantity take-offs and energy analysis. Although in reality a BIM model may not be required for a domestic design, the ethos is that if students are made aware of the processes involved in creating, interrogating, analysing and navigating a BIM model within a simplified context then it should reduce the learning curve on more complex models. The emphasis for second and third year students is larger buildings. Two university estate buildings will be modelled and completed to an intensive level enabling a multitude of interrogation and analysis to be carried out by students and staff for training purposes. The two Building will be the recently opened Engineering and Computing building (ECB) and the student's main place of work within CAB the Sir John Laing Building. The Sir John Laing (JL) case study will provide the opportunity for CAB students to evaluate and analyse the building that they use everyday. The intention is that by using a familiar building the engagement of the students will be stronger. The buildings can then be taken through multiple BIM design processes enabling them to be interrogated, analysed and navigated by staff and students alike. The objectives of creating these 3D BIM model teaching aids are numerous. In one instance the models can be used by teaching staff across numerous programmes allowing lecturers the ability to visualise different concepts to different students. Another use of the models will be to allow students to actively engage within lectures and tutorials by utilising the BIM models. The intention is that the models will not solely be used for teaching BIM. The aim is for staff to utilise the models across multiple disciplines and modules, whether it is a first year construction technology module, showing details of a house design, or a second year lecture on 'BIM Awareness'. Further to this the models can be used as a teaching aid for building service engineers showing service installation details. Therefore, the aim is for the models to become an integral part of teaching within multiple modules.

5 A CRITICAL ANALYSIS OF THE CURRENT AND FUTURE INITIATIVES

The target to provide all students with an awareness of BIM practices, regardless of discipline, is in response to the lack of skills and knowledge across the industry that currently exists in regards to BIM. As stated in the BIS-BIM-strategy-Report (2011, p6) which was carried out by the BIM Industry Working Group, by "engaging providers in the development and delivery of the material and standards will not only accelerate competency and adoption, but also will align the level and calibration of future industry professionals emerging from universities and provide a structure for lifelong development learning around BIM". The expectation is that Coventry will be providing the industry with graduates that are capable of working efficiently as part of a BIM project. It is questioned that currently as things stand within the construction industry a severe lack of skills and knowledge exist which needs to be addressed. It is this within this area that Higher Education has not only the facilities and ability to assist the industry but also the responsibility to provide graduates and the industry alike with skills which are transferable and applicable to what the industry requires today and in the future in regards to BIM and all other industry practices.

6 CRITICAL REVIEW OF THE CHALLENGES

A framework developed by Hopkins (2006) on the ‘Challenges and Barriers to Education for Sustainable development (ESD)’ has been used to review the challenges and barriers that Coventry University may face in the process of integrating principles of BIM into all aspects of course and modules delivery. Even though the framework developed by Hopkins was focusing on the challenges faced by ESD, many of the issues identified are applicable to the challenges that will be faced in the adoption of BIM in education. One of the first challenges is to increase the awareness of BIM amongst the existing teaching staff within the Department. If BIM is to be developed across all undergraduate courses then staff that may not be directly impacted by BIM still need to be made aware of it and why the Department is pushing forward in this direction. Additionally, more specialised individual professional learning will be required by staff to ensure that all those involved in the delivery of BIM are competent. However, individual professional development is something that is welcomed amongst all those involved. The next issue concerns the integration of BIM across the CAB curriculum. It has been decided early on that all students should gain an awareness of BIM. The difficulty with this is ensuring that the differing disciplines gain the appropriate amount of awareness and skills needed, beyond that of the initial ‘BIM awareness lectures’. This is something that will be continually developed and assessed as the research continues. Another issue is dealing with the complexity of BIM concepts. It is paramount that the skills and theory that are to be taught do not confuse students more than when they started. As Charles Hopkins (2006) stated within his work, when something is hard to define it can also be difficult to teach, an aspect that BIM is guilty of. Another challenge to be considered later on will be changes to the current courses, in regards to BIM. The courses within the department are set up carefully to cover many specific learning outcomes needed within the professional context. The challenge will be for the Department to integrate BIM seamlessly within the structure of existing courses and modules. Therefore, an important criterion concerning the success of the adoption of BIM will be the sharing of the responsibilities. The team feels that the adoption of BIM into an education setting cannot solely be the work of one BIM initiator. The correct framework needs to be in place amongst all staff. Departmental heads have provided support regarding the adoption of BIM, which each member of the team is aware of. This has ensured that everyone involved is pushing in the same direction.

7 CONCLUSIONS

BIM is a crucial part ensuring a reduction in time, cost, waste and carbon consumption. The skills gap in the industry can only be closed through integration of the principles of BIM throughout the fabric of undergraduate courses in HE. The CAB department is making good steps towards the adoption of BIM across the undergraduate degree courses at Coventry University. This case study reflects both the current stages and future plans for the integration of BIM in the department including critical evaluation of possible challenges and opportunities. Over the next few year's valuable data and insight will be gathered by the Department to assess the effectiveness of the steps taken. The Department will continue to develop new ways of engaging students and improving their soft and hard skills, relevant to successful practice in a multi-disciplinary field of construction. The aim is to teach more efficient design processes which lead to reduced time, cost, waste and carbon consumption whilst also enhancing skills of building design and information sharing processes leading to greater integration and collaboration. The interrogation of designs will also be a large aspect of the student's studies, with improving the sustainability and efficiency of building a key theme. The next steps for the Department will be to continue to develop new BIM integration strategies whilst at the same time continually assessing the effects of the current strategies that have been implemented. The path forward will include the creation of BIM modules at Masters Level, to provide further opportunities for improving the skills in both project and strategic level of decision-making relevant to the implementation and management of BIM processes in the construction industry. The Department feels that BIM will be a major aspect in the future of the construction industry; the aim is to prepare Graduates with relevant skills and knowledge to be able to succeed within a continuously homogenous and collaborative industry.

REFERENCES

Balfour Beatty Signs agreement with Autodesk to expand Building Information Modelling capabilities, Available at - http://www.balfourbeatty.com/index.asp?pageid=42&newsid=340 [Accessed in February 2013]

BIS-BIM-strategy-Report (2011), Available at - http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf. [Accessed in February 2013]

Capita Symonds Announces BIM Plans - Available at - http://www.capitasymonds.co.uk/news__events/latest_news/capita_symonds_announces_bim_p.aspx. [Accessed in February 2013]

Government Construction Strategy (2011), Available at - https://www.gov.uk/government/publications/government-construction-strategy. [Accessed in February 2013]

C. Hopkins et al., *Education for Sustainable Development in Action Learning & Training Tools N°1*. Publication through UNESCO in support of the United Nations Decade of Education for Sustainable Development (2006),

F. Maude, *The BIM Task Group* (2012). Available at - http://www.bimtaskgroup.org/. [Accessed in February 2013]

D. Smith and M. Tardiff, *Building Information Modelling*, John Wilev & Sons (2009).

The National BIM Report (2012), Available at - http://www.thenbs.com/pdfs/NBS-NationalBIMReport12.pdf. [Accessed in February 2013]

M. Barison and E. Santos, E., *BIM teaching strategies: an overview of the current approaches*. Nottingham University Press (2009).