ICT in Construction and Facilities Management

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ICT in Construction and Facilities Management

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Preface

The use of ICT in project based industries such as construction is maturing fast. It is seen as a catalyst for change and an enabler for better planning, monitoring and control of construction and facilities management activities. Nevertheless, there is much that remains to be done as the construction sector exhibits a set of key characteristics that differentiate it from other sectors as reported by Hannus et al. [1] and Kazi and Charoenngam [2]:

- The sector is heterogeneous and highly fragmented, depending on a large number of very different professions and firms, which are mostly small in size, tend to respond to local market needs and control only one element of the overall building process.

- Construction is one of the most geographically dispersed sectors with marked regional differences.

- Construction is highly project oriented. Any ICT used within a project must be deployable and profitable to all / several partners.

- Each construction project, whether to create a new facility or a renovation/repair project is typically unique. The final product tends to be very durable, lasting 25-50 years and longer, and represents one of the few non-transportable industrial products.

- When construction facilities become obsolete they are most often repaired, modernised and sometimes radically transformed to suit new requirements rather than disposed of and replaced with new, which is more typical for manufactured products.

- The sector is highly regulated. Regulations and standards are more rigorous in construction than in most other sectors of economy, with the involvement of several levels of governments (local, provincial, national).

- The sector is very labour intensive, with high mobility of the workforce and growing skills needs as construction technology becomes more sophisticated. The duration of contracts is often linked to the length of the site construction phase.

- Business relationships are temporary and often short-term, bringing together partners who may never work together again.

In fact, ICT usage in the construction sector is limited when compared with other industries such as manufacturing. While in part this may be due to the unique characteristics of the construction industry, there is a tendency for late take-up of ICT solutions, or when no appropriate solution exits, construction organisations develop closed proprietary solutions. Based on a wide industrial analysis and set of consultations, a set of current ICT usage trends were identified by Hannus et al. [1] as shown in figure 1.

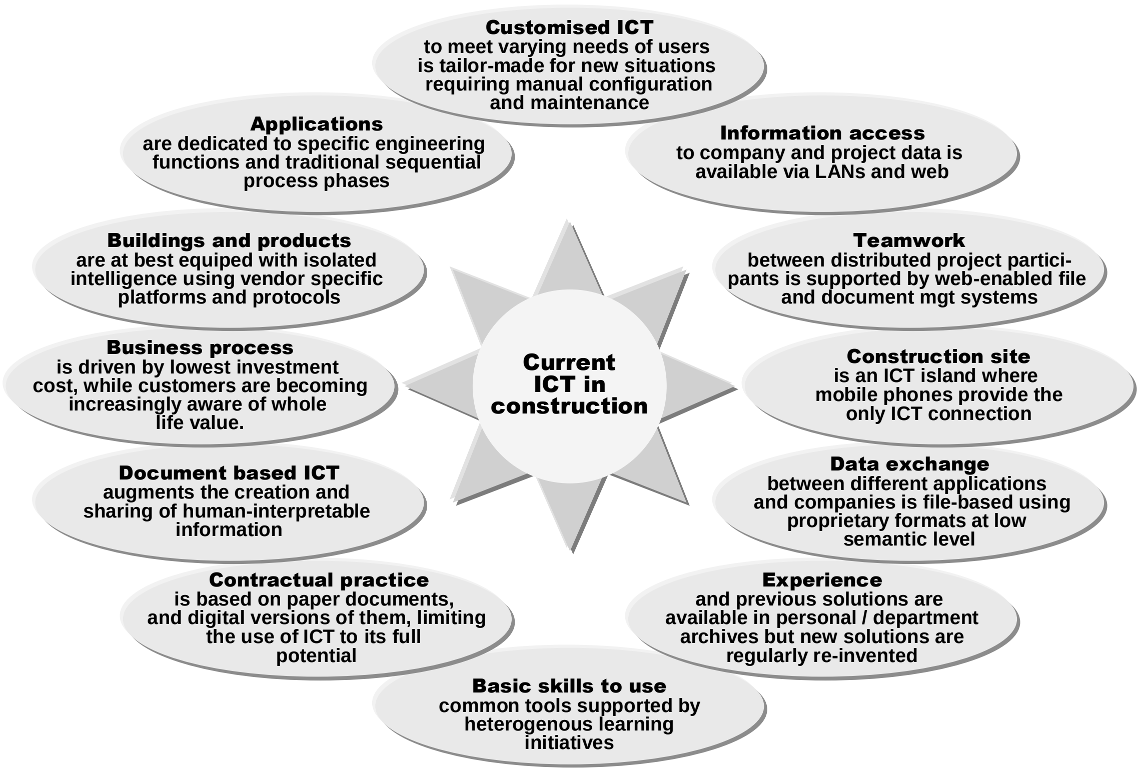

Figure 1: Current ICT Usage Trends [1]

Using the above trends (figure 1), as a baseline, a vision ICT in construction was defined as: *Construction sector is driven by total product life cycle performance and supported by knowledge-intensive and model based ICT enabling holistic support and decision making throughout the process by all stakeholders*. When compared with the current state (figure 1), it in essence promotes a paradigm shift from customised ICT to adaptive systems, from information access to ambient access, from teamwork to collaborative virtual teams, from construction site to digital site, from data exchange to flexible interoperability, from experience to knowledge sharing, from basic skills to ICT skills and awareness, from contractual practice to legal/contractual governance, from document based ICT to model based ICT, from business processes to performance driven processes, from buildings and products to smart buildings and products, and from applications to total life cycle support (figure 2).

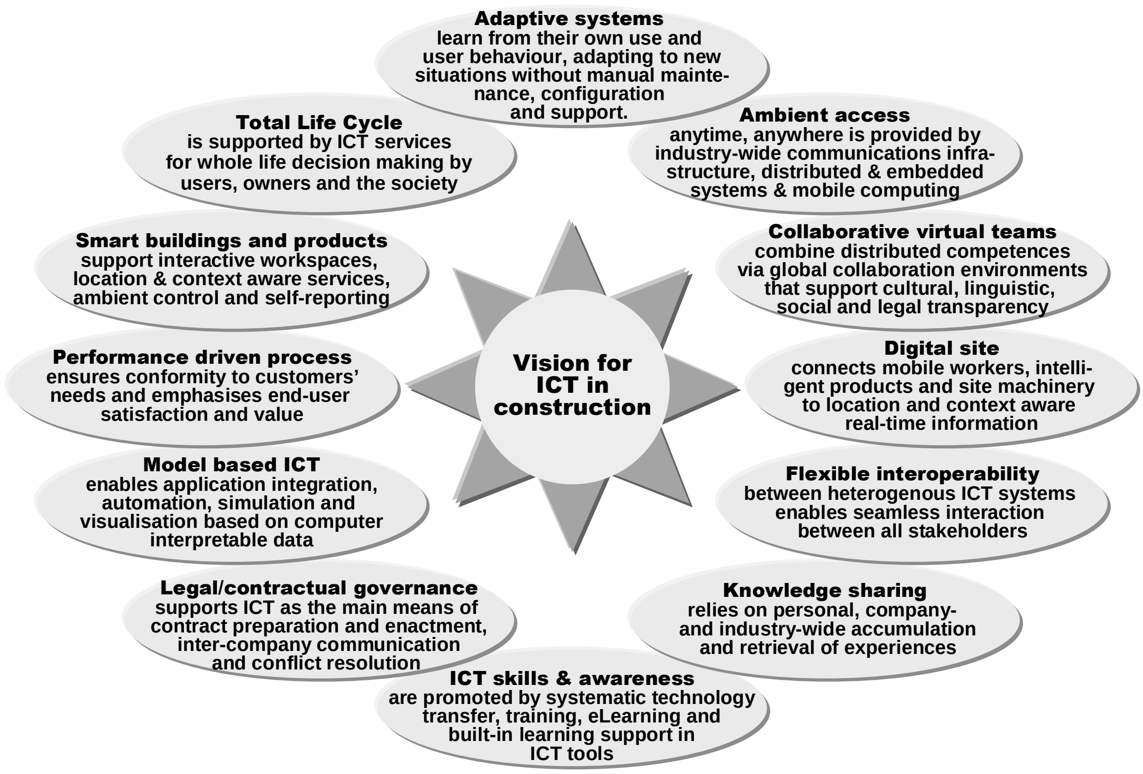

Figure 2: Vision for ICT in Construction [2]

One of the key steps in realising the transformation from the current state (figure 1) to the envisioned state (figure 2), is the mind shift in approach from data exchange and integration to interoperability. Efforts such as the nD modelling project [3] at the University of Salford, and the industry led initiative of the ProIT project [4] in Finland are major steps towards the realisation of the vision for ICT in construction and facilities management.

This book presents a global portfolio of ideas and perspectives in the development and use of ICT in construction and facilities management. The main coverage areas include ICT for design management, ICT in facilities management, the use of product models in construction, and the development and evaluation of ICT systems. While some cover research and development, others provide lessons learned from practice in the use of ICT for construction and facilities management. It is interesting to observe that all can to a certain extent be mapped on to one or more of the ovals (figure 2) contributing to the realisation of the vision for ICT in construction and facilities management.

Acknowledgements

This book would not have been possible had it not been for the untiring efforts of Dr. Kalle Kähkönen, Chief Research Scientist, VTT – Technical Research Centre of Finland, in championing the scholarly book series on *Combining Forces – Advancing Facilities Management and Construction through Innovation*. A special note of appreciation is extended to all contributing authors for their willingness and enthusiasm in sharing their research and experiences from practice.

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Section I

ICT for Design Management

ICT and the Architectural Design Process – Introduction of an ICT Impact Matrix

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Abstract

The essential topic of this paper is the impact of ICT on the architectural design process in the early planning stages. A fundamental pillar of a successful building project is a good design process. The use of ICT has over the years in different ways influenced and to a certain degree also changed roles and processes within the building project. An understanding of how ICT influences the complex mechanisms within the early stages of the planning process can be seen as central to achieve project success. The aim of this paper is to contribute to a better understanding and overview of the current situation regarding ICT related challenges and benefits within four essential aspects of the architectural design process. These aspects are: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. In the first section of the paper based on a literature review, some key elements from previous research in the area will be explored. Furthermore, an ICT impact matrix will be introduced, based on the four selected design process aspects and a definition of three hierarchical levels: the micro-, meso- and macro-level. The matrix outline suggests a way to organize the discussed design process topics on an overall level, and intends to contribute with a better overview of the ICT related impacts on the architectural design process.

Keywords: Architectural design process, ICT impact matrix, overview

1. Introduction

A fundamental pillar of a successful building project is a good design process. A primary idea emerges in a designer's head based on a complex iterative process between problem and solution. Taking into account different constraints set for the project the primary idea "materializes", eventually within a design team, into something that can become the conceptual fundament of the building project [1]. The future and development of a good architectural design solution depends on decisions made on several levels and by different actors. The architect will make his decisions about which design solutions are worth being put to the paper, and the client will be responsible for the crucial decision regarding which proposed concept should be developed further. The evaluation and decision-making due to a design solution depend among others of how it is communicated. The sender (e.g. the architect) of the information (e.g. the design solution) must encode the message in the form of some symbolic language, which is then transmitted, through a suitable medium (e.g. paper drawing scale 1:100), to the receiver (e.g. client) of the information. To access the design solution, the client must decode the message. Both the client and the architect decode and encode information based on their knowledge, or frame of reference [2]. Over the years, the ICT impact has lead to dramatic changes within the construction sector average working day. Both working processes and role definitions have been affected. The participants within the architectural design process face ICT related benefits and challenges at several levels. An understanding of how ICT impacts on the architectural design process and decision-making can be crucial for the overall success of the building project.

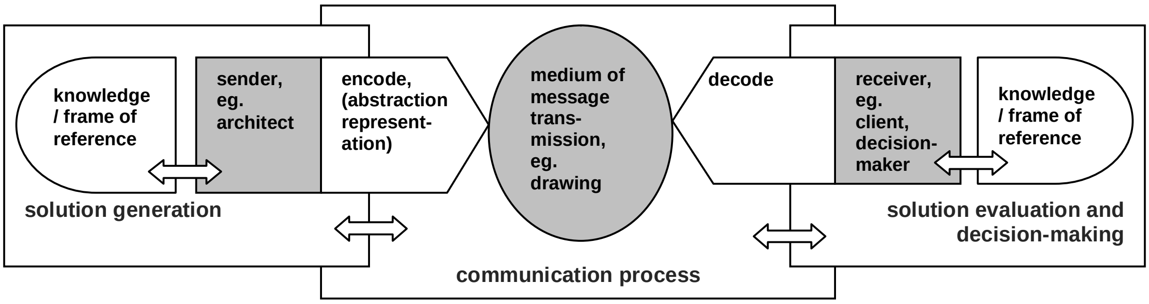

Figure 1: Illustration of the relations between the four selected architectural design aspects

The main topic of this paper is to contribute with a better overview and understanding of the today-situation of ICT related benefits and challenges due to four essential aspects of the design process: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. Figure 1 seeks to illustrate the relations between these four aspects, which are highly interdependent and iterative. The first part of the paper explores some key points, based on a literature review. This paper does not intend to give a complete picture of all ICT related impacts. Rather, the explored key points establish the background for the introduction of an ICT impact matrix, based on the four selected design process aspects and the definition of three hierarchical levels, the micro- (individual, e.g. architect), meso- (group, e.g. design team) and macro (overall/general, e.g. client)-level processes. The matrix outline suggests a way to organize the discussed design process topics, and could be one possibility to gain a better overview of the ICT related impacts on the different levels of the architectural design process. The introduction of the ICT impact matrix establishes the background for a theoretical framework and further research regarding the following issue: the ICT impact on building design management and decision-making – with focus on the architect's role and contribution.

2. The Generation of Design Solutions

There has been a lot of effort to describe and explain the design process and the generation of design solutions since the early 1960s [3]. The first generation design methodologists focus on the design process as something sequential and linear, was to be challenged. Lawson [1] critically emphasizes that there is no clear distinction between problem and solution, analysis, syntheses or evaluation in the design process. The design process is a simultaneous learning about the nature of the problem and the range of the possible solutions. The design problem is difficult to define and reveal, is multi-dimensional and interactive. The challenge for the designer is to understand what really constitutes the problem, to recognize hierarchical relationships, to combine and to integrate [1]. The designer operates in a virtual world, a constructed representation of the real world in practice [4]. Abstract models or the media of communication (traditional: physical models, drawings etc.) allow the designer great manipulative and immediately investigative freedom without incurring time or costs, which would have been the fact if the ideas had to be tested directly at the building site [1]. However, the first generations aim to organize the design process in a rational and logical way, thus saving more time and resources for the intuitive and creative moments of the process [3], still have some relevance. One vehicle of achieving these early aims, although with other means, could be ICT.

2.1 Computer Aided Design or Drafting

The generation of design solutions is still perhaps the area, in which the ICT at least has gained a foothold [1]. For the moment, the CAD (Computer Aided Design) systems used within the design process, supports drafting and modeling rather than special design attributes and analytical capabilities and have not changed the task of drafting or modeling [2]. However, CAD systems have this far definitely brought benefits, such as the possibility of producing a huge amount of drawings in a limited amount of time, and the possibility of creating highly realistic and professional representations of the design solution. But can CAD support the generation of the design solution itself? Or is CAD rather what Lawson [1] calls Computer Aided Drafting? Designer skills such as intuition and the "feeling-of" are difficult to describe and map, and until now the computer has been unable to copy these parts of the human intelligence. In addition, the design process is still not fully understood; the human brain will for the next time probably remain the main media of the creative process.

2.2 ICT as Design Partner

However, there are parts of the solution generation process, in which the computer can support the generation of design solutions. The computer is able to handle enormous amounts of parameters, and combine them to alternative solutions, in much shorter time than the human being can. A research project at the ETH in Zürich, called "KaisersRot" [6], illustrates this. The computer generated solutions and alternative site patterns based on a huge amount of programmed parameters. The human brain would need substantial amounts of time in order to generate solutions matching all these parameters. The computer, however, could only generate sufficient solutions based on parameters recognized and programmed by humans.

Another research direction is the development of virtual reality (VR), which is based on geometrical and graphical representation. VR offers the possibility to navigate within and see the objects and their relation to each other in a 3D space. The possibility of a realistic imitation of a real world environment, combined with the spatial experience dimension, can become a powerful future design tool [5]. New experimental forms and constructions, without the real world constraints, can be realistically visualized. The possibilities of innovative form generation, can perhaps give the designer inspiration to develop an "evolutionary" architecture [1]. The success of such processes depends on how user friendly ICT is. Generally, the development of user-friendly interfaces of the ICT tools is a huge challenge. Thick user manuals and complicated operative surfaces can disturb the mediation of creative processes. Lundequist [5] compares this with driving a car: the driver should not be forced to concentrate on how to drive, but rather where to drive. However, Wikforss [5] compares the impact of the development of new computer media and graphical tools with the break-through of the central perspective in the renaissance. They both change our view of the world.

There is some effort to develop intelligent ICT systems that can carry out design operations on behalf of the human designer, so-called design agents [2]. A design agent can for example make a designer aware of inconsistency with building legislation, for example the minimum height of a staircase handrail. Thus, ICT would develop from being a tool to becoming a design partner. The development of design-agents is promising, but for the moment it seems impossible to replace the human brain completely as the generator of design solutions. ICT can be a tool or a partner supporting and relieving the designer, but the computer still cannot design without some sort of human interaction.

2.3 New Design Methods

The more intelligent ICT design systems could make it necessary to change the traditional methods of design. However, to make the designer change his working methods can be cumbersome. Kiviniemi [7] refers to Freeman's Attractor Theory describing an "energy landscape" in our brains; and he sees this as one reason why it is so difficult to implement new tools which influences the working methods (e.g. 3D product model), although such tools could offer obvious benefits.

3. Communication within the Design Process

The successful planning and realization of a building project depends heavily on the success of communication on many levels. Schön's [4] description of the designer's conversation with the drawing, or what Kalay [2] calls ideation or an intra-process role of communication represents one level. The dialogue between two individuals, the extra-process role of communication represents another. Failed communication can cause conflicts and misunderstandings, and negatively influence the building project, if not recognized and solved at an early stage. As illustrated in figure 1, the sending and receiving of a message (e.g. design solution) depends on the competence, knowledge and previous experiences of the participants in the communication process. If the client does not know the symbolic meaning, or the level of abstraction used, he will not understand what the architect tries to communicate, and this could lead to misunderstandings and conflicts. The architect can assume that the client knows which totality an abstraction represents, for example the plan drawing door symbol, but a problematic case of information loss could arise if the client does not know that the two lines on the paper actually symbolize a door. Generally, some of the knowledge playing a part within the design process is of tacit character. Explicit knowledge can be articulated and is thus accessible to others while tacit knowledge cannot be articulated [8]. Wittgenstein's language game theory is one illustration of this problem area [9]. Misunderstandings can occur when terms from one game are used within another. The language games are based on tacit rules embedded in the context, culture and way of life. Thus, such language games cannot be easily understood when viewed from another context or culture. A central part of the architect's competence is to understand the language games and to use terms in a meaningful way [9].

3.1 The Designer's Conversation with the Design Situation

Schön [4] describes the design practice (e.g. sketching) as a conversation or reflective dialogue between the designer and the design situation or design issue. This conversation is based on the designer`s "…capacity to see unfamiliar situations as familiar ones, and to do in the former as we have done in the latter, that enables us to bring our past experience to bear on the unique case." [4, p.140]. The designer conversation with the design situation allows a fluid thinking process without constraints like disturbing accuracy. The sketching act can mediate creative processes. Can ICT replace the scribbling with a pen at a sketch paper as mediator of creativity, without disturbing the fluid thinking process? Is the computer able to interpret sketches, which can often illustrate a variety of metaphors, and contain a high degree of uncertainty? According to Lawson [1], the answer is no.

3.2 Network Technologies and Collaboration

The importance of collaboration is growing, as globalization and increasingly complex technique and products require more teamwork, and the complexity of the problem becomes unmanageable for one individual. The focus changes from the individual to the collaborative design process, and introduces a new dimension in the idea finding process: the interaction between the individual and the group [1]. Participants with different backgrounds, preferences and experiences try to achieve a common goal. Barrow [10] introduces the term Cybernetic Architecture: "... cybernetic architecture is a return to the pre-Renaissance comprehensive integrative vision of architecture as design and building (…) the emerging architecture process is a "collective" body of knowledge and specialty skills found in many individuals."

Network technologies such as e-mail and the internet have contributed to the most radical changes within the average working day for the building process participants, for instance supporting processes independent of geographical and organizational borders. Collaborative design and communication within a virtual instead of collocated situation inherits many new properties, and this eventually leads to various challenges. The network technologies still offer neither the same social presence and information richness, nor the ability to transfer tacit knowledge that a face-to-face collaboration or conversation does [11]. Herein lies a challenge; to develop network technologies offering the communication possibilities necessary for the achievement of a common understanding, to solve complex problems or to generate complex design solutions. Within the communication process between two or more individuals, ICT have had a dramatic impact on the medium of communication. This could possibly require another use of language and level of abstraction and challenge the skills of the message receiver, hence to another culture of communication.

3.3 Information Access and Distribution

The network technologies make an easy and fast access to and distribution of information possible. This has been a huge benefit within the building project and has, according to Schwägerl [12], contributed more to accelerate the design processes than the CAD tools. The development of the data based technologies, server or internet-based, has been an important support of handling the huge amount of documents and drawings within building project. The pool of material is accessible to the different projects participants, anytime. The participants have to actively retrieve the information they need, and this is different from the traditionally passive “getting-the-plan-with-mail”; there is a development from a push to pull of information. The use of databases, network technologies etc. supports the distribution speed of information required to keep the project continuously running. However, much of the information could be considered more of a distraction than actually useful, given a specific situation. The negative effect of information overload is growing. Thus, the attention of the receiver is becoming an important resource [13].

3.4 Communication Standards and 3D Product Models

Another influential trend within ICT is the development of communication format standards between different programs and systems, ensuring interoperability. An example of such a standard is the Industry Foundation Classes (IFC) [5,7]. The development of communication standards is one of the fundaments for a research field by many seen as one of the most promising within the construction sector: the development of the 3D product model or building information model (BIM). Such models are based on the definition of objects (products) containing intelligent information. The main objects, such as doors and windows, are standardized. According to Fekete [14], such standardisation could become barriers within the creative process; design elements that fall outside the standardized repertoire of building objects could be difficult to generate without special ICT skills. However, every participant (design team, legislators, contractors, manufacturers etc.) in the building process can get access to, make contributions to or receive information from this model in parallel. All building project information is gathered in this one model, and there are no parallel illustrations of building parts comprised of plan, section, detail etc. This can reduce one of the main sources of building site failures: inconsistency within the fragmented drawing and document material [5,7]. From the model “traditional” drawings can easily be generated, and the density of information can be controlled.

3.5 Redefinition of Planning Stages, Roles and Responsibility

Through the use of ICT, processes can be accelerated and traditional stages can overlap. Already at a very early stage of the design process, traditionally later participants can get access to e.g. the 3D product model. Contractors, specialists and manufacturer can contribute with knowledge that helps to reduce uncertainty early in the design process. The “wheel of dominance” [15], illustrating which participants dominating the different planning stages of the design process, could change. But the overlap between earlier and later planning stages can perhaps contribute with constraints that increase the complexity of the solution and problem finding, making it more difficult to focus on the right aspects to the right time. The Figure "Island of Automation in Constructions" [16] illustrates the current construction sector as many separate islands in a big construction sector ocean. The ICT, in this case the product model, leads to a "land raising", the many small islands transform to one big island. Thus, the traditional boarders between roles or planning stages blur and change. The separate bits of the planning process are melting and compressed to a conglomerate. The ICT development changes the human perception of distance and time. The understanding of these different changes is central. ICT impacts on the definition of work processes, roles and responsibility. How can such changes be handled within contract and procurement models? What about the traditional role and contribution of the architect?

4. Evaluation of Design Solutions

The architectural design process is in addition to the measurable, quantitative and conscious based on the qualitative, intuitive and tacit [1,7]. The crucial question within evaluation of design solutions is how to measure or judge the qualitative, tacit and intuitive aspects? "Is it possible to say that one design is better than another and, if so, by how much?"[1, p.62]. This aspect is also challenging within the other three aspects of the design process: the generation of design solutions, the communication and the decision-making. Lawson [1] emphasizes that a crucial skill of the designer is to balance qualitative and quantitative aspects.

4.1 "Almost Real"

ICT Offers A Most Powerful Support Of Evaluation. Through Simulation And Highly Realistic Visualizations It Is Possible To Get An Impression Of The Real-World Building Project Before It Is Finished. Unrecognized Problems Can Be Identified, Uncertainty Reduced And Errors Avoided Already At An Early Stage Of The Building Project. In The Management Area ICT Support Time-, Cost- And Resource Planning, In The Design Process They Simulate For Example The Financial And Climatic Effects Of The Ventilation-And Heating System. Presentation Tools Supporting VR, 3D-Modeling, Animations Etc. Can Support The Evaluation Of Visual Qualities [5]. However, A Conceptual Image Communicated In A Highly Realistic Manner Can Also Give A False Picture Of The Reality. There Can Be A Conscious Or Unconscious Mismatch Between The Intention Of The Sender And The Interpretation Of The Receiver [1].

These Tools Usually Require The Presence Of Something To Evaluate, And Also That Some Level Of Precision Has Already Been Reached. And Such A Level Is Often Not Feasible In The Early Design Stage. Lawson [1] Characterizes The Too Early Precision Temptation As The Design Trap Of Over-Precision, Which Can Become A Creative Process Impediment. Until Now, The Building Of ICT Models As Foundation For Simulations Has Been Cumbersome And Expensive. This Often Resulted In Simulation Of Limited Parts Of The Total Design. But The Design Problem Is Multi-Dimensional And Interactive. Interconnectedness Of Different Factors Is An Important Issue. The Focus Only On Parts Can Lead To A Lack Of Integration, Thereby Reducing The Quality Of The Project In Total [1]. The Possibility Of Importing 3D Product Models Into Simulation Software Reduces The Model Building Effort And Thus The Building Could Be Simulated And Tested In Total [7].

4.2 Information Overload

We do not now much about how the human being handles and edits information [5]. The ability to absorb information is limited, and when confronted with too much information, the receiver can lose the overview, or worse, completely ignore the message communicated; thus leading to crucial information being lost and unrecognized. An information overload could possibly result in a loss of focus on the important aspects within evaluation and decision-making. Valuable time must sometimes be spent filtering relevant from unimportant information. Some ICT development projects try to establish methods for the filtering of internet-based information [5]. Generally, who decide the filtering criteria by information distribution and exchange? How do we know that important, but perhaps not obvious, information actually passes such filters?

5. Decision-making

Faster information distribution, better access to information and more powerful communication tools contribute to an acceleration of the planning process, making a higher decision frequency possible [17]. An important skill of the designer is to juggle with several ideas at the same time, without forcing a premature precision or decision [1]. Does the use of ICT force too early decisions and generate artificial constraints? Is there a limit of time compression within the architectural design process and decision-making? Also Wikforss [5] emphasizes the importance of enough time for maturing in the planning- and decision process, and that there is enough time to reflect and understand the consequences of different solutions and decisions. He emphasizes that ICT tools, e.g. the 3D product model, must allow a step-by-step precision.

Seemingly, it is easier to make a decision if every uncertainty is eliminated. ICT offers the possibility of storing and capturing previous project experiences, as well as reusing and modifying these experiences from previous building projects within new ones. This is an often-used method to reduce the high degree of uncertainty in the early design phases, and to better support the estimate of cost and time factors before the concept has reached the required level of precision. Lundequist [5] sees a possible conflict between the established experience and the will to innovation. The knowledge reservoir is based on tested experiences, repertoires and routines. The inherent capabilities of ICT when it comes to knowledge storage and reuse could lead to a misbalance between previous knowledge and innovation in the creative process.

ICT offers the possibility to simulate and visualize the building in a nearly realistic way, to make information available whenever wanted and to make processes transparent and “reusable”. However, the nature of the design process is also qualitative, subjective and highly uncertain. As “the feeling of” is a part of the design process, intuition and the acceptance of risks are also part of the decision process. According to Griffith [8] ICT supports the declarative nature of explicit knowledge. Possibly the analytic, quantitative and explicit nature of the computer could disturb the balance between the qualitative and quantitative, tacit and explicit, intuitive and conscious. This could potentially lead to a bias within evaluation and decision-making, having negative effects on the total building quality.

6. Introduction of the ICT Impact Matrix

This paper presents a broad range of different ICT related impacts within the architectural design process and decision-making and focuses on four main topics, the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. The main intention of the paper is to be a contribution towards a better understanding and overview of the ICT impact on the selected architectural design process issues. The overview, an ICT impact matrix, is based on the definition of three hierarchical levels:

- **The micro-level:** focuses on the individual and what is going on in the head of the designer, in this case the architect. The designer's conversation with the design situation is an example of micro-level communication. Example decision-making: which idea is worth being put to the paper etc.

- **The meso-level:** covers the mechanisms within the group, in this case the design team. Design management. Collaborative design generation and evaluation. Example decision-making: which concept should be presented etc.

- **The macro-level:** comprises the mechanisms on overall project level, including all participants, such as stakeholders, manufacturer etc. Project management. Example decision-making: which concept should be further developed and realized.

Within each of these levels, the ICT related benefits and challenges due to the four illustrated and described aspects of the design process are summarized. The introduced matrix is not intended to force aspects of the complex architectural design process into rigid categories, rather it could be a help in acquiring an overview and understanding of the complexity within the design of an building project.

Table 1:Outline of the ICT impact matrix

	Micro-level	**Meso-level**	**Macro-level**
Generation of the design solution Examples ICT: CAD, VR, sketching programs, design-agents etc.	**Benefits:** • Development from design tool to design partner. • Handling and combining of amounts of parameters and constraints in short time. • Advanced visualization of design idea possible. **Challenges:** • Computer systems requiring too much precision • Complicated user surfaces can disturb the mediation of creative processes. • ICT should support step-by-step precision.	**Benefits:** • Supporting the development of collaborative design. • Advanced visualization of design idea possible. **Challenges:** • Interaction between individual and group design generation – "cybernetic architecture ".	**Benefits:** • Advanced visualization tools as VR a possible trigger of innovation and "evolutionary" architecture. **Challenges:** • Computer as design solution generator without human interaction until now not possible. • Standardization of design elements leading to creativity barriers? • New methods of designing - difficulty of adapting new ways of work.
Communication within the design process Examples ICT: 3D product models, databases, network technologies (e.g. Internet, e-mail, WorldWideWeb) etc.	**Benefits:** • Better access to information for the individual. **Challenges:** • To replace the power of pen and paper as the media between the designer and the design solution generation. • How to transfer tacit knowledge with ICT?	**Benefits:** • Support geographically dispersed collaboration. • Less inconsistency of project material. • Interoperability within design team • Better access to and distribution of information within design team - speeding up of communication process **Challenges:** • Less social presence and info richness as F2F can lead to misunderstandings and conflicts. • Different knowledge reservoirs within design team– source of conflicts. • From push to pull of information.	**Benefits:** • Better access to and distribution of information within building project. • Interoperability on overall level. • "Land-raising" within construction sector – more transparency – better foundation of collaboration. **Challenges:** • Redefinition of roles, responsibility and planning stages • Misunderstandings due to represented decision material (intention not like intepretation). • New communication and collaboration culture.
Evaluation of the design solution Examples ICT: 3D product models, simulation tools (e.g. cost, time, climatic aspects), 4D models etc.	**Benefits:** • Almost real world simulation and visualization, early recognition of conflicts and problems. **Challenges:** • Information overload – loss of overview and focus for the important.	**Benefits:** • Almost real world simulation and visualization support coordination within design team – early recognition of conflicts and problems. **Challenges:** • Simulation or visualization of only building parts – loss of overview and total quality. • Information overload and loss of focus and overview.	**Benefits:** • More transparency of processes and better access to knowledge, not individual captured. • Almost real world simulation and visualization, early recognition of conflicts and problems. **Challenges:** • How to judge and measure the quality of a design solution? • Information overload and loss of focus and overview.
Decision-making within the design process Examples ICT: 3D product models, simulation tools (e.g. cost, time, climatic aspects), 4D models, VR, 3D modeling tools, network technologies etc.	**Benefits:** • Decision material more consistent and real-world like – reduction of uncertainty **Challenges:** • Realistic visualization and simulation forces too early decision? Obstruction of the creative processes and parallel lines of thought?	**Benefits:** • Decision material more consistent and real-world like – reduction of uncertainty **Challenges:** • Realistic visualization and simulation forces too early decision within design team?	**Benefits:** • Decision material more consistent and real-world like – reduction of uncertainty • Reuse of previous experience easier -reducing uncertainty. **Challenges:** • Misbalance between use of previous project material and innovation? • Forces too early decision not representative for the factual status of project? • ICT focus on quantitative - bias in the decision-making?

7. Conclusion

The introduction of the ICT impact matrix illustrates a possible way to approach the wide range of ICT impacts on the complex field of the architectural design process. The processes within architectural design and decision-making can perhaps be compared with the nature of the design problem itself: as multi-dimensional and interactive, based on an interconnectedness of different factors. On one hand, the four selected design process aspects: the design solution generation, the communication, the design solution evaluation and the decision-making are highly interdependent, as the figure 1 in the introduction part attempts to illustrate. On the other hand, the defined micro-, meso- and macro-level levels are closely interconnected. These issues constitute the challenge and main problem area behind the theoretical ICT impact matrix. In a next step the matrix could be discussed and tested using e.g. real life projects. It could also be interesting to study the interaction between different levels, such as the relation between the architect and the design team, or between the architect and the client. Further inquiry could lead to a modification of the ICT impact matrix, the three level approach and the choice of design process aspects. Generally, the matrix outline could be developed into a filter for deciding the direction and focus of further work and research. From the view of an architect, a crucial question is how the ICT related benefits and challenges impact his role, influence and contribution within the architectural design process and decision-making.

Acknowledgements

This paper is a part of a PhD study and doctoral scholarship financed by the Norwegian University of Science and Technology (NTNU). The writing of this paper would have been cumbersome without the support and good advice from Professor Tore Haugen (main supervisor of the PhD-project) and Associate Professor Birgit Sudbø.

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Cost Management and Estimates in the Infrastructure Design Process

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Abstract

The infrastructure client must know the relation between the variant decisions and the cost already in the beginning of the design process. That is the only way the client can influence on the important decisions made during the design process so that there is real influence on the final cost level.

The Laboratory of Construction Economics and Management in Helsinki University of Technology and Rapal Ltd work tightly together in order to create new methods and databases for cost management of infrastructure projects. There are two different studies going on at the moment.

The one is focusing on the client´s target setting process in planning before the actual design process. The aim of the study is to develop a method and tools for defining a project and it´s targets so, that the client´s needs and will can be clearly expressed. The other one is considering to the cost management during the design process. How the real cost level is estimated in every step of the process? And how the design alternatives are compared? These two studies are introduced in this paper.

The first step in the infrastructure management is to define the project. The definition documents produced, a project plan, form the target for designing. It is a description of the scope of the project. Project plan must not unnecessarily limit the technical solutions made in the following designing phase. During the designing phase the document is updated if necessary.

The cost management of the infrastructure starts from the scope definition of the project. The client defines the needs and the targets of the project. The first cost estimate is based on the costs of the reference projects. The targets and the needs are modelled with the end product elements, which consist of the building element based product model. The end product elements are big functional elements of the infrastructure, for example main route, intersections, lightning system, water management system. The product model gives the target cost of the project.

The product model based target cost gets more accurate when the design process goes on and the product model is changing to the real measured building elements. The price of building element is estimated based on the way the work is done usually in that kind of circumstances. The typical work processes are documented to the cost storage.

In the first study the project plan –document is created and tested for the needs of infrastructure projects. In the second study the cost estimate procedures (the end product element and building element systems) are created and tested. The both testing processes are made in the collaboration with the real infrastructure projects given by the clients of Rapal Ltd, the 10 biggest infrastructure clients in Finland (8 big cities, the Road Administration and the Rail Administration).

The studies are still going on. The project plan is tested and the first results indicate that the systematic scope definition with the project plan clear out the needs of the project more accurate than usually in infrastructure projects. The first results also indicate that the first end product element based estimate, the building element based estimate and the real market price can be inside the 5-10 % marginal. The new method is more accurate than traditionally used experimental methods.

Keywords: Infrastructure, design process, cost management, end product element, building element, project plan, product model

1. The New Infrastructure Design Process

1.1 Overview

Ten big infrastructure clients (property owner organisations) in Finland (National Highway Administration, National Railroad Administration, Cities of Helsinki, Espoo, Vantaa, Turku, Tampere, Kuopio, Oulu and Jyväskylä) and commercial private owned company Rapal Ltd have made an agreement for the cost management development project lasting 6 years (2003-2008). The target of the project is:

- To create a common used and tested infrastructure cost management system
- To create new consulting markets for construction economics in the infrastructure branch

The 10 client organisations made a consortium agreement with each other. The consortium and Rapal Ltd made a partnership agreement for the project. The systematic development project includes:

- The project plan – the systematic scope definition method
- The cost management systems

- End product element based cost management system for the scope prizing
- Building element based cost management system for the design solution prizing

- The systematic cost management database
- The economic trend description system

The target of the project is in year 2008 when all the methods cover the whole product life cycle of infrastructure. There are two specific studies going on related to the project. The first one is related to the project plan and the other one is related to the cost management process. The systematic cost management database and the economic trend system relate to the studies strictly.

1.2 Process Relevance

Nowadays the scope definition, the cost management systems and information databases are organisation related with no common rules. The mean of this project is to organise and to find out the best practise process of the infrastructure cost management in Finland.

The difference between the reasons of the infrastructure project cost is related to three categories:

- The scope
- The design solutions
- The economical situation on the market

The infrastructure (highways, streets, railways and big industry yards) investment and maintenance cost in Finland for example were worth of 1,8 billion euros year 2002. The relevance to the whole society is huge when cost management information is handled in one common and systematic way based on the cost classification (fig1).

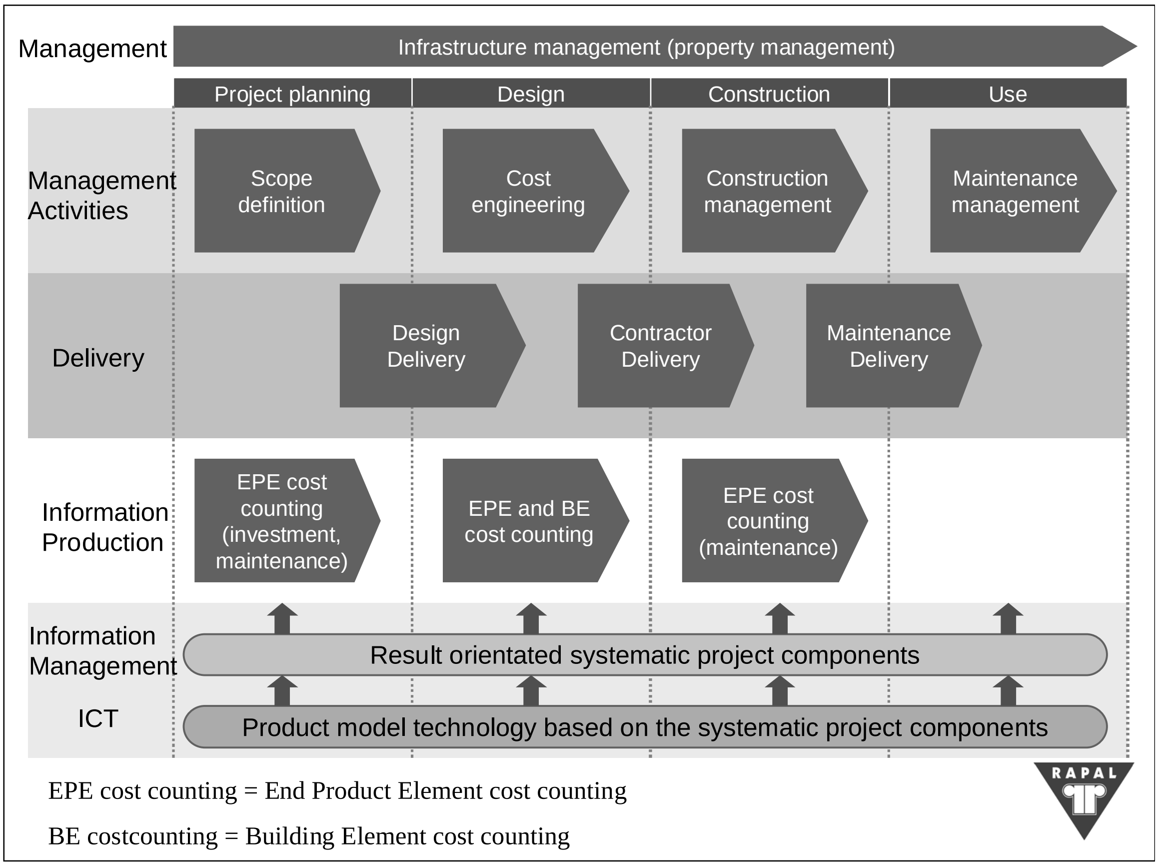

Figure 1 The process of the systematic infrastructure property management system

2. The Scope Management Process

2.1 The Systematic Scope Definition

The infrastructure projects are usually long term projects with lots of interest groups. The better the scope is defined the better the cost management is able to be done. In the development project Rapal has developed a systematic scope definition which includes:

- Project Plan – a document for the infrastructure scope definition
- List of end product elements - Systematic project component list

The project plan is a document which describes the result (the scope) of the project divided to the end product elements. Each element is based on the specific need (fig1) and is systematically described for the starting information of the design process.

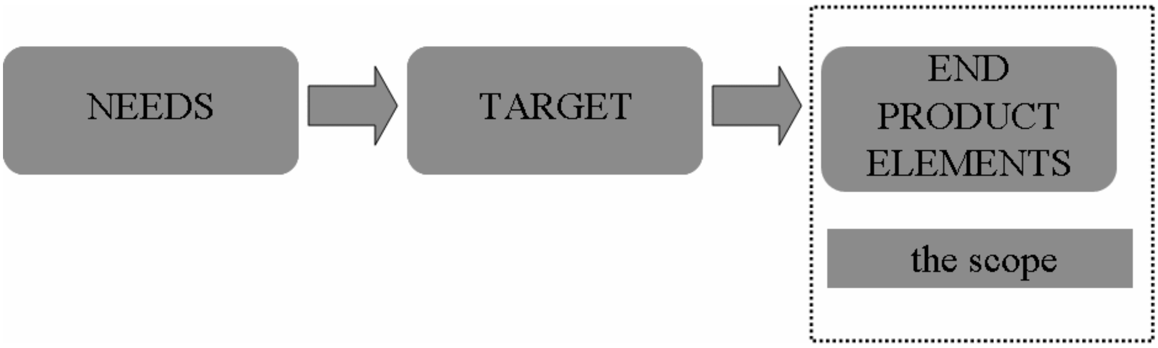

Figure 2: The needs of the project are changed to the targets, which are described as end product elements with the scope.

The end product element list includes the following subtitles:

- Routes for the motor engines
  - Highways
  - Streets
  - Railroads
- Tunnels
- Bridges
- The light traffic routes
- Other routes
- Parks and green areas
- Squares and market places
- Waste management
- Rock facilities
- Traffic areas
- Systems related to infrastructure

The project plan and the systematic project component definition have two major meanings:

- To describe the project
- To create the drivers of the project management

The scope of the end product element includes lots of sub targets (cost, quality, schedule). The cost management is the only one considered in this paper.

2.2 Cost Management by the End Product Element System

The scope defined in the project plan can be executed in many different ways. There are lots of combinations of design, cost, quality and schedule for example. The end product element based cost management system provides a price, which is typical solution of the kind of end product.

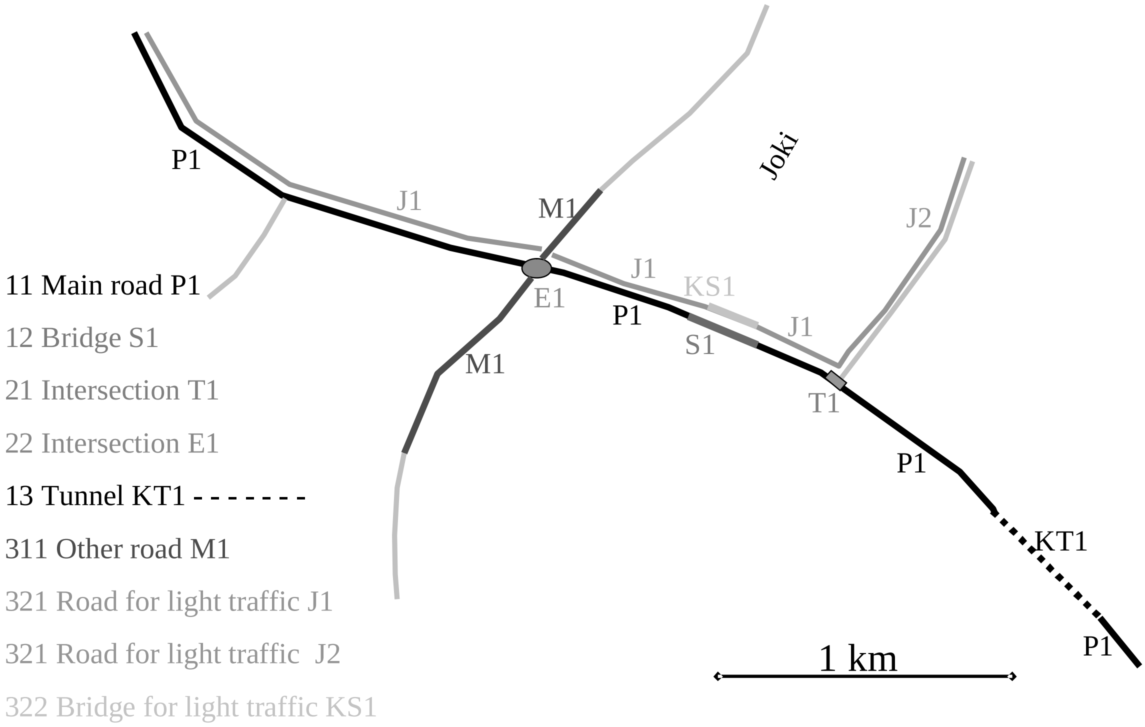

Figure 3Example of the end product element division

The cost management process by the end product elements has the certain steps:

- To identify the components of the project
- To identify the end product elements of the project components
- To get price for each end product element from the price list (fig 4)
- To identify the additional circumstances (for example environmental, interference caused by the built environment)
- To identify other additional costs
- To define the costs related to the project management (for example the difference between big and small projects)

The end product element price of the project depends on the made project plan. If all the big components are taken into account, the additional costs are identified and the desired cost allocations are made the projects scope can be estimated strictly in a very early step of the project. The rest of the project is all about project management.

PRICE LIST FOR TYPICAL END PRODUCT ELEMENTS										
100 ROUTES FOR THE MOTOR ENGINES										
			unit	basic prize	additional cost					
110	ROUTES	FUNCTIONAL FEATURE		A frost resistant ground	rock ground	frost exists	soft ground h = 2m	soft ground h=x (3-5m)	soft ground h=x (over 5m)	needs rock extracting.(h=x)
	111 Highway 4 lanes: 2 x (11,75m/7,5m)	100-120 km/h KVL 9000-30000	m	1180	+270	+230	+710	+650x	+600x	+230
	112 Highway 4 lanes: 2 x (10,25m/7m)	80 km/h KVL 9000-30000	m	1070	+250	+200	+630	+600x	+550x	+200
	113 Main road 2 lanes: 13m/7,5m	100 km/h KVL 6000-9000	m	600	+150	+120	+400	+250x	+300x	+135
	114 Main road 2 lanes: 10,5m/7,5m	100 km/h KVL 3000-6000	m	525	+130	+100	+330	+200x	+230x	+110
	115 Main road 2 lanes: 10m/7 m	60-80 km/h KVL 3000-6000	m	505	+120	+95	+290	+180x	+200x	+105
	116 Local road 4 lanes: 17,5m/14,5m	50-70 km/h KVL 9000-30000	m	900	+200	+160	+500	+500x	+460x	+185
	117 Local road 2 lanes: 8m/7m	70-80 km/h KVL 1500-3000	m	340	+80	+90	+260	+600	+600	+80
	118 Local road 2 lanes: 7m/6m	50-70 km/h KVL 600-1500	m	270	+65	+75	+230	+400	+400	+70
	119 Local road 2 lanes: 7m/7m	80 km/h KVL 100-600	m	260	+60	+70	+230	+300	+300	+70
	120 Local road 2 lanes: 6m/6m	70 km/h KVL 100-600	m	210	+50	+60	+190	+250	+250	+60
	121 Local road 1 lane: 5,5m/5,5m	40-60 km/h KVL 100-600	m	165	+40	+50	+170	+230	+230	+50

Figure 4 Example of the end product element price list

3. The Cost Engineering Process

3.1 The Cost Management by the Building Element System

The cost management by the standard building elements gives the answer for the question: “What is the price of the certain design solution?” The standard building elements consist of the recourse model, which is updated by the market related resource prices.

The building element system has three purposes:

- With the building element price the design result can be compared to the scope (the end product element price)
- It gives comparable prices for different design solutions
- It gives the market price estimate for the contract

The systematically used building element method requires that:

- Many separate nomenclature items are used
- Price lists are tested with the real executed contracts
- Pricelists are maintained (from the resources)
- The price list items and the used design items are comparative

BUILDING ELEMENT ESTIMATE, INFRASTRUCTURE
Version 0.91

Project name

Region 100,0

Basic cost level = 100,0
Cost level = 100,0

RAPAL

Date

BE	BE2	BUILDING ELEMENT	UNIT	QUANTITY	PRICE €	MULTIPLY	COST €
1000	**000**	**Maa- pohja- ja kalliorakenteet**		1		1,00	0
						1,00	
1100	**000**	**Purettavat rakenteet ja rakennusosat** 1				1,00	
1110	000	Luonnontilainen maa ja kallio				1,00	
1110	001	Luonnontilaan muutettu/jätetty alue	erä			1,00	
1120	000	Puut- ja kasvillisuus				1,00	
1120	100	Puiden ja kasvillisuuden poisto				1,00	
1120	110	Hyötypuun hakkuu pienet määrät (alle 10 kpl)	kpl		40,00	1,00	
1120	111	Hyötypuun hakkuu keski määrät (11-100 kpl)	kpl		25,00	1,00	
1120	112	Hyötypuun hakkuu suuret määrät (yli 100 kpl)	kpl		12,00	1,00	
1120	113	Jätepuun ja kasvillisuuden poisto, normaali	m2		0,68	1,00	
1120	114	Jätepuun ja kasvillisuuden poisto, tiheä puusto	m2		1,20	1,00	
1120	115	Jätepuun ja kasvillisuuden poisto, harva puusto	m2		0,30	1,00	
1120	116	Hyötypuun hakkuu	m3		5,58	1,00	
1120	117	Latu-uran raivaus ja tasoitus	m2		1,50	1,00	

Figure 5Example of the building element price list

3.2 The Cost Information Storage

The systematic cost management needs the systematic information storage. The end product elements have certain requirements for use, investment, environment and functionality. Those requirements can be modelled through the certain steps:

- the product elements (for example foundations, surface layers)
- the building elements (for example earth excavation, insulating layer, asphalt layer)
- The production elements (for example mass transportation, vibrations)
- And the resources (for example excavator, asphalt)

The modelling system needs a structured nomenclature for every step of the tree. Nomenclature gives every piece of data a certain individualized code number, which keeps the system in order.

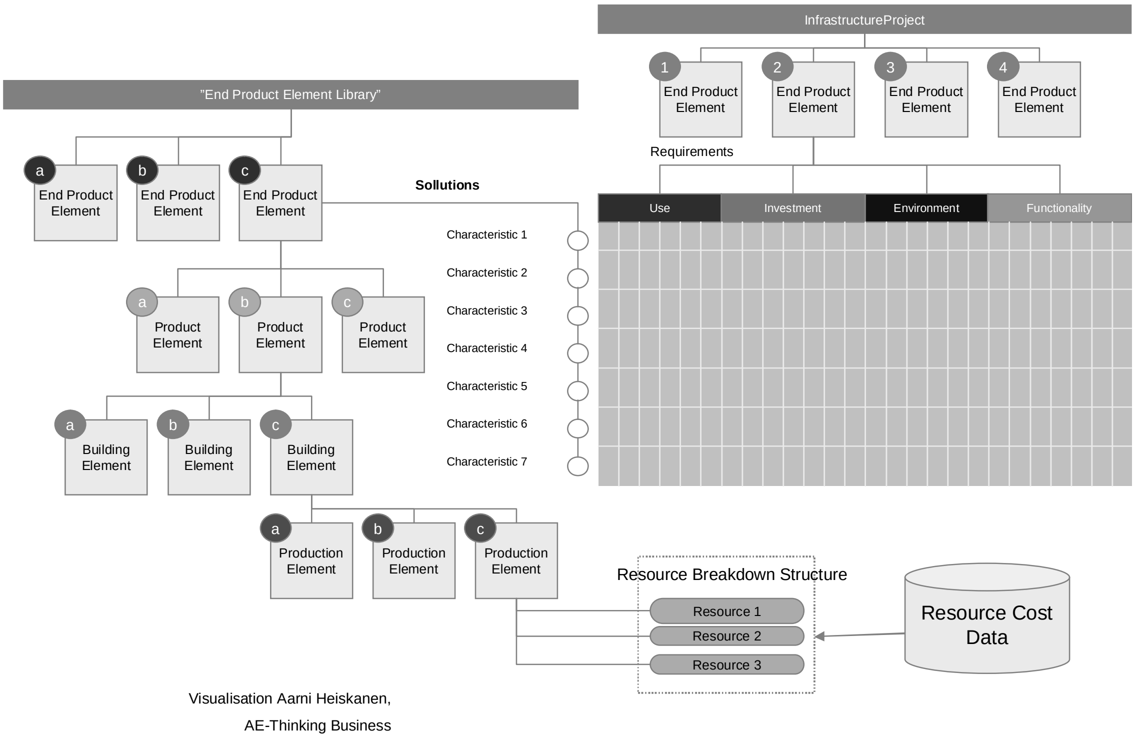

Figure 6 The systematic cost management information storage

The cost management system is built up to the database. The database has the strict structure to keep all the information in order. The Rapal Cost Management system is planned to follow the Finnish common Infra-nomenclature, which is developed by Rakennustieto and Helsinki University of Technology. The product model work is just starting in Finland, but in the basis of today´s information the product model and the end product elements have the same kind of main structure.

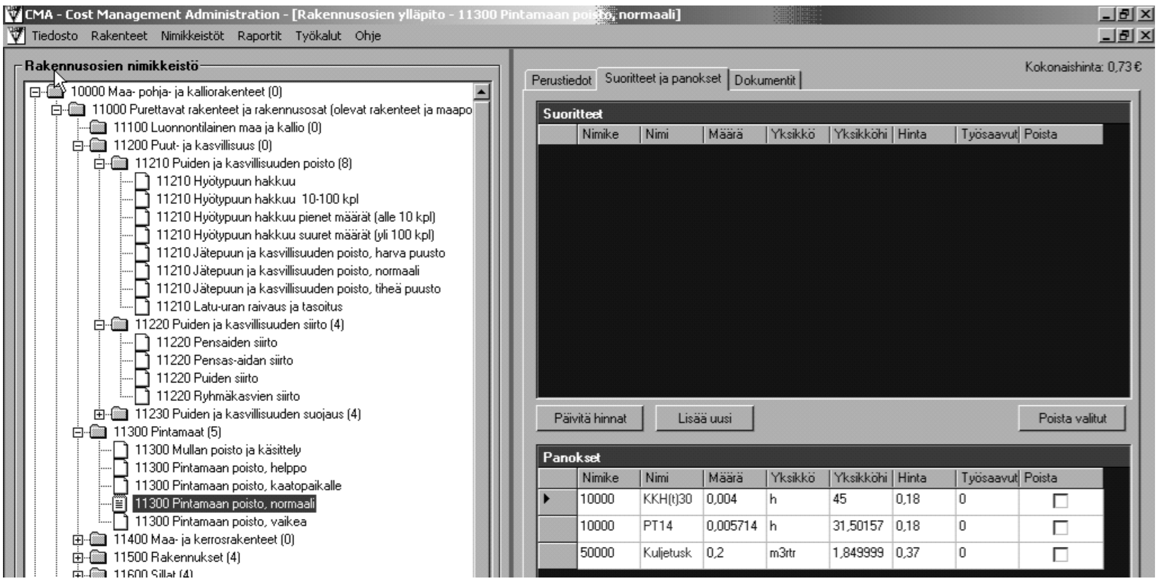

Figure 7 Example of the cost database

4. The Benefits of Process

The benefits of the systematic cost management system are:

- The real needs of the project are identified earlier with the project plan method and the update of the project plan during the process is easier because of the systematic description method
- The cost level of the project can be modelled earlier and more exact than before because of the defined scope
- The cost level in every step of the project is comparative because of the structured product elements
- There are comparative prices in different projects because of the common cost management system
- The feedback of the prices in the executed contracts is straight in the use of the system

5. Conclusions

The infrastructure cost management is said to be difficult because of so many various variables (natural environment, different ground, built environment). In this project Rapal has studied and investigated over 100 real infrastructure cases during 2003-04. The system development is still going on and more information especially about the maintenance is on the scope of the project.

Conclusion of the results so far is that:

- The systematic scope management before the design process is the key to the good cost management
- To get the good cost estimate in the early stage of the project we need new kind of requirement based end product element system
- The building element system needs systematic information storage and continuous systematic feedback from the real projects to remain valid and updated
- The common cost management system gives benefits of synergy to all the organisations

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A Case Study of Project Document Management in Building Design

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Abstract

The problem of managing all the information in building design is a real challenge. Electronic Document Management is growing rapidly and generates the need to structure of design information across building design companies. Lithuanian standardisation organisations, professional associations, user groups, individual companies don't have unified rules of CAD standards and guidelines in building design industry. The most important issue in efficient IT application is the standardized reference of all data definitions.

Keywords: Computer aided design, electronic document management, product data management, building information technology.

1. Introduction

In today's fast-paced economy, building design companies with multiple enterprises such as architecture, engineering and construction (AEC) are seeking for new efficient ways to streamline their business processes, so that the project development time and costs can be reduced. Project development time is typically long due to a considerable volume of documents that required to be transferred between the members of different project teams. Another possible reason for high project development time and costs is that even typical projects have to be developed from the bases, since there is no centrally and easy accessible information storage. It is based on well-know fact that designers spend 75% of their time searching for the appropriate documents, and only 25 % of the time actually modifying it [1].

As an efficient solution the mentioned above problems is the application of the product data management (PDM) systems, that facilitate the management of documents pertinent to particular enterprises, projects and work groups in computer networks. In addition to the basic file management capabilities, PDM systems contain enhanced features related to the life-cycle, revision history and version management of particular classes of documents [2]. A number of commercial tools have been created for document management, project information sharing, online communication, design workflow, construction workflow, time control, and securing information [3]. The case study presented in this work demonstrates how PDM system has become an important element in keeping control of company design activities. It served as a central repository for design information, and digital data documenting the progress.

2. Generic Model of Digital Design Data Archive

A growth of the work intensity in building design companies creates the difficulties of management information flows in the projects. In fact, project management can be accomplished as document life cycle control. The successful application of PDM systems strongly depends on the appropriate structure of the central archive for design information. Preserving information in digital forms is much more difficult than preserving information in forms such as paper. This is not only a problem for traditional archives, but also for many organizations that have never thought of themselves as performing an archival function. The workflow presented for the archive of the construction design documentation is based on ISO Reference Model for an Open Archival Information System (OAIS) for a data repository system [4, 5, 6] (Figure 1). The role provided by each of the entities in OAIS can be described briefly as follows:

- **Ingest**: This entity provides the services and functions to accept Submission Information Packages (SIPs) from Producers (or from internal elements under Administration control) and prepare the contents for storage and management within the archive.
- **Archival Storage:** This entity provides the services and functions for the storage, maintenance and retrieval of Archival Information Packages (AIP).
- **Data Management:** This entity provides the services and functions for populating, maintaining, and accessing both Descriptive Information which identifies and documents archive holdings and administrative data used to manage the archive.
- **Administration:** This entity provides the services and functions for the overall operation of the archive system.
- **Preservation Planning**: This entity provides the services and functions for monitoring the environment of the archive and providing recommendations to ensure that the information stored in the archive remains accessible to the designated user community over the long term, even if the original computing environment becomes obsolete.
- **Access:** This entity provides the services and functions that support consumers in determining the existence, description, location and availability of information stored in the archive, and allowing consumers to request and receive information products.

For the definition of information handled by OAIS the paradigm of the information object is applied. Every submission of information to an OAIS by a Producer, and every dissemination of information to a Consumer, occurs as one or more discrete transmissions. Therefore, it is convenient to define the concept of an Information Package. Three different types of the packages are implemented:

- Submission Information Package (SIP);
- Archival Information Package (AIP);
- Dissemination Information Package (DIP).

Within the OAIS one or more SIPs are transformed into one or more Archival Information Packages (AIP) for preservation. The AIP has a complete set of Preservation Description Information (PDI) for the associated Content Information. In response to a request, the OAIS provides all or a part of an AIP to a Consumer in the form of a Dissemination Information Package (DIP). The DIP may also include collections of AIPs, and it may or may not have complete PDI. The Packaging Information will necessarily be present in some form so that the Consumer can clearly distinguish the information that was requested.

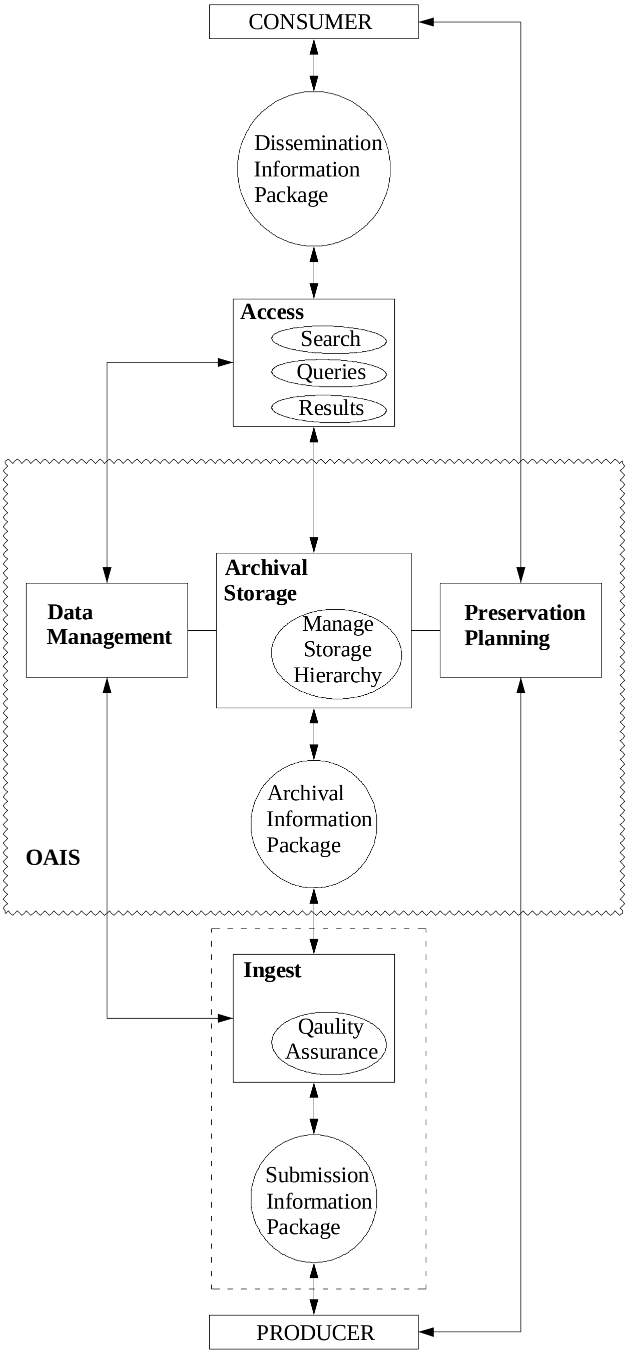

Figure 1: Archival information system

3. Framework for Archiving Digital Design Documentation

The structure of the digital design documentation archive have to be tailored towards the specific needs of the design company and requirements of the construction regulatory laws [7]. For the design management of the building, most documents and communication were exchanged electronically and reflect in a way the name of the project. The developed PDM system stores all documents and communications related to a project in a document repository that facilitates keeping track of those documents throughout the duration of a project and later on. The archive is meant to store in a structured way all kinds of documents and communications to clients, consultants, suppliers and subcontractors. Due the project-centric nature of the construction industry the structure of archiving of the design documents reflects the main parts of the project (Figure 2).

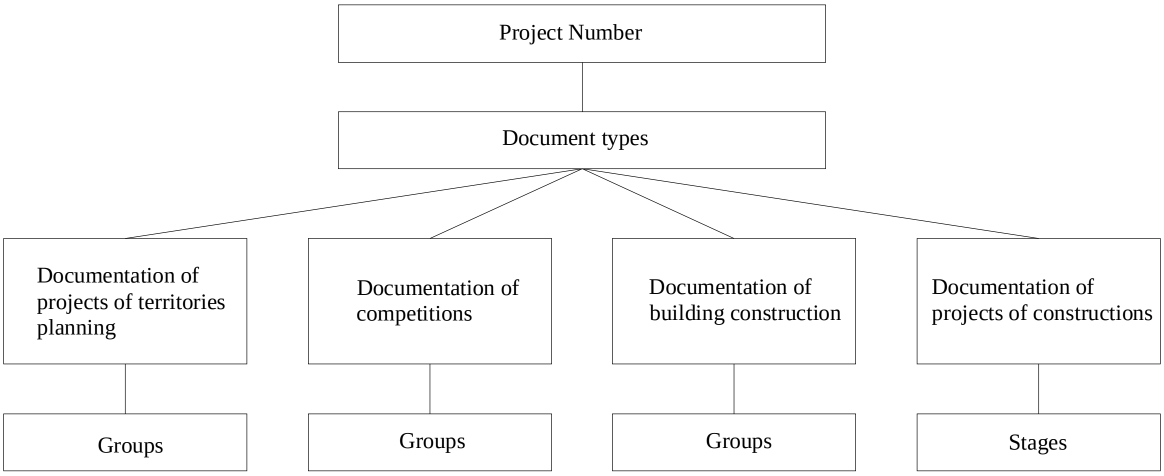

Figure 2: Lithuanian classification of the project documentation

This classification is governed by Lithuanian construction regulatory law [8]. For the illustration one part documentation of projects of the construction is shown separately (Figure 3). Lithuanian standardisation organisations, professional associations, user groups, individual companies don't have unified rules of CAD standards and guidelines in building design industry. This is a first attempt in Lithuania to provide unified reference of all document definitions. On the other hand, this standardized reference is the most important issue for development of the efficient IT applications.

The direct implementation of the document classification system leads to overcrowded hierarchical tree of project information. In order to overcome these difficulties document file naming schema is established for native CAD models. This file naming schema is associated with standardized design document classification. The specific CAD document is named beginning with an optional five digit project code followed by (Figure 4):

- Project number;
- Construction number;
- Project stage;
- Discipline designators;

- Version number.

In a similar way, file organisation structures are defined to represent the hierarchy of the building design project. File directory organization (Figure 5) together with file naming schema provide an effective framework for digital design information archiving.

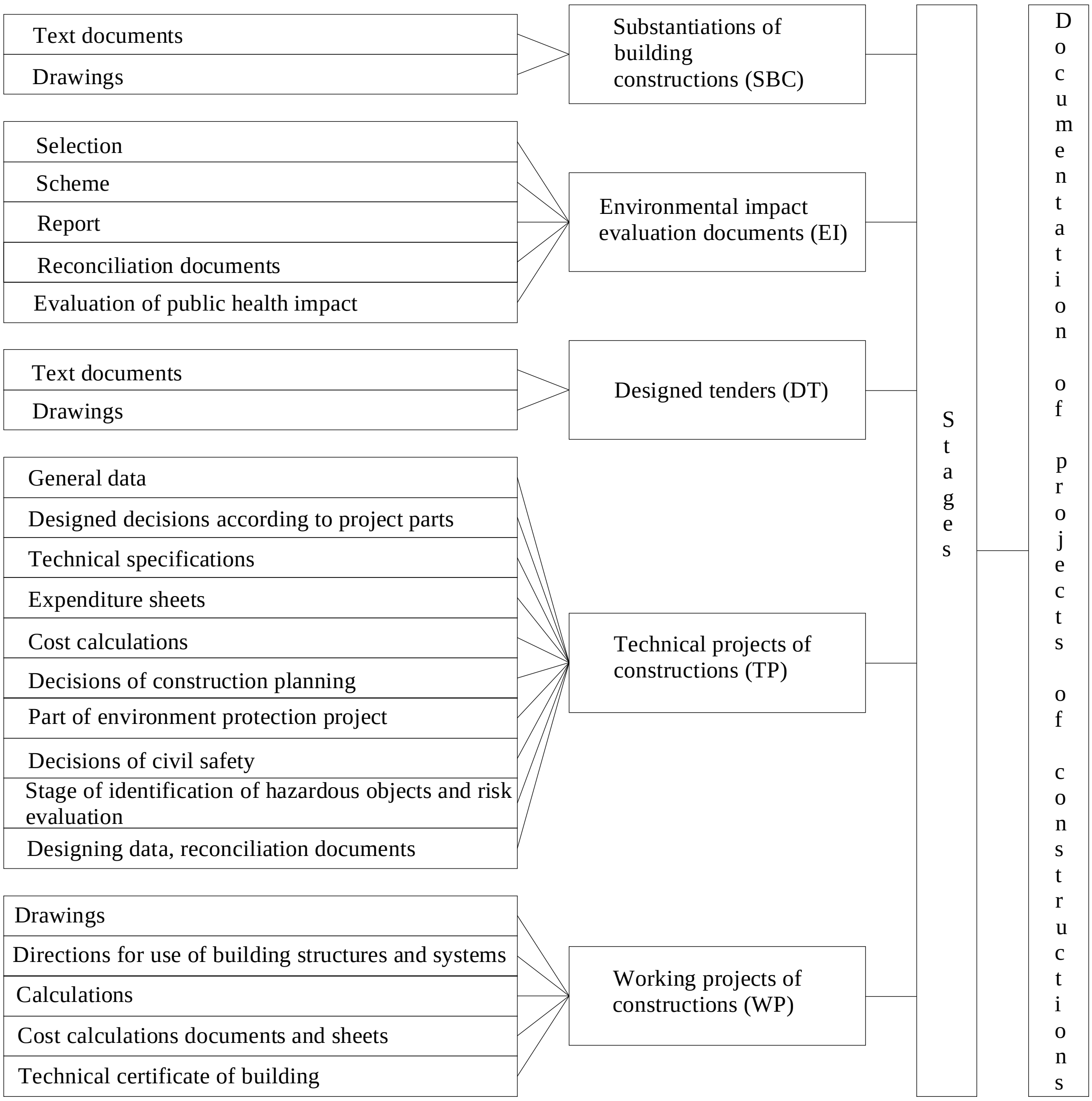

Figure 3:Document classification of projects of the constructions

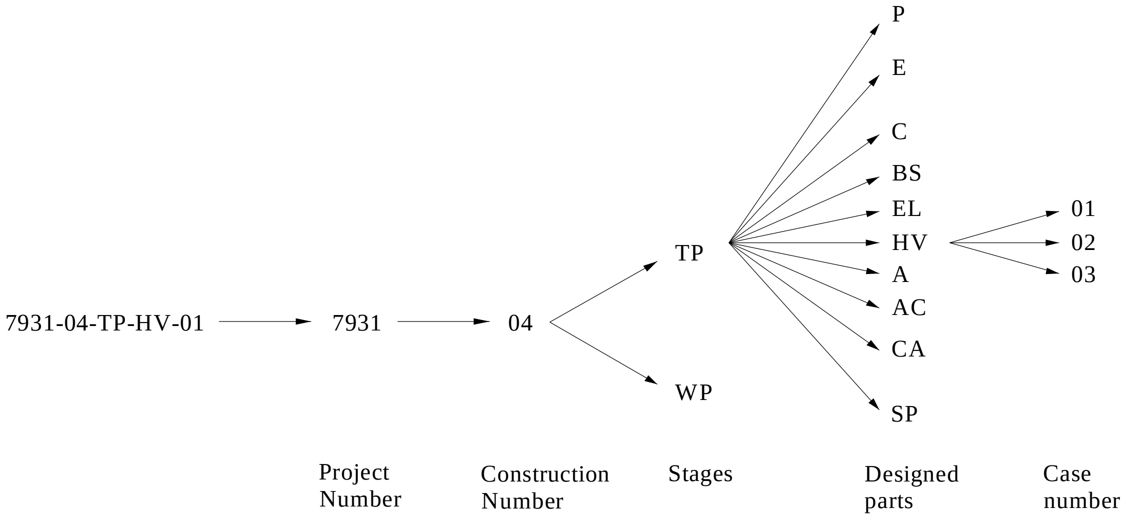

Figure 4: Naming schema of the design documentation

Lettering of designed parts: E – Estimates; C – Communications; EL – Electricity; V – Heating and Ventilation; A – Automation; AC – Architecture and Construction; BS – Building Structures; CA – Calorific; SP – Site plan; P – Plumbing.

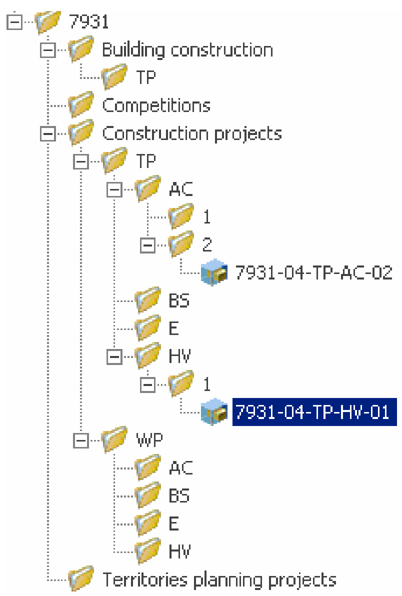

Figure 5: Design information file organization

4. Implementation Technology of AEC Design Archive

For the implementation of the developed model, the AEC digital design archive was chosen, that is “eChange” PDM software of the company ”Empresa Solutions”. For more information about basic features of “eChange”, the interested reader is referred to [1]. While “eChange” was designed with the CAD sector and engineers as the primary users, the system can be used to store any type of file that can reside on a computer’s file system. In our case the largest Lithuanian building design company use “eChange” to manage all of their office documents in addition to the CAD drawings they generate. Lithuanian company performs complete residential and industrial building design that includes architecture, construction and engineering (AEC). UAB Lithuanian Construction Design Institute (Lietuvos Statybu Projektavimo Institutas), which is engaged in the design of construction units and project management has increasing the number of projects per year, at the same time having designed more and more complex objects, the implementation of efficient PDM system has become essential. Tasks that need to be performed for implementation design document archive included (Figure 6):

- Initialization file organization sheet with prescribed project number selection of document format.
- Preparation of electronic document files.
- Automated transmission from SIP to AIP.
- Management of the development team.

The processing of implementation include following steps:

- The design company starting a new project activate structure for a new collection of the digital design data. The project leader or the administrator of the archive initiates this process by entering new project number. By this operation, in the vault of the technical documentation a new tree representing structure of the project documentation is appeared and the SIP of the new project is initialized.
- Each designer of the building design company working with "Architectural Desktop" software and using “Project Navigator” directly connects to general file organization system. By this way separate documents of CAD design are created. Each designer has knowledge about development of the whole project bringing CAD documents into project structure (Figure 5). If changes are made in one part of the project documentation the system automatically shows and other designer can follow what’s going on. That is maintained design chain. At each time the numbers of design chain have information about changes in CAD documents.
- The same tree structure of the project documentation is appeared in the AIP where is “eChange” PDM system. After synchronizing all electronic documents in SIP according to the design parts the archive administrator sets “Archived” status for the documents before that putting them into AIP “eChange” system. By this operation project structure with design information are automatically transformed from SIP into AIP. In AIP all project documents gain “Released” status and if all information is correct documents gain “Archived” status.
- After transforming from SIP into AIP all project documentation obtain metadata properties. The Dublin Core metadata scheme is applied as an initial basis on which the development of more specific relational standard within proposed digital design data archive is performed. There is underway of automated attribution of properties and all documentation that is placed in to project structure adequate catalogues. Hereby all project information being in “eChange” system are accessible for users and groups according to permissions for each document type. The “eChange” system also provides different levels of access rights to documents View/Copy, Check Out/In, Release, Archive, and Delete.

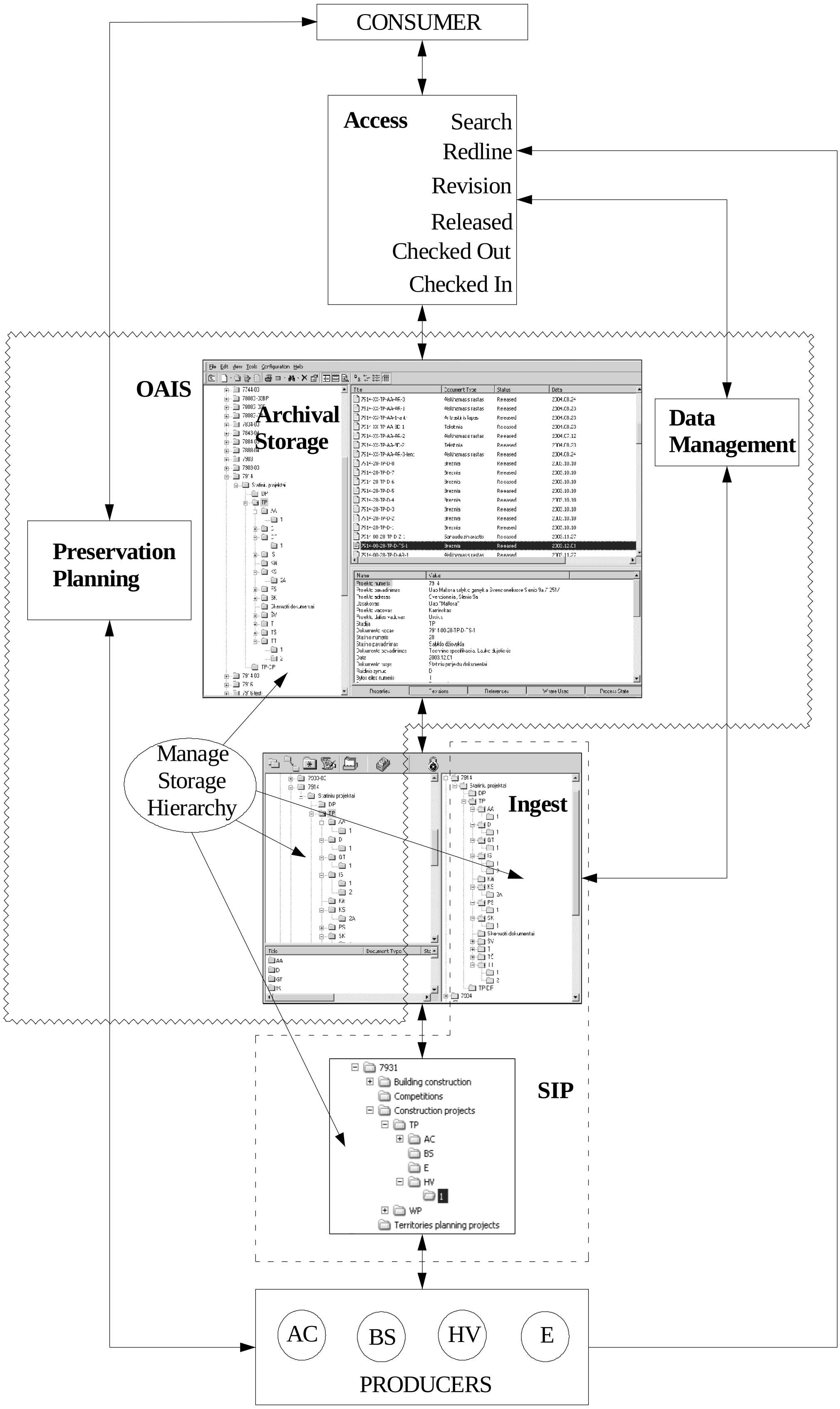

Figure 6: Design information structure

5. Conclusions

The first digital project documentation archive is developed in Lithuanian AEC industry. The modelling of the archive of the construction design documentation is based on reference model for an Open Archival Information System (OAIS). For the creation and management of this archive PDM system of “Empresa Solutions” is implemented. The main strategy was to develop the dynamic archive with information flows in the both directions of the design process chain: consumer-design-archive. The adoption of this digital archive provides a efficient basis for an automatization of Lithuanian construction regulatory rules for building design documentation.

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Transformation of Measured Surfaces of Buildings to CAD Supported Wall Line Model with Joints

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Abstract

The most central and most researched area of construction IT is the design and realisation of new building projects. However, if the building and real estate sector is viewed from the perspective of national economy or the ownership and use of buildings, the management of the existing real estate stock becomes more important.

The manageability of the real estate stock depends directly on the amount and correctness of available input data. The most valid and complete information on existing buildings can be acquired by measuring. Measuring is labour-intensive, but the utilization of results is still technically difficult. Therefore data processing should be as automatic as possible.

This article documents how a measured surface model can be transformed to CAD model. The new approach is based on the use of geometric documentation of intersections and visual marking systems to help the user finish the model.

The solution has been limited to walls and their joints. Other structural elements may be added to the model mainly by intersection methods of CAD programs. For example, a column can be added inside a wall afterwards.

The developed method aims at improving the integrity and technical perfection of models. The connectivity of structural elements is crucial for the usefulness of a model. If walls are not connected, intersections need to be remodelled by the user interface. Without the method presented here, the transferred data could at worst be used as a background image.

Keywords: Measuring of buildings, data transformation, CAD, wall generation

1. Introduction

There are two alternative methods for verifying or retrieving data on the sizes, spaces and structures of existing buildings: either reading the data from drawings or measuring them on site. Drawings have traditionally been made merely to serve the building process. If drawings have not been updated after that, they cannot be considered reliable.

In that situation the real estate sector has an acute need for methods that allow data on buildings to be saved effectively by on-site measurements. Such data are needed especially in renovation planning but they are also very useful for facility management. The main advantage of the on-site measurement method is the validity and completeness of the information

Existing methods for measuring buildings yield a surface model of the building, where the structural elements are depicted by visible surfaces. Invisible structures cannot be measured directly. The surface model is useful, for example, in visualisation.

CAD applications for building design model buildings based on structural elements. If measurements are linked to a special data saving application, the connection of surfaces to structural elements can be stored. A structural element can be generated if all of its limiting surfaces are known. Thus, for example, the surfaces of a fully visible column can be used to generate the actual structural element.

The central structural element in the modelling of a building is the wall, because spaces are usually limited by walls. After defining the walls it is possible to use the model to calculate floor and other areas which are crucial for the occupancy of the building. A major problem with the use of the measured surface model lies with the generation of wall structures, since it is not initially known which wall surfaces measured from different rooms limit the same wall.

2. Wall Generation to a Measured Model

2.1 Measurement of Building

Several methods are available for the measurement of outer surfaces and interior spaces of buildings. The oldest methods are based on measurements with a tacheometer. The method is described, for example, in publication [3]. Instruments designed for terrain measurement can be used to observe the three-dimensional coordinates of individual points. A measurement application can be used to combine the points into surfaces depicting structural elements. A drawback of the method is the slowness of measurement. Every time the measuring instrument is moved it must be set up carefully and its position determined.

The latest methods include modelling based on scanning where the surfaces are formed automatically. The method is described in publication [2] and its commercial application in publication [8]. In this method the distance information obtained by a laser distance meter is added to a digital image. The geometric shape of a surface can be calculated using algorithms derived from photogrammetry. The graphic elements constituting a surface do not necessarily follow the division of structural elements. Data on structural elements must be added to the model through human labour.

The simplest and cheapest measurement method uses a distance meter. A portable computer and a measurement application are also needed. The interface of the application can be used to assign the measured values directly to structural elements and to save the property data of the elements based on visual observations at the same. Although this method also requires much human labour, it is the quickest way to produce a model from measurements inside a building with data on structural elements. The weakness of distance measurements is that they do not include the angle of measurement. Then non- rectangular walls cause inaccuracies that must be addressed separately. There are several software packages on the market that utilise laser distance meters in the measurement of buildings. This method is described in publication [4] and its commercial application, for example, in reference [9].

2.1 Generation of Wall Elements

To enable the generation of structural elements from measured surfaces, the surfaces must be assigned type and material data. Moreover, one surface must not belong to two different structural elements. Otherwise the automatic processing of the model would not be able to make a distinction between such elements as columns and walls.

Many methods that generate walls from wall surfaces require either user intervention or are suitable only for the generation of rectangular walls. Such methods are presented, for example, in publications [6] and [7].

Publication [5] presents a method where wall direction can be used to find the closest other wall surface for each measured surface. The direction is known if wall surfaces of a room are measured in a sequential order when the measurement returns to the starting point. Then the walls can be generated even if the measured wall surfaces are not aligned with the rectangular coordinate axes. The method does not require setting an upper limit for wall thickness, either. The geometric shape of the generated wall base areas is limited to four points. The wall generation method is two-dimensional, which means that the line formed by the lower edge of the wall surface is used instead of the measured wall plane.

3. The Documentation of Wall Intersections by Geometry

3.1 Assumptions

If the wall structure is homogeneous in the vertical direction, the connectivity of walls can be studied based on the intersections of the base areas of the walls. An example of the calculation method is presented in publication [1]. Such a method could be difficult to program because of problems related to calculation accuracy.

The calculation becomes much faster and easier if the intersections can be calculated using lines. Two walls can be considered interconnected if any of their boundary lines intersect. Possible lines indicating an intersection are the boundary lines defining the base area of the wall and other lines defined within the walls such as the centre line of the base area.

The data structure of a wall with a simple geometry can be described by a single line. The wall thickness can be assigned to both ends of the line. The use of this method is supported by simplicity and the utilisation of standard basic functions of CAD applications.

Three-dimensional wall models can be described by base areas if the geometry of the structure does not change in the vertical direction. Then plane coordinates (x and y) remain constant while the z coordinate changes. If height can only change linearly between the end points of the wall, data on the three-dimensional shape can be stored using height data assigned to the corner points of the base area.

3.2 Used Symbols

Intersection types are classified using upper- and lowercase letters. The upper-case letter represents wall properties and the lowercase letter the connectivity of centre lines. The connectivity of wall lines is indicated by a lowercase letter added after the type letter. Connected lines are marked with "c" (connect) and others with "g" (gap).

Wall intersections are divided into intersections of two or more walls. In an intersection of two walls the real structure is usually continuous but the wall has been divided into two elements in the computer model. It was decided to use the capital letter "W" (wall) as the first character of the type designation of this intersection.

Intersections of more than two walls are indicated with a capital "C" (crossing). With such intersections the number of combinations is theoretically unlimited. The classification of these intersections is based on selecting the two walls that form a continuous structure as in the case of an intersection of two walls. All other walls join the walls that form the continuous structure.

The walls to form a continuous structure are determined on the basis of their property data. Exterior walls or bearing walls are primarily chosen as continuous. It is not always possible to reach an unambiguous solution based on these conditions, and additional conditions may therefore be set based on structural thickness and parallelism of walls. In the designations the walls of a continuous structure are indicated by the letters "CC" (crossing continuous).

The fourth letter indicating a wall intersection type is "G" (gable). It is used for cases where a wall gable bounds a space. A gable may be partial, in which case the letter is made part of other type designations. A partial gable is produced if all boundary lines of the connected wall areas do not intersect.

3.3 Types of Wall Joints Classified by Connectivity

In the method presented here walls are assumed to be modelled by lines, which are also used for documenting wall joints. Walls are classified under different categories based on their connectivity. The classification does not depend on the location of the line in the wall base area, provided that the wall line is straight and not, for example, an arc. The examples use the centre line of the wall base area. Intersection type refers to the type of each connecting wall, not the entire intersection.

Intersection types where a wall line is connected to another line are: Wc, CCc, Cc and WGc. Intersection types where the wall lines do not connect are: WGg, CCg, Cg, CCGg and CGg. There may also be walls that end without a connection: G.

Intersection types differ in terms of the intersections of their wall and boundary lines. Boundary lines are defined as discontinuous if at least one line is discontinuous. Then the wall gable bounds a space, and the letter "G" is added to the type designation. The following three illustrations present examples of different joints. There are three different types of two-wall intersections, as shown in Figure 1.

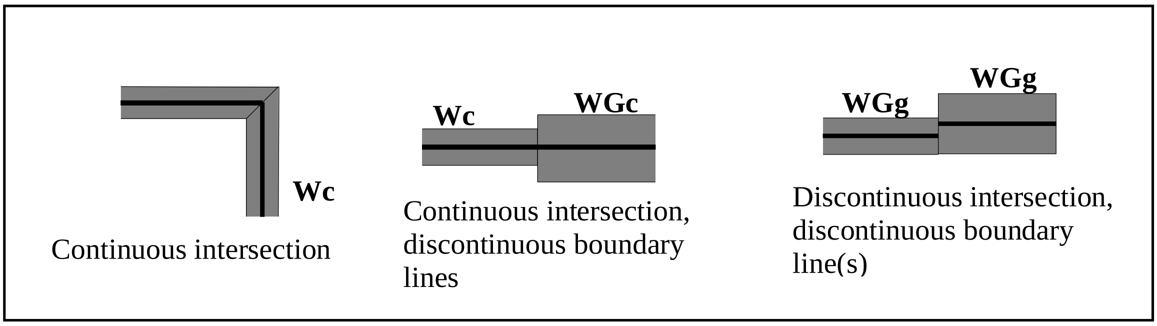

Figure 1. Intersections of two walls.

Figure 2. shows examples of intersections of more than two walls. The walls forming a continuous structure (CC) are darker. In the second example of Figure 2, the centre line of one wall has not been extended to make a connection. This is because one wall would be shortened by the operation. This would also change the original measurement result or the measured surface, which is not permissible.

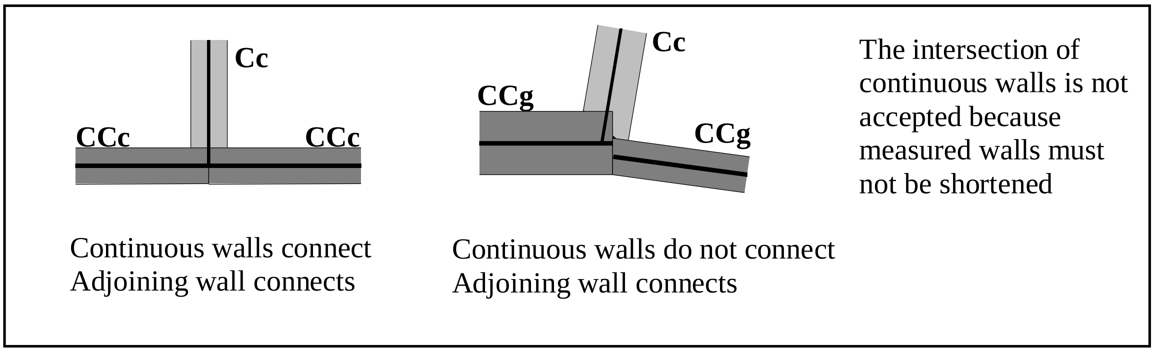

Figure 2. Intersections of more than two walls.

Figure 3. shows examples of intersections of more than two walls where a wall gable bounds a space. These cases occur rarely in actual buildings.

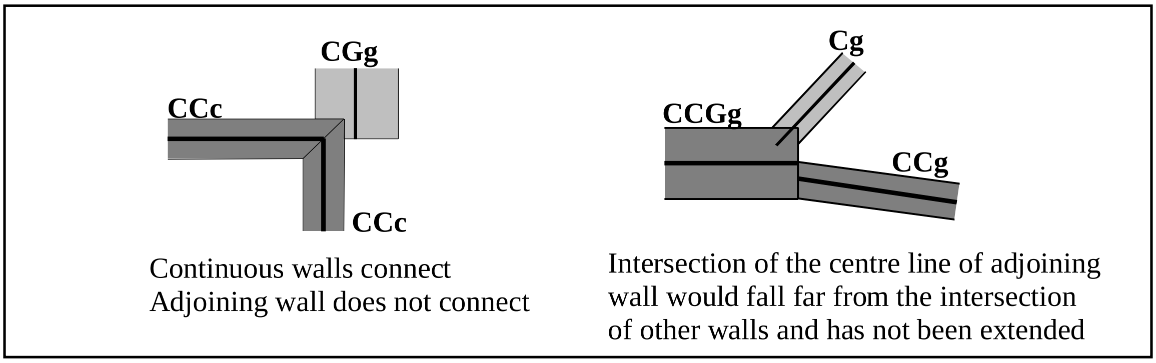

Figure 3. Special cases of wall intersections.

4. Implementation and Results

4.1 Wall Generation

Walls were generated using the method described in publication [5]. In the testing, it was assumed that all walls produced by the measured model are flawless. Actual 4 measured buildings were used as test material. Sample size was too small to be statistically significant, but it gives an idea of whether the method works. Buildings L and N are public buildings of complex architectural shapes. Buildings P and R are rectangular prefabricated buildings. In figure 4. is shown two dimensional drawings of buildings L, N and R. Building P is shown in figure 5.

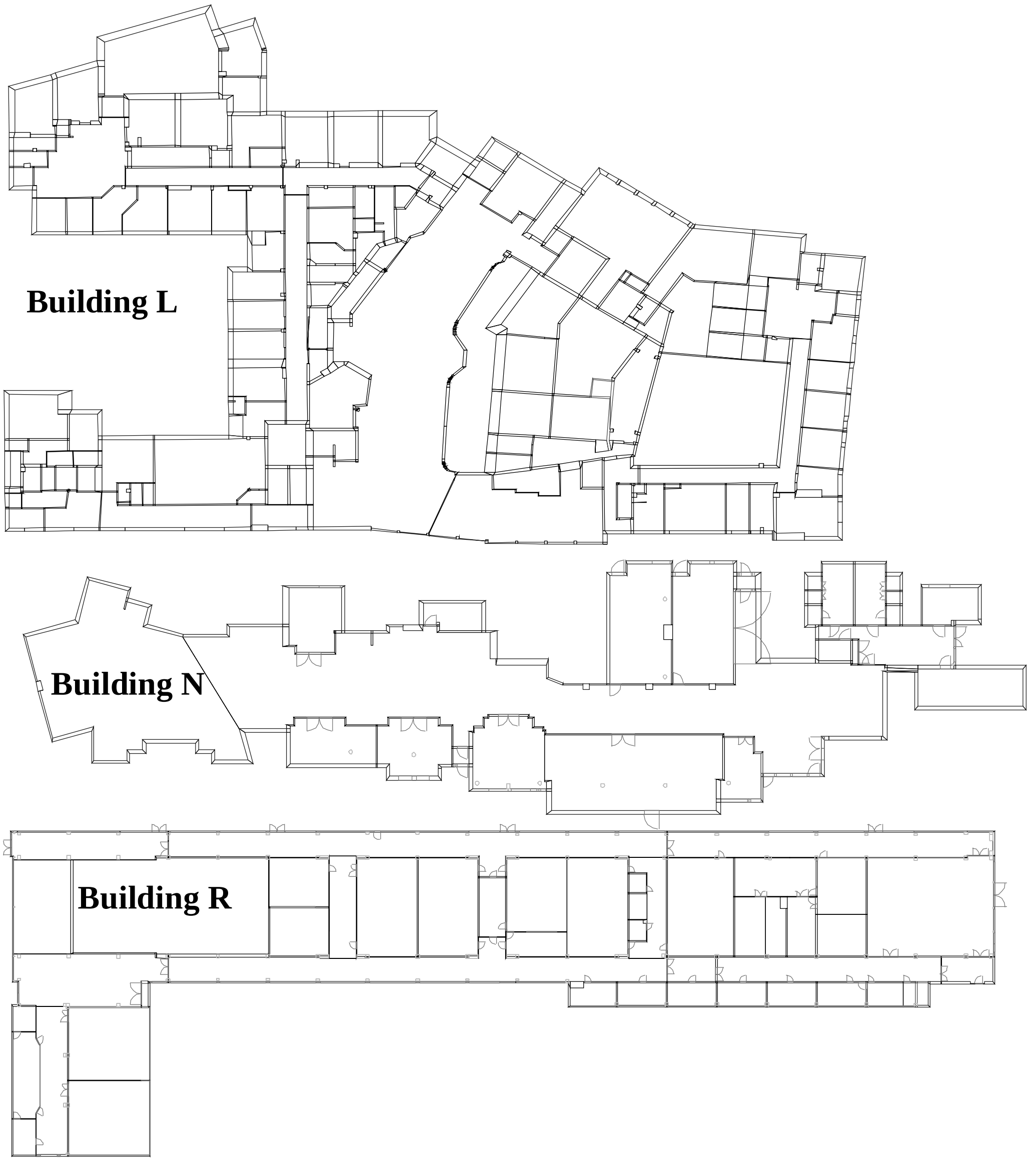

Figure 4. Two dimensional drawings of test material.

Table 1. presents the numbers of generated walls divided according to constant or non-constant wall thickness. If thickness is not constant, it may only change linearly between wall ends, as described above.´

Table 1. The number & percentage of different wall thickness types in the test material.

	Building L		Building N		Building P		Building R	
Thickness	no.	%	no.	%	no.	%	no.	%
variable	801	96.2	25	12.0	11	5.5	26	12.8
constant	31	3.7	182	87.5	187	94.0	176	86.7
unknown	1	0.1	1	0.5	1	0.5	1	0.5
All walls	833		208		199		203	

4.2 Joint Types of End of Walls

The centre lines of the generated walls were extended to intersect each other. Data on the connectivity of wall centre lines were recorded in the database. Different types of wall end intersections were recorded as described in Chapter 3. Table 2. presents wall end types by connectivity.

Table 2. Occurrence of wall end intersection types in the test material.

	Building L		Building N		Building P		Building R	
End type	no.	%	no.	%	no.	%	no.	%
Wc	508	31.1	218	52.7	84	21.1	90	22.2
CCc	150	9.2	99	23.9	121	30.4	77	19.0
Cc	259	15.9	0	0.0	70	17.6	72	17.7
WGc	0	0.0	0	0.0	0	0.0	0	0.0
WGg	132	8.1	30	7.2	20	5.0	46	11.3
CCg	488	29.9	39	9.4	69	17.3	96	23.6
Cg	41	2.5	15	3.6	20	5.0	4	1.0
CCGg	24	1.5	2	0.5	2	0.5	1	0.2
CGg	7	0.4	0	0.0	1	0.3	0	0.0
G	0	0.0	3	0.7	1	0.3	0	0.0
unknown	23	1.4	8	1.9	10	2.5	20	4.9
All ends	1632		414		398		406	
Walls	816		207		199		203	

The case WGc, where the centre lines of two walls connect at the intersection but the boundary lines do not, did not occur in the material. That would be possible only if exactly equal thickness changes were measured from different rooms. Although theoretical, the type cannot be excluded from the classification, because it produces a connection between walls.

Cases where connectivity could not be determined were examined by random samples. In all examined cases wall thicknesses were so small that connectivity could not be calculated. Small wall thicknesses resulted either from measurement inaccuracy or faulty type designations. Imaginary walls of zero thickness dividing spaces were used to facilitate measurements, and were excluded from calculation based on their type designation.

The number of walls is the numbers of wall ends divided by two. 17 of the originally calculated walls in the L building and one in the N building were removed. These walls were also geometrically flawed. For this reason, the number of walls from these buildings is smaller in the connectivity test than in Table 1.

Table 3. presents numbers of wall ends by connectivity. Table 3. reveals that over half of the intersections in all buildings could be documented geometry. On average, two thirds of the intersections in the entire material were documented.

Table 3. Share of connected wall ends in the test material.

	Building L		Building N		Building P		Building R	
Continuously	no.	%	no.	%	no.	%	no.	%
continuous (c)	917	56.2	317	76.6	275	69.1	239	58.9
non-continuous (g)	692	42.4	86	20.8	112	28.1	147	36.2
gable (G)	0	0.0	3	0.7	1	0.3	0	0.0
unknown	23	1.4	8	1.9	10	2.5	20	4.9
All ends	1632		414		398		406	

4.3 Joints of Walls

Table 4. presents the numbers of different intersections. The number of continuous wall intersections is obtained by dividing the number of the respective wall gables (Wc) by two. Likewise, the number of non-continuous wall intersections is obtained directly from wall gables (WGg). The connectivity data of the measurement database allows calculating the number of intersections of at least three walls. In the unknown cases connectivity of walls could not be calculated, and only one wall is connected to the intersection in the database.

Table 4. Number of wall intersections in test material.

	Building L		Building N		Building P		Building R	
Inersection	no.	%	no.	%	no.	%	no.	%
continuous wall	254	41.2	109	61.2	42	28.4	45	28.9
non-continuous wall	66	10.7	15	8.4	10	6.8	23	14.7
joints	291	47.2	54	30.4	94	63.5	88	56.4
unknown	5	0.8	0	0.0	2	1.4	0	0.0
All	616		177		148		156	

4.4 Output to CAD

The model was read from the database by an application written in C language and was transferred to ArchiCAD 7.0 using the functions of the programming interface. Transformed building P is shown in figure 5.

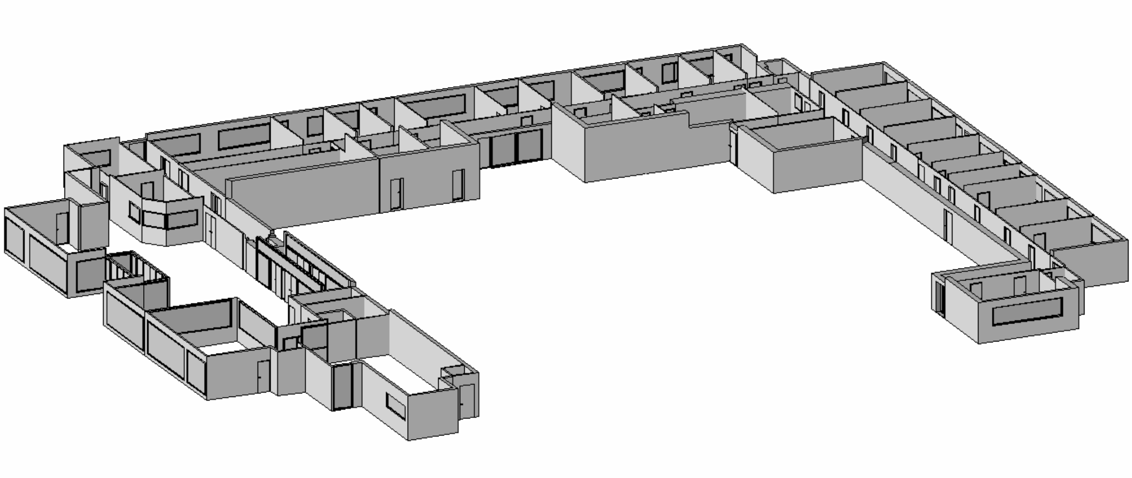

Figure 5. To CAD program transformed model of building P.

In this CAD application the wall line (reference line) may be located in the middle of the wall only if wall thickness is constant. In the other cases the wall line was moved to the edge of the wall when connections between wall lines failed. Building L was not transformed, because only 4% of its walls were of constant thickness

Wall intersections where the centre line of a joining wall did not connect to the others were marked by an alert symbol visible to the user. The example of marked join is shown in figure 6.

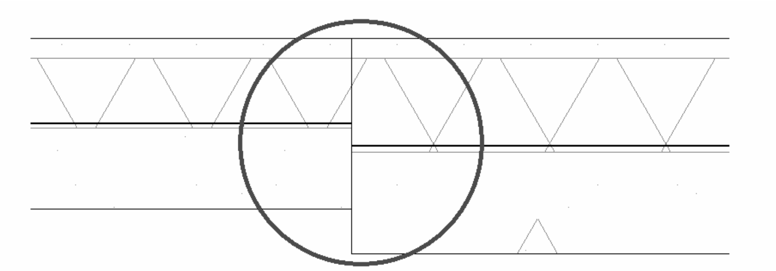

Figure 6. Marking of unconnected wall joint.

The number of marked intersections was calculated from the user interface of the CAD application. Table 5. shows the share of the marked intersections of the total.

Table 5. Intersections marked as non-continuous in the CAD output.

	Building N		Building P		Building R	
	no.	%	no.	%	no.	%
Marked intersections	68	38.2	63	42.6	76	48.7

5. Discussion

The method sets considerable limitations on the model to be used as input data. The requirement can be met by dividing actual walls into a sufficient number of sections in the computer model. In principle it is also possible to assign a wall line to a wall of complex shape, and use it to document connections. This, however, requires a separate data structure to maintain the geometric relationship between the wall area and the centre line. The other possibility is to edit the transferred model by rejoining small walls into bigger ones. This could be achieved by introducing a data structure to indicate which wall sections constitute a uniform continuous wall.

The outer surfaces of the external walls of building are normally continuous between the corners. The distances of wall surfaces between adjacent spaces are difficult to measure in exactly the same way. The wall of the other room may also have a special surfacing which makes it thicker. In both cases the result is that the centre lines of the external walls do not meet. Then the connectivity of intersections would be better if the outer surface were selected as the wall line.

CAD data transfer could be improved considerably. It can be assumed that the features, and in particular the programming interfaces of applications, develop constantly. With new CAD software versions theoretically calculated connections will before long be also attainable in practice.

The geometric documentation of intersections could also be used for general data transfer between CAD applications. Unlike in the measured database, it can be assumed that in the CAD model almost all walls are joined before transformation. The data transformation features for walls of CAD applications could be developed so that connections would occur in most cases. The location of the wall line could also be optimised to enable connectivity in as many intersections as possible. It is important that the method presented here is independent of the CAD application.

6. Conclusions

The main result of the tests was that about two thirds of wall intersections could be documented by geometry, even in the case of complex wall geometry. This leads to the conclusion that if the geometric model of a wall can be reduced to a line, the connectivity of walls can often be documented by simple markings and ten intersection types. The documentation is based on the intersections of wall lines, which means that connectivity can be expressed using geometry. This also means that the model can be transferred between applications with a minimum of external definitions.

Connections between all walls could not be achieved in any of the tested models. The detection and marking of non-connecting points reduced the work of revising and complementing the model considerably. Without the markings, the finding of a single flawed joint would have required reviewing all intersections. The number of connected walls is large enough to use the method compared to the situation where the connectivity of walls is not known.

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UK Construction Processes and IT Adoptability: Learning from Other Industries

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Abstract

Process improvement has been identified as a mechanism of achieving the desired performance improvements of the UK construction industry. During the recent past, researches within UK construction process improvement research paradigm have been influenced by the initiatives of other industries like manufacturing and software. Despite the success stories within such industries, the unique characteristics of the construction industry demand a careful consideration of the applicability of these approaches within a construction environment. Based on a literature review carried out by the authors, this paper discusses the nature of this applicability issue further.

In addition to the above applicability issue, construction industry has suffered from a slow information technology (IT) adoptability issue, while IT has been considered as an effective enabler for process improvement in other industries. This has hindered the potential synergetic benefits of using IT within construction process improvement strategies. As such, it is important to understand the reasons behind this slow IT adoptability in order to ensure successful deployment of process improvement initiatives within the UK construction industry. This paper discusses this issue, by reviewing the literature to compare IT adoptability issues of the UK construction industry and other industries, with the aim of learning lessons from those to improve the UK construction industry.

Keywords: UK construction industry, construction process improvement, IT adoptability, IT-process co-maturation, construction IT

1. Introduction

The need for a change within the UK construction industry is discussed within number of studies during the recent past [1,2,3,4,5]. Growing dissatisfaction found among both its private and public sector clients has been an effective motivator for these discussions [6]. These dissatisfactions are often attached to the poor performance of the industry. The required change has thus been identified to be in a form of performance improvement. Further studies about this requirement have revealed that the fragmentation and confrontational relationships are the major inhibits for performance improvement initiatives [4,3,5]. Fragmentation and confrontational relationships are sharpened due to the traditional functional view of construction projects, where the tasks are assigned to individuals based on their functions with minimum attention given to the integration issues [7,8].

Having identified this nature, Egan [3] highlighted that “focusing on the customer” and “integrating the process and the team around the product” as two of the key drivers to achieve the desired change within the UK construction industry. This emphasises the need of deviating from functionally oriented project structures towards a customer focused, process oriented project delivery mechanisms. It appears that the above recommendations from Egan are based on the view that the process improvement is the way forward to improve the performance of the UK construction industry [9].

2. Process Improvement

2.1 What is Process Improvement?

In literature “process” is often defined as a set of related activities attached to outputs, value and customers [39]. Davenport [10] states that “a process is simply a structured, measured set of activities designed to produce a specified output for a particular customer or market”. Hammer and Champy [11] defined a process as, “a set of activities that, taken together, produce a value to the customer”. As identified within above definitions, the process view integrates the product, procedures and the customer, so that the stakeholders of an organisation can view the big picture which they are contributing to. This essentially synchronises the individual functional objectives with the overall organisational objectives, enabling opportunities for improvements.

Literature covers a wide spectrum of terms related to process improvement. Business Process Improvement, Continuous Process Improvement, Business Process Re-design, Business Re-structuring, Business Process Re-engineering are some of those which appear frequently within literature [12,13,14,15,16]. All these concepts appear to have the major objective of achieving performance improvement within organisations, but vary from the magnitude of the desired level of change. It varies from continuously improving the processes to total re-structuring the organisation [17]. This determines the two extremes of the process improvement spectrum and defines the two major approaches to process improvement, the evolutionary approach and the revolutionary (radical) approach [18]. Within literature some times the term “process improvement” is synonymously used with the evolutionary approach and “process innovation” is synonymously used with revolutionary approach. Within this paper, “process improvement” is used for both the cases, and where appropriate, evolutionary and revolutionary approaches are explicitly indicated.

2.2 Process Improvement in Construction

Recent construction literature show a clear focus on construction process improvement strategies. Within these literature, the best approach for construction process improvement is often debated (see: [4,19,20,21]. Historically, most of the process improvement strategies have evolved within production line based industries like manufacturing. Business Process Re-engineering (BPR) is one such strategy evolved to address the supply demand gap existed within most of production line based industries during early 90's due to the globalisation trend. BPR is an attempt to eliminate chronic wastes within processes in practice, by introducing new processes. The focus here resides within the ultimate outcomes of the processes in place rather than on the processes it self. Thus the existing processes attract minimum attention when designing new processes and a whole new set of processes could be the ultimate result. Due to these radical changes to processes, often this approach claims to produce significant level of improvements. Despite being a fashionable theme within some of the industries, BPR has received number of criticisms as a construction process improvement strategy (see: [4,19,20]). Considering the applicability of this approach, Love and Li [4] pointed out that the implementation of the BPR within construction is difficult due to the fact that the array of construction have not been designed systematically but have evolved in an ad-hoc manner. Further, direct applications of BPR in construction might lead to complications, due to the fact that the construction often consists of complex supply chain arrangements. Due to these complex relationships, there is a danger that the re-engineering exercises might impose negative effects on construction organisational processes, which would not be apparent for some time after implementation [22]. In addition, since BPR pay less attention to the "human side" of an organisation [23], it may adversely effect the construction organisations as it is perceived as labour intensive.

Another process improvement strategy visible largely within manufacturing and automobile industries is the Continuous Improvement (CI). This is an evolutionary approach, based on the statistical process controlling. This strategy has its roots in the Japanese "Kaizen" approach to quality control, and to the Total Quality Management (TQM). It concentrates on planning and monitoring existing processes with the aim of continuously improving the same. The main problem of this approach, when applied to construction, is based on the project based nature of construction. Unlike in a production line environment, it is difficult to identify a linier relationship between processes in place within a project based environment. This limits the possibility of setting targets for processes in place and hard to monitor the performance of the same. On the other hand, this approach is largely depending upon repetitive nature of the processes visible within the production line environments. Thus, the "unique" nature of the construction product questions the applicability of this approach within a construction environment.

However, the above problems do not eliminate the possibility of using the principles of above process improvement approaches within a construction environment. As Lillrank [24] pointed out, the innovations in one industry do not provide direct solutions to the problems of other industries. Rather those innovations have to be recreated within the receiving industry considering the capabilities and the characteristics of the same.

Considering the apparent problems above, some studies have suggested that, irrespective of the approach to process improvement, construction organisations need to embark on adopting quality management principles if the desired improvement to be achieved [4]. Within this context, it is suggested that an underlying process improvement culture has to be established before embarking on process improvement initiatives [4,8]. The major emphasis here is to prepare the organisation to receive the process improvement initiatives by increasing the capability of the organisation in question. Considering the different maturity levels of different construction organisations, a stepwise approach to process improvement is suggested by some recent studies [9].

Being a project based industry and showing some similarities to the construction, software industry has exemplifies a successful process improvement initiative based on the principles above mentioned. This approach has gained its popularity under the name "The Software Capability Maturity Model (CMM)". This model was developed for the US department of Defence (DoD) who is a major software purchaser [25]. The use of CMM includes the evaluation of software manufacturing organisations prior to award them contracts. CMM is based on a five levelled structure. Within this, organisations are ranged from level 1 to level 5 based on their maturity. Within this framework, a maturity level has been defined as "a well defined evolutionary plateau towards achieving mature processes. Each maturity level provides a layer in the foundation for continuous process improvement" [26]. Level 1 organisations are the least matured organisations where as level 5 organisations being the most matured organisations. In order to achieve a specified maturity level, organisations must satisfy all the key processes defined within the immediate below maturity level. The organisations are tested against "key enablers" to determine weather they have satisfied each key process. Through this framework, organisations are guided to adopt stepwise process improvements. This framework ensures that the organisation in question is ready for the next level of process improvement. This, intern initialise a process improvement culture within the organisation and guides the procedures and the people towards improvements, using the available and potential tools.

Sarshar et al [25] have attempted to apply the principles of this model within the construction industry. This attempt was named as the Structured Process Improvement in Construction Enterprises (SPICE). This research was carried out in stages, and currently, the dynamics up to the level 3 of the CMM were explored and customised to the UK construction industry (See: [9,25] for further details about this approach). While lower maturity levels of CMM establish the required capability and the background of the organisation, the higher maturity levels are responsible for dramatic and sustainable process improvements. Within the SPICE, the dynamics of higher maturity levels were not explored thoroughly, leaving its full potential unexplored.

The above exemplifies that possible solutions for some of the problems identified within the construction process improvement, have already been explored within other industries. A careful consideration of the characteristic differences and unique requirements of the industries in question should then provide a mechanism for sharing knowledge between industries.

Apart from the process control mechanisms explained above, the information technology (IT) has been identified as the major enabler of the process improvement [10]. However, the construction industry has been criticised for its slow IT adoptability [27]. Further more; the industry has become frustrated with the falling of IT as many companies have invested in the wrong technologies without addressing the business needs [28]. The following section discusses the stand of the role of IT as an enabler for the construction process improvement.

3. Process Improvement and Information Technology

3.1 IT for Process Improvement

While process improvement is not purely a technological endeavour, Information Technology has been identified as a key process improvement enabler [10,11,29]. Within this context, new advancements of IT triggers new operational and management processes within organisations, creating a technology push for process improvements. On the other hand, the process improvement initiatives create an opportunity to change existing processes to be benefited from existing information technologies in place, creating a process pull for technological advances. This reveals a concept of duality between the process improvement and use of information technology [30].

The slow IT adoptability does not mean that the construction industry lags in implementing IT systems; rather, it suggests that the construction industry lags the other industries in impact of IT to the business [31]. Even though the issue has been identified as lack of awareness of how to exploit technology, a careful consideration of the “lack of awareness” relates the problem to the roots of “processes”, as often immature management processes are responsible for internal and external communication gaps. In other words this suggests that, proper processes have to be in place in order to harness the actual benefits of the IT capabilities within construction organisations.

On the other hand, it could be argued that information technology has created a significant impact on some of the work patterns and processes of organisations irrespective of their industries. As an example, it is difficult to identify a an organisation today, which uses any report producing, letter writing mechanisms or tools other than personal computer based word processing solutions even within the construction industry. Further, emails have become a powerful and commonly used communication media commercially and individually. A survey conducted by Construction Industry Computing Association [32] based on over 400 construction organisations revealed that 97% of the construction organisations have access to email. Further, computer aided drafting tools such as AutoCAD have shown influential impacts during the recent past, and traditional drawing boards are becoming redundant rapidly. Above exemplifies the fact that, irrespective of processes in place, IT has influenced organisations to change their work patters and processes. This further stresses the existence of the concept of duality within the construction industry as described above.

4. IT as a Change Agent

The concept of duality discussed above, creates a clear link between the organisational processes in place and the IT adoptability. This suggests that IT adoptability in a particular industry or an organisation, especially with the intention of improving its performance, should not depend entirely on the capabilities of the technology in question. Rather, the organisation and industry specific characteristics and processes in place will have to be investigated prior adopting such technologies. The next section discusses some evidence from literature highlighting IT usage patters of construction and adoptability problems visible within other industries especially related to processes in place.

4.1 IT Usage Patterns in Construction and Adoptability Problems

In order to understand the IT adoptability problems within construction, it is vital to identify the IT usage patterns within the construction industry and at the same time it is important to identify the drivers behind these usage patterns. A study carried out by Construction Industry Computing Association (CICA) gives an insight to the IT usage patterns and drivers behind the IT usage in UK based construction companies. 73 construction related companies were surveyed and one of the objectives of the study was to identify the drivers of the investments in IT [33]. It is visible from the survey results that the IT investments in construction is generally driven by short term tangible benefits rather than long term strategic benefits. For an example, the survey results reveal that general client expectations / requirements attracted 68.5% response rate as a driver for IT investments where as only 17.8% have indicated strategic board level decisions as a driver for IT investments in construction. On the other hand it is visible from the same survey that an imbalance between the technology-push and process-pull is visible within the industry. For an example, 60.2% and 40.0% of the respondents have indicated that affordability of technology and exploration of new technologies respectively as a drivers for IT investments where as only 32.8% respondents have identified process improvement as a driver for IT investments. The statistics show that construction lacks the strategic usage of IT. It also reveals that IT usage within construction is largely technology push driven.

Few facts can be highlighted as reasons for this. Most importantly, there is a clear communication gap and a conflict of interests between the IT implementations and decision makers. This gap is widened due to the absence of dedicated IT specific functions (roles) within most of the current construction processes. This leads to another reason for the visible gap between actual IT potential and its usage, a lack of formal approach to incorporate IT within organisation's development plans. It is also visible that the current usage of IT within most of the construction organisations are based on short term objectives such as gaining speed, minimising human errors, etc. And in many cases, little consideration has been given to understand the function of the system in relation to the business [34]. Thus the short term, tangible benefits of IT, has become the driving force of IT adopting policy, while hindering the possibilities of tailoring IT to support actual system and process improvement requirements. Hence, it is also visible that current IT usage within the construction industry is more functional oriented.

This leads to the problem of IT stagnation within the construction industry, as the use of IT is not being looked at from an organisational wide angle rather from an individual, functions based angle. This has witnessed by some of the existing IT usages. Software based project planning tools are widely being used within the construction industry. But the fact that, it is being used in an uncoordinated manner has hindered the possibilities of using those to the maximum potential. For an example, most of the modern project management software (e.g. MS Project) are capable of analysing financial capabilities and requirements (e.g. cash flows forecasts) of organisations in addition to the obvious scheduling capabilities. But at point of usage, most of these functions are neglected due to the functionally oriented work patterns. This complies a classical example of the need for an industry wide, process based approach to IT implementation strategies within the construction industry.

The above situation drives the construction industry to a dilemma, in terms of the process improvements and the use of IT. It is important to have matured processes that support IT integration to enhance the maximum benefits from IT capabilities, and at the same time, new IT capabilities lay solid foundations for successful process improvements [30]. This is not a construction specific problem; rather it is visible within some of the IT adoption initiatives of other industries. The following case highlights a similar scenario within the healthcare sector.

4.2 An Example from the Healthcare Sector

A number of information technologies have been adopted in medical practice over the last century [35]. Some of the attempts to adopt various technologies have found ready acceptance (e.g. digital transmission of X-Ray images) while number of others have failed so far to gain acceptance [36]. Videoconferencing has been one of such technologies which have been tried since 1950s in several countries [37]. Bower et al [36] have investigated the adoptability of videoconferencing technologies within the health care sector and have presented some insights to the problem.

A technology push for the use of video conferencing in Scottish healthcare sector was visible due to the rapid fall of equipment prices, improvements in quality of transmission and installation of the basic telecommunication infrastructure. This was further reinforced by the policy pull of the Scottish office since 1998. The Scottish office has advocated proactive adaptation of visual communication technologies in healthcare to share the same basic communication infrastructure with other information and communication technologies in place [38].

Despite the strong encouragement from technology push and policy pull for adopting visual communication technologies in Scottish healthcare sector, [37] have sighted a study of ICTs in Scottish healthcare delivery, which concluded that rejection of innovations and technologies was probable where these have shown significant disruptions to the crucial process of the established practices. It has further been emphasised that the problem was evident in use of videoconferencing where it had the potential to change the clinician / patient relationship and the relationship between the professional groups within the health care delivery context. Moreover, Bower et al [38] highlight that organisations with unstructured and ad-hoc processes have more tendency to reject new technology and innovation.

This example case stresses the fact that the mere balance between technology-push and policy-pull (again technology driven) does not provide the perfect platform for IT adoptability. The strong processes and cultural concerns have a major impact on innovations and technology adoptability within a particular industry. Construction industry can also put within the same context, as it demands strong relationships between various stakeholders as with the clinician / patient, professional groups relationships within the example above discussed. Further, it emphasises that the construction has the potential to take the examples from other industries and as exemplified by this case, there is a need of compiling a balanced and process oriented IT adoptability strategy. Further, this demands the construction to consider this IT adoptability strategy as an integral part of its process improvement strategies.

5. Conclusions

Process improvement has been identified as a mechanism to improvement the performance of the UK construction industry. Despite the various strategies available for process improvement initiatives, the characteristics of the construction product and the industry have created a discussion on direct applicability of those initiatives within a construction environment. Identification of these characteristics enables the construction industry to evaluate other industries experiences within a construction specific framework. Success stories of process improvement within the industries like manufacturing and software then provide a platform within the construction to learn process improvement lessons from other industries.

A close relationship is visible between the information technology and some of the existing process improvement initiatives. Construction industry has shown a slow IT adoptability creating concerns about synergetic benefits between IT and process improvement in construction. Studies related to IT and processes have identified a duality between the IT adoptability and the organisational processes in place, emphasising the importance of considering IT adoptability strategies within process improvement initiatives. Some literature have provided empirical evidence from the industries like healthcare to strengthen this importance specially to justify the significance of considering industry specific characteristics and processes within its IT adoption strategies. Similarities and differences between other industries and construction provide a comparison basis to evaluate the ability of the construction to learn these lessons from other industries with the aim of maximising the synergetic benefits of IT adoptability and process improvement.

Since this discussion has considered the common characteristics of the construction product and the production process, the genaralizability of the above conclusions are straightforward. This means that even though the examples discussed within this paper based on the UK construction industry, the arguments built upon those examples can easily be validated to the construction industry beyond geographical limitations.

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Section II

ICT in Facilities Management

The Design of Best Practice Framework in Information and Communication Technology Management in Facilities Management: Case Study in Malaysia

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Abstract

Information and Communication Technology (ICT) become more important nowadays. The Malaysia government has also define attractive policies to make our economy environment more attractive such as Multimedia Super Corridor which is emphasize the implementation of ICT in various economy sector and also to make ICT as an important agenda. This includes facilities management sector in Malaysia. Therefore, this research will be planned to build a best practice concepts of ICT Management Framework for facilities management in Malaysia. This framework is a strategy and synergistic combination of a number of key components, working in tandem. The framework is best viewed as an interconnected triangle consisting of three key elements, namely, people, infrastructure and applications. The ICT Management framework must identify the importance to innovation of building strong link between ICT and facilities management sector. These will enhance facilities management sector capability to produce and deliver globally competitive product and services, to facilitate growth.

Keywords: Best practice, frameworks, facilities management, information and communication technology

1. Introduction

As the use of computers and telecommunications have changed over time, the portfolios of information systems suitable to an era of inward-focus automation of basic activities are unlikely to be suited to an age which focuses on information to support executive decision making, connect the organization to another organizations in the business environment. According to Konsynski and Tapscott (1992), ICT is a factor in contemporary business environment to growth and as agent to link between two or more organizations with distinct and probably different structures, strategies, business process and organizational cultures. The companies must take part and alert with new ICT system because to enter in globalization business, all the management system must be up date and all staff in the companies should know about ICT very well especially for the management.

All the companies in Malaysia must take action to build their company ICT system and there must have a good ICT framework. Framework is very important because framework is a collaborative community based effort in which these commonly needed data themes are developed, maintained, and integrated by organizations. Companies see the framework as a way to share resources, improve communications, and increase efficiency. Framework is best viewed as an interconnected triangle consisting of three key elements, namely people, infrastructure and applications. Many types of organizations participate in developing and use the framework for their management. Although different organizations have characteristics data use pattern, all organizations need different resolutions of data at different times, particularly when they are working together. The framework represents a nationwide community for data sharing, and provides the benefits for the companies as a guideline to involve in globalization market.

Developing the ICT framework take a long time but, it is very important especially for facilities management in the companies. In Malaysia, facilities management stills a relatively new concept, which makes it difficult to present a definitive description. Facilities management can be described as multifarious because of the diversity of its core component such as technical, financial, administrative and management skill.

The scopes of facilities management will depend mostly on the company of which it is a part. Some companies may consider that the facilities management department should manage all non-core activities. This could therefore include departments such as purchasing, accounts, legal, and travel. Other companies may have their facilities management department incorporated into another support service function, such as finance or personnel. Nowadays, facilities management has become a profession. Quite different from the role taken on by the engineer in the early eighties which was described by Becker “Facilities management resided in the boiler room not the boardroom” (Becker, 1990). Facilities management is important and the companies should take serious with facilities department.

The companies can manage their facilities management very well if they have a good system. For this situation, a framework is important to clearly for organize their company as a guideline and basic step to make any changes their process management to enter in era globalization.

2. Materials

2.1 Information System Planning in the Modern Context

By the mid 1990’s, it was arguably reasonably well established that some sort of formalized strategy information system planning was an appropriate undertaking for most organizations. Information system planning is to be closely allied to the organizations business planning activity, the accept wisdom at the time suggesting that ICT should only be attempt once a business strategy have been develop and articulate, and hence understanding reach of direction the organization planning to follow for the next few year, its goal, objectives, core business processes and its changes agenda, for examples. With this business strategy establish and share understanding reach among executives, an information system plan could be develop, determining the information and information system needs to support the business strategy, and thus guiding investment decision into the future.

An interactive and generative process is envisaged, recognizing a general trend of establishing a business strategy, then an information system strategy, and finally information technology, but acknowledging the constraints and pressures in the real world which may act to limit the strategies somewhat. Given the rate of technology change, and the potential and impact that modern ICT could have directly on business strategy, and the outset o this process it is important to be aware of technological advances that may impact or alter the chosen or desire course for an organization (Peppard,1993; Liedtka,1998). The examples for the strategy framework it shows at Figure 1.

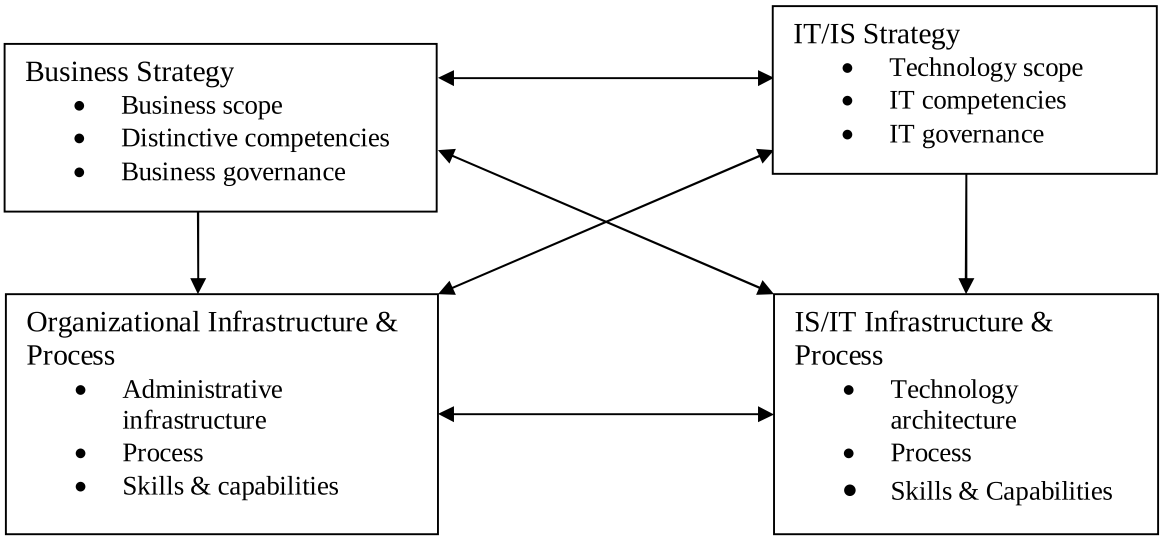

Figure 1: Achieving Strategic Alignment (Adapted from Henderson and Venkatraman, 1994)

3. Rationale for Facilities Management

Most buildings represent substantial investments for organizations and usually have to accommodate and support a range of activities, taking into account competing needs. Within those activities is the organization core business, for which an appropriate environment must be created in buildings that may not have been designed for the purposes on organization might be on its core business, it cannot lose sight of the supporting services-the non-core business. Company may have already considered the distinction between their core business and non-core business (such as cleaning and security) as part of the drive to deliver customer satisfaction and achieve better value for money. Since running costs account for a significant part of annual expenditure, there is bound to be pressure to look for savings in non-core business areas. Cutting operating budgets may be a financial expedient, but may not foster the company's long term development. Since the running of a company involve complex, co-ordinate process and activities, it is necessary to take an integrated view. A piecemeal approach to cutting costs in unlikely to produce the require savings and may impair the company’s ability to deliver high-quality services.

Facilities management can therefore be summarized as creating an environment that is conductive to carrying out the company’s primary operations, taking an integrate view of the services infrastructure, and using this to deliver customer satisfaction and value for money through support for and enhancement of the core business. Facilities management also can describe as something that will sweat the assets, that is make them highly cost effective, enhance the company’s culture and image, enable future change in the use of space, deliver effective and responsive services, and provide competitive advantage to the company’s core business. Relationship between core and non-core business in company shows at Figure 2.

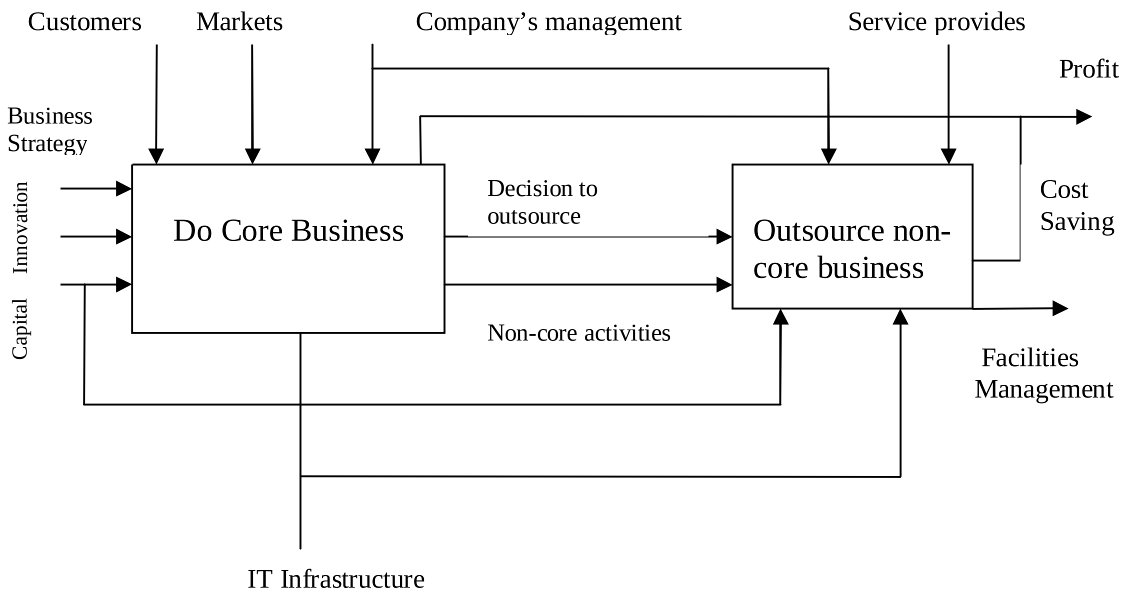

***Figure 2**: Basic relationship between core and non-core business*

Company may not be aware of the extent to which value for money in facilities management can be improved. There are common themes and approaches to facilities management, regardless of the size and location of buildings, although these may not necessarily result in common solutions to problems. In some cases, estate-related and facilities services outsourced (contracted out) and in others retained in house for good reasons in each case. There are also many companies that operate what might be described as a mixed sourced in some measure as well as being retained in house. Whichever course of action has been taken, the primary concern is the basis for the decision. Where the companies approach has been arrived at for entirely proper reasons, such as demonstrating better value for money from one approach as opposed to the other, facilities management is working effectively.

4. The development of ICT in Facilities Management

The use of information technologies without the overarching direction of and information system, more often than not, leads to generation of voluminous, poorly focused and irrelevant information. The creation of excess information in this way is a good reminder of the need to evaluate an information system on the basis of a cost-benefit analysis. The lack of information on products and components in terms of usage and cost can lead to difficulties in focusing the role of Facilities Management and establishing the supply chain within it. Difficulties in monitoring and tracking financial information can also prevent efficient budget control, accurate estimation of work, and contract and purchase management. Good planning in maintenance, operation and refurbishment can be hindered by the availability of life cycle information that is, for instance, crucial in the planning the replacement of components.

Currently, there are no standards that support information exchange and sharing across the building life cycle. Given that there is potential for improvement in business process though the exchange data on the facilities management process, there is a growing need to investigate the issues involve in developing a standard that can benefit this most important part of the business life cycle. This standard could then be use to assist in the development of an information management system to support the exchange of information and the assessment of facility requirements. Such an information system requires a large volume of data. Accurate assessment of a facility's needs requires knowledge of equipment standards from a design and construction information systems, access to accurate maintenance records and repair and replacement costs, access to operation and occupancy information, other operating costs, space management data, operation standards and data from occupational and health and safety information system and from a financial and commercial information system. An integrated information system as shown in Figure 3 could assist facility managers and other project tem members to combine data and information on a facility's life cycle, and base on the integration of cost and commercial data, design and manufacturing and construction data together with facility operation and maintenance data.

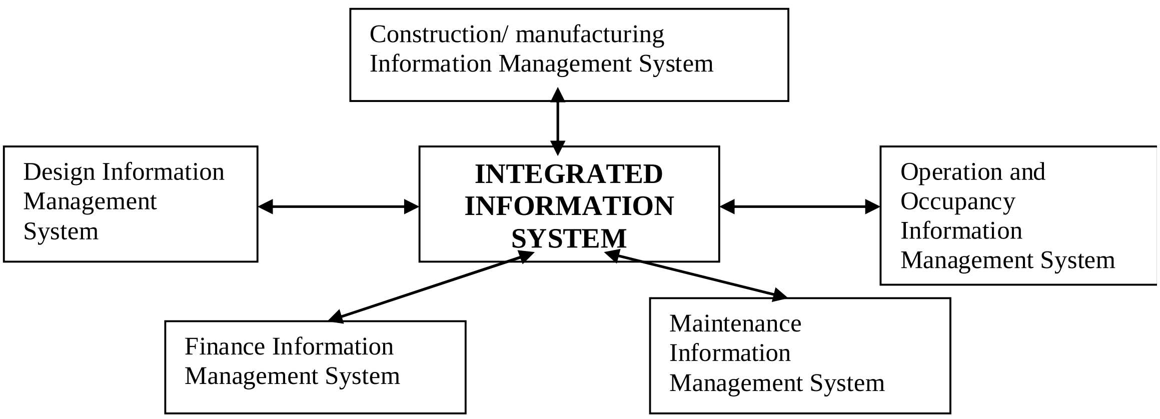

Figure 3: Integrated Information Management System

Technology systems used in FM have developed along a similar timeline to the development of technology in finance and accounting. Figure 4.0 is a diagrammatic interpretation of the fundamental components of an FM technology system. The arrow indicates the communication pathways between the various components of the system. Where each component is physically located is unimportant to the user of the system. There are four aspects that are fundamental to all information technology applications. They are relational databases, networking infrastructure, computer aided processes and data communications technologies. In present FM systems data communications technology is equivalent to Internet technology. Additionally, FM technology tracks advances and applications of technology to management in the manufacturing sector and to changes that have occurred in the management of workplace. Figure 5.0 illustrates the relationship between FM technology and management innovation (Stuart Smith, 2003).

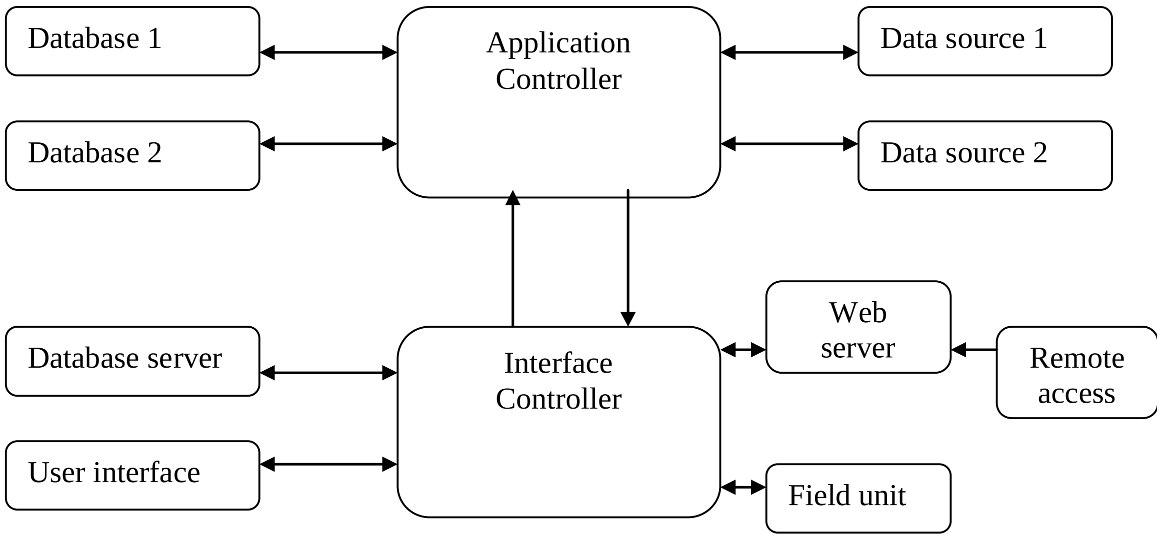

Figure 4.0: Basic components of an FM system

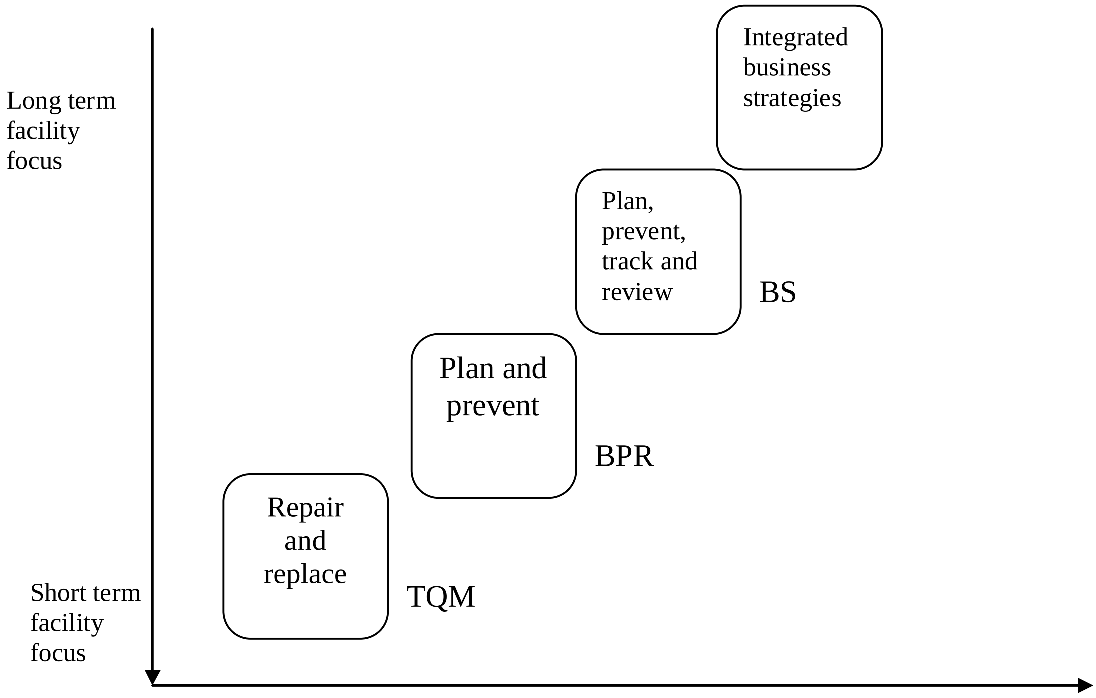

Figure 5.0: Focus and new business technology

5. Conceptual Framework

The overall conceptual framework that forms the basis of this pilot research project is shows at Figure 6.

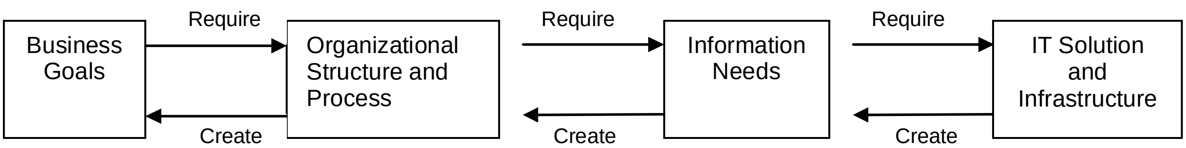

Figure 6 : Sample of Conceptual Framework

This conceptual model hyphenise that information technology acts as both amenable (provides new possibilities for organizations to achieve business goals) as well as a source of innovation (emerging technology provides new possibilities for organizational structure and processes and may generate new business goals)

In addition, this model may influence organizations in at least three different ways:

1. Strategic positioning

Information technology may provide a means for organizations to uniquely position themselves in the market place in a manner that would be impossible without the availability of information technology. Examples of strategic positioning are emerging in the form of 'virtual organizations' which provide substantially improved value to customers compared to traditional organizations. Strategic applications of information technology may involve inter-organizational information sharing, such as the use of distributed database.

2. Work group productivity

Instead of affecting the entire organization, work group productivity effect subsets of an organization. The use of groupware (e.g., Internet collaborative applications) has the potential to empower and integrate project teams for substantial improvements in project productivity and at the same time reduce the need for middle management.

3. Process redesign

Process redesign may affect the productivity of one or more individuals as jobs are reconfigured and processes simplified. Information technology can facilitate the task of process redesign by providing tools that eliminate routine jobs and decentralize decision-making.

6. Conclusions

In Malaysia, the facilities management concept is still relatively new concept. However, Centre of Excellence for Facilities Management, KUiTTHO is struggling to introduce this concept to government of Malaysia. Even tough this still new concepts, due to rapid development in ICT, FM in Malaysia also have to integrated with ICT. Strategies for use the ICT are not universal. Countries face different circumstances, priorities and financial means and should therefore adopt different strategies accordingly. The framework can be help in determining a strategy regardless of what goals have been established, since coordinated action along the five areas identified in the framework is always likely to yield more effective results. However, the evidence and analysis presented suggest that strategy that focuses its ICT interventions towards the achievement to development goals is more likely to achieve marked socioeconomic development. Facility management is essentially workplace management. In essence, it is a manifestation of facility management as the interface that manages changes in people, facilities and technology. They are many opportunities and expansion areas are it in properties, human resources, finance or ICT. Facilities management should have the ability to anticipate as to what organizations will require in future years. In the past, the role of facilities was merely that of service provider, and now, facilities management as business solutions. This paper hopefully can be a guideline for companies to implementing an ICT in their companies as well as facilities management concept especially in Malaysia.

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Integrating Building Performance Assessment Concepts in Shared Building Models

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Abstract

Traditional modeling efforts in AEC have generally focused on design descriptions. As a result they do not consider information on how settings perform during use in areas critical to building owners and users. The authors argue that integrating performance data in building models will greatly enhance the end-uses of conceptual modeling efforts in AEC in facility management and design evolution. The authors describe a modeling study that integrates descriptive and evaluative/ performance concepts in existing building models, and illustrate several end-use scenarios to support their assertion.

Keywords: Conceptual model, building performance, post-occupancy evaluation, building procurement.

1. Introduction

The lack of attention on the formal representation of data from building (facility) evaluations represents a missed opportunity in modeling efforts in AEC. Traditional modeling efforts were geared towards the ‘as-designed’ (‘as-designed’ as distinct from ‘as-used’ and ‘as-experienced’) environment to aid facility management. But are as-designed data sufficient? Can data from buildings-in-use potentially enhance end-use of building models? As-designed data pertains to data available up to the final stages of design development and specifications of a building. Such data relates to the properties and performance of the systems and sub-systems, and are based on existing knowledge on building physics and standard performance assessments in a-contextual settings, i.e. not specific to the context (social/ cultural/organizational setting) in which a building is situated. Typically the performance assessments are obtained from accepted building simulation practices that assume a “controlled environment with standard users” as the basis for the simulation.

The importance of context-specific data, from buildings-in-use, is beginning to get reflected in recent literature. For instance, Becker [1] advocates the necessity of data from buildings-in-use in the domain of material durability, and propounds the creation of predictive tools based on such data. Current building models, however, do not reflect the variations in usage pattern across setting types (from hospitals to schools, offices or courthouses) in buildings-in-use. The fact that such buildings-in-use data are becoming widely available brings this issue to an even sharper focus. Post-occupancy evaluations (POEs, or FPEs - Facility Performance Evaluations) are regularly conducted by large organizations with building portfolios. They are used not only in problem identification and modification in built settings, but also in informing portfolio management decisions. From a purely facility management viewpoint, buildings-in-use data could supplement existing data in two significant ways: 1) reduce uncertainties arising from simulations in controlled environments, and 2) reflect variances across setting/ occupancy types, and, thus, improve context specificity.

Performance can also be viewed beyond the performance of systems and sub-systems. Gross [2], for instance, underscores that users' requirements are not well understood at present. He emphasizes the variations that exist in culture, economic capabilities and expectations, and asserts that such human factors have not been accorded due importance in performance assessments, such as productivity in the workplace, health, and well being. POEs happen to address some or all of these issues. Integrating performance (POE) data with other descriptive data, thus, promises to enhance the end-use of building models in facility management, and possibly in design decision-making. POE and other descriptive data currently reside in disjoint representations and formats. This prohibits their integration in and joint use in decision making. The key question addressed in this paper is the need for a proper mechanism to capture rich facility evaluation data and integrate it with other building data in such a way that FM decision making is optimally informed.

2. Integrating Descriptive and POE Data

The investigators started off the study with two main questions: 1) can evaluation/ performance (more specifically, POE) data be meaningfully integrated with other descriptive (as-designed and as-built) data in a shared building model based on a unified conceptual building representation, and 2) if so, in what conceivable way could it expand the end-use of building models?

2.1 The Georgia Tech Study

This paper draws on a Georgia Tech modeling study that integrated as-built data and facility evaluation (POE) data in courtroom settings [3]. The study focused on courtrooms as setting types for several reasons. Courtrooms constitute setting types with a range of complex and conflicting functions, ranging from the instrumental (visual, auditory, and access) to more intangible symbolic functions (portraying the openness of the judiciary and authority of the State). Secondly, courtrooms are physically self-contained spaces, thus rendering the modeling effort relatively simple. Finally, the investigators had access to courtrooms and courtroom users (judges, deputies, reporters, attorneys, security staff, etc), courtesy of the CourtsWeb project at Georgia Tech.

2.2 Methodology

POE and descriptive data from 26 courtrooms in 16 courthouses were used in the model. The data included 43 descriptive and technical performance measures (lighting, thermal, acoustical, physical/ spatial configuration, etc.), 27 evaluation measures (users' evaluation of the supportiveness of their work setting for instrumental and symbolic functions), and, finally, six personal/ cultural measures (users' role, age, gender, etc.). A conceptual model integrating the different types of data was developed using EXPRESS-G [4]. The presented schemas of the model, for the purpose of this study, should be viewed as an aspect model [4] that would go through an integration cycle to be finally integrated with a comprehensive and complete building model such as the IAI-IFC [5]. Schemas of the aspect model were translated into database schemas and were instantiated with the data collected in the POE studies. A range of queries was implemented to assess its meaningfulness in supporting various end-use scenarios. Important modeling aspects such as extensibility, IFC integration, and others were not considered at this stage of the research as the emphasis was on the feasibility and adequateness of the proposed semantic integration of POE and other descriptive building data.

3. The Data Model

The primary focus of the modeling effort was in integrating data pertaining to the physical envelope, functions of settings defined by the envelope, evaluation/ performance data of such settings in use, and finally the attributes of the users using the built settings (figure 1 articulates the fundamental direction of this inquiry).

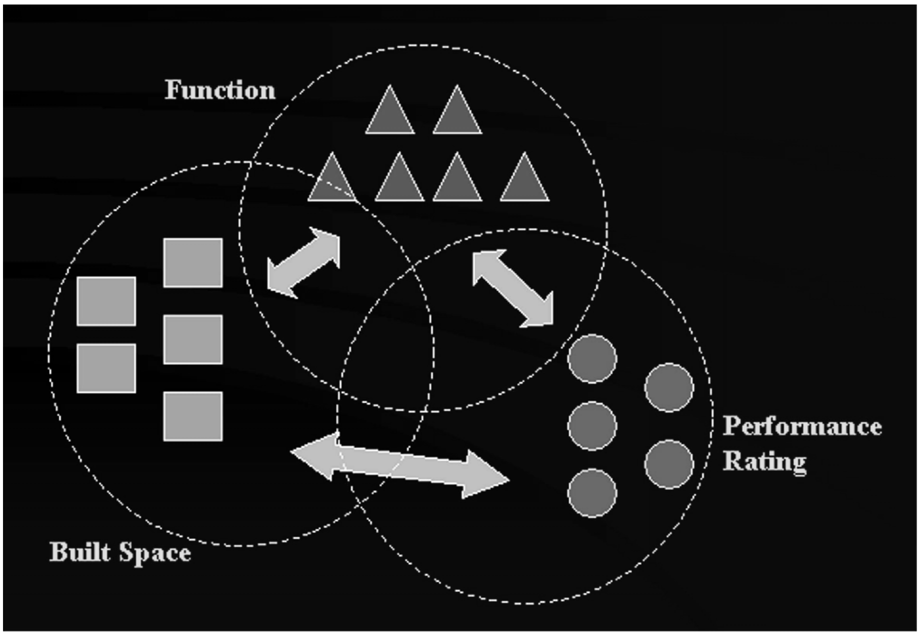


Figure 1: The key modeling concept involved the integration of as-built data with data pertaining to functions and performance.

Figure 2 shows a stripped-down model with entities alone (without the attributes) to provide a birds eye view of the relationship structure. The central concept of the model is ‘space’ The model can be viewed as four chunks of data, linked through the entity ‘space’: 1) identifiers that hold data that would enable identification of a particular site, project, building, and floor, 2) the enclosure system, 3) various functional areas within an enclosure system, and finally 4) evaluation data from POE studies.

Owing to paucity of space detailed schemas on the first two data chunks are not included in this paper, which are conceptually similar to the corresponding parts of the IAI-IFC. Data on site, building and floor are essentially used as higher-level identifiers and classifiers, such as city, state, jurisdiction, and building type. Schemas on the enclosure system are designed to hold as-built and as-designed data on elements that physically define (enclose) the courtrooms. Such elements include the walls, floor, ceiling, and the services support systems. The remaining model is described below.

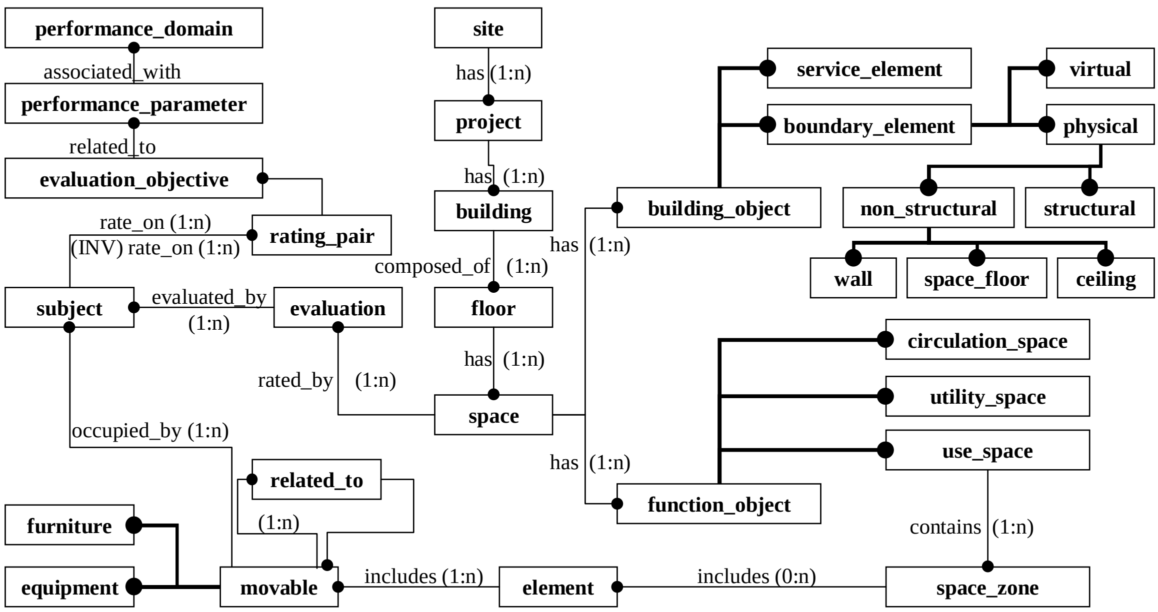


Figure 2: The model (without the attributes) showing the basic relationship structure.

3.1 Functional Entities

Functional entities hold data on spatial functions and sub-functions physically enclosed by the enclosure systems. The schema captures the major (higher level) functions, various sub-functions or functional zones that organizationally cluster together to define a functional unit, key elements within the functional zones, and movables (furniture and equipments) within the key elements. Relationships of interest between each pair of movables are included, such as the distance between elements or the level difference. At the highest level, each function type is described as a *function_object*. For simplicity sake, the *function_object* types have been defined as *use_space*, *circulation_space*, and *utility_space* (figure 3), while it is appreciated that various combinations of these function types are also possible. Each use space is identified by a *use_category* and a *use_type*. Use category refers to the primary function of the use space, such as ‘courtroom’. Use type provides further information by stating the particular subtype of the primary function, as in ‘magistrate judge’ (courtroom). Each use space could be host to one or more space zones (*space_zone*). These are more specialized functions conducted within a larger functional unit, for instance, courtroom “well” (the part of the courtroom where all trial

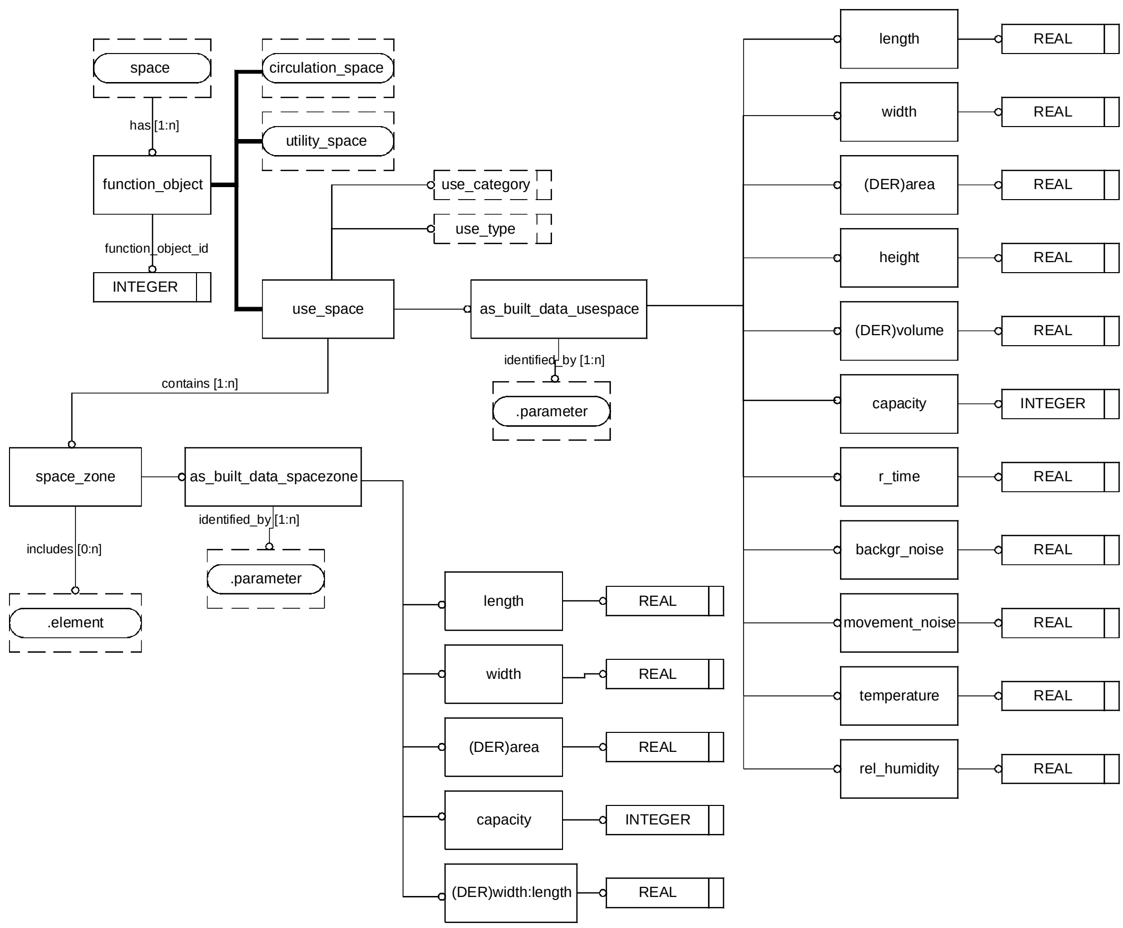
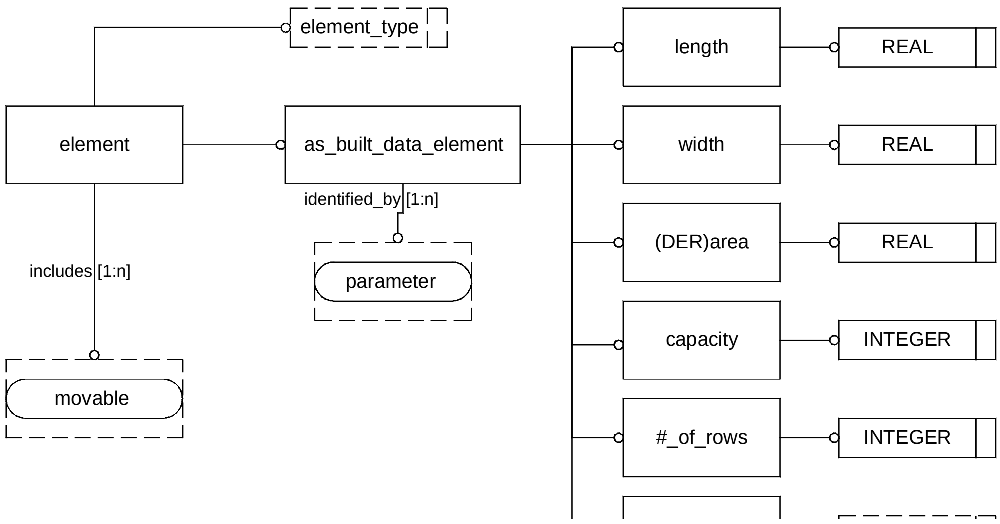


Figure 3: Use space and space zone as function entities.

Within each space zone there can be none or more elements (element). Elements are base-level specialized functional units where very specific functions are performed. In a courtroom well, the elements include the bench, the reporter station, the deputy/clerk’s station, the security personnel station, the attorney area, the jury box, and the witness stand. Similarly, courtroom galleries have spectator seats. Figure 4 illustrates the element schema.



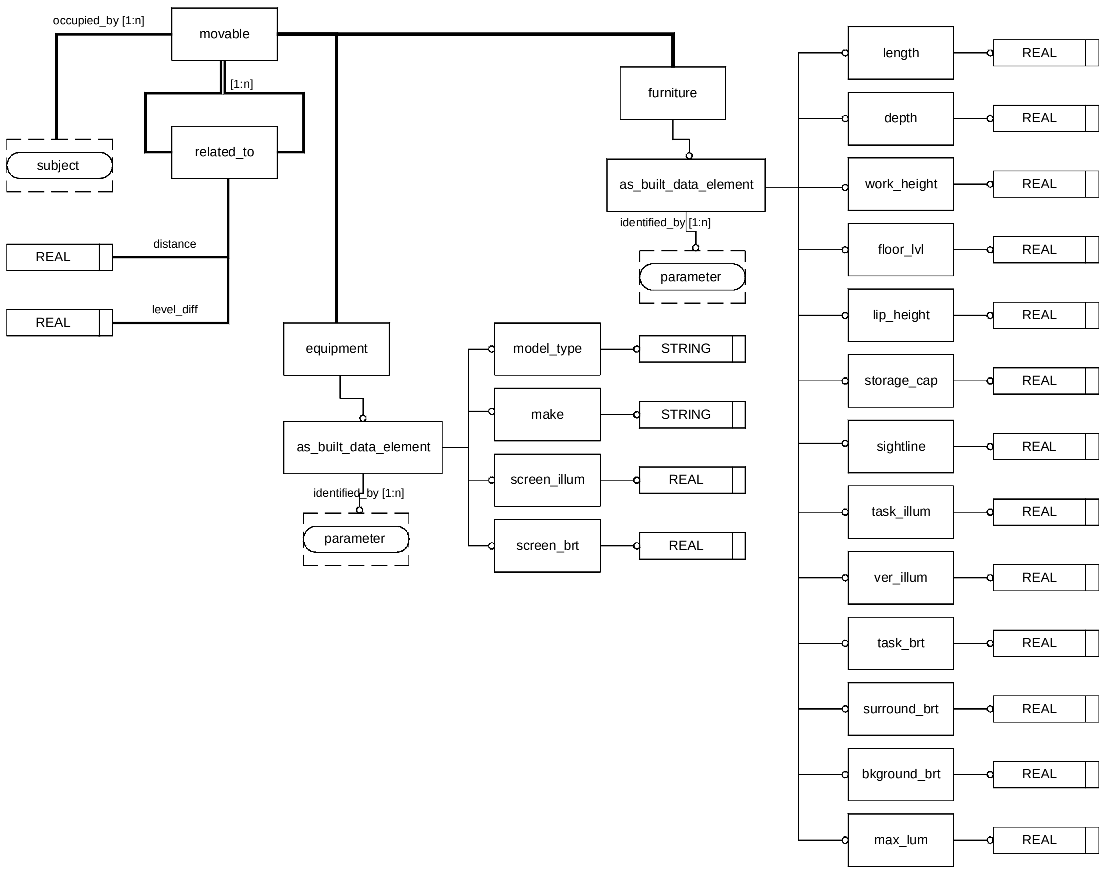


Figure 5: The movable schema.

Each element in a space zone includes one or more movables (*movable*). For instance, the reporter's station typically has only one piece of furniture (movable) where as a jury box can have as many as 21 or more piece of furniture. Movables are essentially *furniture* and *equipment* associated with a particular element, with base-level specialized functions (figure 5). Relationships between movables are some key areas of interest. For instance, the *distance* between each pair of movable in a courtroom well (witness to judge, for instance) influences the clarity of observing witness testimony. Similarly, the level difference (*level_diff*) between each pair of movable in a courtroom influences the lines of sight as well as the symbolic rendition of the courtroom.

3.2 User and POE data

The remainder of the model pertains to performance/ evaluation data. Data on performance issues/ dimensions and users constitute the main focus of these schemas. Evaluation of settings could be conducted on several issues or performance dimensions (this model is limited to issues specific to courtrooms, but expansion to other issues is straightforward). A classification structure for the issues, based on literature, is created to ensure better comprehensiveness of the data structure. Figure 6 shows the schema on user and performance/ evaluation data.

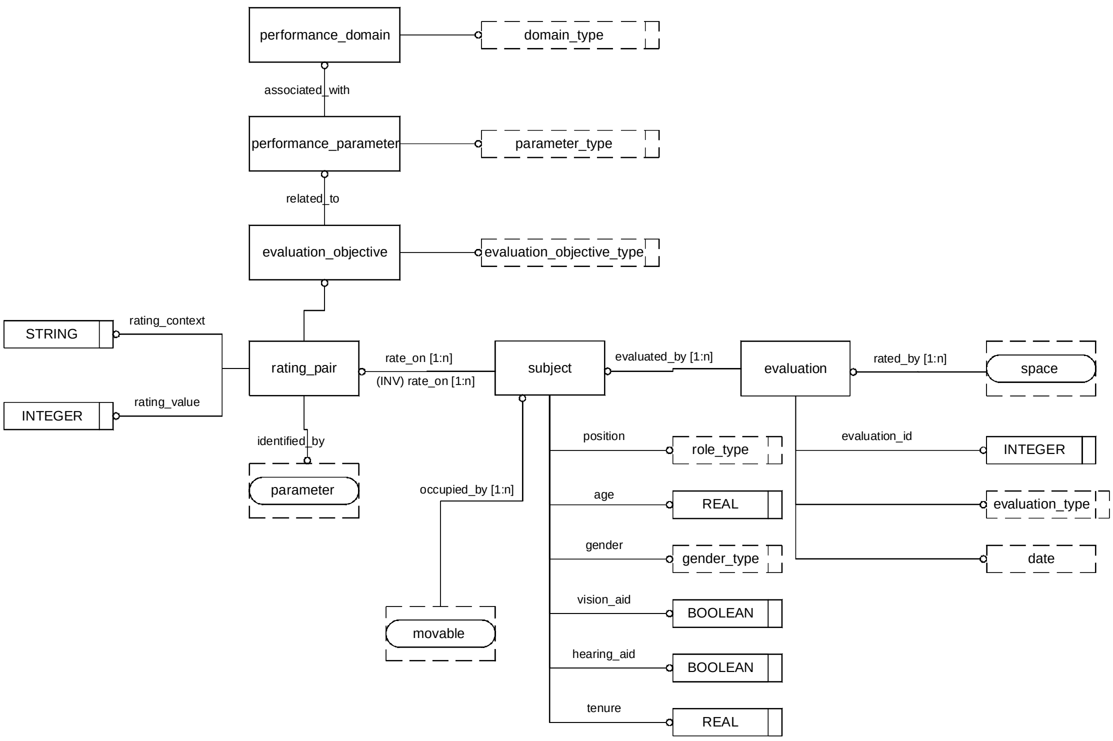


Figure 6: Schema representing data related to user and POE.

One or more users (a more generic term *subject* is used in the model) occupy each movable. The type of POE considered in this study is one where users of buildings-in-use evaluate their setting on an assigned scale. As a result, each instance of evaluation data is associated with a specific user who, in turn, is associated with a particular movable in an as-built setting. Further, POEs target one or more spaces in a facility, and each space is rated by one or more evaluation studies (*evaluation*). Each evaluation has an associated *date*, and an *evaluation_type* (POE, in this study). Typical POE studies collect various kinds of demographic data from the participants/subjects. In this study six types of data were collected. User *role_type* pertains to their position in the organization, for instance judge, reporter, and deputy/clerk. The data types *age* and *gender_type* are self explanatory. User *tenure* relates to the number of years the user has worked in the current position, which bears psychological connotations on evaluation data. Data on *vision_aid* and *hearing_aid* are yes/no Boolean data types that provide information on whether the user relies on the aid of hearing or visual devices for performing standard tasks in the courtroom. Evaluation data are captured in the element *rating_pair* where *rating_context* describes the context of evaluation (or the specific thing being evaluated) and *rating_value* is the actual numeric rating.

Rating pairs are classified based on knowledge from existing literature - the entities *evaluation_objective, performance_parameter,* and *performance_domain* provide the framework for classification. Gifford [6], for instance, lists performance, feelings, and stress as some key objective (outcome) areas in studies on office settings. Many POEs include user preference and productivity as study objectives. The objective associated with a rating pair determines the evaluation objective of that particular rating pair. Further sub-classification of evaluation data into parameters and domains is also supported by literature. For instance, Gifford [6] contends, “the work environment can be considered not only as a collection of physical stimuli (noise, light, temperature, etc.), but also as a physical structure (size, furniture, hallways, etc) and as a symbolic artifact” (p.340). The segregation of data into environmental (‘physical stimuli’) and physical (‘physical structure’) provides a meaningful classification structure that corresponds well with established classification structure in literature.

4. Outcomes

A database was generated according to the schemas of the previous section and filled with data from courtroom and POEs conducted in those courtrooms. The database was used to assess if and how the integrated information augments/ informs decision making in facility management and design decision-making. It is expected that the addition of evaluation/ performance data opens up potential end-use opportunities in at least four different areas: 1) monitor facilities, 2) identify best practices, 3) manage building portfolios, and 4) inform design evolution.

4.1 Monitor Facilities

As asserted earlier, in the absence of performance data one could predict performance of building systems based on standard simulations in a-contextual settings. Integration of evaluation data from buildings-in-use adds specificity to monitoring everyday performance. Moreover, facilities could be monitored in their supportiveness to the functions performed in the built settings, in addition to the performance of systems and sub-systems. In courtrooms, for instance, regular organizational POEs could inform courthouse building managers about how well the courtrooms support the major tasks/ functions conducted within it, which may change over time owing to physical and/or personal/ cultural/ organizational factors. A specific example will help illustrate this end-use scenario. Consider, for instance, a simple example of reading task in courtrooms (reading from legal documents, exhibits, etc.). Existing literature takes into account various factors to predict lighting conditions for certain reading tasks. Such predictions are generic, and applicable across setting types. The POE data augments such information is in two ways. First, it provides evaluation data from actual settings-in-use, and is specific to a context type (in this example, courtrooms). Second, it brings into consideration other personal and cultural factors that are not considered in lighting models. Thus, the data extracted pertains to specific areas in a building, dealing with a specific set of users, with known user characteristics (collected through POEs). Such specificity of information supplements the generalized prediction models in lighting. A more compelling factor is one of human psychology. Referred to as the 'halo effect' in psychological literature, users of built settings tend to consider newer settings more supportive irrespective of actual performance of settings. Such factors are reflected in POE data. The contextualized, specific, evaluation data would enable facility managers to monitor facilities in a more efficient way. Table 1 shows an example where the users' ratings of the supportiveness of the courtroom (on a scale ranging from 1 = very unsupportive to 7 = very supportive) for reading task, along with lighting data, are extracted from the database. In a similar manner, other important functional aspects of built settings could be monitored on a regular basis to identify areas that need improvement.

Table1: Query result showing users' evaluation of the supportiveness of the courtroom for reading task, in Clarke County Courthouse, and data on a sample set of lighting parameters.

building_name	**work_plane_illuminance**	**vertical_illuminance**	**task_brightness**	**surround_brightness**	**background_brightness**	**user_role**	**rating_context_type**	**rating**
Clarke County	155.3	94.1	482.4	79.17	165.1	judge	reading task	7
Clarke County	64.8	25.1	191.6	79.17	80.91	deputy	reading task	7
Clarke County	64.8	25.1	191.6	79.17	80.91	deputy	reading task	6
Clarke County	76.4	22.2	236.1	79.17	84.01	reporter	reading task	7
Clarke County	84.9	33	241.7	12.96	75.38	attorney	reading task	7
Clarke County	84.9	33	241.7	12.96	75.38	attorney	reading task	7

4.2 Identify Best Practices

While monitoring settings for improving context-specific performance, facility management could gain from knowledge on best practices in similar settings. Such information could enable the facility managers to arrive at improvement options that predict most favorable outcomes. Consider for instance, in case of a certain courtroom, a facility manager finds low evaluation rating from courtroom users, in the setting's supportiveness to reading tasks (same example as above). Querying the database enables extraction of data that shows the values of environmental parameters that could predict favorable evaluation. For instance, an end-user might wish to focus exclusively on best practices in illuminance for reading tasks (performance rating > 5) in Superior Courts Courtrooms. The outcome (figure 7) shows the proportion of users within each interval of illuminance level, across all courtrooms, that have rated a particular illuminance level above 5 for reading task support. It looks plausible from the chart that the best possibilities of favorable evaluation are associated with illuminance between 30 and 65 FTC. Since these evaluations are not immune to personal and organizational factors, they could vary from lighting guidelines and could vary across setting (building) type. The context-specificity of the information generated promises supplemental information support over traditional information available to stakeholders in facility management. Further, similar routines could be used to assess other environmental parameters in built settings.

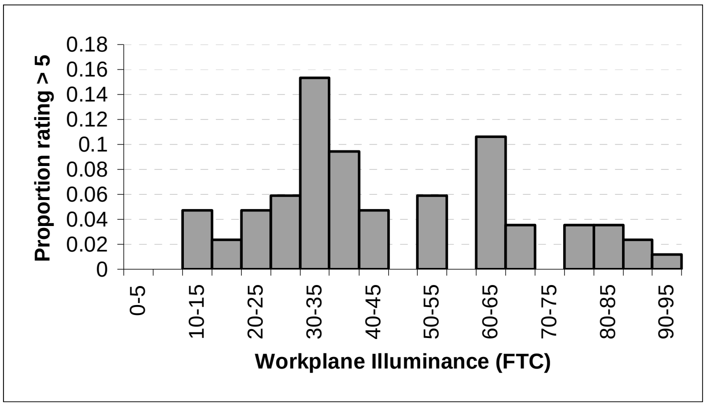


Figure 7: Chart generated from query showing the percentage of users rating their environment greater than 5 for reading tasks, within each interval of illuminance level.

4.3 Manage Building Portfolio

Regular POEs conducted in large organizations with building portfolios (such as US GSA, US Courts, USPS, etc.), that would enable the scenarios discussed in 4.1 and 4.2, would also aid in managing building portfolios. Since the evaluation data obtained in the example cited in this paper pertains to the functions carried out in a setting, longitudinal assessment of the data would provide visual as well as numerical feedback on the extent to which different facilities are supporting the functions they are designed for. The fact that the evaluation data captures psychological factors, such as the halo effect, contributes more utility to the feedback, since reduction in perceived supportiveness of settings to the functions conducted (irrespective of actual performance of settings) could contribute negatively to organizational objectives. Data on actual technical performance, as well as assessment of supportiveness by users, together, in longitudinal assessments, would provide information not only on the projected performance of systems but also on when users of settings could be expected to perceive their environment as unsupportive.

4.4 Inform Design Evolution

Many of the features described above bear potential to inform design evolution phases of facility procurement. Existing literature on the design process by Zeisel [7], Lang [8], and Kalay [9] articulates at least five end-use scenarios where the integration effort could inform decision-making: 1) case exploration, 2) precedence analysis, 3) identifying best and worst cases, 4) rating design decisions, and 5) predicting performance. The same features that aid in monitoring facilities support case exploration and precedence analyses. Similarly, identifying best practices is not only informative for facility management but also to design decision-making (owing to paucity of space only a few scenarios are described here; more scenarios and details are included in Pati 2004).

5. Conclusions

While the possible scenarios of end-uses could be many, the few illustrated above exemplifies how integrating evaluation/ performance data with traditional building models could provide (augment) meaningful services in facility/ portfolio management, and expand the utility of the modeling efforts to end-uses in design evolution. This begins to address needs expressed not only in the domain of building engineering, but also in the field of Environ-Behavior studies, where interfacing building research with design practice constitutes one of the primary objectives.

Although this study focused on just courtrooms as built settings, it can be asserted that the direction of inquiry could also fit other setting types. For instance, it could be argued that issues and classification structure developed in this model also hold true in (or can be expanded to include) office settings. Privacy, stress and many other issues seem to be common to offices and courtrooms. Similarly, relationships between movables (distance, elevation, angular dimension) are probably also important in office settings. Literature survey conducted for this study suggests that offices, schools and courtrooms share many of the issues included in this study. The definition of the elements and attributes in this model reflects possible generality to offices and schools, although expandability of the model to other setting types remains a question for further academic inquiry. Despite the limitations, the outcomes of this study suggest a robust and potent direction of inquiry for modeling efforts in AEC, leading to extensions of comprehensive building models such as the IAI-IFC.

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Development and Implementation of an Open Source Software FM-System

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Abstract

Bergen Bolig og Byfornyelse KF (BBB) – a public housing company comprising 5000 dwellings – has been looking into the possibility to utilize some of the vast pool of open source software for maximal flexibility and minimized costs of tailoring a fm-system to its needs. This work has been undertaken as part of a phd thesis at the Norwegian University of Science and Technology by the same author as this paper.

The objective of this work has been to reduce license costs of software, improve the flexibility of software development, improve the information flow, to improve the quality of data (centralized documentation and history), to lower the general threshold for implementing a fm-system and to reduce manual handling of invoices through utilizing principle of e-commerce by the use and development / adaptation of open source software.

Keywords: Open source software, FM-system, web, php, e-commerce

1. Open source software

Open Source Software is not only about free software – but an important concept within decentralized software development founded on knowledge, idealism, interest, anti authoritarian rebellions and the communication power of the internet.

"It gives customers control over the technology they use instead of enabling the vendors to control their customers through restricting access to the code behind the technologies." [1]

Free Software Foundation (FSF) was founded in 1985 by Richard Stallman – and is dedicated to encouraging users to use, study, copy, modify and redistribute software.

The definition of free software is defined by [2]:

- The freedom to run the program, for any purpose.
- The freedom to study how the program works, and adapt it to your needs. Access to the source code is a precondition for this.
- The freedom to redistribute copies so you can help your neighbor.

- The freedom to improve the program, and release your improvements to the public, so that the whole community benefits. Access to the source code is a precondition for this.

1.1 A Hacker's Motivation / Ideology

Two degrees of variation [3] seems to describe the motivation and ideology for a typical hacker:

1. Zealotry; enthusiasm regarding open source software in itself.

2. Hostility to commercial software.

The most visible and best organized part of the hacker culture – represented by FSF - has been both very enthusiastic and very anti commercial. After the Linux explosion of early 1993-1994 the culture has moved towards the pragmatic end.

In addition to the ideology there are motivations like "ego-boosting" (status in the hacker culture) and that it is fun and intellectually stimulating to participate.

2. The Software Project

The project started out as an attempt to simplify the maintenance management provided by a commercial fm-system – which at the time seemed to be a very complex – and to some extent – rigid environment. One other motivation was the high costs related to customizing – and the fact that all customization was depended on the vendor.

In the search for an appropriate platform - an Open Source project came to attention that had some interesting capabilities which could serve as a base for development.

Since this project provided a high level free entrance to an appropriate system – it is also fair that the work based on this project should be free.

2.1 PhpGroupWare

phpGroupWare - is a multi-user groupware suite written in PHP that provides about 50 web-based applications, as there are the Calendar, Addressbook, an advanced Projects manager, Todo List, Notes, Email, Newsgroup- and Headlines Reader, a Filemanager and many more Applications.

The system supports user preferences, themes, user permissions, multi-language support and user groups. It includes modules to setup and administrate the working environment. The groupware suite is based on an advanced Application Programming Interface (API).

There are currently about 25 active developers/contributors.

The project is hosted at savanna.gnu.org which is a central point for development, distribution and maintenance of GNU Software.

2.2 Property – A FM System

Property is the name of the FM-module of phpgroupware. It started out as a rewrite of the project module – where the most significant change was the change in perspective from vendor to buyer – and the introduction of a location hierarchy. Later on it has evolved as a fullblown maintenance / project management system with e-commerce and documentation capabilities.

2.2.1 Model - Context

To place this software in its right context – it is useful to locate a spot for it in an information system model.

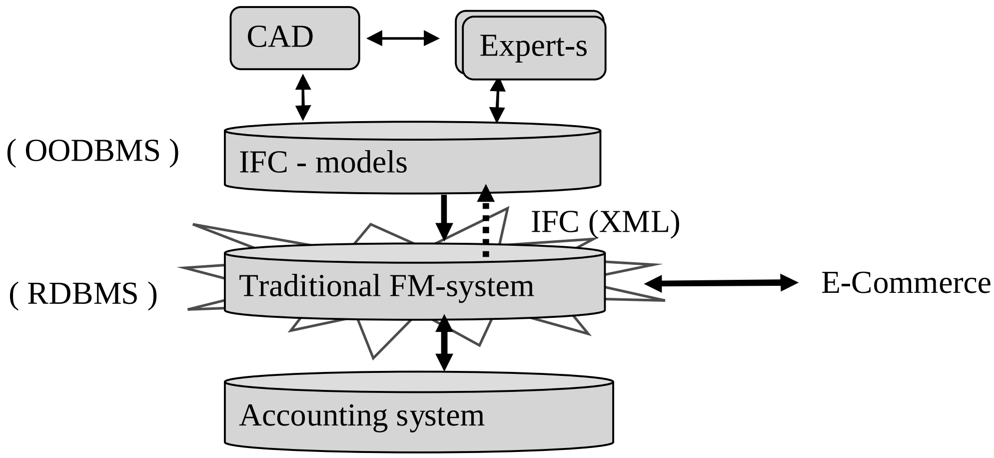

Figure 1FM-system related to IFC

It is the author's opinion that the introduction of IFC-models [4] not for many years will become a common platform for operation phase data handling due to the costs related to converting existing models to IFC. In addition – as IFC is based on an Object Oriented Database management system – performance (speed) – might be an issue. This leads to the assumption of the need for a RDBMS FM-system that is fed by relevant data from the IFC-model where this is possible.

2.2.2 Technology / Principle

There are some fundamental blocks to relay on: A database, a script interpreter and a web server. This kind of technology is often described as a 3-tier architecture [5] – which means that the system is separated into a client-tier, an application-server-tier and a data server tier. The client tier is in this case a standard web-browser, the application server tier is the collection of scripts used by the web server and the dataserver tier is the databaseserver.

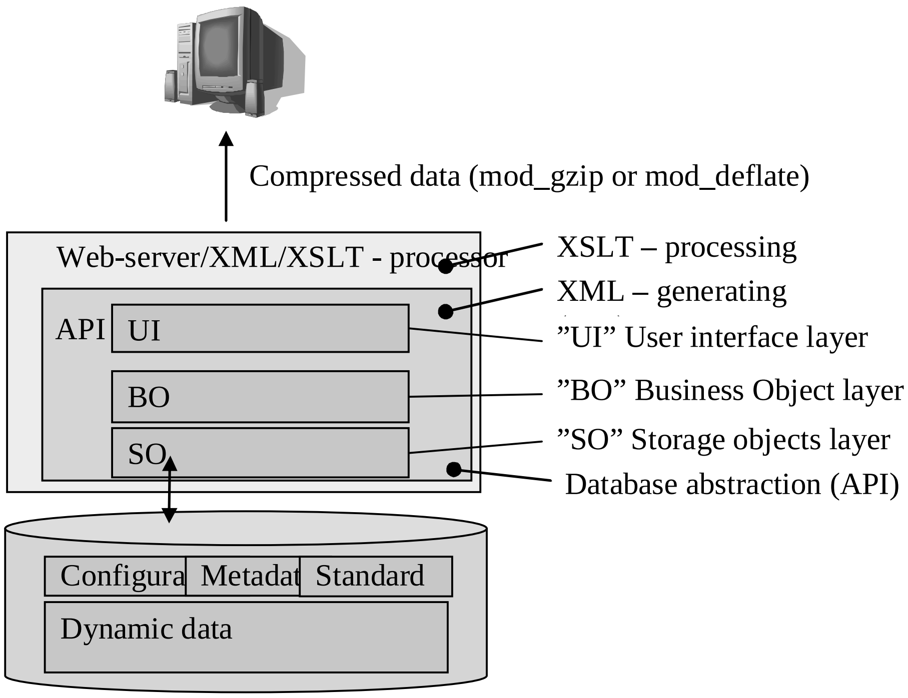

Figure 2 Principle technology

The middle –tier is the actual “program” – representing the logic operating on the data. This tier is also separated into a common API for the whole project – and a set of layers within each module which represents a typical responsibility.

The output from the UI-objects is an array – which is converted into XML and fed into a set of XSL-stylesheets for processing to XHTML.

2.2.3 Architecture

The database is in general built on some fundamentals as locations, physical objects, documents, actors, their conditions, relations and operations:

- *Locations* – is organized in a highly customizable hierarchy
- *Entities* - is a generic class of objects, that can be defined as reports, equipment and so on - which can be linked to locations or other entities
- Actors
- Tenants/User of location
- Vendors
- Owners
- Operation/events
- Request for action of any kind
- Workorders - organized into projects

- Service agreements
- Payments/Cashflow

2.2.4 Meta-database

Certain elements in the application as location, service agreements, entities, actors, are organized in a meta-database which contains information of tables, columns, relations and attributes.

The database queries and name of columns to return (visible and hidden) is dynamically created on the fly the first time - and stored in a cache table (fm_cache) for later use to save processing overhead.

2.2.5 Location

"Location" is a physical part of the property - and it is common to organize the locations in a hierarchical structure with "part-of" relations

- Name Level
- -- Property 1
- /-- Building 2
- /-- Entrance 3
- /-- Apartment 4
- /-- Room 5

Example 1: location hierarchy

The hierarchy is configurable in both width and depth - that is: one can define as many levels as one like - and each level can also have as many attributes as one would like

- Name Level Relation
- -- Property 1 <--- Owner,part of town
- /-- Building 2
- /-- Entrance 3 <--- Street
- /-- Apartment 4 <--- Tenant
- /-- Room 5

Example 2: location hierarchy with configurable external relations

Each level has a primary key - composed by the foreign key to the parent - and this levels ID. In addition - there is a "superkey" named *location_code* for indexing and searching across the hierarchy

location_code	loc1	loc2	loc3	loc4
5000-01-01-001	5000	01	01	001

Example 3: part of the table location4

- Primary key: loc1 + loc2 + loc3 + loc4
- Foreign key: loc1 + loc2 + loc3
- Superkey : Location_code

Example 4: keys for level 4: Apartment

When querying location on a certain level - it is joined with all its ancestors to make inherited information available.

2.2.6 Entities

Entities is a generic class of objects that all have in common that they can be placed in a location and/or linked to other (only one) entities.

Entities are organized in class of entitity and entity category: each entity_category is represented by their own table:

- Equipment
- Elevator
- Fire alarm central
- Cable TV
- Building components
- Reports
- Condition report
- Insurance damage
- Elevator control report

Example 5: Structure of entities at the BBB implementation

Reports are configured to be linked to both Equipment and location — that is: One can write reports on both Equipment and location.

The table representing the category elevator in the entity-class Equipment is here named fm_entity_1_1

Information about the different attributes and their datatypes is held by the metadatabase

2.2.7 Projects

A project is a collection of orders/contracts. The project is linked to a location or entity_category (equipment). Projects are separated in orders/contracts that could be subject to bidding contest amongst vendors. Each order is linked to its parent project and to a vendor - and consists of a series of work-descriptions to perform and / or items to deliver.

An order can be defined as simple as a brief description of simple tasks - or as a detailed complex tender document with a full blown deviation auditing system per record in the contract.

The perspective of the projects is from the receiver of the product delivered.

2.2.8 Helpdesk

The HelpDesk submodule is a hacked version of the phpgroupware's standard Trouble Ticket System application (TTS). The main differences is that the tickets are fixed to a location or entity_category - and that one is able to start projects and entities (i.e. reports) from a ticket - which enhance the trace-ability

The owner of a ticket is notified by mail when the ticket is updated if the user doesn't choose not to.

2.2.9 Invoice Handling

A very important feature is the ability to interact with accounting systems. The invoices are imported into the system by fileformat agreed upon by the vendors – granted for payment by users based on roles – and then exported to the accounting system for payment. Both import and export filters are very easy to adapt to the current implementation – and appear as independent drop in filters.

2.2.10 Alarm Handling

It is possible to notify alarms on timers as email – along with any other predefined task. This is accomplished by a cron job that checks if there is something scheduled.

2.2.11 Documents – File Handling

Drawings, pictures, signed contracts is examples of documents that is handled by the vfs – virtual file system. This enables any type of file to be uploaded as attachment to a range of elements in the system.

2.3 Development

The work on the system has been done in very close cooperation with the organization in a dynamic process with the users as a very important source for demands, feedback and bug testing. There is a set of roles and their needs to satisfy related to the topography of the organization and the surrounding systems which it interacts with.

The work has derived advantage from the open source community as it has been designed as an add-on module to the open source project phpgroupware – and has had access to their development resources and a handful of very skilled programmers.

The source code is stored into the main phpgroupware project at http://savannah.gnu.org – using cvs (Concurrent Versions System) - which allows the project member to revise the code and collaborate on joint development.

The property module is developed at BBB – and implemented gradually as it has evolved. The first feature implemented was the ability to place a simple workorder – linked to a location. In the beginning this system overlapped with the former system in that way that it also wrote a copy of the order to the former system. This strategy made it possible to go back if it turned out to be a bad solution.

The system has been developed on a dualboot windowsXP/Linux laptop – that is – written on Windows and tested on Linux.

The actual data stored in the database-backend is organized as a well normalized relation database – which makes it an easy task to convert data from or to other FM-systems. The logic operating on the data is located as the middle tier in a three-tier architecture implemented on a centralized web-server which simplifies the administration and maintenance of the software as no client installation is needed.

All files have been saved to the cvs-server at savannah.gnu.org – this enables in theory simultaneous remote collaboration by many parties in addition to enable a view of historical changes. The cvs-server allows parallel versions to live together (branches). The idea is to have a stable release where only bugfixes is performed – and one (or several) development branches where new features and ideas is tested.

Savannah also provides some other useful collaboration tools:

- Several informal mailing lists (for users and developers) where questions and opinions are posted.
- A helpdesk in four categories where items are assigned to part of the system and a developer:
  - Support – user questions
  - Bugs – for registering errors found in the software

- Patches – fixes and codesnips prepared for reviewing.
- Requests – feature request for the next release

3. Sample Implementation at BBB

Phpgroupware with the application property is implemented as part of the total FM-system at Bergen Bolig og Byfornyelse KF (BBB) – integrated with a tenant / lease administration system and the company's accounting system.

The webserver is a linux box based on a Mandrake 10.1 distribution which communicates with a database server (MSSQL) and a fileserver (Windows 2000).

So far 25000 orders are served by the system.

3.1 About BBB

BBB is a public housing company comprising 5000 dwellings located at the city of Bergen, Norway.

BBB has about 40 employees organized in a central head quarter in downtown and three satellite offices. All employees have access to both intranet and the Internet.

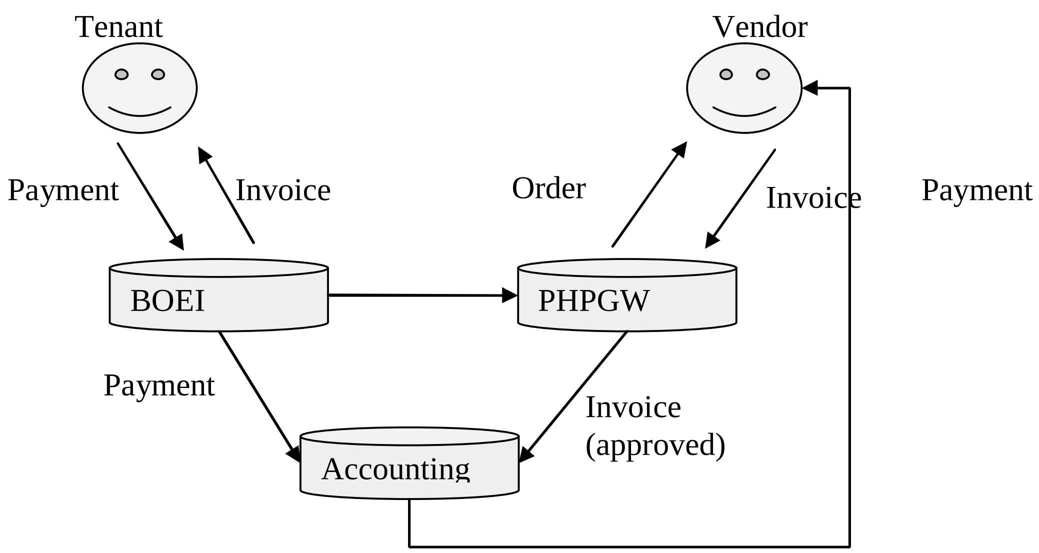

Figure 3Integrated systems at BBB

3.2 Integration

The location hierarchy and tenant information is "owned" by the tenant lease system (BOEI) – that is – all such information are originated in BOEI – and automatically transferred (or updated) to phpgw. The initial integration was implemented as two databases at the same database server (mssql) – and the synchronization was performed as scheduled jobs by executing stored procedures. Later – the database for phpgw was transferred to the linux server at a postgresql database. This was decided due to a 5 times gain in speed.

Now the synchronization is kept in order by a shadow set of synchronization tables at the originator database server to identify changes to transfer. The jobs are run as cron-jobs from the linux server via php-scripts that connect to phpgw_postgres and phpgw_mssql. To perform the actual comparison one need the master-tables from BOEI_mssql – and these tables are mapped as views in phpgw_mssql.

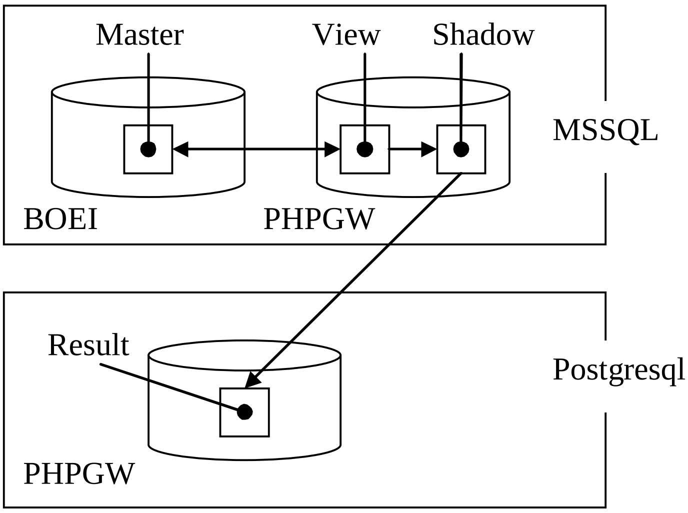

Figure 4 Synchronization model

3.2.1 Accounting System

Orders are sent by email to the vendors – which return the invoices at a monthly basis – and imported into the system for approval. Both approved and not approved invoices are exported to the accounting system to reflect the total claim for payment. During the import – the invoices are assigned to a supervisor and a budget responsible which both have to approve the invoice for payment.

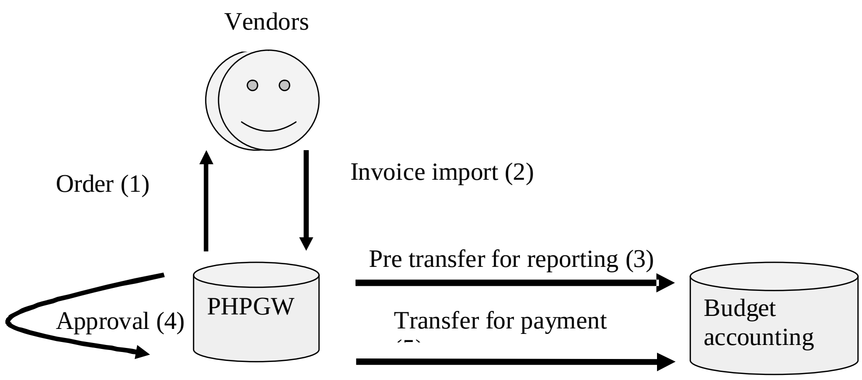

Figure 5 Dataflow –order/ invoice

Export:

The invoices are exported to the accounting system at a remote ftp-server as a set of files - and a backup-file is kept locally as reference. In case of error during import to the budget accounting system – the error is reported back – and a rollback is performed in order to correct the error.

4. Conclusions

The open source fm-system built upon phpgroupware has proven very successful – and has replaced commercial fm-system previously implemented in the organization. The system is very flexible as the organizing of locations and components are modeled in a metadatabase. The system is also integrated with the municipal accounting system as an automated e-commerce solution which greatly has reduced manual handling of orders and invoices – and increased the quality of control, workflow and the ability to do historical analysis.

The system is very adaptable and integration-friendly, given a certain general competence on programming database- and web-technology.

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Section III

Use of Product Models in Construction

The Use of Product Model Data in Building Construction Process

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Abstract

For the different parties of a building construction project, product modelling is an efficient data management method. Product model based data can be utilised and exchanged in various ways in and between different sectors of design, construction site management, and product industry. The product models of the different parties in a construction project can be integrated into a shared model which is augmented with data as the project progresses. In designing, both common product libraries and company-specific product libraries are used, enabling the transfer of product data from design to manufacturing. Creating guidelines for architectural, structural and HVAC design is necessary in order to make sure that data is stored in a concise way and that each designer can make use of the other designers' plans. In addition to design guidelines, another important prerequisite for this is IFC, a data transmission standard that allows information to be trustworthily stored and transferred between different software. Product model based construction process has been tested in several pilot projects where the results have been promising. Developing common principles and operating methods further will speed up and streamline product modelling in the building construction industry. As a whole, a product model -based process will improve companies' customer service, productivity, and construction quality.

Keywords: product model, data transfer, product component libraries, IFC data transmission standard

1. Introduction

During years 2003 and 2004, the Finnish construction industry has developed design, construction and maintenance in the building construction process based on product modelling. The development has taken place within the framework of a technology project called Pro IT –

Product Model Data in the Construction Process, in which businesses, research organizations, governmental organizations as well as interest organizations have participated. More information on this technology project can be found in a recent article [1].

A product model means a description of the building in such a way that, in addition to the geometrical 3-D visualisation, the model contains data defining the building and its components. The data may apply for example to the finishing structures in spaces, the characteristics of the materials, fire-resistance, colours, environmental impacts or sound insulation.

A product model is composed of product components, which can be modelled either on a case-by-case basis or by using ready-made product component descriptions in a product library. A product library is a collection of product components in an electronic form. The libraries contain the components commonly used in design, such as walls, doors and windows. It is also possible to make libraries of other product components, such as furniture and interior design accessories.

In the Pro IT project, a standardised method is developed for the design of a product model in the stages of architectural, structural and HVAC design. The starting point in the different design stages is the model created by an architect. The data exchange between the parties is developed on the basis of the international Industry Foundation Classes standard (henceforth referred to by the abbreviation IFC [2]). The main advantage of the IFC standard is that a number of designers from different fields can take part in construction projects irrespective of the software and file formats they use.

In construction industry, product modelling is still a relatively young technology and is not in widespread use. Despite the shortage of published information on or studies about practical applications and working methods of product modelling, there are some pilot projects on which the method has been tested with good results.

This paper proceeds as follows. In section 2, the benefits of the construction process based on product modelling as opposed to traditional processes are described, before the new process is briefly summarized. Subsequently, the need for developing general guidelines for product modelling designers is established in section 3, and the existing design guidelines as well as those still under development are described. Section 4 examines the IFC data transmission standard which is essential for the practical exploitation of product modelling, and section 5 casts a brief look into the different product libraries currently being developed. Section 6 sheds light on the pilot testing of the project. Finally, the conclusion summarises the essential points about product modelling and sets some directions for future development of the method in construction industry.

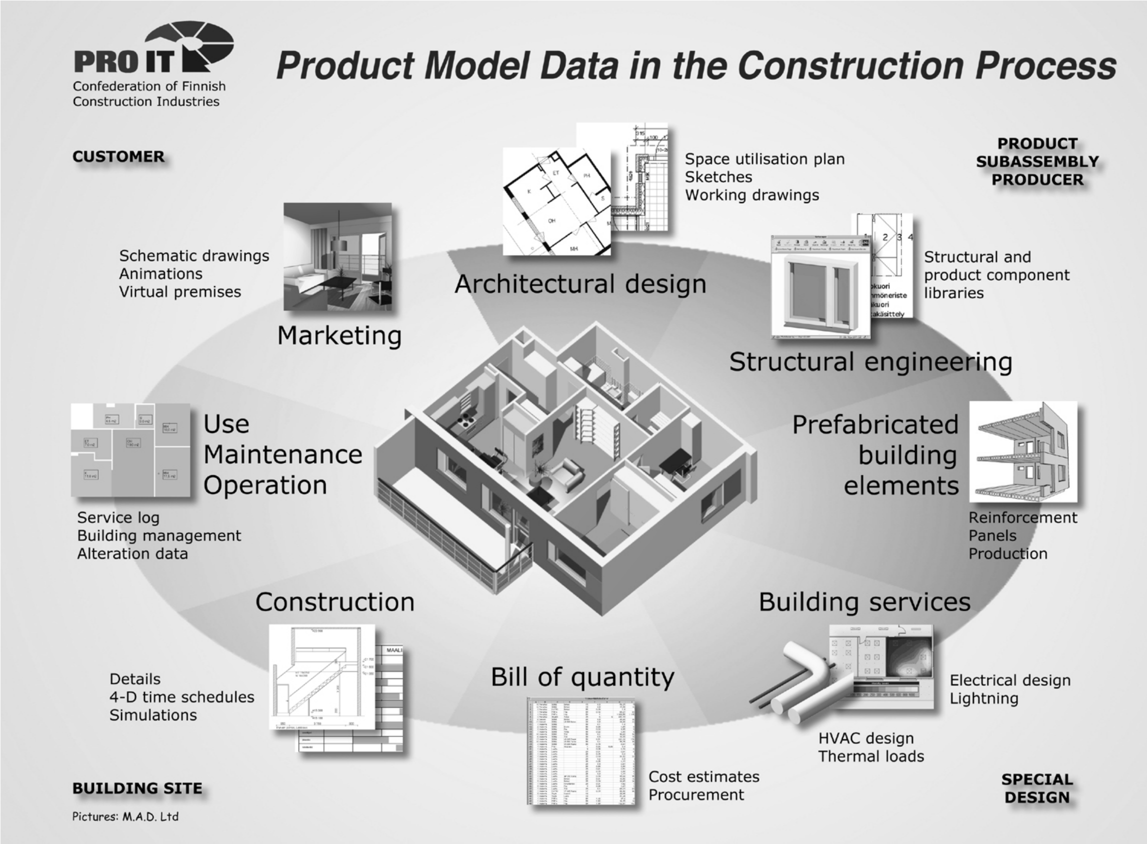

Figure 1. Product model-based data management for a construction project integrates the data needed for design, product manufacturing, construction, and the use and maintenance of the building.

2. The Advantages of the Product Model Based Process

2.1 Product Model Based Data Management

With the help of a product model, it is easier to keep under control all the data needed for the design, construction, usage and maintenance of buildings. The data can be managed in real time and in an intelligent and graphical form. The huge quantity of information needed in the successful realisation of a construction project can be transmitted between participants as well as managed more reliably and efficiently than before. An important possibility is to employ the structure and data content of the standardised product model to streamline and speed up the planning and control of construction projects. One of the most tangible direct advantages of standardised product models is that bills of quantities can be generated directly from the model for use in cost estimating, production planning and procurement.

The product data used in product modelling opens up a number of possible applications for the product industry [3]. Using a product description selected from a product library as part of a plan ensures a good technical and economical result, transfers the product data to manufacturing in good time, and also serves as a marketing tool.

Product modelling transforms building design from traditional line-drawings to visual 3-D design. In addition, a product model has in-built information available about the spaces, structures and furnishings it consists of. The structures of a product model such as walls and slabs contain information for instance on the materials they are made of, the measurements needed, and their thermal insulation, strength and environmental qualities.

When a 3-D product model and a time schedule are combined, the result is 4-D design. It enables site management to determine the most advantageous order of construction and the most economical time schedule from within an array of possible options. 4-D design also visualises the flow of worksite production and particularly problematic stages which demand more attention than usual from the site management.

After the planning and implementation phase of a construction project, it is possible to use product modelling to create a data store covering the entire life cycle of a building. The final product model shows all the materials and products used for the building, and can be updated when needed.

2.2 Product Model Based Operating Process

When one changes over from 2-D drawing to 3-D modelling, the production and management of designs are made more efficient: there is less routine work and fewer design flaws. Input data, such as quantities, are obtained automatically for various purposes and in the form of time-saving lists. The design geometry and dimensional accuracy come in handy in the design and manufacture of components.

Expertise from various fields of design and construction specialists is, through product modelling, usable in a practical form from the start to the end of a construction project. The inclusion of construction specialists in the design process improves cost-awareness and the possibility to figure in technical aspects of installation and manufacturing as well as allows room for innovative solutions. Instead of viewing the economy of a building in separate parts, it can be planned and assessed as a whole.

The last but not least of the ways in which product modelling improves construction processes is that it helps to achieve the goals the construction industry sets for customer satisfaction. It is crucial that the clients and end users of buildings are aware of the characteristics of the buildings built for them, that the buildings as end results correspond to their needs, and that unpleasant surprises are kept to a minimum. With the help of product modelling, the clients and end users of the building are provided with more information and specialist assistance to support their decision-making. The techniques used for this are visualisation and simulation.

2.3 Description of the Product Model Based Construction Process

The product model-based process supports exchanging and sharing data throughout the life cycle of a building. The ultimate aim is a process in which the product model data is produced, exchanged and utilised in an easy-to-use digital format between different software packages and participants. In order to arrive at this aim, it has been deemed most necessary that the participants of construction projects and the flows of information between them are systematically listed and described with respect to the different stages of projects.

The product model-based process has therefore been described by a systematic method (so-called IDEF0), in which the process is divided into sections. These are pictured as compatible diagrams which constitute a hierarchy. The diagrams represent the functions of each section, the programs used, the participating partners, and the data flows between them and their design software. The process model covers the life cycle of the construction project and the building from the preliminary design to the operating and maintenance.

3. Design Guidelines

3.1 Basics and Objectives

Uniform modelling guidelines for various designers of the construction process are necessary in order to transfer product models from one program to another. Being able to transfer product models between programs is a prerequisite for clash detection analyses of the models created by different designers and for ensuring that the bills of quantities extracted from the models are accurate. Furthermore, the data on the characteristics of product structures stored in a product model should be defined by a commonly shared method.

The modelling guidelines for the architect are the most crucial and demanding, as the model made by the architect serves as the input data for quantity surveying, for structural and building services design, and for marketing. It must therefore contain information for many different purposes – for example, spaces, building components and the principles of their connections. It is particularly important to transfer measurements to other plans correctly.

A key aim of the modelling guidelines for structural design is to provide basic data and instructions for the product-model-based description of structures and to influence that computer programs and the libraries on structural parts, details and joints are drawn up in line with the same principles of product modelling. General modelling guidelines also serves as an aid for drawing up project-specific modelling instructions. The guidelines can also be used to harmonise and standardise terminology, operating procedures and working methods.

So far, the third version of the guidelines of architectural design has been published in Finnish under the name Product Model Design Guidelines for Architects – General Rules and Fundamentals [4]. The first version of the guidelines for structural modelling has been completed, and at the moment it is being tested on real construction projects. The guidelines for modelling building services have also been started: currently, the content of the guidelines is being defined.

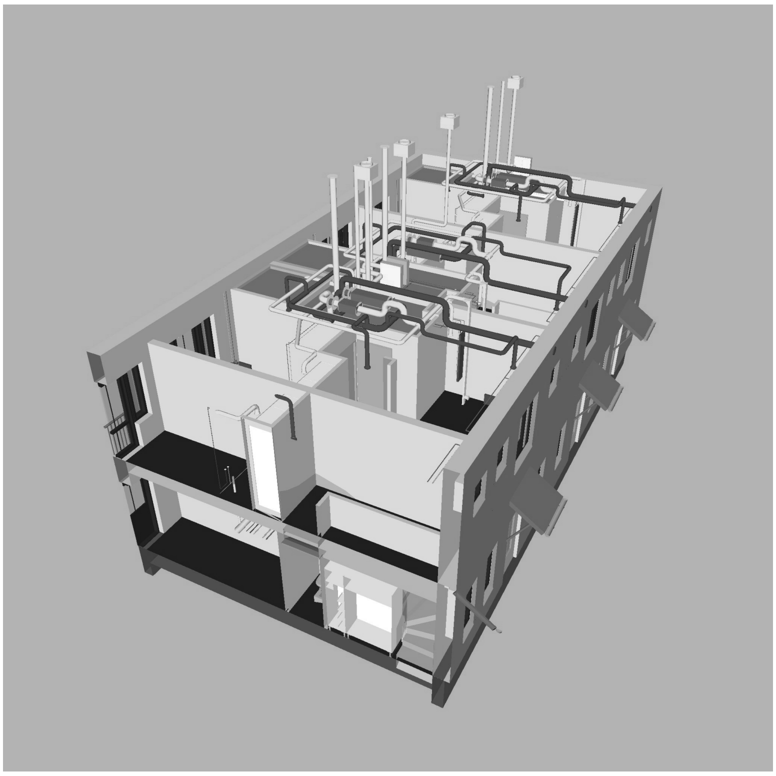

Figure 2. Combining the architect’s model and the building services model and clash detection analysis reduces errors on the worksite.

3.2 Stages of Product Modelling

The designing of product models is divided into stages in accordance with the construction process as a whole. Descriptive terms have been agreed on for the different stages. These differ from the conventional terms, because product model-based design does not comply with traditional practice. The design model includes four stages: the requirement model, the space model, the preliminary building element model and the final building element model. The requirement model may be for instance a description of the client’s needs and the building authorities' requirements, as well as the parameters set by conditions. This model may be represented in a spreadsheet application or other digital format.

The space model, in its turn, covers spatial solutions. The model does not yet necessarily include walls distinguishing the spaces from one another. The basis for formulating this model is the space utilisation plan together with its data on the individual spaces.

The preliminary building element model includes the elements which delimit the spaces and correspond to drafts in present-day design practice. Requirements are set for the elements, such as the fire class and thermal conductivity, but the structural solution is not yet selected. The building elements are defined at a construction type level. Ready-made construction types from the general product libraries can be used to create this model.

In the final building element model, the construction types shown are building elements together with product data, like the actual products of suppliers. In this model, supplier-specific data have been added to all the elements, accessories and so forth. The final element model may also include other information, such as time schedules and job plans. The models following the four actual stages of the design model are the as-built model together with site and installation data and the maintenance model in a life-cycle program. The maintenance model can later be updated with spatial alterations and additional construction.

4. Data Exchange and the IFC Standard

4.1 Data Exchange Use Cases

One of the key aspects in the product model-based building process is the interoperability of computer programs, and the support for the life cycle of the building information throughout the construction and operation process. A prerequisite for the realisation of this is to enable the digital data exchange of building information between the participants of the process and their programs. Then information once created by a participant and his or her program can be exchanged and shared with the downstream programs of other participants.

To enable the support for the many required data exchanges within the multidisciplinary building process, these exchanges need to be first defined, and then implemented as data exchange interfaces in the programs. The definition of the exchanges can be done by so-called *data exchange use cases*. A data exchange use case is 1) an identification of a business need for the data exchange, 2) definition of the information to be exchanged, and 3) definition of its implementation, for example, using a data exchange standard.

In the pursuit of advancing the practical product model data exchange, the Pro IT project has defined a set of necessary data exchange use cases. The use cases defined include the following exchanges:

- from architectural design to quantity take-off and cost estimation
- from architectural design to HVAC design
- from architectural design to structural design
- from various designers to design coordination and clash detection
- general quantity information exchange, e.g. from quantity take-off to tendering
- from product libraries to various programs.

4.2 The IFC Standard and How It Works

A data exchange specification called IFC (Industry Foundation Classes, [2]) has an important role within the data exchange use cases defined by the Pro IT project. The use cases define how IFC is used to implement the support for the exchanges.

The IFC is an open specification for AEC/FM interoperability. The scope of IFC is AEC/FM over the life cycle of buildings. IFC is developed by IAI (International Alliance for Interoperability, [5]). IAI's mission is to develop, promote and support the implementation of Industry Foundation Classes.

IFC specifies a neutral format in which programs can exchange digital building information. Using IFC, an architect can for instance send a digital building model created with a model-based CAD programs to an HVAC designer. The HVAC-designer could then use the model, its spaces, building elements, and 3-D geometry directly as input data for the thermal simulation program to calculate thermal loads and requirements. The same building model could also be used by a cost estimation program to automatically extract a bill of quantities and to calculate an initial cost estimate for the building.

All the Pro IT use case definitions follow same content structure: In the first part of it the purpose and scope, typical participants, and their program types are identified. Then the data content or the information requirements of the exchange are defined. The second part of the use case defines the subset of IFC object model which is required to support the use case. Examples and usage rules of the IFC are also given. The use cases are defined using a methodology including re-usable definitions, such that new data exchange use cases can easily be addressed and defined.

The data exchange use cases serve the purpose of a proposed common agreement on how IFC can be used to address real-life exchange requirements. The target audiences for the use cases are on one hand the participants of the construction process, and on the other hand the software developers, who may be implementing exchange interfaces for their design and construction programs.

5. Product Libraries

The Finnish construction industry has sought to standardise the data content and presentation of product structures so that the various participants in the construction process can use them. Both the definition of data with building component cards and product libraries for use in 3-D design are needed, so that designers are able to plan and manage customer demands, builders are able to estimate quantities and costs, and operators are able to use completed buildings and perform maintenance tasks.

One of the completed tasks is creating a structure library common to the construction cluster containing the most frequently used types of structure. The library currently includes over 200 different structures, which are mainly structures used in housing construction. However, the principles used there could be applied in the future to describe other, even totally new structures. With the common product model library as their starting point, companies will be able to create their own product libraries compatible with commonly agreed specifications.

The next challenge in the development of product libraries is to establish a link between common product libraries and specific products included in the product portfolios of manufacturers. The link would make it possible to choose specific products suitable for the design based on the general characteristics defined in common product libraries. The search for the specific products needed could be carried out for example by Internet search devices.

6. Pilot Testing

The piloting of the use and exchange of product-model-based data is an important prerequisite for the broader utilisation of product modelling. The construction companies involved in the Pro IT development project for product modelling are responsible for this. In the course of 2004, two contractors implemented and further developed the model-based process in their own housing output [6]. The software packages used in Skanska Oy’s pilot project were ArchiCAD (architectural design), Tekla Structures (structural design), MagiCAD (building services design), Solibri Model Checker (checking models), ScaleCAD (element design) and NavisWorks (integrating different models and clash detection analyses). On NCC Construction Ltd’s pilot, Bentley MicroStation Triforma (architectural and structural design) and MagiCAD (building services design) were used. The subjects of the testing were the use of modelling guidelines and product libraries, the transmittance of product models between programs, and the utilisation of product libraries in the design process.

In a pilot project of a shopping centre extension by Lemcon Oy, Tekla Structures software was used to model the structures. After the modelling of the steel frame, precast concrete units and the façade’s thermo spar elements, these submodels were combined into a single structural model for the worksite. The main emphasis in the piloting work was on time schedule planning for the frame work stage and on monitoring installation data. By specifying the order of installation of the building components of the 3-D model and by inputting the scheduled installation dates of the building components into the product model, a 4-D model was obtained, containing the time schedule data for the construction project. The product model was placed on the Internet, enabling all the partners in the project to view a real-time 3-D image of the situation for installation on the worksite using nothing more than an Internet browser.

Advantages of product modelling among others that were repeated in different pilot projects were that it facilitated change management as well as the production of bills of quantity and various images and views. In principle, it is possible to generate all the conventional design documentation, such as drawings, from the product models drawn up. Product models have also permitted quantity listings of all the modelled construction components. As an example of the main benefits, it was noted that the time taken to calculate bills of quantities was reduced by an estimated 30-50% when using the new method. It must be admitted, however, that it is a prerequisite for such significant time savings in calculations that the subject building has been modelled comprehensively and extensively enough. The quantity data taken from the model have been estimated to be as much as 80–90% usable in making a time schedule for the construction project. In the project for an extension to a shopping centre, a graphic 4-D model proved itself to be an efficient tool for time schedule planning.

Other advantages include, for example, the possibilities to use three-dimensionality to assist design work and in integrating the work of different fields of design. A further prime advantage of product modelling that has emerged was the reduction in errors. For example, it was possible to eliminate measurement errors from designs almost entirely. It was also possible to use the product model on the worksite in many ways in the management of installation, logistics and complex delivery chains.

Most needs for further development were identified in data exchange between different software packages. Because IFC standard data exchange did not yet run satisfactorily, it was necessary to exchange data also using other, program-specific formats. The piloting will continue in 2005 on projects by four different contractors, in which the operating model and data exchange will be developed on the basis of the feedback received.

7. Conclusions and Directions for Further Development

The experience gained of the use of product modelling in the construction industry indicates that there is considerable scope for increasing efficiency in various subdivisions of the design and construction process made possible by this new method. The increased efficiency requires that common product modelling operating methods and data content definitions are finalised and taken into more widespread use.

The feedback so far indicates that compliance with architectural modelling guidelines and the use of general product libraries facilitates fast and efficient calculations of quantities. On the basis of the quantities, one may separately derive the costs and time schedule data. Quantity calculation and time scheduling are the first widely usable application methods where product modelling has proven its benefits. These methods are increasingly being used by construction companies.

Structural modelling is developing dynamically, and models can already be used not only for design but also for worksite 4-D time scheduling and production management. The structural model yields considerable benefits for the worksite using visualised plans and material listings. A structural model can also be used in the further design of building components, as has been done on the pilot sites of the Pro IT project. Building services modelling provides a visualised image of systems for purposes of installation, and it permits clash detection analysis and the design of the necessary provisions. The building services model can be used, for example, for simulating indoor air conditions and for dimensioning the energy consumption.

The main requirements for the onward development of product modelling relate to data exchange and the improvement of overall levels of expertise. For the development of data exchange, systematic work for the adaptation of the IFC standard must be continued so that it can be used to transfer the data required for different plans and for production between program solutions. Current data exchange is still based on file transfer. In the future, however, efficient team design will require the use of dynamic product model servers. From these servers, each designer will be able to access only the part required and to update the plan back onto the server. The first product model server solutions based on the IFC standard have already been created.

As a whole, the product model-based process is expected to yield substantial benefits to all the parties in the process. However, widespread adoption will still require considerable efforts. Particular attention should be devoted to developing standards for data exchange between design software, determining product attributes and creating product libraries.

Data exchange between different software should be developed by making it possible to widely apply the IFC standard. In practice, this will mean developing and expanding the IFC standard in such a way that it covers all the usage of data exchange required by the industry better than at present. Also, greater efforts on the implementation of the standard will be required of the software industry so that software will support the standard. Therefore, the standard needs to be developed a strong and international one.

The use of product data in the design, construction, use, and maintenance stages of a building requires information on the materials and solutions used as well as efficient and reliable electronic archiving. For it to be possible to create electronic product descriptions on the basis of the product data, the attributes of the product data should be defined internationally. On the basis of common attribute definitions, it will be possible to build jointly used product libraries and product symbols for software and to establish connections from them to different types of product libraries. This kind of product libraries will facilitate efficient marketing and comparisons between different products as well as promoting procurement on a broad level.

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Product Model Based Infrastructure Design

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Abstract

- There is a great need to develop the following sectors of the infrastructure branch:
- The quality of the design process
- The cost management during the design process
- Information management and communication between the different members of the design team

The result and the major cost level of the infrastructure project are defined in the beginning of the project planning and during the design process. Then the scope of the project is defined and the project is designed. Traditionally there have been problems related to the scope and information management. Now three companies have developed together with the Helsinki University of Technology the new product model based infrastructure design process. The process uses the best practise process of the cost engineering and the common product model.

Rakennuttajapalaute Rapal Ltd has developed with 10 major Finnish infrastructure clients (Cities of Helsinki, Espoo, Vantaa, Turku, Tampere, Oulu, Kuopio and Jyväskylä and the Finnish Road and Rail Administrations) the best practise process for scope management costing and cost engineering during the design process. Viasys Ltd is a member of the worldwide Vianova Systems Network and has developed the design software called Novapoint based on the product model. DSS Ltd has developed a program called DYNARoad for optimizing the earthmoving operations. Three companies have developed together a design process based on the product model, which is compatible with the InfraRYL (the new common finnish civil engineering terminology system). The product model based design process contains:

- The project scope setting method for infrastructure client before the design process
  - Systematic project scope definition method for the use of design management

    - The cost estimation based on the scope definition
- The design of the highway based on the previous definitions
- The optimizing of the mass operations in the project
- Cost engineering during the planning process
- The final cost estimate based on the infrastructure building element method
- Quantities of the final result of the design are given to the contractor for further studies

The developed design process with the common product model saves the great amount of resources during the long design process. The result of the design process matches the defined scope better than in traditionally used processes. The cost engineering and the product model can save millions of Euros in the big highway projects.

Keywords: Virtual enterprise, information exchange, information systems, distributed engineering, product model, cost management, earth moving operations, infrastructure management

1. The New Infrastructure Design Process

1.1 Overview

Three commercial companies (Viasys Ltd, Rapal Ltd, DSS Ltd) has collaborated with the Laboratory of Construction Economics and Management of Helsinki University of Technology to create new kind of product model and systematic cost management based infrastructure design process. Traditionally in the infrastructure branch there are many different kinds of data models in use and that makes lots of information waste during the process. The cost management process is not scope oriented and cost engineering in the means of getting economical and quality oriented design solutions compared to the scope is not in the common use. The new infrastructure design process is described in this paper concentrating on the cost management and data transportation.

1.2 Process Relevance

The difference between the reasons of the infrastructure project cost is related to three categories:

- The scope
- The design solutions
- The economical situation on the market

This article concentrates on all three categories in the view of cost management and the data transportation. The main benefits of the new design process are:

- The result of the design process corresponds to the defined scope better

- Data is not wasted during the long process
- The focus of the planning process is getting to the earlier stage of the process than before
- The focus is on the result of the process, not in the process

The infrastructure (highways, streets, railways and big industry yards) investment and maintenance cost in Finland for example were worth of 1,8 billion euros in year 2002. The relevance to the whole society is huge when lots of working hours are saved because of the more complete design process.

2. The Cost Management Process

2.1 The Systematic Scope Definition

The infrastructure is build because of the need to develop or to maintain the basic functions of society. The maintenance of the infrastructure is based on the need to sustain the standard of service of the invested infrastructure network. The change in the functions or the standard of service creates the need to invest more. The needs of the public and the resources in use with the property owner organizations are usually not at the same level. The building process of infrastructure is a long term process including lots of public organizations and ordinary people related to it.

The infrastructure cost management process described in this paper starts with the definition of the needs of the project. The client of the process (usually the public organization) has the responsibility to describe the need, give reasons to the need and take care of the cost management process to reach the target. The needs are modified to targets which are described with end product elements, which are big work breakdown structure components of the project like for example the main way, intersections, bridges and the lightning system (fig 1).

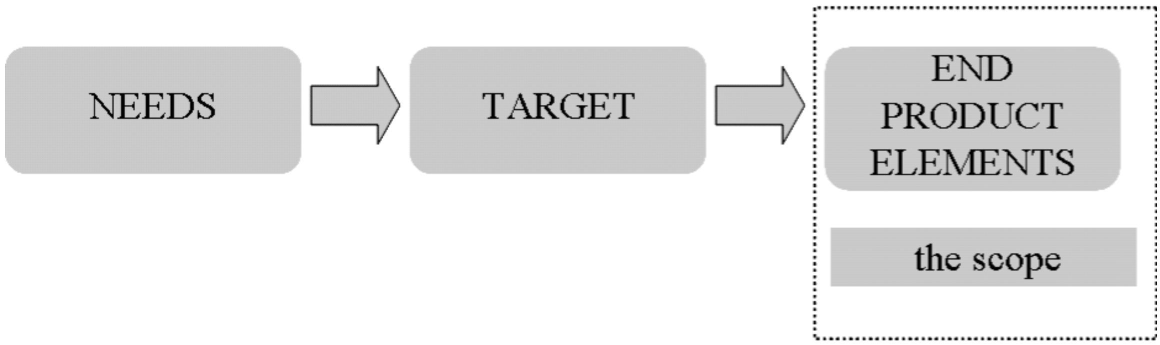

Figure 1: The needs of the project are modified to the targets, which are described as end product elements with the defined scope..

The list of the end product elements creates the framework to the project management based on the systematic and strictly defined project components. The systematic project component division with the end product elements has two purposes:

- To describe the result of the project
- To create the drivers of the project management

Traditionally in the infrastructure branch the process is design and project orientated. In this systematic scope definition the focus of the design process is moving to the earlier stage. There are three benefits of the earlier target orientated scope management:

- The design organisation has clear definition for the scope
- More cost orientated decisions can be made
- The design process can concentrate to the design process and innovations instead of definition of the whole project

2.2 Cost Engineering During the Design Process

The cost management of the project can be based on the estimate theory or on the steering theory. The difference in the two theories becomes concrete in the decision making points (fig2). According to the steering theory the decisions are made so that the cost is under the cost level accepted with the scope.

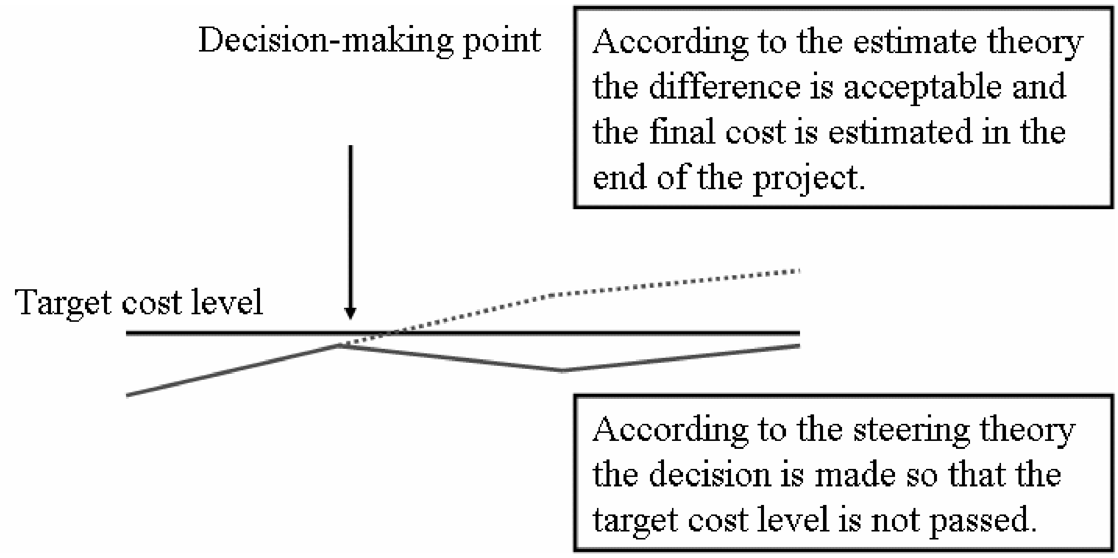

Figure 2: The difference between the estimate and steering theories

Traditionally the cost management is the final action of the design process and the result is more or less declaratory. The cost engineering during the new process is a continuous decision making process. It has three purposes:

- To get comparable prices for different design solutions
- To compare the design solution with the scope
- To estimate the market price for the execution of the project

The cost management during the design process is made with the building element system. The building element is a piece of the product defined in InfraRYL - the new common finnish civil engineering terminology system. The building element consists of the typical production structure in use and the price consists of the prices of resources (work, material, machines). The resource list is updated continuously by the data received from the markets.

2.3 Earth Moving Operation as The Important Part of the Infrastructure Cost and Schedule Management

Mass economy consists of the cost of earthmoving operations and the effect that used design alternatives and the available schedule have on them. These costs are always project specific and that is why it has been difficult and time consuming to estimate them in the past. If this has been done, the results have always has a high degree of uncertainty in them. DSS Ltd has developed a tool called DynaRoad to simplify parts of the process and remove some of the uncertainties related to it. The mass haul planning in DynaRoad is assisted by algorithms that do the all the haul and some of the schedule calculations for the user.

Mass economy calculation yields two major benefits to the design process: the cost of earthmoving operations and the weak spots in the designs that are likely to cause unnecessary costs during construction. The costs and weak spots are discovered by creating a resource based schedule and mass haul plan. This plan can be done in early stages of the project by using information on haul and resources costs that are readily available in the industry. A finished schedule and mass haul plan show an estimate of the project’s haul amounts, distances and resource and time requirements that are then combined with other cost calculation information. Analysing the mass haul plans gives the weak spots in the plan. These are for example:

- Structures that have a mass deficit or surplus.
- Structures that have long and large hauls related to them.
- Structures that may cause unnecessary delay to other tasks.

This information can then be taken back to the designers that can check if it possible to alter the plans in some way to get rid of these problems. For example, a mass deficit or surplus could be avoided by changing the vertical alignment of designs or changing the structure type to something that is (or can be made) readily available near by. Structures that cause unnecessary delay to other tasks could for example be embankments that rely on a cut that can only be done later in the project. This causes a delay on the fill and also all the tasks succeeding the fill.

The use of product models in mass economy calculation speeds the process by eliminating many of the complicated stages that have been previously necessary to get the required data from a design platform to a mass economy calculation system. Instead of using a day to set up a complicated project in the system the required data can now be imported directly from the design platform. After the product model development is complete it will be possible to visualise all the mass economy related information directly in the design software. This will further ease and speed up the work of the designer.

2.4 Benefits of the Systematic Cost Management

The cost management based on the scope management, the active cost engineering and active earth moving operation design gives the systematic approach to the infrastructure cost management. The new process makes different costs comparative and easily managed. The focus of the cost management and the planning of the earth moving operations are moving earlier than traditionally in the process. The more cost oriented design process gives resources to important points of the process and is feasible especially in the tight economic situation when the real cut resources are lower than needed (fig 3).

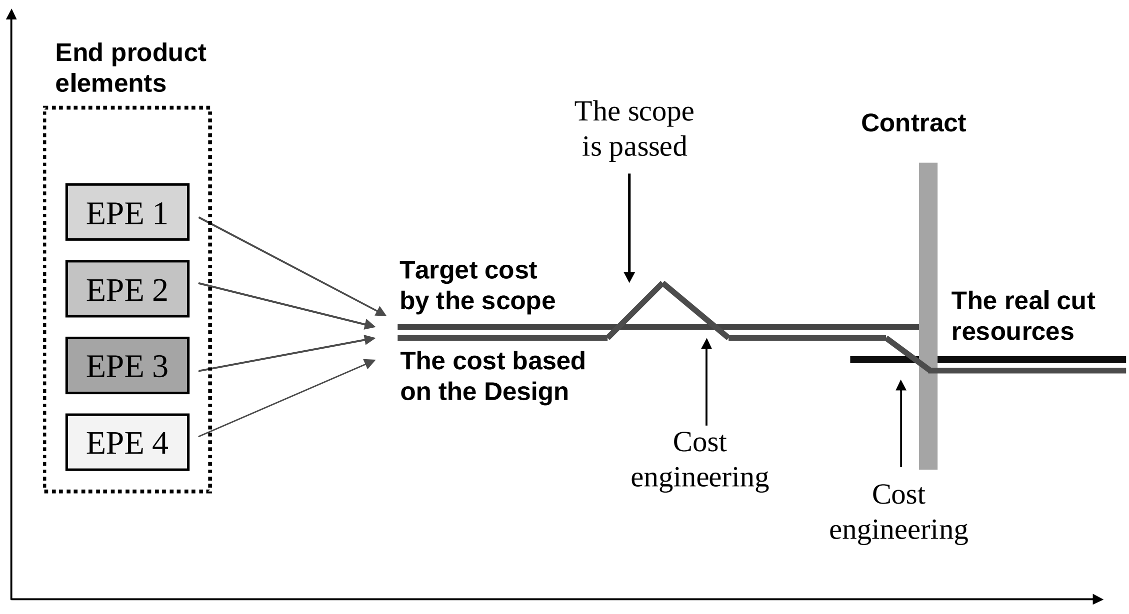

Figure 3: The systematic cost management process in the infrastructure design

3. The Information Process

3.1 The Common Product Model Description

Product model, in general, is an abstract class model describing real life objects and phenomena. Each class describes one type of real-life object. Class description consists in properties and methods. Classes are hierarchically associated with each other and properties and methods are inheritable based on association type. When any class in initialized, it becomes an object signifying a real-life object. During the object initialization, initial values of properties are supplied and initial methods are carried out. Thus, an object always contains some information. Furthermore, each object has a life-cycle and state of existence. With these basic construction blocks and rules, rather complicated real-life models and systems can be reproduced and utilized in computer memory.

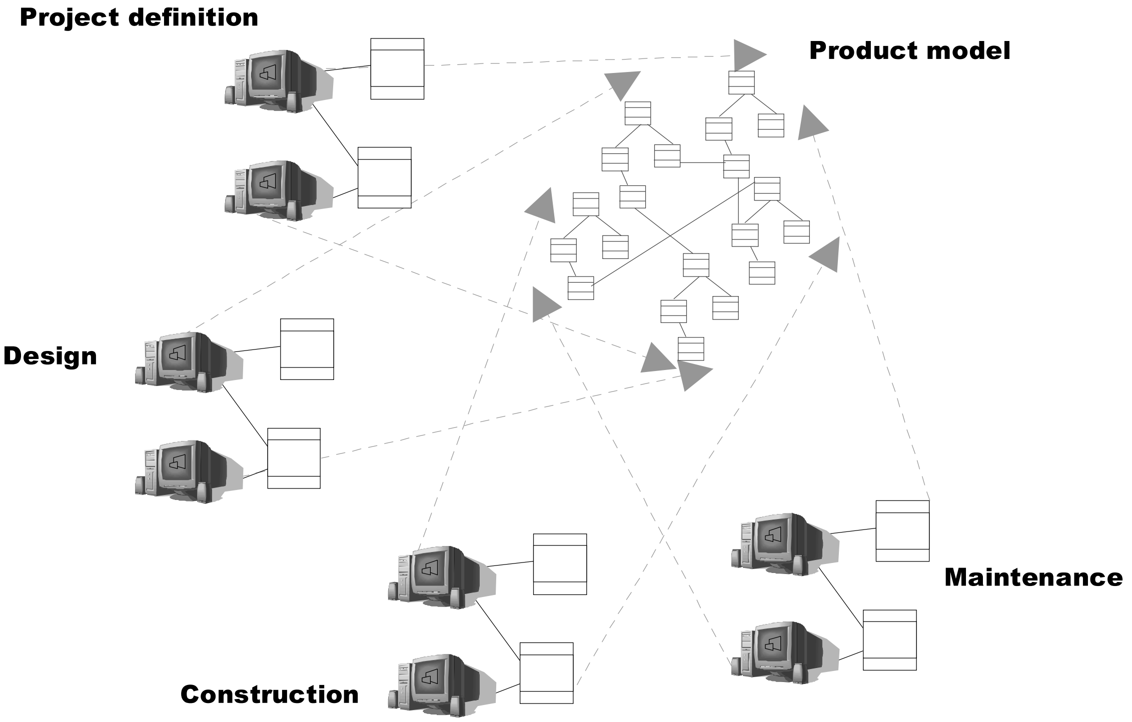

Figure 4: Different views to common product model.

Comprehensive and commonly accepted product model enables communication between different software with minimal or any data-loss. In ideal case the product model is well considered so, that the same product model is utilized in all software used in particular field of expertise. Figure 4, illustrates how the same product model is shared by different software in each phase of a public infrastructure management project. In each phase the product model is updated and developed further to meet the demands and outputs of the project phase at hand.

General methods and tools for holding a product model are, for example, databases, XML-files, text and binary files, in general, and data models in computer memory. Each application is able to read the common product model, or suitable parts of it, into application memory. Depending on the needs of the task at hand, the application view to the product model can be rather different from another application. For example, a cost management application does not need a detailed 3D-model view of a road, when a CAD-system is rather dependent on one.

Software used to produce and maintain the infrastructure design product model, in the concept described in this paper, is Novapoint product family (http://www.novapoint.com). These product model based design and management products are developed to meet the needs of Civil Engineering computing. The individual application modules, sharing the same product model, used in this concept are:

- Novapoint Road Professional
- Novapoint Terrain
- Novapoint Noise
- Novapoint Traffic Signs & Road Markings
- Novapoint Civil Construction & Novapoint SiteTools

3.2 Engineering with Product Model

The product model based infrastructure design process builds up gradually the road model in different project phases. Other relevant models included in infrastructure design process are some basic models, like ground and map models, and some domain models like road, water & sewer, traffic sign and road marking models. Thus, the comprehensive infrastructure design product model consists all of these models associated in strictly ruled ways. Each project phase uses the road model and other relevant models to achieve ones objectives and passes the evolved road model to the next project phase. This data flow in infrastructure design process is illustrated in Figure 5. Process phases are taken from a road design process and they are shortly described in paragraphs after this picture.

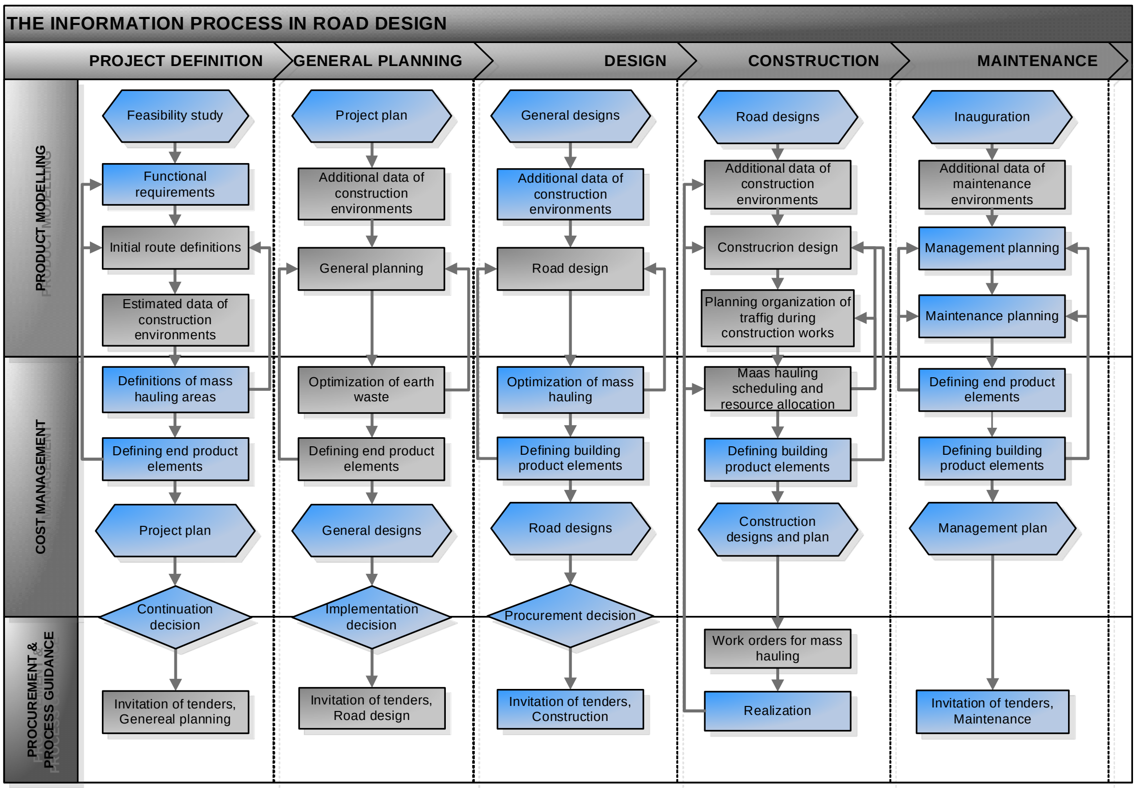

Figure 5: Road design, data flow in the information process.

In *project definition phase*, the product model is initialized against one or more very roughly defined routing alternatives. Systematic project scope definition process generates initial product models and sets of end product elements, with different functional requirements and routing, for comparison. Construction environments conditions and characteristics are roughly estimated in order to gain comprehension of construction difficulty level and costs. Also the first definition of mass hauling areas should be carried out. The risk of miss-approximating the costs, at this phase, are relative to the level of information about construction environment. The systematic project scope definition process outputs are one or more product models with "one-dimensional" parametric road model. The road model, in this phase, lacks any geographical manner of expression. The parameters of the road model set rules for design process in following phases.

In ideal design process the designer receives, after project definition phase, the initial product model in digital form. The designer is able to start more detailed design work immediately. The design work is guided by the product model parameters. The designer is able to deviate from rules set by parameters, but the designer is obligated to have good arguments for any deviation. *General planning* includes also environmental impact evaluation, like noise calculations. Combining all available information the designer is able to produce further developed product model. The road model gains initial alignment and horizontal profile. This enables first trend-setting mass calculations and optimization of mass usage. Basic information gets more specified and the set of end product elements can be decided. After the first ground setting designs, the costs of the construction are quite fixed with some deviation limits. Cost deviation is possible within the allowed change-limits of alignment and horizontal profile. Also the costs of actual building process elements can vary.

During *road and construction design* phases the product model is developed into very specific level. The product model is completed and the basic information of construction environment is detailed enough for construction planning purposes. Based on completed road model, the designer and the contractor are able to decide the comprehensive list of building process elements. The completed product model is delivered to mass optimization software for analyzing. The mass hauling optimization process is carried out and earth moving operations scheduled with allocated resources. The mass hauling optimization process is iterative in nature. If it becomes obvious, that in order to achieve mass balance, there has to be some design changes, the product model is returned to design software for revision. After this, the economical risks are again estimated based on the amount and accuracy of construction environment information.

The mass hauling schedule becomes the backbone of infrastructure construction project. Surprisingly, in modern road construction projects the mass haul planning can be quite demanding task. In major, road construction projects realize in road sections already in traffic-use. Construction works are not allowed to cause disproportionate blocks of traffic. Based on mass hauling plan, the planning of traffic organization during construction works is carried out. This action requires that the product model enables delivery of mass hauling plan to design software. In design software, the mass hauling plan is analyzed and required temporary structures, traffic signs and markings are designed.

During the construction works, the product model is utilized again. By the use of product model, the contractor is enabled to produce, within design software, daily or weekly work orders with guide maps for mass handling actions. The work order can also be used for reporting the realization of mass hauling works. These reports are inputs for realization analyzing. Based on realization analyzes, the contractor can produce estimates and revision of the construction schedule. Quality control of the infrastructure is carried out by as-built measurements during the construction works. As-built measurements are inputs for analyzing, among other things, realized masses, structure thicknesses and slopes, as well as keeping the agreed tolerances. While analyzing the as-built measurements against the product model, one builds up the product model of realized infrastructure.

3.3 Benefits of the Product Model and the New Design Process

The benefits of product model based design process are quite obvious when one thinks the process trough. One might ask, is there any other intelligent way to do this? All information produced during the process is somehow linked or based to previously produced data. So called rule based designing, managing data in similarly controlled way in all project phases and utilizing common product model in design process enables guidance of the design output and ensures that the functional requirements of the structure are fulfilled. This process approach also brings more economical predictability and fewer risks to infrastructure design and construction. Also, when the product model is sensitive against inaccurate or faulty basic data, the economical magnitude of possibly realizing risks is known and can be budgeted for.

4. The Benefits of the Process

The benefits of the new product model based design process are:

- The cost management is based on the real defined scope, which is a target for the cost management
- The scope and the design solutions are comparative through the design process
- The data transportation between the systems and the organisations is fluent because of the product model and data is not wasted
- The systematic cost management and data transportation save the amount of the working hours, which were used to routine work
- There is more time to research the alternatives and innovate

5. Conclusions

The infrastructure management is traditionally organised by public organisations. The cost management and the data transportation were developed by the organisations in the branch separately with no collaboration. Now the world has changed. In Finland the public sector is concentrating to the property owner duties. The actual construction and maintenance work is done by the private companies. The property owner has to concentrate to the role of owner in the world of tighter resources. The product model based design process is still developing. The companies are building up a new development project with the University. The results from the piloted process so far indicate that:

- The focus of the design process needs to be in the earlier stage of the process
- The design should be more cost oriented, now many cost effective decisions are passive parts of the process
- The new common nationwide or even more nations covering data model should be developed and taken in the use
    - now too many resources are wasted to routine work
    - now too much data is wasted

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The Virtual Cooperative Project: An Aid to Building Cooperative Design

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Abstract

The main objective of our research is to develop a tool that helps the management of a building project and aids cooperative design. In this paper, we present a cooperative system called Bat'Map developed according to the model of the Virtual Cooperative Project. This new model of cooperative design takes into account the relational organization of the project and the semantic meaning of works. This system lets geographically dispersed project actors model the project context of a building. More specifically, it allows interpreting, using and exchanging project works in a centralized virtual environment during the building life cycle. This system uses IFC objects which associate in the same model the semantic and the 3D representation of building works. This research represents a new approach because it not based on management of documents but on all data relative to works. So, in the first part of this article, we propose to view collective typology of building domain activities and the exchanging data mode of cooperation tools. The second part of this article illustrates the IFC model. Then we justify the interest shown in a model of cooperative design used for defining a design-aided tool, to deduce advantages and limits of the "Virtual Cooperative Project".

Keywords: Cooperation model, cooperative work design, project management, digital mock-up

1. Introduction

Architecture design is by nature an integrative discipline, drawing upon a wealth of knowledge. It has a strong tradition of interpreting its results not by scientific metric knowledge but through self-referential validation [1]. In fact, an act of design is a designer's interaction in a group of designers. Points of view are often shared between contributors, and decisions about different project aspects are submitted for common approbation. The global organization of the design process allows actors to develop and to prescribe tools and methods improving design. Most of these tools are unsuitable because they don't sufficiently take into account the cooperative dimension and the implicit nature of building designer work [2]. It does not enable them to treat all the semantics of the works especially the one relative to cooperative design (difficulties in tracking actor's work, lack of all the required information, coordination problems, etc). So, in this paper, our objective is to define a tool that must help designers to obtain maximum project context data and structure works semantic meaning, which allows good objectivity in decision evaluation. This will be able thanks allowing actors to get reliable data concerning the state of the project in order to determine what the actions to be carried out are.

This paper will briefly review collective typology of building domain activities as well as the data exchanging modes. It will then illustrate one vision of the digital project deduced from the analysis of the IFC object model "Industry Foundation Classes" imported for construction. The aim is to identify the capacity of the current IFC digital mock-up to structure the cooperative design activity. After that we justify the interest shown in a new model of cooperative design where the relational organization of the project and the semantic meaning of works are taken into account. Finally, we use this new model for defining a design-aided tool, to deduce advantages and limits of the “Virtual Cooperative Project”.

2. Cooperative Design in the Building Domain

Design activities correspond to a sharing of a space, which contains common and shared objects. This space is always extended by individual contribution (in cooperation) and by collective contribution (in collaboration). This co-production is structured by actors’ coordination.

2.1 Collective Typology of Building Domain Activities

We differentiate three categories of collective building domain activities:

- Cooperation is defined by acting jointly through a non-structured informal relationship. The rules are invented progressively. The coordination is founded on an implicit mode between the actors.

- Some authors like Dillenbourgh (1995) and Lonchamp (2003) [3,4] explain that collaboration is one elaborate form of cooperation. It consists of teamwork producing common work. It requires a large amount of explicit coordination with precise and hierarchized progress (Table1).

- Coordination allows the group members to articulate each action to design and to realize together collective products. Coordination is the mechanisms through which individuals integrate their productive activities [5]. It interferes either at the moment of the final assembly of the partial contributions in a cooperation setting, or throughout a task realization in a collaboration setting. The coordination organizes and structures the cooperation and the collaboration activities: it is inseparable from either of them. The coordination constitutes the mode by which the collective activity is sure to be efficient.

Table 1: The difference between cooperation and collaboration.

	Cooperation	**Collaboration**
Work mode	Acting jointly	Working in a team
Objective	Actors have a common objective but don't have a common underlying objective	Actors have a common objective and a common underlying objective
Evaluation method	Actors are evaluated in group	Every actor is evaluated independently
Relation nature	Relations are not definite and are unstructured	Relations are lasting
Activities progress	The rules are invented progressively	Activities' progress is known and hierarchized
Coordination type	Large amount of implicit coordination	Large amount of explicit coordination

The collaboration, cooperation and coordination operations are the basis of group activities. Collaboration is an activity where processes are known and repetitive. On the other hand, every building actor works to carryout underlying tasks, and cooperates to assemble their contributions in a common production using coordination. Design is an important building collective activity of reciprocal prescriptions. In a design project, actors cooperate to achieve a same objective, which can be the production of documents, solutions, comments, etc. Criticism and negotiation represent important decision actions. Because of the implicit character dominating in the building domain, a great number of heterogeneous variables are taken into account to design and to construct. As result of this, actors must cooperate successfully and have assistance to save time and money. Today, actors use more and more tools to assist their work, and technologies to structure their exchanging of data and to manage building project.

2.2 Data Exchanging Modes in the Building Domain

In construction, there are two types of cooperation approaches. The first one is founded on documents and exchange files. It is structured by several data exchange practices: manual management of exchanges (sending disks, maps, etc.), exchanges by electronic Email, exchanges through PDM, cPDM[1], etc. Some of these practices save time and are efficient through big projects, etc. Some others show little trace of sharing and are submitted to precise structuring rules for drawing up documents, etc. The second cooperation approach is based on the use and the manipulation of the semantic meaning of a project. It constitutes an experimental practice

[1] Product Data Management (PDM) is a component of the technologies of data products. This concept covers the set of techniques, methods and tools aiming to communicate, on an electronic support, the product data within a company. CPDM is a cooperative Internet version of the PDM.

which consists of sharing a digital mock-up[2] and modeling building projects with interoperable objects. This practice has not yet shown its efficiency, but is being followed with great interest.

3. IFC Digital Mock-up Model

A large variety of CAD software is proposed in the engineering domain. CAD software is specialized for civil engineering professions and has its own modeling concepts [6]. The data exchange between CAD software is so difficult, due to the heterogeneity of the modeling field. Most of these software solutions are based on proprietary solutions with their specific technical model [7], and model the building with 2D geometry. In this formalism, no semantic information specific to the building objects is modeled. To bridge this gap, the International Alliance of Interoperability has proposed a standard called IFC that specifies object representations for construction projects. Industry foundation classes[3] (IFC) include object specifications, or classes, and provide a useful structure for data-sharing among applications. A door IFC, for example, isn't just a simple collection of lines and geometric primitives recognized as a door; it also has a door's attributes (material specifications, prices, etc.). The adoption of this standard by all the leaders of CAD software allows a better interoperability in the exchanges of information between the various civil engineering professions.

The IFC product model is a universal model for the description of buildings over their complete lifecycle. It has been one of the strongest aims of research and development since the early days of Computer Aided Design in the building industry [8]. In the IFC, we found a "product model" that uses the STEP[4] norm. IAI had adopted many STEP industrial standards, but their building sector adjustment raises some data exchange problems:

- The trace of actor actions: IFC model show tangible blanks about intervention traces and the actor role definitions in the development process of a digital mock-up. Until today, we cannot indicate whether an object has been proposed or validated by an actor (IFC 2.X release) [9].

- The project evolution cycle in digital mock-up: During the design of the different objects making up the project, the IFC model doesn't permit us to assign them the progression levels defining the project evolution. We cannot know if an object is under design, under modification or already validated.

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[2] The digital mock-up is a graphic computer representation, in 3 dimensions, of project works and spaces evolving throughout a life cycle. This representation is partial and reflects a given point of view of an actor. (Ex: the digital mock-up of a climatic engineer, of a structure engineer, etc.)

[3] Industry Foundation Classes are currently the more successful to constitute the shared digital mock-up realization in the building domain. The IFC represent a standard of exchange and sharing of data [10].

[4] Standard for The Exchange of Product data model: are international computer exhaustive descriptions of physical and functional features of any industrial product type during its life cycle.

- Semantic meaning used to design works: In the latter IFC update, we cannot attach to every object its manufacture constraints, its rules for setting up, etc. (Among the set of model attributes, there is no specification about regulation rules, structural characteristics, plastic qualities, etc.)

Thus, IFC model shows lacks relative to the cooperative dimension. This model must takes in account the flexibility of current practices and operating mode of project building: so the structure interest of the all exchanged semantic meaning relative to project works.

4. A Cooperative System Developed According to the Model of the Virtual Cooperative Project

In a design cooperation process, the fact that building actors get reliable data concerning project states, helps them to determine what the actions to be carried out are. When concentrating on the data exchanged during the project design, the works are the main focal point. In the same way, every project work holds some relation with its 'environment': with the actors who designs it, the documents that represent it and the activities that create it. Our objective is to provide actors with a real vision of the design process evolution thanks to a digital project (Figure1).

The digital project constitutes the set of data defining works constituting a building. It is an expanded data representation of the different updates of digital mock-ups during the building's life cycle. This project is created and shared by all building actors (according to right to access) on an Internet platform. Every actor's action on documents and works is traced and linked back to the actor. In a digital project, exchanges are managed and facilitated thank to the use of interoperable standard data. The digital project constitutes a virtual cooperation environment for structuring cooperation and communication activities.

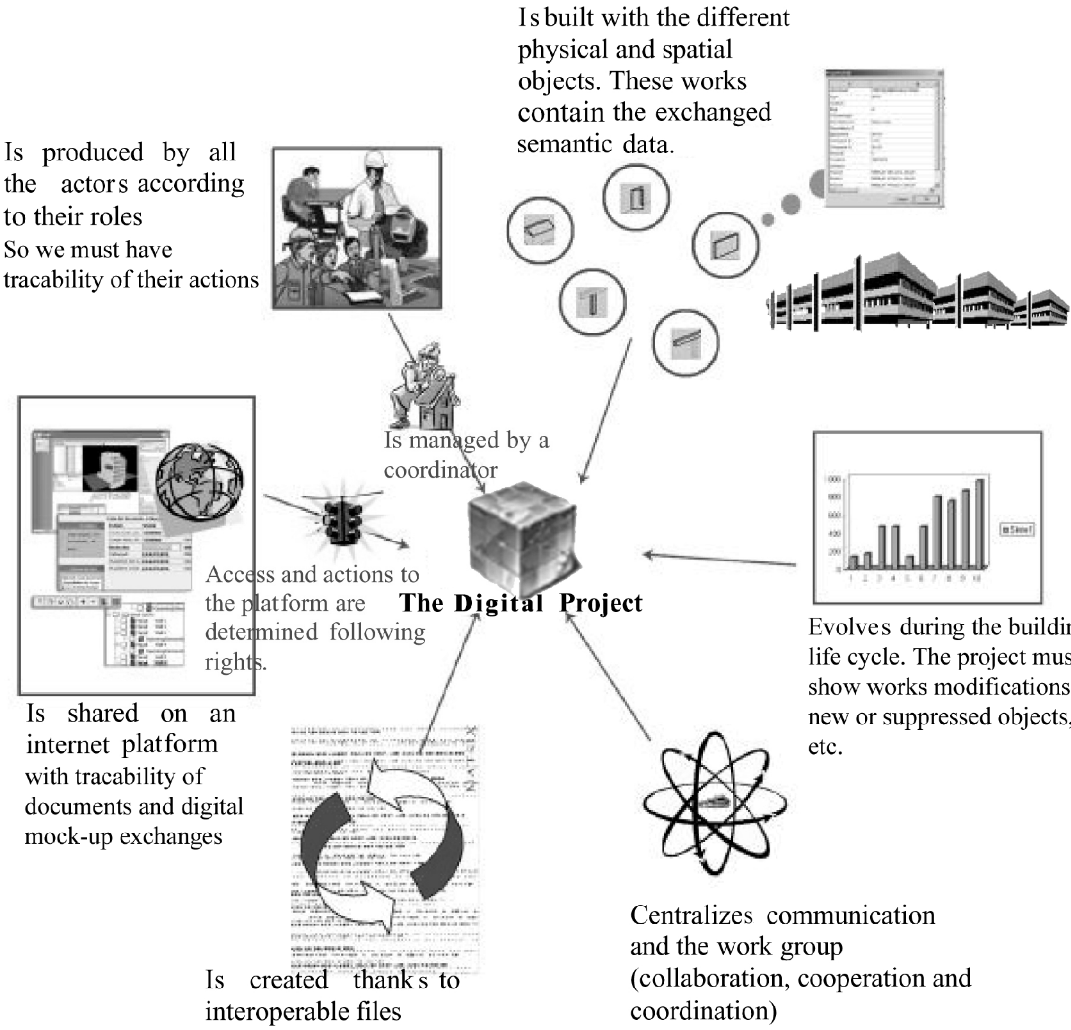

Figure 1: The different dimensions of a Digital Project

4.1 The Meta-model of Cooperation and the Work Model

We propose a cooperation meta-model[5] that allows the taking into account of the existing relations between the elements of a project (actors, activities, documents and objects). The instantiation of the objects allows the definition of the VCP. The Virtual Cooperative Project (VCP) is a project that we have initiated in the co-designing domain, having as a target the definition, the design and the realization of a model able to assist cooperative design in architecture using works (instantiation of objects).

5 This meta-model is described in MOF 'Meta Object Facility' [11], and used to distinguish concepts, which are common to every design project practice.

A work represents a physical object making up the basic brick of a digital mock-up. This object is characterized by its geometrical and topologic data but also by its semantic meanings. Every work belongs to a class, possesses attributes, relations and is set according relative constraints. A work is the result of coordination activities given during the project and throughout the design cycle until the realization. The works have different design phases and indicate the modifications that they have incurred as being associated with the actors who use and modify them. In the Virtual Cooperative Project, the model of work is structured on 'simple work' (indivisible building work) and 'composed work' (composed of simple works)

The work's semantic meaning represents all data excluding geometrical and topologic data, and is used to define work all along its life cycle. So, in the objective of structuring an aid to the works' design, trying to group maximum data throughout their creation, we have set up a classification table of semantic meaning used to design a work (physical attributes, regulation constraints, structural properties, financial aspect, etc.) However, we distinguish five subtype classes of the 'simple work' following a professional logic taking account of the notion of design evolution during building life cycle: we design structure works first, then those of partition, of equipment, of cladding and finally accessory works. Finally, works maintain four types of relations:

- The relationship between activities and works is distributed in time and shows the works' evolution during the building's life cycle. It is a dynamic relationship. For example: a project generates a digital mock-up; a digital mock-up evolves in a phase; tasks and requests concern works, etc.

- The relationship between actors and works is referential and associative. It indicates actor's interventions on works. It is a dynamic relationship and allows us to distinguish each actor's design work and reflect point of view. For example: an architect creates, modifies, deletes, or validates a work, etc. The study of the relationship between actors and works allows us to identify the relevant semantic meaning related to building works, for each actors' profession. So we have used the classification of works' semantic meaning and the several actors' professions, to set up a table identifying semantic types that interest mainly each actor[6]. This table enables us to develop in Bat'Map a personalized digital mock-up visualization for the different actors.

- The relationship between documents and works is relative to the data specifications. It is a static relationship. For example: a document describes a category of works, a work makes reference to some documents, etc.

- The relationship between works is relative to their design. We distinguish those linked to their development and those linked to their space organization, as a dynamic relationship. We distinguish too those linked to the nature of the relationship between physical parts, as a static relationship. For example: a wall is set on a floor, a beam holds a column, a window is situated in a wall, a digital mock-up evolves in another update, a wall is subdivided in to several walls, etc.

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[6] This table is established thanks a statistical survey applied to a several number of actors in four French building analyzed projects.

4.2 The implementation of Bat'Map

To manage a project 'type VCP', which generates a great quantity of information; we have used an interactive navigation interface to develop Bat'Map. This graphic interface constitutes a tool for the cooperative management of a digital project. Bat'Map aims at total structure of the project context using nodes and links. Different types of icons represent the fundamental concepts of a Virtual Cooperative Project (Figure2).

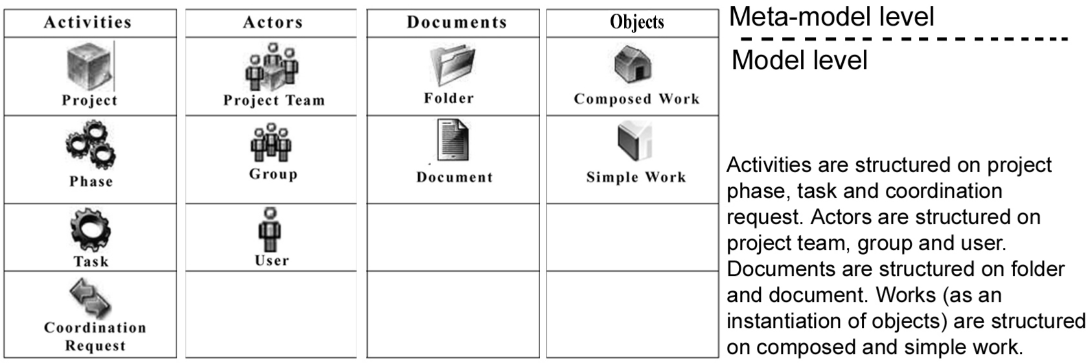

Figure 2: Icons representing concepts of cooperative activities in Bat'Map

On the other hand, Bat'Map is a computer-based system that supports actors engaged in a goal and provides an interface to a shared environment. Bat'Map allows users to initiate a cooperative project environment by identification of actors, activities and documents. When the first update of the digital mock-up is created ('.ifc' type file), a coordinator proceeds to its download from a Bat'Group[7] web platform (Figure 3). The system interprets (thanks to a parser[8]) IFC's data relative to the works; visualizes digital mock-up using a "composed work" node and the works composing it using a "simple work" node. When deposing this first version of the digital mock-up (for example by the architect), the creator will have an automatic link with all works making this digital mock-up.

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7 Bat'Group is a groupware developed in our laboratory CRAI-France. Bat'Group as Bat'Map gives to each actor an adapted vision of the project context, concepts of actors, activities and documents [12].

8 We have developed a parser, which converts data relative to works contained in the IFC file (written in Express) to compatible data with Bat'Map interface (written in Java)

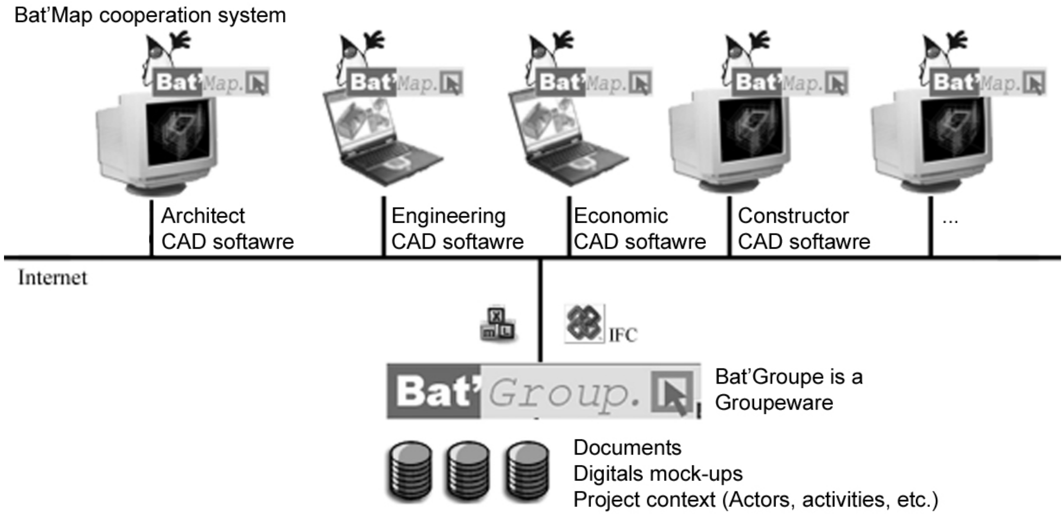

Figure 3: The Bat'Map context use.

When updating digital mock-up, the works evolve. So to identify the new modifications, we adopt 8 states relative to the works. Every work evolves and has different states. A node state represents one work evolution context and is represented by different icons. We have used colors to distinguish cooperation states: inactive object, active object, an object submitting a problem and an approved object. Then, we have used different icon forms to distinguish development states: a suppressed work, a new work, a modified work and a work without change.

Every digital mock-up update, the system proceeds automatically with identifying changes to works, thanks to a comparison between the ".ifc" data. Then, the system proceeds with linking works to the actor (author of the new update) as the one responsible for the suppressed, modified and new works. Works without change are linked to the last update designer, etc. These links between actors and works allow action tracability during the project design.

To facilitate navigation in Bat'Map, we have developed filters and functions allowing an adapted navigation following user needs (to show only works nodes, only actor's nodes, etc.) On the other hand, we have integrated an 'IFC 2.X Release' viewer to allow designers to visualize works. A 3D visualization lets participants move around and in the building. That allows designers to obtain information about the objects that comprised it. Likewise, users can specify in Bat'Map links to other software, in the objective of visualizing text documents, pictures, maps, etc. Finally, we have adapted and developed in Bat'Map works representation and semantic table visualization for each actor's profession.

We conduct two experiments to test the Bat'Map capacity to assist cooperation design in a building project. The script adopted for the experiments describes the design of two buildings (a wooden salt store[9] and a building extension in France). Actors coordinate themselves in a distributed asynchronous mode. The script steps cover: the building evolution throughout analyzed phases, the cooperation activities solving design problems, the digital mock-up updates, the validation of phases, etc (figure 4).

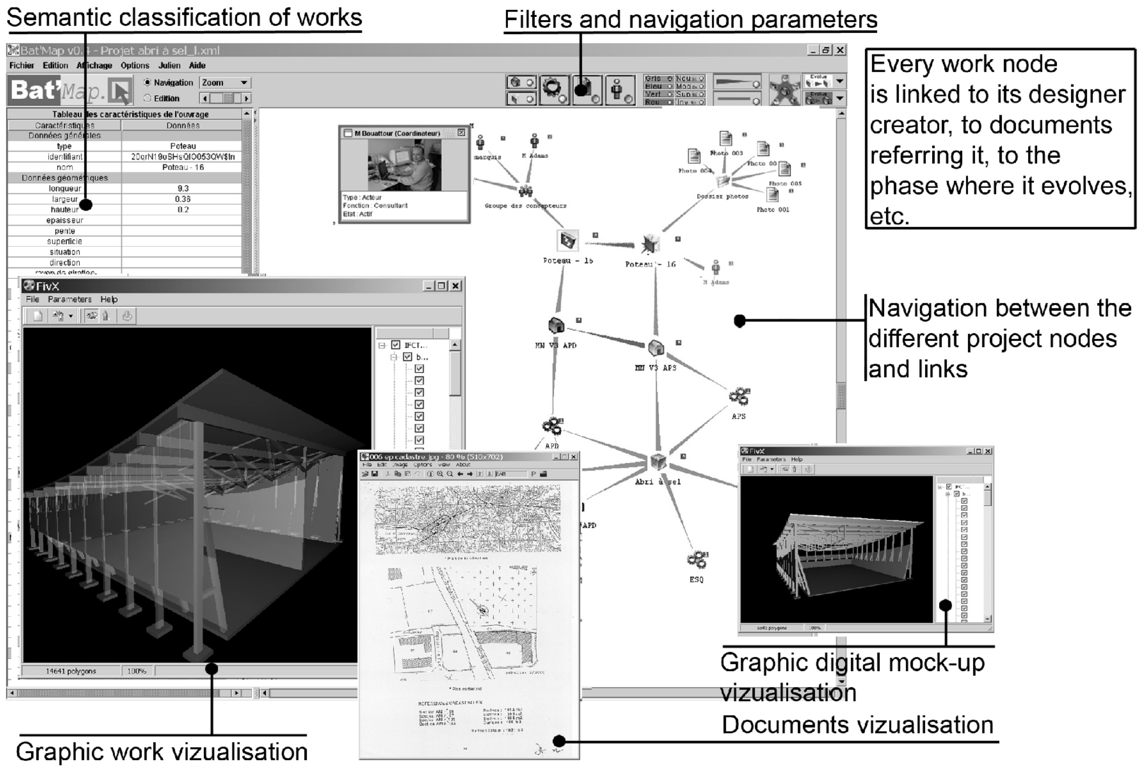

Figure 4: Visualization of the project context of the salt store with Bat'Map.

As a result of experimentations, we notice firstly that the representation of cooperation design context of a building permits a global view of the project: actors, phases, tasks, documents, works and relations between these concepts. Secondly, comparison of several digital mock-up updates during all the phases of the project allows designers to save time when they have to identify changes between updates. Bat'Map allows users to have a clearer view of the building life cycle, and to trace all actors' actions on works and documents. This constitutes a great assistance to the project management. Thirdly, semantic meaning management of works represents a design aid. The fact that designers use all the documents and data relative to a given work, allows for good objectivity in their choices, and enables them to take into account a maximum constraint. Finally, like filter functions, the visualization adapted to actors' professions allows users to have a clearer personalized vision of digital mock-ups and work semantic meaning (figure 5).

[9] Salt store is a building used to protect salt against damp. It is employed for the bulk storage of salt. Salt is sprayed on roads against to protect frost.

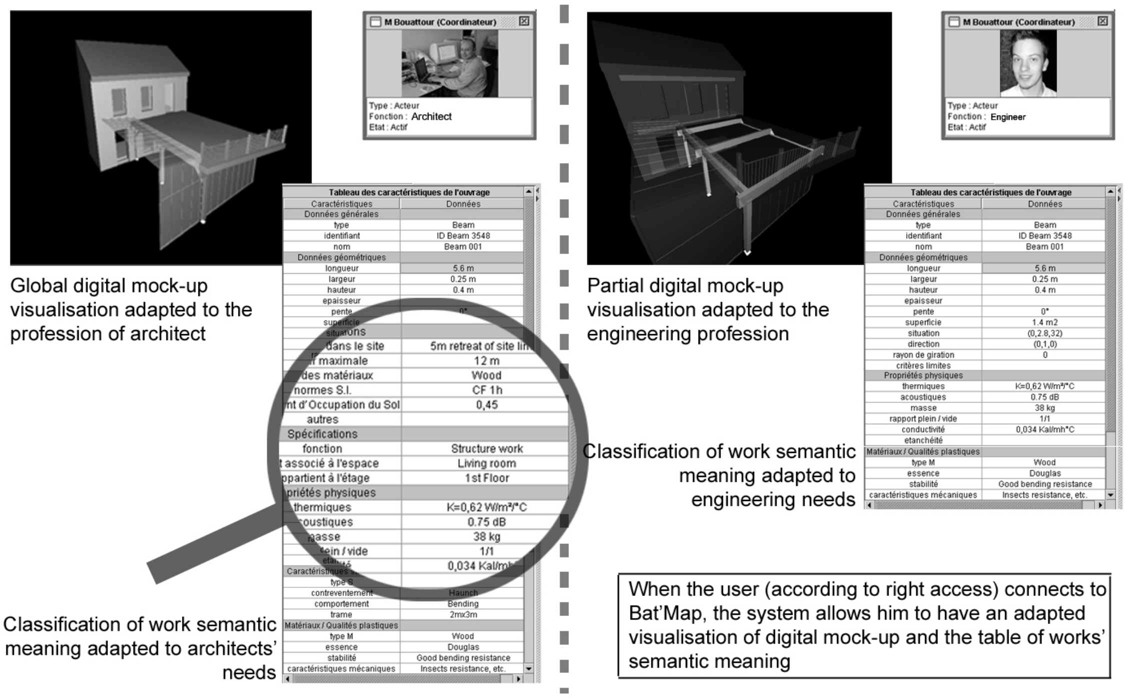

Figure 5: Adapted visualization in Bat'Map.

5. Conclusion

The European Building and Construction industry is to a great extent dominated by small and medium size enterprises. The fragmented nature of this industry necessitates cooperation assistance tools to enable users to design buildings efficiently and manage projects. This paper presents a new approach of cooperation aided-design, which proposes a new data organization of building context, by the representation of the existing relations at same time on the site, and also inside the project. The works are on the basis of Bat'Map (V4.0) development. This cooperation system provides a set of processes, functions and databases placing the IFC at the heart of the project context. The main advantage of using these objects is to provide actors with structured data related to the semantics and the 3D representation of building works.

Bat'Map is developed according to the model of the Virtual Cooperative Project in order to reinforce cooperation and group awareness. This system proposes the structuring of a cooperative project context. It proposes partial views which allow actors to navigate in a virtual environment, to be informed of the progress state of cooperation activity, to study latest digital mock-up updates and changes brought about, etc. The identification of the different states of works allows actors to have a clearer idea of every work and digital mock-up statute. The semantic meaning thus obtained permits actors to adapt their vision of the design evolution and to avoid wrong decisions. The results of the study also show that the visualization of the different digital mock-up updates allows us to have a trace of actors' actions (author, date and modification objects), saves time in the identification of changes and allows us to specify the respective responsibilities linked to modification, creation or forgotten works.

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Attaching Requirements Management to IFC Product Model

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Abstract

In this paper, preliminary results from the ongoing Finclad2 project are described. Finclad2 is an enterprise driven synthesis of two bridging projects coordinated by the Finnish Constructional Steelwork Association (FCSA). The focus in these projects is on the development of design and decision support tools and on combining requirements management with product model environments. Foundations for the current work date back to the earlier Finclad1 project (2002-2003).

The requirements management process is to ensure that we know the customer needs and that the solutions efficiently meet those requirements, thus increasing the final products value. Even though life cycle approach has become increasingly popular, an illusion of sequential process phases still dominates esp. in construction industry. In practice, due to the parallel nature of design and construction phases (and to some extent, even operation), requirements setting, updating and verification have to take place throughout the project.

Recently, the open international standards for building design information exchange have become more robust and more widely used. In particular, the International Alliance for Interoperability (IAI) is continuously developing the Industry Foundation Classes (IFC) open model based information exchange specification. The coverage of IFC product model has enlarged during past few years, and nowadays it contains project information related to, for example, actors and assets; elements and spaces; structures and zones; systems and environmental impacts; schedules and costing; equipment and work plans; associated documents and classifications. Focus has also started moving towards service life and requirements management. This shift is expected to enable and motivate developers and practitioners moving towards consumer driven process.

In the present IFC version (IFC 2x2) expressing product requirements is supported in a modest way. However, it is evident that product model technology has developed to a level where extensive requirements management could be enabled. This progression leads to increased interoperability between customer needs and design solutions, by defining explicit “requirement”-objects and their relationships to design objects. The authors highlight though that there are still many open questions needing answers.

The results from Finclad2 project define classification for requirements managed in product model environment, as well as guidelines for their attachment to IFC product model design object. It is apparent that in this approach requirements are set in various levels, such as component, system, space, zone or building (or even project) levels. Traditionally, requirements have been captured on a very generic level (project or building), whereas in the Finclad2 case the target is on exterior wall level, which introduces challenges in linking of space requirements to wall properties and production planning; also, design application developers have challenges in including requirements management in their software. In result, a test environment for requirements management is created and set of requirements is exported in an IFC file.

Keywords: Requirements management, classification, IFC, interoperability

1. Introduction

Finclad2 project was launched at the beginning of 2004. It is an enterprise driven synthesis combining two bridging projects, led by Finnish Constructional Steelwork Association (FCSA) and Tekla Corporation, respectively. Results introduced in this paper are a part of a research activity carried out by Technical Research Centre of Finland (VTT) and belonging to the FCSA part. Foundation for the current work was laid in Finclad1 (2002-2003) project, which among other tasks, described common cladding wall structure types and the use of IFC specification for exterior walls, as well as listed the basic requirements to be considered [1].

The goal of Finclad2 is to implement previously described wall structure types as adaptive objects to software. Firstly, the purpose is to take advantage of the previous development results in practice. Secondly, the project emphasizes production chains by offering means to exploit product models more efficiently, especially for capturing and managing requirements during a project.

This paper discusses the issues of requirements management in general, and possibilities of model based design and requirements management using IFC product model in particular. Main goal is to find solutions on cladding wall structures and how their properties can be managed and how the process can be supported by ICT tools and model based information exchange/sharing, through the life cycle of buildings.

The final outcome of the project will be presented at the end of year 2005. Finclad2 is financed by Tekes, the National Technology Agency of Finland, and the enterprises participating.

2. Requirements Management

2.1 Requirements Management in Building Process

Requirements management is targeted to increasing final products value; it is a process assuring that the building performs as expected or better in its intended use. Overall goal is ensuring customer satisfaction. It is described in numerous sources as a set of procedures helping to understanding, modelling and analysing the needs of users and other participants' processes, and tasks in a realisation process towards a common vision [2, 3, and 4]. Life cycle view has become stronger and the ideology is supported by various practices, such as value management and commissioning, that are used for assuring convergence of building performance towards user needs set in the beginning.

In construction industry a false illusion of sequential process phases still dominates. Clear indication that is also understood in practice is parallel nature of design and construction phases. Kiviniemi represents difference of sequential and parallel process view clearly (see Figure 1) [5]. In this context the requirements management practices need improvements; the procedure evolves during project execution and at the moment the practice doesn't support rapid changes taking place in projects, especially during design phase.

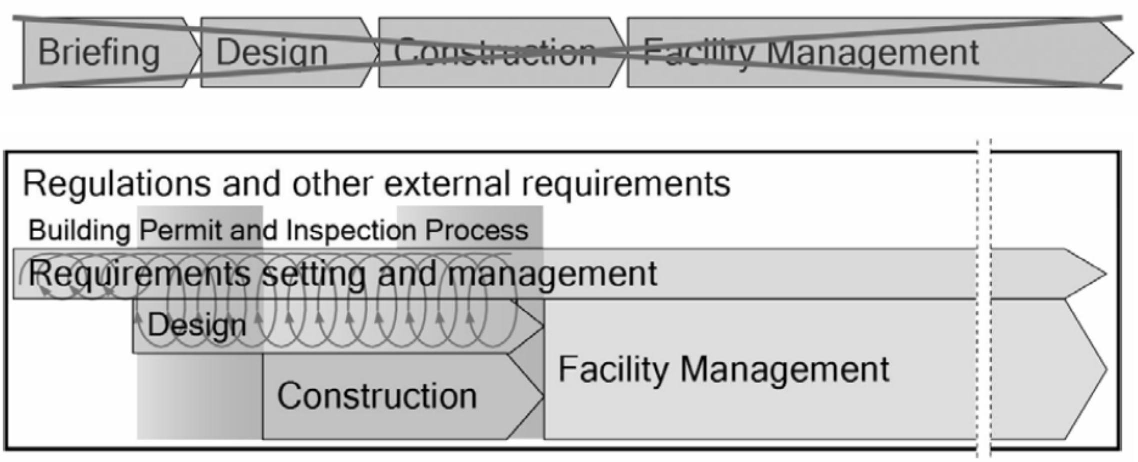

Figure 1: False illustration of sequential process and more realistic parallel process view (Kiviniemi 2005).

General requirements management process phases are:

1. Requirements setting,
2. Requirements updating
3. Verification of the requirement realisation in practice.

Buildings are unique solutions, each having individual requirements. Careless requirements setting increases risk of ending up in significant problems later. If the purpose of requirements management is not understood correctly, it might be seen as a mandatory task producing nothing, which is not the case. Actually, great potential lies in requirements management: it should be seen as an intermediate tool between user and design team, helping to reach satisfactory end result. The most critical step should be capturing user requirements instead of getting straight into technical solutions. Users look for a building that is customisable to their operations, not vice versa. Far too often requirements are lost or misinterpreted during design and construction phases. Figure 2 describes the possibilities of loosing or adding value. Practitioners should be able to offer new and innovative solutions along the building process; at the moment tools enabling this are still lacking.

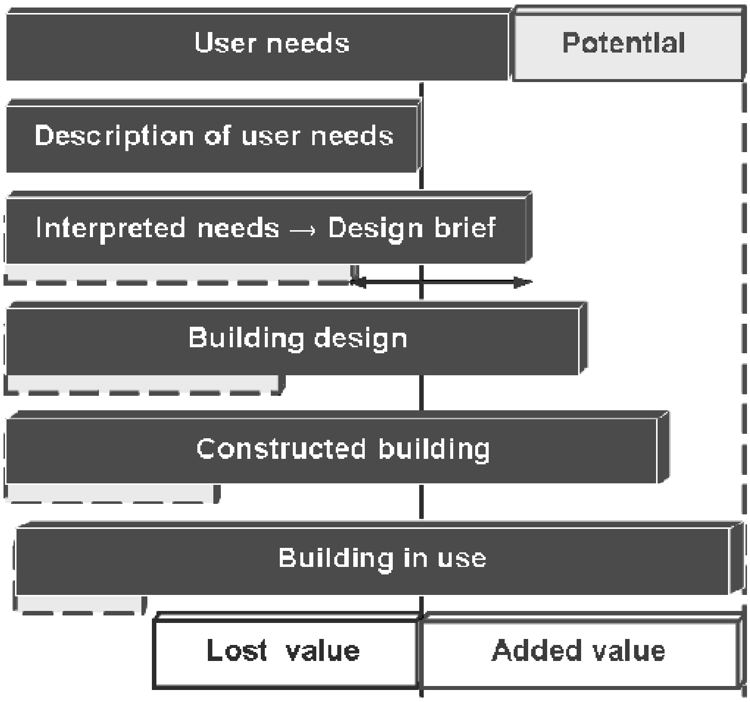

Figure 2: Potential of Requirements Management [6].

There are many kinds of problems existing; such as [7]:

- Communication problems (between process phases and in connection to users),
- Lacking of a systematic and standardised data transfer,
- Binding strength of requirements and design solutions,
- Inadequate change management practices,
- Insufficient verification practices

Change from prescriptive approach to performance based approach is taking place. Prescriptive approach describes first building parts and attributes and comes backwards to requirements (technical solution oriented). Performance approach specifies requirements for building parts and then various solutions meeting these conditions are provided by designers [8].

2.2 Requirements Management in Exterior Cladding Walls

Investigation of current practises in requirements management was carried out. Since the current development efforts are directed towards model based design, the ProIT process model [10] was analysed and the essential feedback gathered from participants was projected on it. Figure 3 describes main information flows in current process and it is intended to visually express certain bottlenecks and weak spots. Main processes are: 1) Architectural design 2) Structural design 3) Manufacturing 4) Installation 5) Use and maintenance.

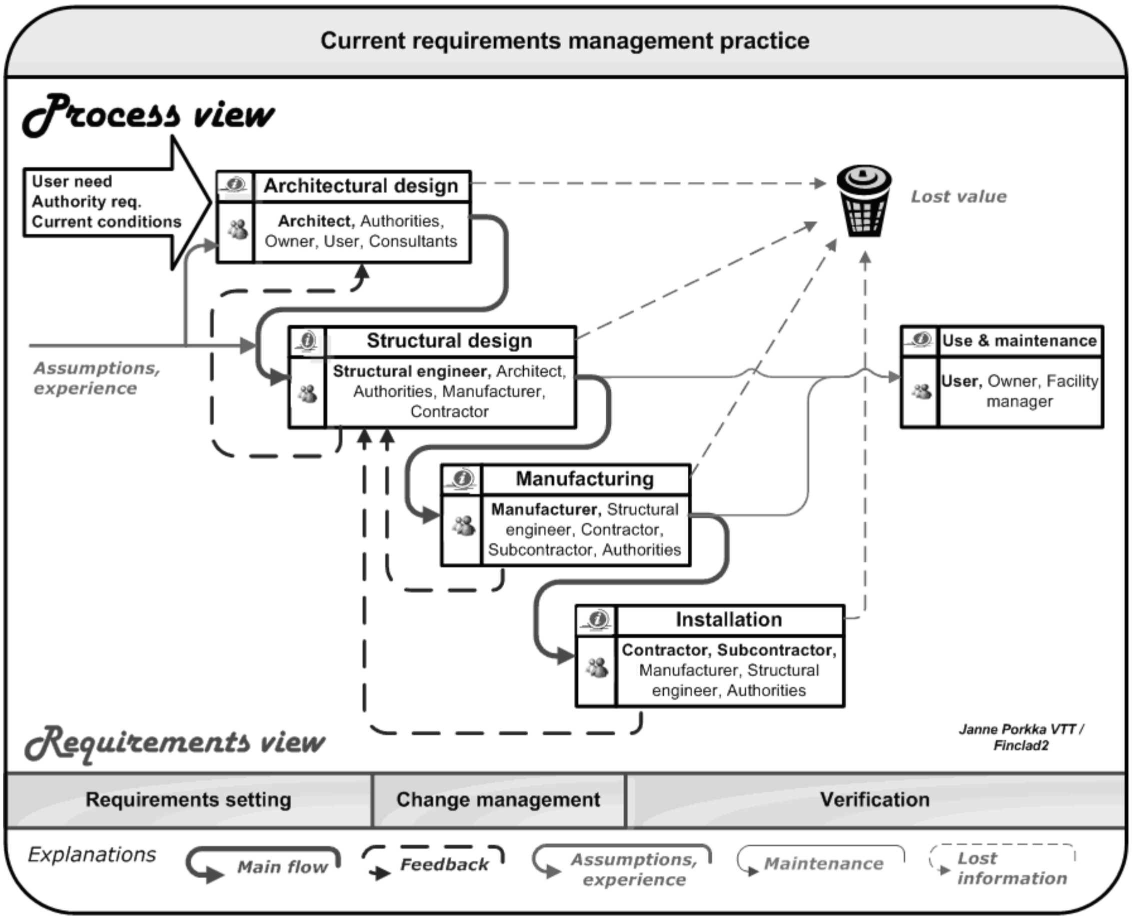

Figure 3: Current requirements management practice in Finland according to cladding walls.

Nature of requirements setting is consistent; process goes from general level towards details and specifications. Practices of requirements management by individual participants vary greatly. Even with the most organised practitioners improvement needs exist. When individual participants express requirements differently– the overall process with interfaces to many participants gets even more problematic. Main bottleneck in current requirements management practice is lack of standardisation and large part of requirements never get documented during architectural design. This knowledge reserve is covered by tacit knowledge - or leads to lost value.

Architectural design captures main requirements set by owner, users, authorities (standards, specifications) and current conditions (location, surroundings). Finnish construction practise is rather well standardised and therefore large share of requirements come directly or implicitly from standards such as National Building Code of Finland [9]. Only a limited group of owners are willing to put more effort in setting requirements; additionally, user requirements are described rather in every-day-language than technical terms. In detailed cladding solutions architects rely on experts and consultants. Requirements are expressed in drawings and textual documents, such as design brief. Bottleneck in current practice is data sharing between architectural and structural design. Large part of the requirements remains only in architects mind and do not reach the structural design and later phases. From experts point of view information is partly considered too obvious and standardised way of sharing requirements is missing.

Structural design provides detailed requirements for product manufacturing, installation and also to use and maintenance phase. As described earlier, the starting point is the weak spot. Shortage of requirements in kick-off increases iteration work and leads to assumptions; this also increases the risk of ignoring essential requirements. Overall, the nature of requirements management in structural design evolves from requirements setting to change management and finally to verification. Standard on how requirements should be described is missing, and current practise vary by case.

Manufacturing and **installation** have very specific requirements. Manufacturing produces also requirements back to structural design, and further to installation. It requires active cooperation with structural engineer, especially when making iterations on change management. Phase includes also detail and product reviews. In installation, the end result is verified against the set requirements. Installation is considered as a task producing feedback to structural design on work sequences; the working order must be considered already in structural design, and therefore details of installation must be considered at early stage.

Overall, the weak spots detected in current practice are:

- user requirements capturing,
- communication between architectural and structural design,
- the quality of set requirements, standardisation lacks,
- specific manufacturing and installation requirements and maintenance manual,
- change management and verification of set requirements and end result,
- knowledge reserve among stakeholders – tacit knowledge (or lost value).

A lot of headache is caused by the gaps between participants: fragmental data exchange leads to rework and confusion. Other development needs are seen in the learning process; past mistakes should lead to immediate development and to process changes if needed. We should consider methodical development possibilities, such as commissioning and performance based approach. Both highlight the continuous requirements management as a development enabler.

3. Model Based Requirements Management

Recently, the open international standards for building design information exchange have become more robust and widely used, in particular the product model specification for AEC/FM, the Industry Foundation Classes (IFC) [13]. The IFC is developed and published by the International Alliance for Interoperability (IAI), established in 1995 and currently operating as a not-for-profit company in the UK, with 10 active chapters globally (about 500 member companies and other organizations in these chapters). The mission of the IAI is to enable ICT interoperability, based on open specifications, in the AEC/FM industry processes throughout the building lifecycle. The IFC is a specification for data exchange and information sharing between computer applications used by project participants in design and construction as well as operation and maintenance phases.

The first set of IFC was published in 1998 as Release 1.5; current version IFC2x2, released in 2003 utilizes extensibility mechanism by which new concepts can be added to support areas not previously existing in the IFC model (e.g. structural engineering and steel construction were introduced in 2x2); a new release (IFC2x3), extending the IFC model in the same manner as IFC2x2 did, is expected in spring/summer 2005 (with some improvement in requirements management).

The IFC specification aims to cover information in all aspects of buildings and processes encountered in their production and operation; the IFC product model may contain information related to e.g. actors, assets, elements, spaces, structures, zones, systems, environmental impacts, schedules, costing, equipment, work plans, associated documents and classifications. At the moment the focus of development is moving towards life cycle management, meaning improvements on requirements management support also. In practise this would mean that in addition to ‘conventional’ design objects, such as *IfcBuilding*, *IfcSpace*, *IfcWall* etc., also objects representing requirements as *IfcConstraint* could be defined independently and associated to those design objects as (and when) appropriate. The requirement objects would also have capability of being classified (an essential feature, as discussed later) and having owner and history, as well as relationships to other requirements.

Many research and development efforts are aiming to take advantage of product model technology. Finnish ProIT project has targeted to improvements in practice [10]. It declares information management of whole life cycle where data management takes place in process by product models. Product models in different phases suggested in ProIT are:

- requirement model
- design model

- planning model
- as-built model
- maintenance model

It’s evident that model based approach has more strengths than weaknesses - though application interfaces need to be developed to support the exchange cases. For requirements management this means that early phases of projects are seamlessly connected to later ones. Industry is provided with means to set more detailed requirements separately for certain types of cladding walls. Overall target is to provide way to transfer data in same format through the architectural and structural design further to manufacturing and installation as well as use and maintenance - with requirements and verification data. In this context individual requirements are better managed and verification of received quality improved.

3.1 Combining Requirements from Authorities and Users

In this context a user means relevant project stakeholders, like occupants, owners and financiers of the building [11]. Requirements management in the building process deals with unique solution and diversity of participants. There are certain mandatory requirements steering the process, such as laws, standards and directives set by authorities. Amongst requirements there are also recommendations and rules that can be waived. Mandatory requirements contain basic conditions such as safety, conformity, performance, functionality and usability. Another group of requirements is optional requirements, such as user requirements.

During the requirements management process the set of user requirements is adapted to authority requirements. The compliance of design with the requirements should be verified constantly during the project. Participants should be involved in project from the very beginning; other enabler is functional communication. Purpose of requirements management is establishing a complete, consistent and unambiguous requirements specification [2]. There are certain characteristics portraying good requirements, such as being complete, unambiguous, consistent, feasible, solution neutral, traceable, necessary, used for right purpose, concise, correct and verifiable [10].

3.2 Considering Stakeholders

Nature of construction projects includes large variety of participants in decision making. It is very common that opinions vary greatly. In these cases judging methods and decision support tools are needed. It’s suggested that the ranking of stakeholders’ opinions is based on three attributes - power, interest and proximity [3]. This means that participants with high ratings are very likely to have their requirements accepted. Using the same analogy, stakeholders with low ratings don’t have as strong influence to the performance of final product. Various stakeholders also see the requirement management effort differently – some like it while others see it as a disturbance to their routine work [3]. In cladding walls the requirements are mostly transferred simultaneously with drawings. It's important to name the responsible people for requirements management. Also judging methods for prioritising requirements should be defined. At the moments standards in data transfer in requirements management are lacking, therefore actions of change management should be clarified.

3.3 Temporal Progress of Requirements Management

Phases of requirements management are described in Figure 4. In the beginning the emphasis is on requirements setting. After setting of requirements the overall process starts finding technical solutions and emphasis evolves towards change management and verification. The possibility to influence the end result is biggest at the project start. This is also the period when the practitioners have the best possibilities to effect the costs. Owners may allow certain investment cost for cladding walls per square meter; yet the solution must fill certain other requirements such as energy efficiency in buildings life cycle. Therefore, the most of the requirements management effort is committed to projects two first phases, architectural and structural design. Effort should diminish after these phases and change nature to change management and verification. The cycle defined in Figure 4 is done multiple times while adjusting requirements management; nature of setting requirements is consistent.

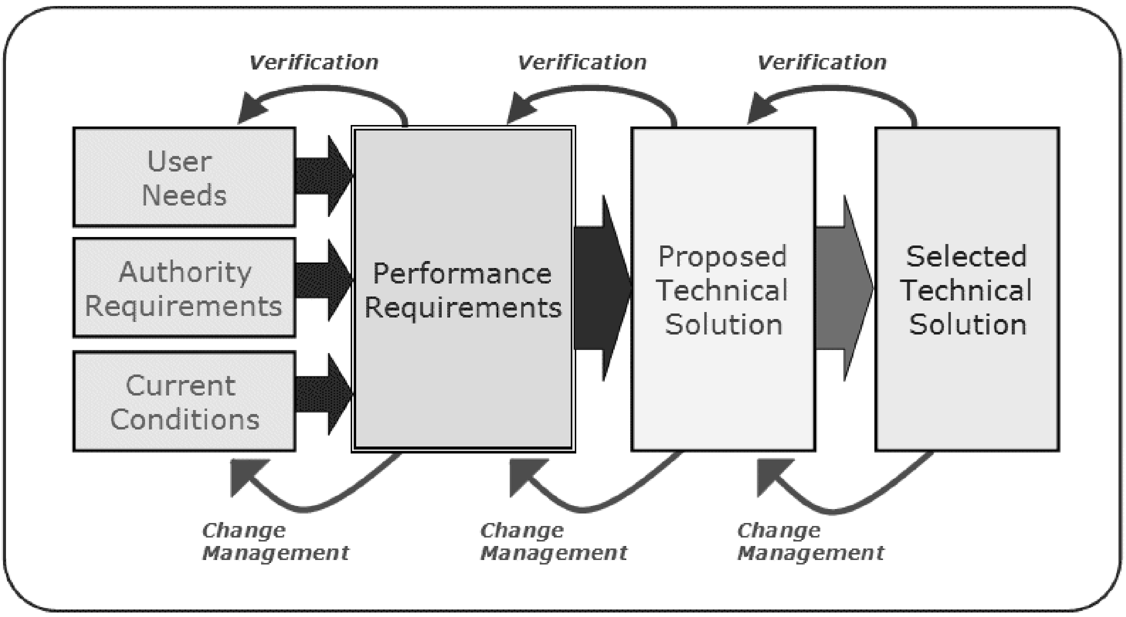

Figure 4: Requirements management process in performance based building [6].

3.4 Detecting Hierarchy of Requirements

Hierarchy of requirements means in this context the requirements classification. Classification is the way how the large information content can be managed. During Finclad2 project the requirement classification for exterior cladding walls, VTT ProP® Finclad2, was specialised form the general VTT ProP® classification. Classification contains structural description of requirements, expressed by categories such as safety and adaptability (see Figure 5) and individual requirements placed under these categories. One of the categories, adaptability is opened in Figure 6. Classification is important for meaningful data transfer between applications. It is also a guideline for producing complete and consistent information for later project phases; classification expresses the data in a form understood by all participants.

VTT ProP® Finclad2 CLASSIFICATION	
A CONFORMITY	**B PERFORMANCE**
A1 LOCATION	B1 INDOOR CONDITIONS
A1.1 Site characteristics	B1.1 Indoor climate
A1.2 Transportation	B1.2 Acoustics
A1.3 Impact on surroundings	B1.3 Illumination
A2 SPATIAL SYSTEMS	B1.4 Vibration conditions
A3 SERVICES	B2 SERVICE LIFE AND DETERIORATION RISK
C COST AND ENVIRONMENTAL PROPERTIES	B3 ADAPTABILITY
C1 LIFE CYCLE COSTS	B4 SAFETY
C1.1 Investment costs	B4.1 Structural safety
C1.2 Operation costs	B4.2 Fire safety
C1.3 Maintenance costs	B4.3 Safety in use
C1.4 Demolition and disposal costs	B4.4 Intrusion safety
C2 ENVIRONMENTAL PRESSURE	B4.5 Natural Catastrophes
C2.1 Biodiversity	B5 COMFORT
C2.2 Resources	B6 ACCESSIBILITY
C2.2.1 Energy consumption	B7 USABILITY
C2.2.1.1 Non-renewable energy consumption	**D PROCESS**
C2.2.1.2 Renewable energy consumption	D1 GENERAL INFORMATION
C2.2.1.3 Process energy consumption	D1.1 Collaboration
C2.2.1.3.1 Process electric energy	D1.2 Participants
C2.2.1.3.2 Process fossil energy	D1.3 Materials
C2.2.1.3.3 Process bio-energy	D2 BRIEFING
C2.2.1.4 Transportation energy consumption	D3 DESIGN AND CONSTRUCTION
C2.2.1.5 Feed stock energy	D3.1 Design
C2.2.1.5.1 Feed stock fossil energy	D3.2 Construction
C2.2.1.5.2 Feed stock bio-energy	D3.3 Tolerances and dimensions
C2.2.2 Raw materials	D3.4 Quality assurance
C2.2.2.1 Non-renewable raw materials	D4 MAINTENANCE AND REPAIRING
C2.2.2.2 Renewable raw materials	D4.1 Maintenance
C2.2.2.3 Hidden raw material flows	D4.2 Repairing
C2.3 Emissions	D4.3 Replacement
C2.3.1 Emissions to air	D5 DEMOLITION AND DISPOSAL
C2.3.2 Emissions to water	D5.1 Demolition
C2.3.3 Process waste	D5.2 Disposal
C2.4 Specifications	D4.3 Recycling
	D4.3 Reuse

Figure 5: VTT ProP® Finclad2 classification.

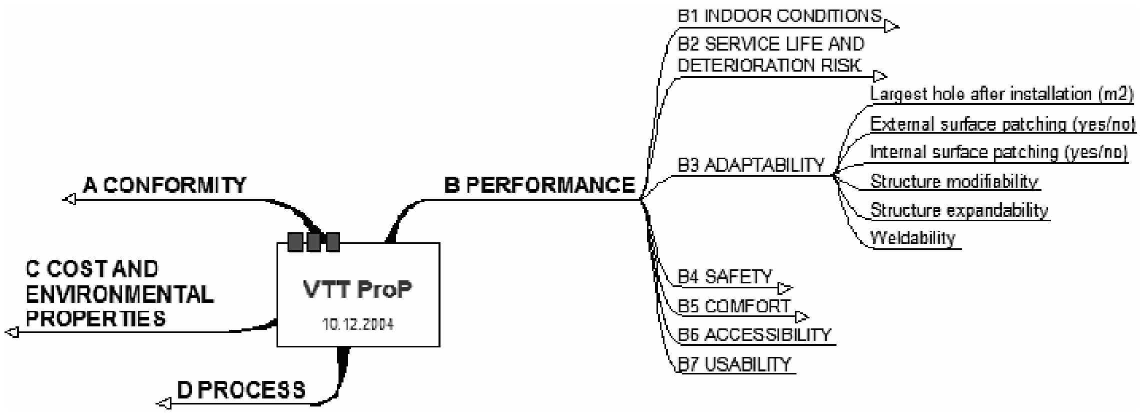

Figure 6: VTT ProP® Finclad2 classification, adaptability opened.

The nature in construction projects also is that level of detail changes during projects; from scheme in the beginning to details for the manufacturing. Biggest advantages of using classification are gained when early architectural design starts using classification and produces data in a form updatable in later phases. This procedure also helps to verify fulfilment of user requirements. Hierarchy of requirements is different from building model hierarchy or configuration which can be set up in various ways, e.g. as: building level, zone, space, system, element, component and property.

3.5 User Interface to Software

Linking model based technology and requirements management offers new possibilities for software development. Imagine an architect or structural designer viewing requirements parallel to actual design and verifying that everything is in order. Development of requirements management features should also be remarked in the next generation quality assurance systems. But before model based technology can be utilised in this respect, the appropriate data structures must be built into design systems and interfaces must be developed. At the moment this is still lacking; an illustration by a user interface mock up was presented by Kiviniemi as a link from CAD software to requirements setting [5].

4. Conclusions

Building process has been analysed with respect to present requirements management in exterior cladding wall models. Appropriate techniques and reference models for this purpose have been selected. Overall, the process deals with many problematic issues and at the moment combining requirements management with model based information technology is rather unexplored field, but product model technology is very promising for future development in requirements management procedures.

In general, it is often remarked that complicated system is the main limitation of wider exploitation. According to requirements management, a user friendly and understandable systematic structure is brought to practice by classification. For the case of cladding walls, new performance based classification, VTT ProP® Finclad2, has been introduced at the national level; the model based exchange specification is using IFC, with eventual additions as appropriate. Requirements representation in IFC model, as well as the classification is part of VTT task report (to be published).

The various participants and ICT tools used by them in activities concerning requirements are identified. At the moment the field of requirements management lacks appropriate tools, especially model based ones. Requirements management can form the basis of specific software or it can support larger content, such as guide designers as part of a modelling tool.

The target process for the future is capturing requirements, verifying satisfaction and thus increasing the quality and value of the product. A corner stone of the target process is highly semantic interoperability between various applications - enabled by product models.

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Section IV

Development and Evaluation of ICT Systems

Towards Web-based Learning System for Engineers Integrated with Problem-based Learning (PBL) Approach in Construction

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Abstract

In order to enhance the e-learning for engineers participating in construction projects, it is necessary to provide these engineers to a learning platform to study and understand how the construction operation and important events concerning about construction projects in advance before or during the construction execution. The online use of the system and project discussions help the engineers to relate better their previous academic knowledge to “real-life” problems, enhance their creativity, and increase the level of retention of the new knowledge acquired. Future enhancements and learning possibilities are discussed with the use of additional capabilities of information technology. Integrated with the application of Problem-based Learning (PBL), the e-Learning system can provide the engineers with an active role in learning and to allow the engineers to take responsibility for learning. The e-Learning system has integrated different disciplines and input from the project managers, engineers, and instructors of different disciplines. This system includes hypertext links to past experience, knowledge and stratified information including text, graphics, and videos. The e-Learning system presents a teaching platform that enables junior engineers to learn about construction phases of a construction project. Main contribution of this system are as the following; (1) Provide safety learning environment (2) Maintain and manage effectively the past knowledge and experience from past projects; (3) Reduce the cost and time of training and education; (4)Overcome the time and space

barriers of learning. Finally, the efficiency of the proposed system is demonstrated through case examples.

Keywords: E-Learning; problem-based learning; knowledge management; construction project.

1. Introduction

E-learning refers to any form of learning delivered or supported by the use of web-based technology or other electronic media. Compared with traditional classroom learning, e-learning has shown its advantages by its nature of flexibility, accessibility and convenience to learners. Given the broad deployment of network technology and increasing on-line communication in teaching and learning, there is an urgent need for a guidance on web-based instruction. From a combined perspective of constructivism and semiotics, e-learning is regarded as a process of Knowledge Management (KM). Many organizations are now engaged in knowledge management efforts in order to leverage knowledge both within their organization and externally to their shareholders and customers (Malhotra 2000, 2001). Knowledge management in the construction phase mainly deals with the process of creating value from construction operation, organization to company knowledge. Valuable knowledge can be available in different forms and media, such as in the mind of experts, in operation procedures, and in documents, databases, intranets, etc.; however, knowledge management in the construction phase of projects aims at effectively and systematically collecting and sharing the experience and knowledge of the project by web-based and intranet technologies.

Problem-based learning (PBL) is a teaching strategy that applies complex real-world problems to introduce concepts to students. PBL got its start in medical education and is now used at most medical schools (Hendley 1996). Integrated with PBL concept, the reuse of information and knowledge from past projects enhance learning quality during the construction phase of a construction project. By sharing experience and knowledge, the same and similar problems do not need to be solved over and over again. To improve the learning quality for engineers special in practice, this paper provides web-based learning system for "lifelong" learning and applies techniques integrated with PBL concept for engineers. Learning environment give engineers freedom to perform learning from different paths. In this way, engineers are put in the centre of a learning process, and construct knowledge through their own experience. Based on the construction project characteristic, the specific course - Taiwan Expressway Project is chosen to be an example for illustration. The outcome of our work is expected to be applicable for e-learning platform in construction practice.

2. Problem Statement

Construction projects are intricate, time-consuming undertakings. Usually, construction projects are typified by their complexity, diversity and by the nonstandardized nature of their production (Clough 2000). Professional competency in project management is attained by the combination of knowledge acquired during training, and skills developed through experience and the application of the acquired knowledge (Edum-Fotwe and McCaffer 2000). During the construction phase of projects, one of the improvements for construction management is to share experiences amongst engineers, which helps prevent mistakes that past projects have encountered already. Reusing experience also avoids problem-solving from scratch, i.e., already solved problems do not need to be solved over and over again. However, there are no suitable platforms to assist senior engineers or experts with sharing and collecting their know-how and experiences when general contractors execute the project. This is a major loss for general contractors who do not preserve the know-how and experiences of senior engineers and experts. When these engineers and experts finish the projects or leave the company, they usually take the domain knowledge with them and leave little or nothing for the projects or the company. In the view of knowledge management, these know-how and experiences of construction engineers and experts are the most valuable because they not only need manpower; they also require major cost and time to be accumulated.

3. Research Objectives

The main purpose for conducting this research is to develop a Construction Problem-based Learning e-Learning (ConPBL learning) system for general contractors, to provide knowledge exchange and management service in the construction phase of a project for the reuse of domain knowledge and experience in future and other related projects. Usually, it is possible for general contractor to execute similar or same projects. Therefore, problems in executing those projects can be considered to refer and learn for other similar projects (see Fig 1) Thus the capture, transfer, reuse, and maintain of the construction project knowledge are critical (Kamara et al., 2002). Knowledge management in the construction phase of a project is a knowledge-intensive organizational environment where knowledge creation has critical importance for general contractors. To be competitive, a general contractor has to make innovative use of knowledge created and accumulate through project activities, and share it across the rest of other relative projects. Engineers and experts participating in projects act as knowledge workers facilitating the collection and management of knowledge between current and past projects. In order to apply knowledge management to construction projects, the process and content of working construction knowledge need to be modified because of construction project characteristics. With the evaluation of the case study on the Taiwan highway project, the results show that the ConPBL learning system is effective in sharing the knowledge for a construction process. The case study also highlights the need for improvements to knowledge management and exchange platforms.

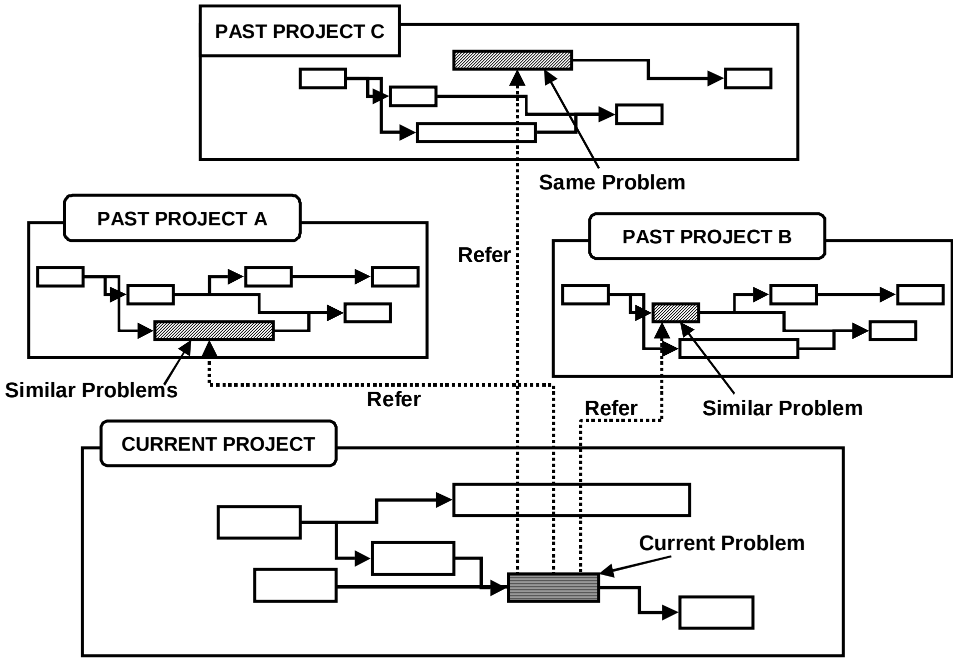

Figure 1 Problem-based experience management used in the construction phase of a project.

4. Knowledge Management in Construction

In construction projects, knowledge management is a discipline that promotes an integrated approach to the creation, capture, access, and use of a profession's domain knowledge on products, services and processes. During the construction phase of a project, most project-related problems, solution, experience, and know-how are in the heads of individual engineers and experts. Implicit knowledge usually is not documented or stored in a system database. To reuse the knowledge in other projects and also preserve it as corporation property, how to capture the implicit knowledge and make it become available as explicit knowledge is important in the execution of knowledge management in the construction phase. Experience, problem-solving, know-how, know-what, and innovation are created in the construction phase of any project. By practicing knowledge management, tacit knowledge can be reused for other projects and speed the improvement of operations in the construction phase. Undoubtedly, tacit knowledge is corporate property.

Usually, knowledge content in the construction phase of a project can be classified into two broad categories; tacit knowledge and explicit knowledge. Tacit knowledge is personal, context-specific knowledge that is difficult to formalize, record, or articulate; it is stored in the heads of people (Hart 1992). The tacit component is mainly developed through a process of trial and error encountered in practice. Tacit knowledge is personal knowledge embedded in individual experience and is shared and exchanged through direct, face-to-face contact (Tiwana 2000). Tacit knowledge can be communicated in a direct and effective way. By contrast, acquisition of explicit knowledge is indirect: it must be decoded and re-coded into one's mental models, where it is then internalized as tacit knowledge. Explicit knowledge that is formal knowledge can be codified and transmitted in a systematic and formal language; documents, database, website, etc.

It can be found in the documents of an organization: reports, articles, manuals, patents, pictures, images, video, sound, software, etc. It can also be found in organizational documents such as organizational charts, process maps, mission statements, domains of experience, etc.

Explicit knowledge is easier to collect and manage during the construction phase of a project because the information and knowledge are available in document form. With document management, information and knowledge can be preserved and managed effectively without explicit knowledge extraction. Therefore, explicit knowledge is easier than tacit knowledge in the field of knowledge management. However, the main problem in the view of tacit knowledge is how the tacit knowledge can be extracted into structured information and unstructured information effectively. After the extraction of tacit knowledge, the explicit information can be maintained and managed with the assistance of document management tools.

5. Problem-based Learning in Construction

Problem-based learning emphasizes learning by doing. It also provides a motivating context for learning. In construction projects, junior engineers are given a real-world problem similar to those they would face as professionals. They take ownership of the problem, and the problem solving process. Instructors (senior engineers), in turn, take the role of a cognitive coach. A pedagogical goal of PBL is to help junior engineers develop their own problem-solving skills, rather than tell them how to solve the problem.

The literature on problem-based learning in engineering education suggests many educational and professional benefits of this approach (Hendley 1996; Dutson et al. 1997; Johnson 1999), which support the findings of other professional literature (Albanese and Mitchell 1993; Chen et al. 1994). The benefits of PBL are examined here, focusing on five main themes—applicability, problem solving, active learning, motivation, and professional skills (Anne 2003).

In order to reduce the training time for junior engineers participating in construction projects, it is helpful to provide these engineers with a learning platform to study and understand which problems the construction process happens and related solutions concerning problems. With the application of PBL approach, the problems and solutions from past projects can be reused and learned with junior and senior engineers. The integration of PBL and knowledge management in construction is shown in Figure 2.

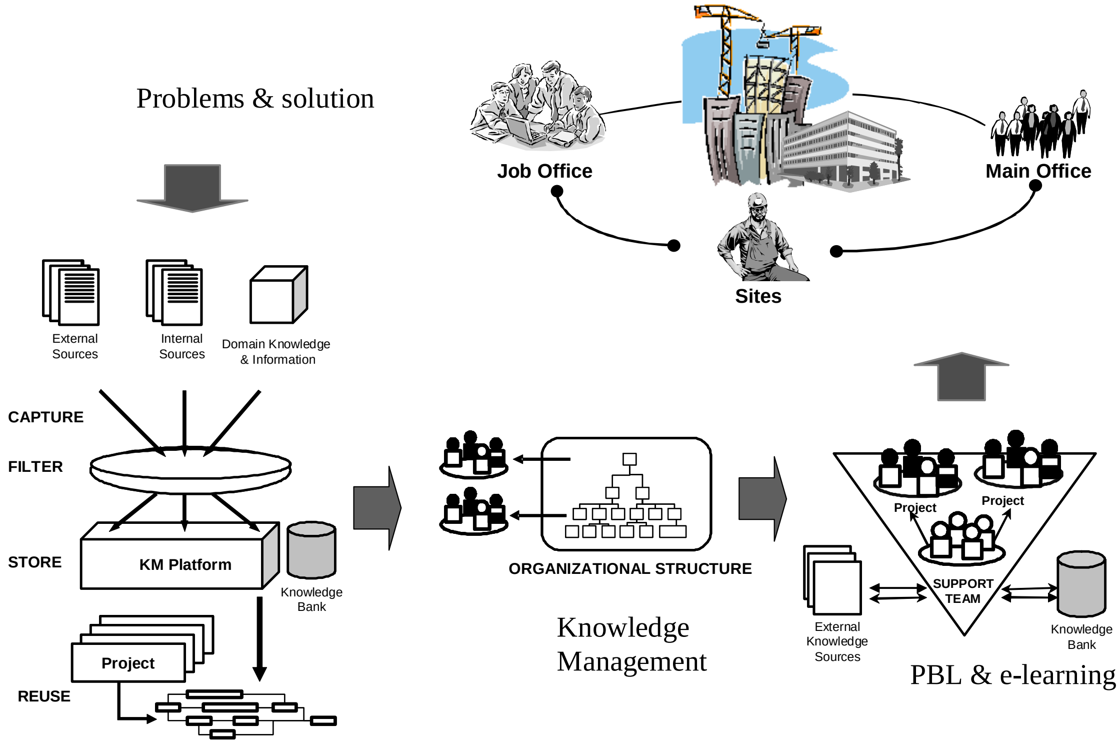

Figure 2 Construction knowledge management integrated with PBL Concept

In construction projects, the knowledge includes both tacit and explicit knowledge. In terms of explicit knowledge, project-related information or knowledge usually include specification/contract, reports, drawing, change order and data. Actually, each project does not contain one-to-one information or knowledge because some of them belong to project-oriented information. In contrast, tacit knowledge may include process records, problems-faced, problems-solved, expert suggestions, know-how, innovation, and experience notes. The relationship of current and past same or similar problems is important for users to link related information and knowledge together. Furthermore, not only the information and knowledge of the current project can be applied, but also same or similar solutions of past projects can be referred to as experiences are recorded. When experts or engineers have problems they cannot handle in the project, they may learn the solutions regard to the same and similar problems. Figure 3 shows e-learning environment designed by PBL concept.

With the assistance of e-learning and knowledge management, junior engineers may acquire the know-how and experience directly from past projects, reducing the time and cost of training. By sharing past experience and knowledge, the same and related problems in executing projects do not need to be solved over and over again. Furthermore, the junior engineers can understand how the construction process works more quickly and easily by utilizing an e-learning platform.

In order to enrich the knowledge bank in the system, the system is designed to encourage all engineers and experts to submit their domain knowledge and valuable experience to the knowledge bank. Traditionally, companies included mostly numeric, structured data in their data warehouse. From this point of view, decision support systems are divided into two camps: data warehouses deal with structured data; knowledge management involves unstructured data (Ponniah 2002). It is a need to integrate both structured (such as data and text) and unstructured information (such as image, video, audio, image, and drawing) in the knowledge bank for further decision-making and reference. The main purpose of a knowledge bank is to provide the rich source of content concerning all projects and gather project-related explicit information and tacit knowledge together for involved engineers and experts.

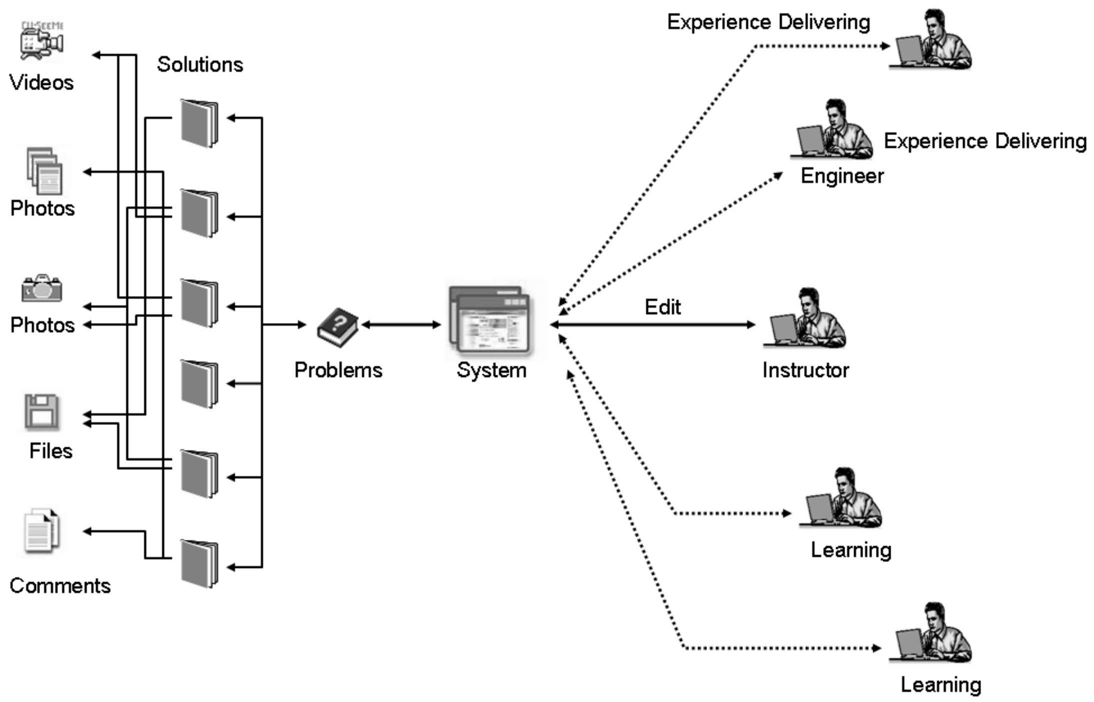

Figure 3 Problem-based Learning (PBL) E-learning for knowledge management.

6. System Development

The system is developed and implemented with an interactive e-learning platform using web-based technology and knowledge management concepts. The multimedia courseware provides junior engineers with illustrations specific to operation procedures using web technology. In addition, digital films record the whole construction operation. The digital films helps the junior engineers understand the process easily and effectively. Furthermore, digital films are recorded and clearly describe the progress and operation of the construction operations. In other words, junior engineers can access the digital illustrations and digital files for each activity or event in the system. Of course, those e-learning materials must be confirmed before being published in the system.

In construction projects, most project-related problems, solutions, experiences, and know-how are recorded into multimedia-based content. Also, multimedia systems are particularly suited to interactive applications since they allow huge collections of visual media, text, and other data to be stored in a single digital document and accessed easily and quickly. Usually, implicit knowledge is not documented or stored in a system database. It is important to capture the implicit knowledge and make it available as explicit knowledge. In this study, most tacit knowledge will be recorded as multimedia-based content for knowledge and experience exchange during the construction process. In other words, the valued knowledge can be collected and edited into explicit knowledge by the knowledge management team.

A detailed description of the ConPBL learning system will be given in this section. Figure 4 shows the system architecture. The server of the ConPBL learning system provides four distinct types of layers: interface, access, application and database layers, each with its own distinct responsibilities. The interface layer defines administration and end-user interfaces suited to his/her work. The users can access information through web browsers such as Microsoft Internet Explorer or Netscape Navigator. Administrators can control and manage information through the web browser as well as a separate server interface. The access layer provides system security and restricted access, firewall services, and system administration functions. The application layer defines various applications for information collection and management. These applications provide indexing, full text search, collaborative work and document management functions. The database layer consists of a primary SQL Server 2003 database and a backup database (also based on SQL Server 2003).

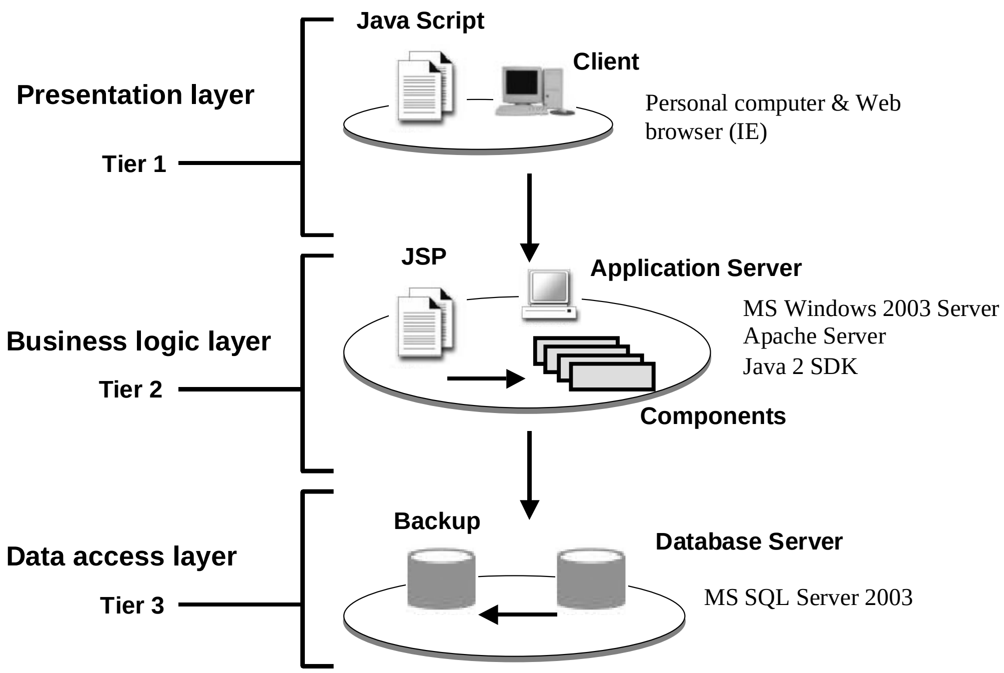

Figure 4 System architecture.

The ConPBL learning system services described in this paper are made available to all the participants of the company through a specially designed portal, which also serves as a messaging (mail) server for the company (organization). The portal is a key element of the proposed system and it consists of three content areas: public, member, and knowledge manager areas. The public area is open to anyone who is interested in the project. On the contrary, the project member and knowledge manager are restricted to members with password protection.

Since anyone can access information from the public area, it is a logical place for project managers (or developers) to utilize for public relations – to post project descriptions, news, announcement, etc. In the project member area, project members can use ConPBL learning services, such as messages, data, and files. Any information and knowledge concerning the projects can only be accessed by project members. Only knowledge managers have the rights to log onto the manager area, where they can access all information in the project server. Figure 5 illustrates the application of knowledge sharing in ConPBL learning system.

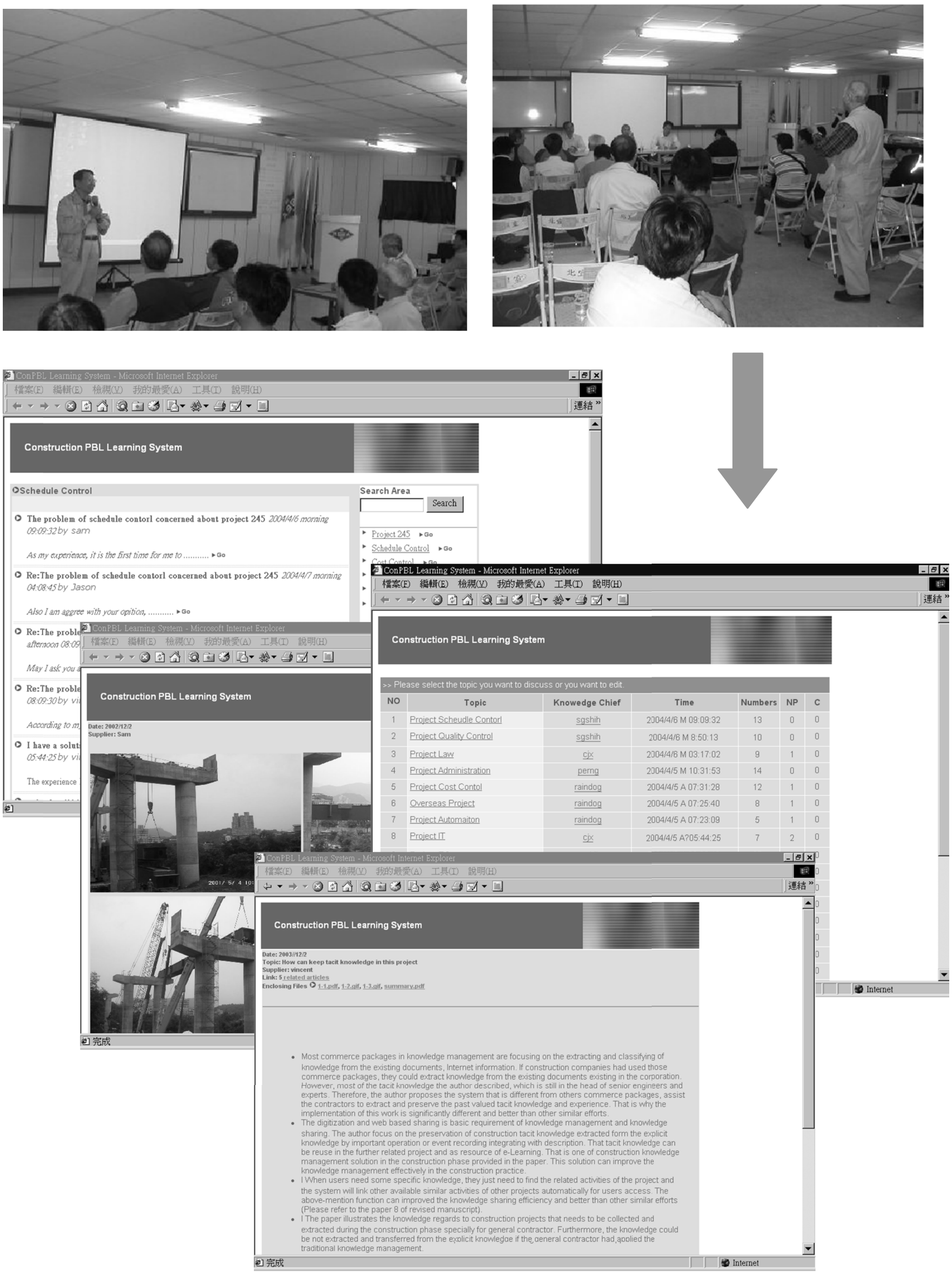

Figure 5. The application of knowledge sharing in ConPBL learning system.

7. Conclusions

The application of knowledge management for construction project in the construction phase is discussed in this paper. Also, the main purpose of this paper presents a construction Problem-based Learning (ConPBL learning) concept and system for general contractors as a knowledge-sharing platform. Construction Project-oriented knowledge management maps the valued information and knowledge into project units for a project during the construction phase. The development of the ConPBL learning System employing the integration of web technology with a portal is delineated and it has been illustrated through a case study in the Taiwan Highway Project. The ConPBL learning system is advanced at least in the following aspects: the ConPBL learning system enables gathering insight into the factors having impact on construction management activities; in turn this will help engineers share knowledge to improve operation performance. Junior engineers can interact with the computer so that they can understand the domain knowledge to prepare and participate in a construction project. In short, the ConPBL learning system is able to assist engineers by providing accurate and rich information for knowledge reuse and reference. The integration of knowledge management and web-based technologies appear to be a promising way to improve construction operation management during the construction phase of a project.

The collection of explicit and tacit knowledge for any project and non-project in construction projects allow engineers and experts to reuse most project-related knowledge/information during the construction phase. The content of the knowledge bank in the system not only provide the specific problem-solutions, but also support all area domain knowledge and experience from the projects. Although effort is required to update the explicit/tacit knowledge for various types of projects, the developed system will benefit construction management by (1) providing an effective and efficient computerized environment to assist knowledge management tasks, and (2) facilitating the implementation of a web-based knowledge management system pertinent to these activities in the projects. With the evaluation of the case study in the Taiwan expressway project, the questionnaire results show that a ConPBL learning system is effective in sharing knowledge for construction projects. The case study also highlighted the need for improvements to knowledge management and exchange platforms.

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Realising Electronic Purchasing in the Irish Construction Industry

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Abstract

The use of Information Communication Technologies (ICT) in construction purchasing has been sporadic and piecemeal. Very significant inefficiencies and problems still exist in both paper transactions and non-integrated electronic solutions. At the simplest level, the electronic transmission of business documents offers savings in paper and postage. By going a step further, businesses can make strides in communicating with their partners, at relatively low cost, through direct links between their computers. Existing ICT such as the Internet, Bar-Coding, Radio Frequency Tagging, Electronic Data Interchange (EDI), Electronic catalogs and Enterprise Resource Planning Software (ERP) have facilitated electronic commerce (EC) functionality within many business sectors. However, the adoption of such technologies in the Irish construction industry has been very slow with only limited evidence of their application. The results of a Proof of Delivery (POD) pilot project carried out by the Construction Information Technology Alliance (CITA) in 2004 indicates that significant cost savings can be achieved by trading partners by the adoption of existing technologies.

Keywords: Construction, e-commerce, information technology, procurement, purchasing.

1. Background

CITA is a collaborative organisation aimed at bringing together academia and practitioners, with a common purpose to promote the application of ICT in the Irish Construction Industry [1]. A Special Interest Group within CITA was formed in 2002 to consider specifically the administration involved in ordering, delivering and invoicing of building materials. CITA approached a number of interested parties within the Alliance to lead a proof of concept pilot project to show how costs can be minimised and efficiencies gained in the ordering, receipt and payment of construction materials by the effective use of ICT.

It is generally accepted that building materials account for up to 50% of all construction costs. In this field of business-to-business (B2B) interactions, there is a huge untapped potential for productivity gains. In Sweden [2], Finland [3] and in the UK [4], materials management has been identified as an area where significant cost savings could be made. Laage-Hellman and Gadde gave an account of the progress made by the Swedish construction company Skanska in its attempts at introducing EDI into its purchasing system. The cost of processing an invoice was found to be SEK 300 (approximately US$45). Laage-Hellman and Gadde concluded that this cost could be reduced by 90% by using EDI.

The purpose of this paper is to share the experience gained by the authors in carrying out a pilot study and to identify the main problems that exist with the current mainly paper-based process adopted in the purchasing of materials in the Irish Construction Industry. The authors conclude that the re-engineered solution proposed will explicitly deal with all the problems that currently exist.

2. Traditional Purchasing Practice in Construction

Purchasing procedures typically involve a paper-based communication process between the purchaser and supplier. Evidence shows that the construction industry is lagging behind other industries globally in adopting new technologies [5]. The process invariably commences with the sourcing of the materials. This typically involves site personnel requisitioning the project material requirements on a daily basis. Once a suitable supplier has been selected, the next step is to raise and issue a purchase order to the supplier. On delivery of the materials to site, a delivery docket is signed by the contractor and forwarded to head office as proof of delivery. Payment of the invoice is made following the matching of the invoice to the original purchase order and signed delivery docket. Kong et al identified the limitations of the traditional material procurement process [5]. As every step is reliant on input from one or more individuals, there are frequently problems in the process. For example, the requirements of the contractor are misinterpreted by the supplier, a docket goes missing, transcription errors occur, the invoice is not correct, the goods are not all delivered at the same time, the delivery docket does not match the order, payment is held pending matching of documents, etc. Any of these problems can add significant delay and cost to the process.

3. Available Technology

Technologies are in place to process electronic transactions more easily and at less cost than one can process paper transactions [6]. ICT is changing almost all functional aspects of a modern business in Ireland, particularly in industries such as financial services, travel and retailing. With the continued expansion of the Internet, EC provides unparalleled opportunities for businesses to bring greater efficiencies in transaction based commercial activities [7]. Technologies such as Automatic Identification (Auto-ID) and bar coding have become widespread within manufacturing, medicine and retail industries. However, the rate of adoption in other business sectors, such as the construction industry has been very slow and piecemeal [8]. Li argues that the benefits of ICT deployment are marginal, if simply imposed on an already inefficient construction process [9]. He argues that the processes should be redesigned to maximise the use of ICT. Hammer described how heavy investments in ICT in the 1980's delivered disappointing results, largely because companies tended to use technology to mechanise old ways of doing business [10].

4. The Pilot

4.1 Aims and Objectives of Pilot

The overall aim of the pilot was to prove that delivery data can be captured electronically and be acceptable as "Proof of Delivery" for the construction industry by use of readily available technology. The underlying objectives of the pilot project included: -

- To develop a clear understanding of how the existing purchasing systems operated in both contractor and supplier organisations.

- To confirm ICT operational systems and their current reliability in both the contractor and supplier organisations.

- To investigate the ease/constraints with which information can be captured from or added to contractor and suppliers existing purchasing systems.

- To test and confirm ICT handheld usability in a construction environment.

- To confirm productivity improvements and potential savings as a direct result of this pilot with both the contractor and the supplier.

4.2 Methodology

The methodology adopted for the pilot included five inter-related steps, involved: -

1. The vision/scope of the pilot,

2. proof of concept,

3. pilot itself,

4. evaluate pilot and

5. post pilot evaluation.

The methodology process is shown in Figure 1.

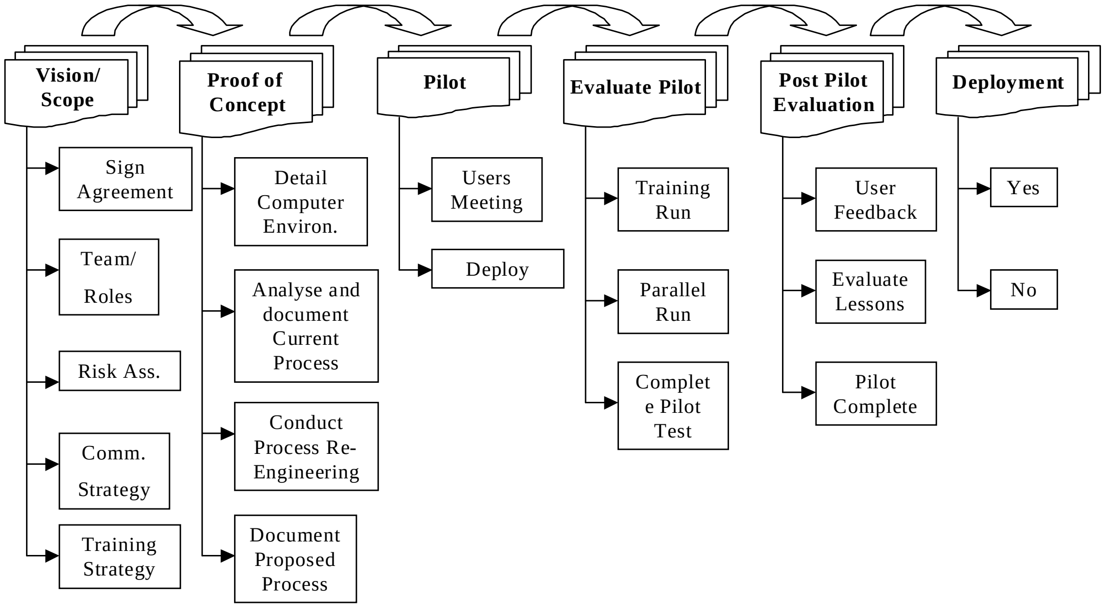

Figure 1. CITA Pilot Project Methodology

4.3 Pilot Team

The pilot team members principally included the lead author, main contractor, building supplier, ICT providers and an independent monitoring consultant, all of which were members of CITA. Figure 2 illustrates the communication relationship between the parties.

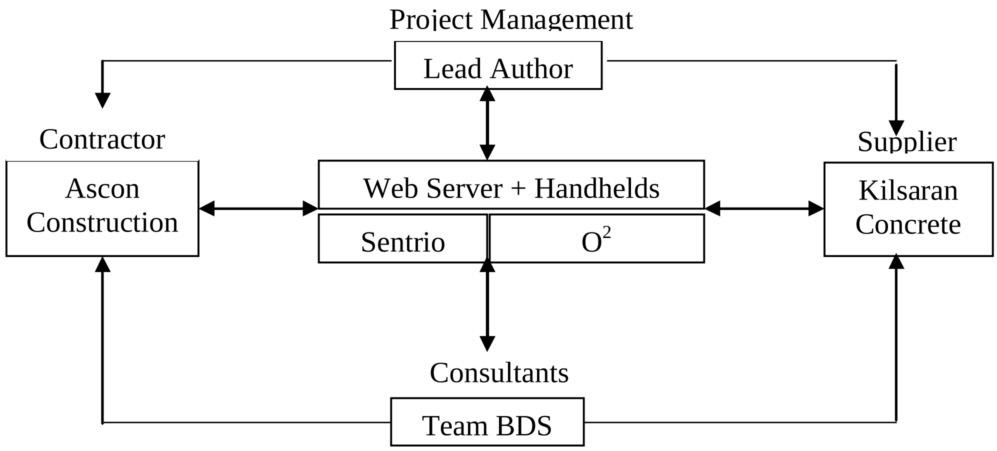

Figure 2: Pilot Team

4.4 Problems to be Addressed

The main problems encountered by the contractor and the supplier included very large volumes of paper generated in their purchasing processes; a significant amount of time spent in carrying out repetitive tasks such as scanning, photocopying, matching documents; inaccuracies in the ordering and delivery process and the degree of mislaid delivery dockets, leading to delays in payment and in many cases non-payment. Table 1 documents the magnitude of the documentation that are created annually within the contractor and supplier organisations.

Table 1. Estimates of purchasing documentation created by contractor and supplier

Pilot Contractor	Pilot Supplier
78,000 invoices per annum with an average of 5 lines per invoice	31,000 invoices per annum with an average of 20 lines per invoice
390,000 goods received notes per annum	1,250 invoice queries per annum
20,000 missing documents per annum	375,000 delivery dockets for scanning per annum
10,000 order amendments	

It was decided by the pilot team to approach the pilot project in two phases. The scope of Phase 1 sought only to address the delivery aspect of the purchasing process as illustrated in Figure 3. The precise scope of phase 2 would be decided following an evaluation and review of Phase 1.

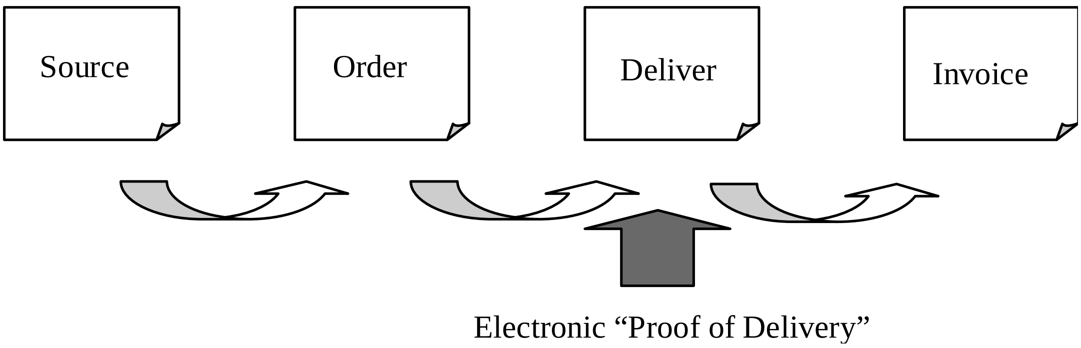

Figure 3. Focus of Pilot

4.5 Technology Landscape

The technology landscape selected for the pilot was a web-based solution, as illustrated on Figure 4. This allowed for the capturing of the POD on a handheld device. The ICT landscape adopted did not in any way require the contractor or the supplier to re-configurate their back-end ICT systems. The technology simply allowed for the purchase order to be captured on a mobile handheld device, which in turn allowed for the POD to be captured by way of a wireless connection on an independent website.

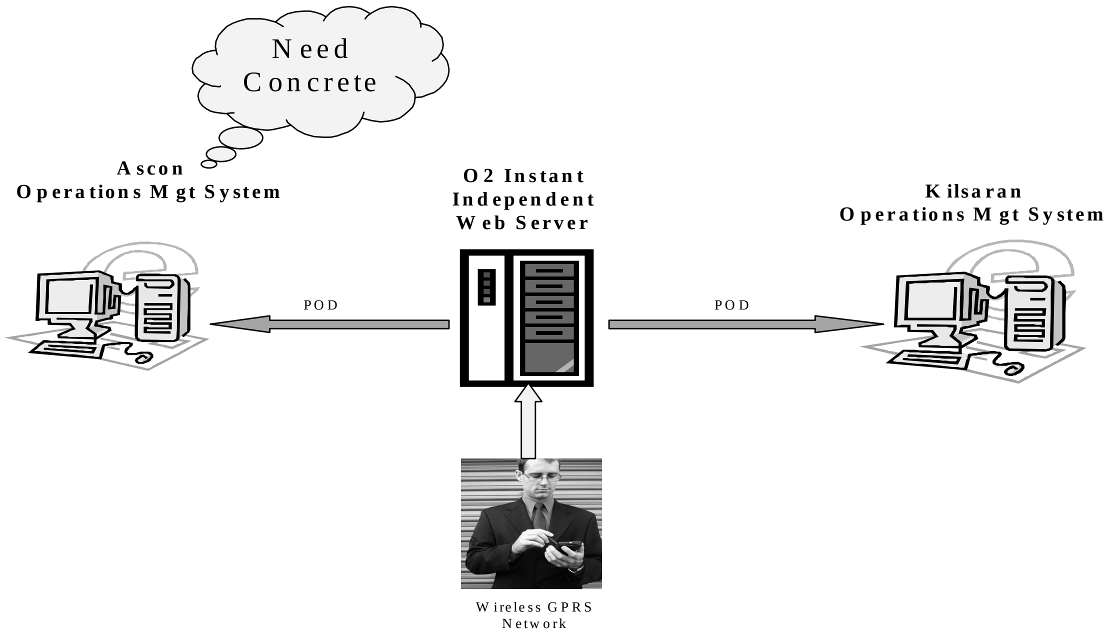

Figure 4. Technology landscape of Pilot for concrete supply

4.6 Pilot Process

A more detailed overview of the pilot process is shown in Figure 5. The pilot process commenced with the contractor calling-off material by phone call and confirming their request by use of facsimile. The supplier in turn generated the order details onto their ICT document management system and simultaneously onto the central web repository. Order details were then transferred onto a handheld device, which, on delivery to the site, were presented in an electronic format for signature on the device. Once signed the POD was instantaneously sent back to the central repository. This allowed both companies to check the delivery information and customer signature online. This enabled the parties to query delivery information using the central web application.

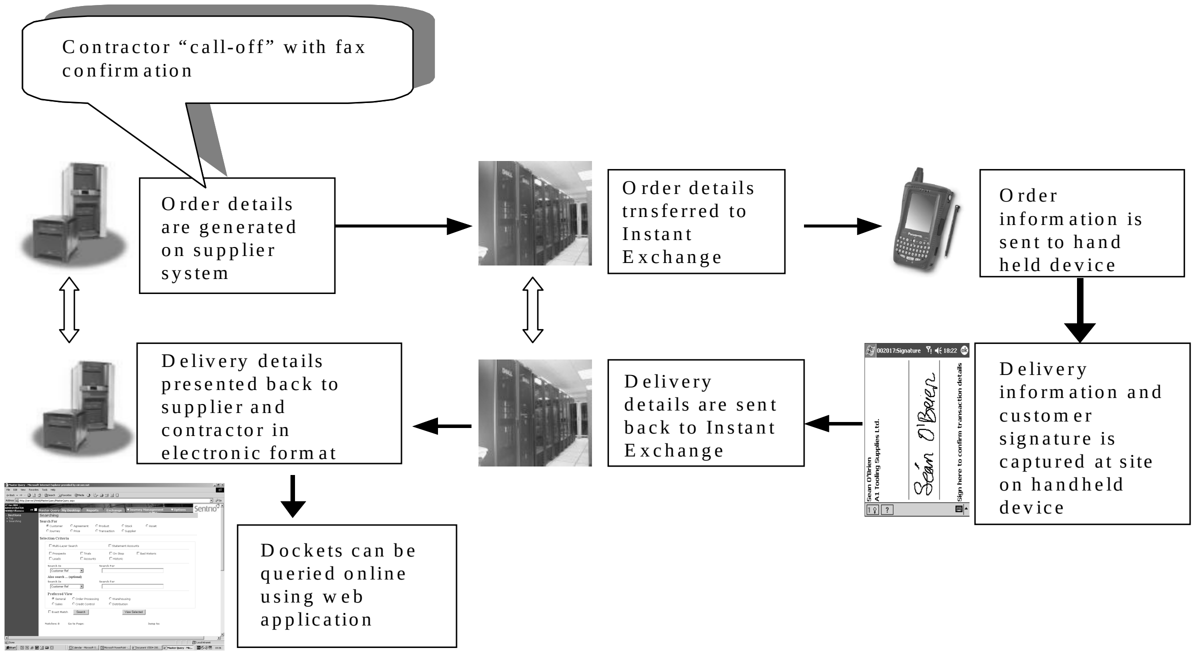

Figure 5. High Level Process for POD Pilot

4.7 Remaining Constraints

The pilot project allowed both the contractor and the supplier to report on the business benefits that would accrue if ICT was deployed in the ordering, receiving and invoicing processes of the purchasing cycle. Table 2 and 3 summarise the internal processes, constraints and opportunities for a further pilot project. It can be seen from both tables 2 and 3 that the pilot project only addressed the delivery element of the process. There remained a large number of constraints in both the contractor and supplier purchasing processes. For example, it was still necessary for the contractor to manually input a Good Received Note (GRN) of the POD information into their ERP systems. It is intended that all these constraints will be systematically dealt with in Phase 2 of the pilot, which is due to commence in spring 2005.

Table 2. Contractors constraints with existing process

4.7.1.1 Contractor – Processes and Current Constraints				
Process	**Current**	**Constraint**	**Pilot Objectives**	**Opportunities**
Ordering	Supplier "Open Order"	Keep order adjustments	Auto order adjustments based upon delivery information	SIG 1 – Phase 2
Receiving/ GRNs	Hard copy Delivery Dockets	Missing documents. Scanning documentation. Manual creation of GRN in ERP system.	Electronic proof of delivery. Eliminate scanning. Auto generation of GRN in to ERP system	SIG 1 – Phase 1 SIG 1 – Phase 2 SIG 1 – Phase 2
Invoicing	Cross referencing Invoice with scanned delivery dockets/GRNS	Missing GRN/scanning documents.	Auto generation GRN in to ERP system	SIG 1 – Phase 2

Table 3. Supplier constraints with existing process

4.7.1.2 Supplier – Processes and Current Constraints				
Process	**Current**	**Constraint**	**Pilot Objectives**	**Opportunities**
Demand from customer	Phone and facsimile	Need to put manually into system	Auto ordering into system from customer	SIG 1 – Phase 2
Delivery	Hard copy Delivery Dockets	Missing documents. Packaging of delivery dockets from site. Scanning of delivery dockets in accounts.	Electronic proof of delivery. Electronic proof of delivery. Eliminate scanning.	SIG 1 – Phase 1 SIG 1 – Phase 1 SIG 1 – Phase 2
Invoicing	Invoice issued once delivery initiated	Missing GRN/scanning documents.	Auto generation GRN in to ERP system	SIG 1 – Phase 2

4.8 Pilot Results

As a direct result of the pilot project, both the contractor and the supplier reported the savings that would potentially accrue should the technology be adopted in a second phase pilot to address the constraints identified in Tables 2 and 3. Tables 4 summarises these savings.

Table 4. Summary of Potential Savings for Phase 2 of Pilot

Contractors Annual Costs in Euro			Suppliers Annual Costs in Euro		
78,000 Invoices per annum 390,000 GRNs per annum			60,000 Invoices per annum 2,400 queries per annum		
Process	Ordering	20,000	Process	Demand from customer	20,000
	Receiving/GRNs	15,000		Delivery	100,000
	Invoicing	67,000		Invoicing	24,000
Total Savings Projected		102,000	Total Savings Projected		144,000
Add Work Study Factor +30%		31,000	Add Work Study Factor +30%		43,000
Other savings		5,000	Other savings		5,000
Total Savings Projected for Phase 2		138,000	Total Savings Projected for Phase 2		192,000
Less predicted technology costs		38,000	Less predicted technology costs		108,000
Nett Saving predicted for Phase 2		100,000	Nett Saving predicted for Phase 2		84,000

The savings reported in table 4 are based on calculations and data furnished by the contractor and the supplier during the pilot and not by a direct work study. The figures presented by the authors are considered to be conservative, as additional indirect savings in regard to office expenses such as use of paper, printing and copier consumables are not included.

From a pilot perspective the supplier gained the more immediate and tangible benefits, from the first phase of the pilot. Table 4 summarises the financial benefits that should accrue to both the contractor and the supplier should the technology be deployed in a second more dynamic B2B pilot project.

4.9 Pilot Feedback in Phase 1

Feedback has been seen as a critical part of the pilot study, as it not only provides “lessons learnt” but also substantiates the credibility of the technology deployed in the first phase of the pilot. There were teething problems in using the technology, however these problems bated as familiarity emerged during the pilot study. Both the contractor and the supplier felt that there needed to be more time spent on training personnel on using the technology. They also felt that the website was not user friendly and did not produce suitable reports for their records. There was also strong opinion that the Personal Digitised Assistant (PDA) screen was not displaying the requisite information prior to signing the PDA screen. All the feedback gathered from the participants will be consulted in the planning and implementation of the second phase pilot.

5. Proposed System Architecture for Effective ePurchasing

The first phase of this pilot project only dealt with the delivery aspect of the entire purchasing process. Figure 6 illustrates how existing technologies can be fully integrated to eliminate paper-work from the entire purchasing process. All purchasing documentation, such as requisitions, purchase orders, delivery dockets and invoices can be passed electronically through the central web server, which in turn can be electronically posted into both the contractors' and suppliers' ICT back-end systems. The architecture of the platform will enable a handheld application with an electronic signature capture capability to transmit wirelessly a POD from the PDA to both the suppliers and contractors ICT systems via an independent central web-based server. The web-based solution will provide on-line access to an image of the signed POD, which will allow for automated matching of the order, the delivery record and the supplier invoice.

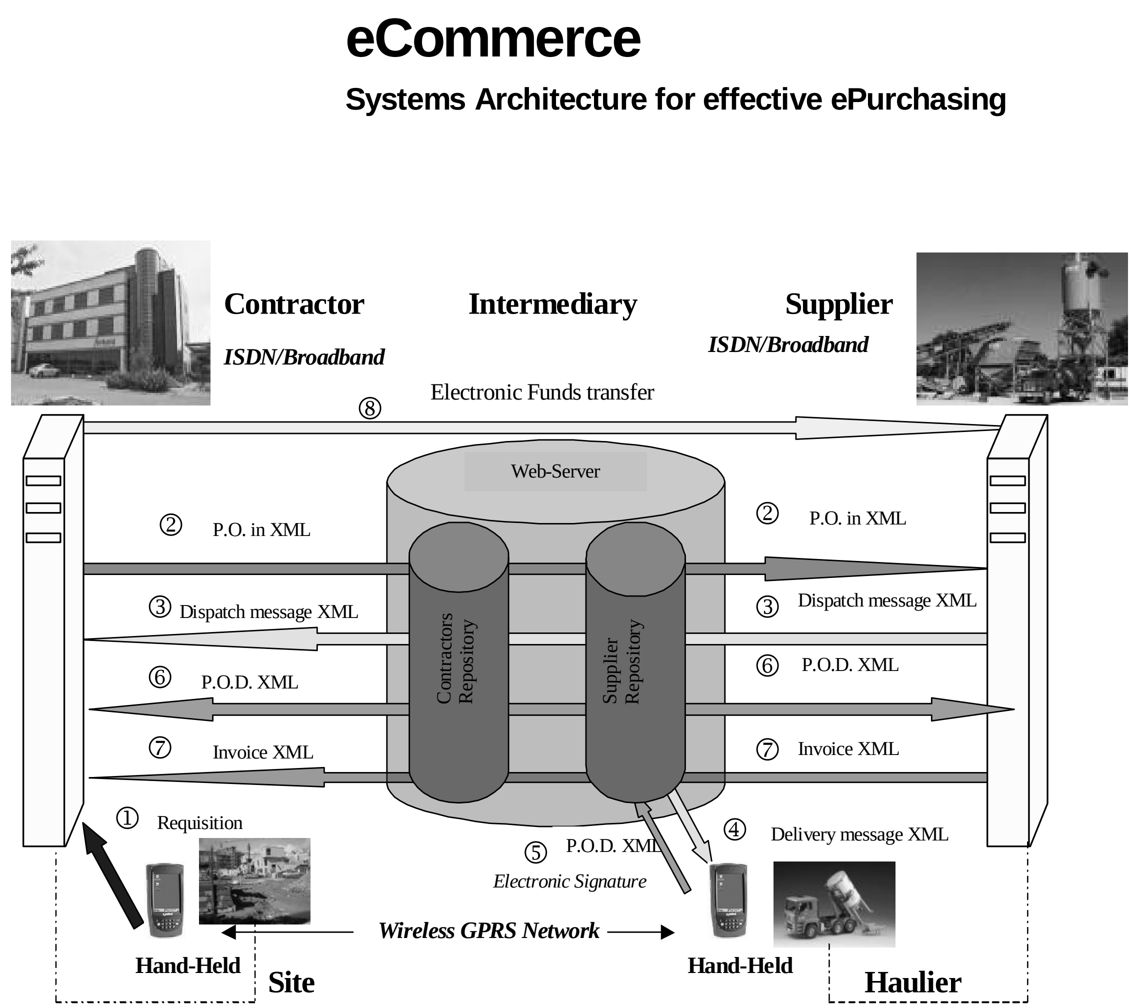

Figure 6. Systems Architecture for Effective ePurchasing

The operation of the proposed solution will involve the following sequential tasks, as identified in Figure 6.

1) Site requisition goods via a hand held device or mobile data terminal.

2) Contractor ICT system passes purchase order to the independent web-server, which ensures that the purchase format is correct and passes it to the suppliers ICT system.

3) The suppliers ICT system creates a dispatch notice and informs the contractor system if there is any variation between the order and dispatch notice.

4) The delivery details are sent to a delivery driver's hand-held device in XML format via a GPRS network. This message is triggered from the independent web-server based on the supplier dispatch message.

5) Once the delivery is complete the driver captures a signature on site, that is transmitted back to the independent web server.

6) The POD is then sent from the independent web-server to both the supplier's and contractor's ICT systems.

7) Supplier invoices the contractor via the independent web-server, using XML messaging technology.

8) On electronic invoice approval the contractor authorises electronic funds transfer direct to supplier.

6. Conclusions

Technologies are at last in place to process electronic transactions more easily and at less cost than one can process paper transactions [6]. ICT is changing almost all functional aspects of a modern business, particularly in industries such as financial services, travel and retailing. With the continued expansion of the Internet, EC provides unparalleled opportunities for businesses to bring greater efficiencies in transaction based commercial activities [7] and [11].

Specific EC deployment is having a varying impact on different business sectors. It will take the main players within each sector to adopt a new technological strategy. ICT is this driver that will force companies to embrace EC in B2B purchasing transactions. The technology behind EC is not the problem. The problem is getting the buy-in from all parties concerned. The biggest savings from eBusiness can be achieved from exchanging orders and invoices electronically. B2B savings can be realised on the elimination of duplicate data entry by achieving a three-way match of the purchase order, delivery advice note and the invoice. Increased awareness within the Irish construction industry is likely to be the key factor in encouraging wider uptake of EC technologies. An industry-wide education initiative, which combines the results of a pilot programme with dissemination of information within the technical press, could, in part achieve this goal. Such an initiative would most fruitfully comprise of a special interest group to pilot test the technology [12]. Particular efforts should be made to increase awareness of EC technologies among contractors and suppliers with lower levels of ICT utilisation [13] and [14].

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CDBKM- A Construction Draw-based Knowledge Map System

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Abstract

Knowledge Management (KM) has become an important term in the construction industry. Knowledge management involves creating, securing, capturing, coordinating, combining, retrieving and distributing knowledge. Most know-what, know-how and experience exists only in the minds of individual participants during the construction phase of construction projects. The knowledge can be reused and shared among the involved engineers and experts to improve the construction process and reduce the time and cost of solving problems. Sharing and reusing knowledge depends on acquiring and preserving both tacit knowledge and explicit knowledge as the property of a corporation. This study addresses application of knowledge management in the construction phase of construction projects and proposes a construction draw-based knowledge management (CDBKM) concept and system for engineers. This paper proposes a practical methodology to capture and represent construction project knowledge by using shop drawings. Using shop drawings as knowledge maps, users can get an overview of available and missing knowledge in core project areas and take appropriate management in tacit and explicit knowledge. Also, a web-based system is developed to assist and present project-related knowledge by providing keyword and map search on the Internet environment. The CDBKM system is then applied in a case study of a construction precast building project in Tainan to verify our proposed methodology and demonstrate the effectiveness of sharing knowledge special in the construction phase. By effectively using information and web technologies during the construction phase of a project, knowledge can be captured and managed to benefit future projects. The combined results demonstrate that, a CDBKM -like system can be an effective tool for all experts and engineers participating for construction projects by utilizing the knowledge management concept and web technology.

Keywords: Knowledge management; knowledge map; web-based application; information systems; construction project

1. Introduction

Thousands of construction drawings are produced for each construction projects. During the construction phase, engineers usually execute the project according to the shopping drawings. Therefore, the experience and knowledge concerned about the project will be resulted from those engineers. Recently, many organizations are now engaged in Knowledge Management (KM) efforts in order to leverage knowledge both within their organization and externally to their stakeholders and customers (Malhotra, 2000, 2001). Knowledge management in the construction phase mainly deals with the process of creating value from construction operation, organization to company knowledge. Valuable knowledge can be available in different forms and media, such as in the mind of experts, in operation procedures, and in documents, databases, intranets, etc.; however, knowledge management in the construction phase of projects aims at effectively and systematically collecting and sharing the experience and knowledge of the project by web-based and intranet technologies.The reuse of information and knowledge minimizes the need to refer explicitly to past projects; reduces the time and cost of solving problems, and improves the quality of solutions during the construction phase of a construction project. If experience and knowledge are shared, then the same problems in construction projects do not need to be repeatedly solved. Reduced problem-solving has the following advantages. (1) The cost of problem solving is reduced and (2) the probability of repeat problems is decreased. Several enabling activities should be considered to help to achieve the ultimate goal of efficient experience and knowledge reuse; experience and knowledge should be preserved and managed; that is, they should be captured, modeled, stored, retrieved, adapted, evaluated and maintained (Bergmann, 2002).

2. Problem Statement

Construction projects are characterized by their complexity, diversity and the non-standard nature of the production (Clough et al., 2000). Professional competency in project management is attained by combining knowledge acquired during training and skills developed through experience as well as the application of the acquired knowledge (Edum-Fotwe and McCaffer, 2000). Whatever successful and unsuccessful projects have been executed by the general contractors, a valuable record of each one should be kept to identify best and worst company practices. During the construction phase of projects, an effective means of improving construction management is to share experiences among engineers, which helps to prevent mistakes that have already been encountered in past projects. Drawing on experience avoids the need to solve problems from scratch: problems that have already been solved do not need to be solved again. According to a survey conducted for this study, most engineers and experts agree that KM is necessary and expect that knowledge management may benefit a construction project. However, no suitable platforms exist to assist senior engineers or experts in sharing and collecting their know-how and experiences when general contractors execute a project. This situation represents a major loss for general contractors who do not preserve the know-how and experiences of senior engineers and experts. When these engineers and experts complete projects or leave the company, they normally take domain knowledge with them and leave little or nothing that will benefit subsequent projects or the company. From the perspective of knowledge management, this know-how and these experiences of construction engineers and experts are the most valuable because their accumulation depends not only on manpower but also on the spending of much money and time.

3. Research Objectives

The main purpose for conducting this research is to develop a Draw-based Knowledge Management (CDBKM) system for engineers, to provide knowledge exchange and management service in the construction phase of a project for the reuse of domain knowledge and experience in future and other related projects. Usually, the management of knowledge in general contractor revolves around projects. Thus the capture, transfer, reuse, and maintain of the construction project knowledge are critical (Kamara et al., 2002). Knowledge management in the construction phase of a project is a knowledge-intensive organizational environment where knowledge creation has critical importance for general contractors. To be competitive, a general contractor has to make innovative use of knowledge created and accumulate through project activities, and share it across the rest of other relative projects. Engineers and experts participating in projects act as knowledge workers facilitating the collection and management of knowledge between current and past projects. In order to apply knowledge management to construction projects, the process and content of working construction knowledge need to be modified because of construction project characteristics. In order to improve the knowledge capture function, knowledge map assists the user as a tool to quickly note key concept, identify important processes and tools, and gain insights into associated behaviors.

4. Concepts of Draw-based Knowledge Management

A knowledge map is used to categorize the content within a particular discipline area. Knowledge map (Wexler, 2001) is a consciously designed communication medium using graphical presentation of text, models, numbers or symbols between makers and users. Knowledge mapping helps to understand the relationships between knowledge stores and dynamics. Davenport and Prusak (1998) note that developing a knowledge map involves locating important knowledge in the organization and then publishing some sort of list or picture that shows where to find it. The knowledge map plays important roles in implementing knowledge management. All captured knowledge can be summarized and abstracted through the knowledge map. The knowledge map also gives a useful blueprint for implementing a knowledge management system. The knowledge map in the system mainly deals with the assistance to find the needed knowledge easily and effectively. Furthermore, applying knowledge mapping technique has following two advantages. First, the knowledge map is represented in a simple, clear visual presentation in the knowledge management system. Second, the mapping methodology helps users to identify key most critical and available knowledge areas to the project. A knowledge map can be defined as a diagrammatic and graphic presentation of knowledge linking the relationships between knowledge and knowledge attribute.

Knowledge and information associated with units of shopping drawings in previous projects may be reused and applied in future projects. Information and domain knowledge from all projects are divided and saved as units for knowledge maps uses in categories related to the projects for collection and management. The main advantage of Draw-based knowledge management is easy for engineers to understand and find which past information and knowledge are available to refer and reuse.

When knowledge is captured duration the construction phase, the knowledge should be recorded in the platform for exchanging. In terms of explicit knowledge, project-related information or knowledge usually include specification/contract, reports, drawing, change order and data. Actually, each project does not contain one-to-one information or knowledge because some of them belong to draw-unit information. In contrast, tacit knowledge may include process records, problems-faced, problems-solved, expert suggestions, know-how, innovation, and experience notes. The information and knowledge is better to save by draw units as knowledge map because the result makes it easier to be classified and searched by users. In addition, users may search and refer to related information and knowledge from related activities in past projects. The tacit and explicit knowledge of Draw-based knowledge management is the same as the duration and relationship of Draw-based project management.

The relationship of current and past draw-units is important for users to link related information and knowledge together. Furthermore, not only the information and knowledge of the current project can be applied, but also same or similar draw-units of past projects can be referred to as experiences are recorded. When experts or engineers capture related information and knowledge regard to the project, they may edit information or knowledge into the drawings in the project. Of course, the system is designed to link among same or similar activities together based on high similarity automatically or manually. As shown in Figure 1, using draw-unit as knowledge map applies for knowledge management.

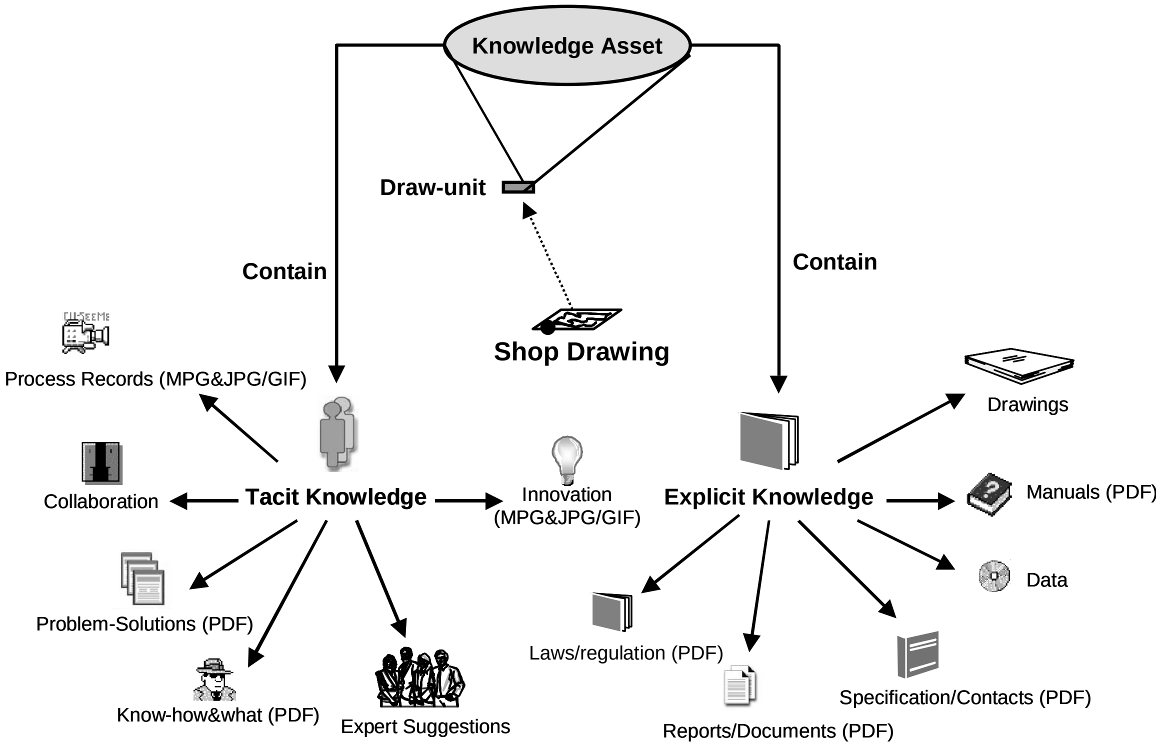

Figure 1. A concept map of the Draw-based knowledge management integrated with drawing units

4.1 Procedures for Utilizing the Knowledge Map

According to the construction knowledge management framework, procedures are proposed for applying the knowledge map in the CDBKM system. The procedure consists of the following three phases: knowledge determination phase, knowledge attribute phase, and knowledge linking phase.

4.1.1 Knowledge Determination Phase

The purpose of this phase is to provide a uniform, text-based intermediate representation of the knowledge types specific to construction projects. This phase includes defining knowledge and baseline taxonomy within a project. The scope of the knowledge map decides whether the knowledge map is constructed throughout a specific project. After deciding the scope, we determine the detail level of knowledge analysis. It is necessary and important to determine the proper level of detail to meet project-based knowledge demand effectively. When analyzing the source of knowledge within a project, activity is suggested as a unit to analyze the construction project knowledge. We analyze related knowledge based on draw-units of shop drawing. Tacit knowledge and explicit knowledge may exist in any project. After identifying knowledge through those activities of the project, we decide which knowledge needs to be extracted from the activities of the projects. Following suggested knowledge extraction techniques include interviewing with experts, making system analysis, and digital process record.

4.1.2 Knowledge Attribute Phase

A knowledge attribute illustrate the basic description of extracted knowledge and derive relationships with project and similarity draw-unit. The main purpose of knowledge attribute is provides the relationship and available knowledge information for knowledge workers and general users. Knowledge attributes include the keywords, description, project name, activity name, contributor, and attached files.

4.1.3 Knowledge Linking Phase

The knowledge link is identified after completing the knowledge attribute. The knowledge link is first indicated when the tacit or explicit knowledge is available and documenting, and is later confirmed. Two types of knowledge linking are proposed in the paper. One is draw-unit link draw-unit based on high similarity. Second is draw-unit link knowledge based on relationship between draw-unit and project. When the contributor creates a new link, the link needs to be examined and confirmed before knowledge map is published. Finally, all knowledge map need to be validated before the map is published. All the validation process must be communicated with domain experts, knowledge worker, and knowledge map producer in the enterprise knowledge management division.

5. The System

This section describes in detail the CDBKM system. The system architecture includes the Presentation Layer, the Business Logic Layer and the Data Access Layer (see Fig 2). After the user logging in, user is taken to the respective interface wherein information is classified under sections of ‘Project Info’, and the related entity. The architecture used is a three tiers model, with HTML, JavaScript /Servlets forming the user interface (presentation layer), the connection layer (JSP / JDBC) (Business Logic Layer) and the SQL RDBMS forming the Data Access Layer. The server of the CDBKM system supports three distinct layers - interface, access, application and database layers; each has its own responsibilities.

- *Presentation Layer:* Presentation Layer is responsible for the presentation of data, receiving user events and controlling the user interface. HTML/DHTML with JavaScript is used for developing User Interface Screens. Furthermore, Uses Socket class to communicate with server and Client side validations are done through JavaScript.

- *Business Logic Layer:* Business logic layer is created using ServerSocket class. It keeps listening for the clients to communicate with it for service. Every time a new client logs on, a separate session is created for processing its the following modules are developed in the Business Logic Layer.

- *Data Access Layer:* Data Access Layer tier is responsible for data storage. Relational database systems and MS SQL 2003 is adopted in the system. All the changes to the database occur after the exceptions are caught handled and confirmation for changes received. Also, system is developed to backup the system database automatically whenever required.

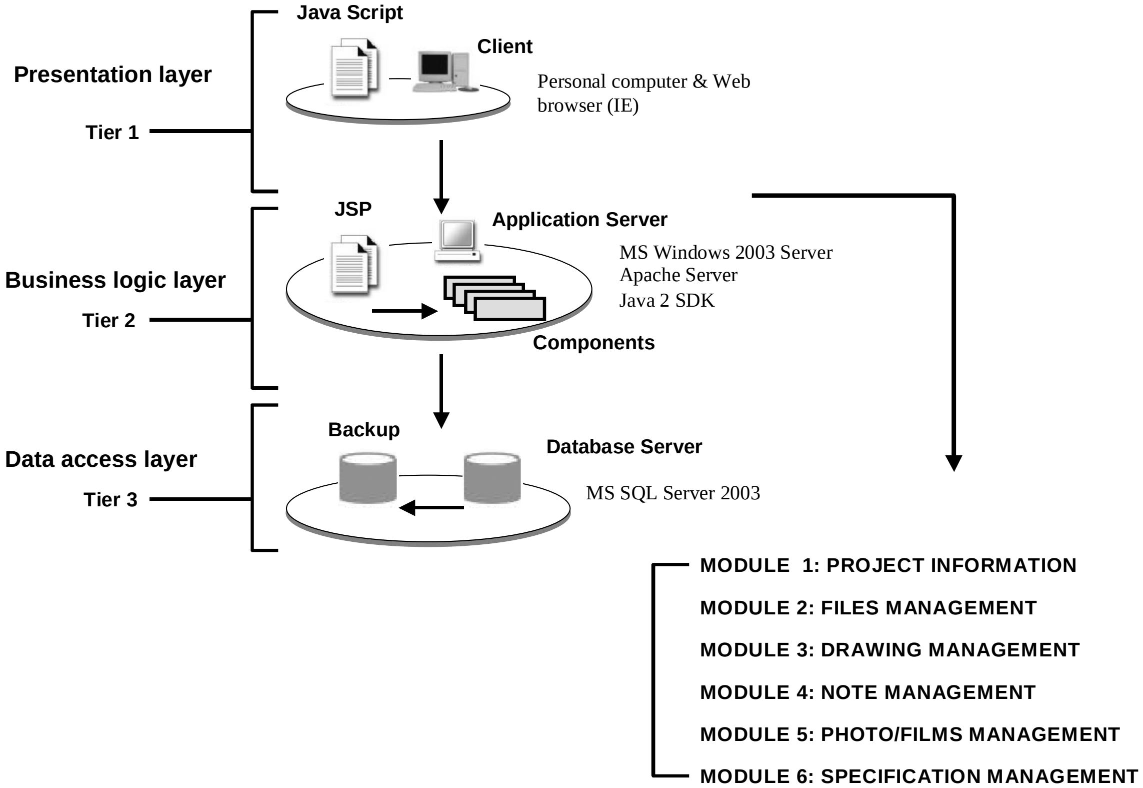

Figure 2. The system architecture and function modules

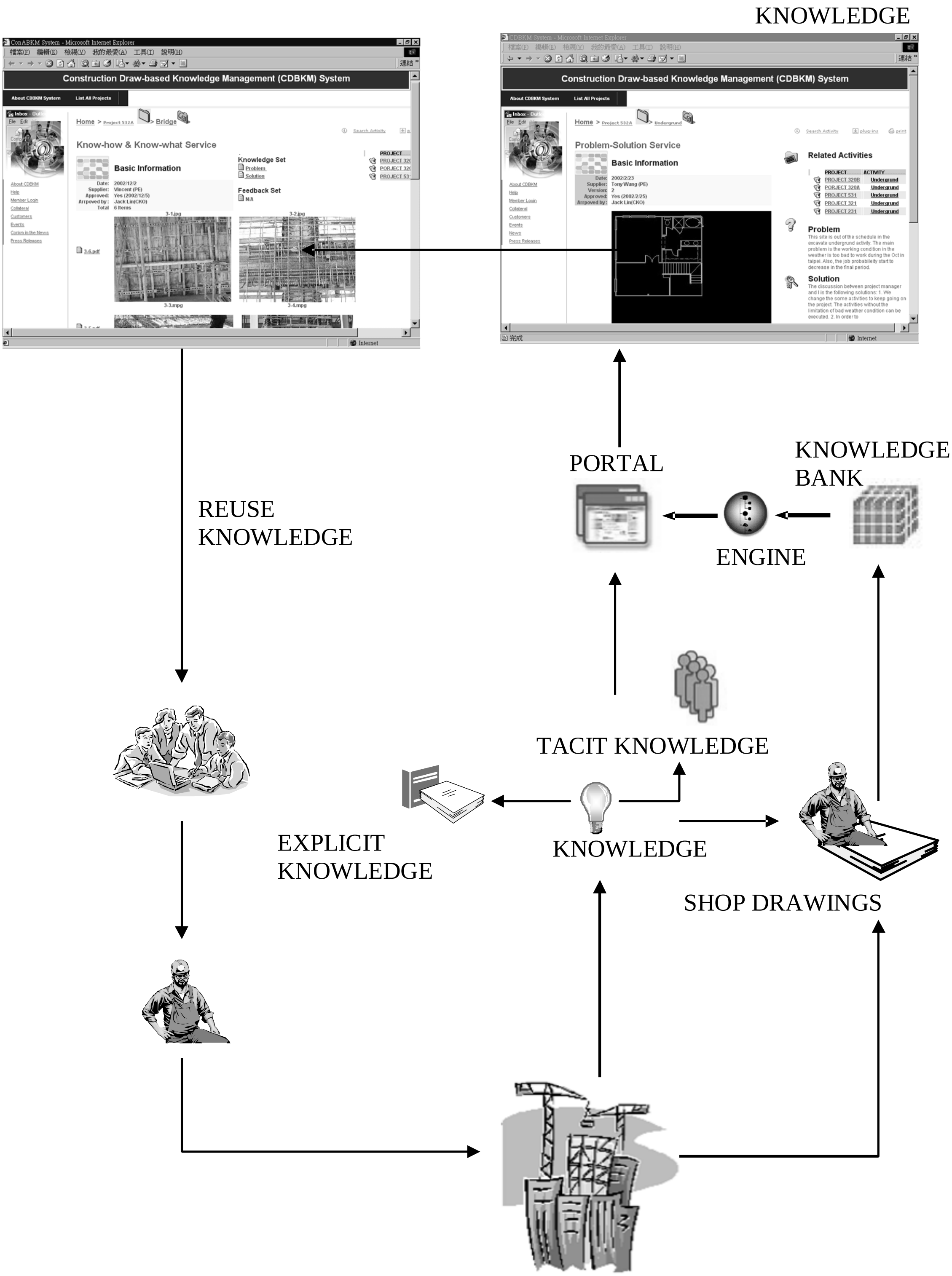

Figure 3. The application of knowledge sharing in CDBKM system

6. Case Study

In the following case, the general contractor won the bid of a precast project, to construct a High-tech office building within one year in Tainan. However, the contractor has no experience of precast construction and the contractor wants to record the whole valued experience and knowledge regard to the new project for further reuse. Therefore, the contractor decided to hire three construction specialists, particularly in precast construction to assist the senior engineers in order to finish the project on time as required. For the future precast projects could process more easily, the company decided to take a good advantage of knowledge management to pass on the valuable know-how to the engineers and manage it well to keep the knowledge inside the company. The following case study is the contractor applied and practiced knowledge management by using construction draw-based knowledge map system.

6.1 Knowledge Acquisition Phase

Knowledge workers help the senior engineer to collect related information/documentation and coverts it into digital format. After the related information and documentation have been digitized, the senior engineer edits descriptions/notes concerning that digital information and packages them as knowledge set into the related drawing-units.

6.2 Knowledge Extraction Phase

The senior engineer and knowledge workers record all the operating procedures by taking digital video and photographs. The senior engineer discussed problems with experts every week twice to accelerate the solving of the problem in question. All discussions were recorded and summarized as suggested by experts. Discussions and meeting with experts continued for ten months, until the problem was solved. The senior engineer recorded and summarized his experience and domain knowledge into the draw-units in the system to enable the problem's solution to be reused in other and future projects. The domain knowledge included the problem description (including documents, photographs, drawings and specifications), the problem's solution (including related documents and photographs and video of processes), and expert suggestions (such as notes, discussions and meeting records). Knowledge was extracted according to each process defined as related to the draw-units of shop drawings. Domain knowledge and experience was organized according to the attribute of the draw-units concerned. Furthermore, every senior engineer in the project is required to provide his own knowledge concerning the tasks for which he is responsible.

6.3 Knowledge Storage Phase

When the submitted knowledge set is approved, knowledge workers manage knowledge sets and classify this knowledge by placing it in an appropriate position (the draw-units of shop drawings) in the system. In other words, users can find and read related domain knowledge directly just clicking these draw-units of shop drawings. All knowledge map (draw-units of shop drawings) need to be validated to perform well before the map is published. All the validation must be conducted with domain experts, knowledge worker, and knowledge map producer in the enterprise knowledge implantation term. Finally, the knowledge set is automatically backed up from the knowledge bank to another database. After approving and storing knowledge, the system sends a message regarding the updating of the knowledge to the appropriate users automatically.

6.4 Knowledge Sharing Phase

The general contractor bid another precast project after the High-tech office building constructed six months ago. A senior engineer with no prior High-tech office building experience meets a similar problem and tries to locate past knowledge/information to help him solve the problem. The senior engineer uses the keyword search to find the expert who has domain knowledge concerned precast building. The senior engineer finds the experts and retrieves, refers to and studies the knowledge set (including digital video and documentation) supported by these senior engineers. He starts to apply and reuse the knowledge in his own project. Also, the senior engineer gives some feedback and offers knowledge that can be reused when others face new problems. Additionally, some senior engineers in other projects and reuse the same knowledge to solve the same problem at reduced cost.

6.5 Knowledge Update Phase

After applying knowledge and information to the other similar projects, the senior engineer solves his problem and finds a new solution in collaboration with other engineers. Finally, the senior engineer notes and submits the new suggestion and experience to project map, associated with the original knowledge. Furthermore, the knowledge is updated later because further feedback and another solution is provided regarding the same problem. After the approval process has been completed, the updated knowledge set is republished in the draw-units of shop drawings and notice message will be sent to the authorized members.

7. Conclusions

This study proposes the application of knowledge management in the construction phase of construction projects using a web-based technology and portal. The integration of knowledge management and web-based technologies appears to be a promising means of improving construction operation and management, especially in the construction phases of projects. The concept of Draw-based knowledge management (CDBKM) is presented, and a system for use as a knowledge-sharing platform in construction projects is presented. The construction Draw-based knowledge management system maps valuable information and knowledge into draw-units of shop drawings during the construction phase. The CDBKM system is advanced, at least in the following respects; the CDBKM system provides insight into the factors that have an impact on construction management, and so helps engineers to exchange knowledge and enhance the quality of the project. Participating engineers can interact with the computer to gain domain knowledge, and thus prepare for and participate in a construction project. Briefly, the CDBKM system can assist engineers by providing structured and unstructured information and knowledge by referring draw-units of shop drawings. The knowledge map in the system mainly deals with the assistance to find the needed knowledge easily and effectively. The primary purposes of using draw-units of shop drawings as knowledge map in the system are as follows; (1) the draw-units of shop drawings is represented in a clear and visual way to identify key knowledge areas that are most strategic and critical to the project, and (2) deals with the assistance for users to find the needed knowledge easily and effectively. The major contributions of the study are as follows; (1) proposing better solutions for construction knowledge management using draw-units of shop drawings, and (2) developing a construction knowledge management system specific for managing construction projects with reference to activities by using a knowledge map.

The demonstration of the system in a case study of the new precast office building located in Tainan indicates that the CDBKM system effectively promotes the sharing and reuse of knowledge for new construction projects. The case study also highlighted the need for improving knowledge management and exchange platforms. However, the received feedbacks based on the use of the system are as follows; (1) the content of knowledge bank in the system is not enough to support and provide the junior engineers to get past experience and knowledge in the beginning; (2) most of senior engineers and experts have low willing to share their knowledge and experience without the proper reword policy and strategy; (3) it takes time and is very inconvenient for senior engineers to edit and record the knowledge without any assistance form knowledge workers; (4) it takes time for knowledge workers to convert shop drawings into system, and (5) most senior engineers agree the CDBKM system is a useful platform for them to edit and manage their knowledge and experience.

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How to Describe and Evaluate Management System with the Unified Modeling Language

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Abstract

This paper reports how to use the Unified Modeling Language (UML) as a methodology of the development of computer systems, especially for project management in building construction. First, the paper introduces the features of construction project. The authors value the end user computing (EUC) from the viewpoint of organization, and Design Pattern of user interface from that of viewpoint of computer system structure. Secondly, the paper explains the role of UML, and design patterns of user interface with UML. Thirdly, the paper describes the process of actual system developments with UML: Mobile Computer-Aided Management System, Schedule Simulator for Repetitive Construction Work, Long Term Repair Planning System, and Life Cycle Cost Estimation System. Moreover, it develops the evaluation of system with UML. Finally, the paper summarizes the methodology and discusses the effectiveness.

Keywords: Project management, building construction, computer-aided engineering, end user computing, modelling, unified modeling language

1. Introduction

1.1 Building Construction and Project Management

Building Construction has some features as follows. It is unique and local production. The design and specification is unique. Production is usually executed as a project. So, members in a project such as an architect, a general contractor and subcontractors are usually organized each project. On the other hand, project management for construction has unchangeable and important core. For instance, quality, cost, deliver, safety and environmental control are essential these days. Many check points for them have already arranged. However, at the same time, project managers must cope with the diversity of projects. The strategy in project will change priorities in project management. The structure and specification of building may affect the process and the point in project management. The adoption of construction methods such as precast concrete will change the work flow of management. That of construction methods such as the division of work area will change the frequency and time of management work. So, project management for construction needs the variability corresponding to the project[5, 7].

1.2 Rapid Expansion of Information Technology

Information technology has rapidly expanded in construction project. Construction managers have recently handled various types of digital information such as drawings, specification, checklists and daily reports. They use computers for construction planning and management. They also use networks: the internet, the intranet, and LAN for the communication among project stakeholders and their data exchange. On the other hand, they need to access the real construction site to manage the construction project. Now the current mobile computing can improve the management work in construction site, and enhance the total productivity of construction management. They have recently used mobile computers for the site management [3, 7, 8]. Information technology is essential in the current construction project. At the same time, it must have the variability corresponding to the feature of construction project.

2. Application of IT in Project Management

In the application of information technology in project management, the authors have practiced the application of EUC and design pattern. The former is the approach from the viewpoint of organization, and the latter is that from the viewpoint of computer system structure. Both are the mechanism to get the variability in computer systems.

2.1 End User Computing

The authors recognize that EUC is a useful concept corresponding to enhance the customer satisfaction. Strictly speaking, EUC means that end users develop computer system to support their own work. However, it is still unrealistic that end users, architects and/or construction managers, develop the whole of the computer system for their work. In general, their current literacy for the development of the system is not enough. So, the authors have promoted that end users, architects and/or construction managers, take part in the development of computer system supporting to project management for construction. The EUC means that the collaboration of end users and system developers. The EUC makes it easy to consider the opinion of end users. However, there is another opinion that EUC derives many poor imitations from the original easily. As a result, the use of computer in the organization gets confused. So, a useful mechanism about the structure of computer system is necessary.

2.2 Modularity and Design Pattern

The authors adopt Modularity and Design pattern as key concepts to realize the EUC. Figure 1 shows their overview. A module is a part that performs a particular function. A system component is an embodiment of module in computer system. The feature is the encapsulation of the internal mechanism, and the interface between the internal and the external. The interface means the connection between components. The components realize Object-Oriented Design.

The practice of Object-Oriented Design produces design pattern. Design pattern is repeated and regular forms in the diverse combination of system components. For instance, there is a scrollbar. This is a system component about user interface for the change of objects such as data and/or screen. If the object is the second dimension, the user interface with two scrollbars is adopted. If it is the third dimension, the user interface with three scrollbars is adopted. Either of them is mostly used in real works. They are design patterns. The rule about design pattern, including how to combine system components and how to combine design patterns, is design rule. The authors regard design pattern of user interface as important. End users can take part in the design of user interface because it is directly related to them. That is, they can customize and combine the design patterns of user interface freely under the design rule. After the completion of the preliminary design with design patterns by end users, system developers can complete the computer system easily. They can develop the computer system corresponding to unique features of project quickly. This is the mechanism of diverse and rapid design [2, 4, 8].

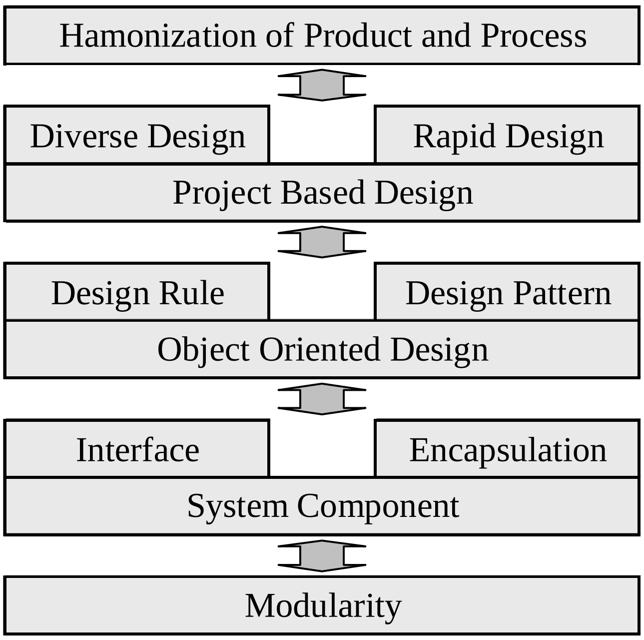

Figure 1: Concept of Modularity and Design Pattern for Product and Process

2.3 Problems to be Solved

The authors have developed actual computer systems based on EUC and design pattern: Mobile Computer-Aided Management System, Schedule Simulator for Repetitive Construction Work, Long Term Repair Planning System, and Life Cycle Cost Estimation System. Through these developments, the authors understand that the modelling, which both end users and system developers can understand, is necessary and important. There are two points in the modelling. One is the expression of system mechanism such as design pattern and system component. It is necessary for end users to recognize the function, control, and behaviour of computer system. It is also important for system developers to be able to build a computer system with the model. In other words, the modelling must be a design tool from the view point of end users, and be the blueprint from that of system developers. Design pattern can satisfy both requirements. The other is the function of a communication tool between end users and system developers. Common language between them is necessary. A useful language not only between end users and system developers but also among system developers is important.

3. UML as Methodology of Description and Evaluation of Management System

UML is a graphical language for visualizing, specifying, constructing, and documenting the artefacts of a software-intensive system. UML offers a standard way to write a system's blueprints, including conceptual things such as business processes and system functions as well as concrete things such as programming language statements, database schemas, and reusable software components [10]. UML defines some diagrams to describe complex systems. There is some possibility of using UML as a useful design and communication tool.

The authors arranged UML diagrams and set up the modelling flow for this research. Figure 2 shows the flow and the role of each diagram. Users in this modelling are end users and system developers. Diagrams are classified in three broad categories. They are basically used in ascending order, but sometimes in parallel.

- The first category is the description of use case. Step 1 is the description of use case. Users arrange actual use cases and define the relationship among them with Use Case Diagram. Users describe a scenario each use case. The scope and use of system becomes definite.
- The second category is the description of model behaviour. It is the description of dynamic structure of system. Step 2 is the description of model process. Users describe the work flow of the model with Activity Diagram. This helps the definition of scope of computer system. Step 3 is the description of message flow. Users describe the message flow in the model with Sequence Diagram. This helps the definition of data flow in system. Step 4 is the description of the flow of user interface model. Users describe the flow with Sequence Diagram. As mentioned above, user interface is an important component in EUC. Authors arrange the model with UML diagram. Step 5 is the description of state transition. Users describe the state transition of the system condition with Statechart Diagram. This is especially useful for the description of the repetitive procedure.
- The last category is the description for the implementation of system. Step 6 is the description of class structure. Users describe class structure with Class Diagram. Class is an abstract concept and is refined through the description of case studies and model behaviour. Step 7 is the description of system structure. Users describe the dependencies among software and the structure of hardware with Component and/or Deployment Diagram.

Case Study	1	Use Case Diagram	Description of Use Case
Model Behavior	2	Activity Diagram	Description of Model Process
	3	Sequence Diagram	Description of Message Flow
	4	Sequence Diagram	Description of GUI Flow
	5	Statechart Diagram	Description of State Transition
System Structure	6	Class Diagram	Description of Class Structure
	7	Component Diagram Deployment Diagram	Description of Ssytem Structure

Figure 2: Flow in the Use of UML

4. How to Describe Management Systems with UML

Examples of the description of systems with UML from the viewpoint of both the definition of system and the communication between end users and system developers are as follows.

4.1 CASE 1: Mobile Computer-Aided Management System

The inspection system with the personal digital assistants (PDA), especially for finish work of dwelling apartment, is a subsystem of Mobile Computer-Aided Management System [7, 8].

The first step of modelling in this research is the description of the use case. Figure 1 shows Use Case Diagram of the system. It shows that an inspector is an actor of using the system, and that a rectifier is one of receiving the benefit of the system. Clients, supervisors, construction managers and foremen can be the user of the system. Foremen are the rectifier of defects. Moreover, the diagram shows that the system includes five sub works such as “record the position” and “issue site instruction”. These sub works show a scenario in the case that an inspector inspects dwelling units. In a scenario, a construction manager in general contractor uses the system, and issues site instruction to foremen. The work of “record defects in dwelling units” extends to the overview of the system. The inspection for common corridor is possible as another use case.

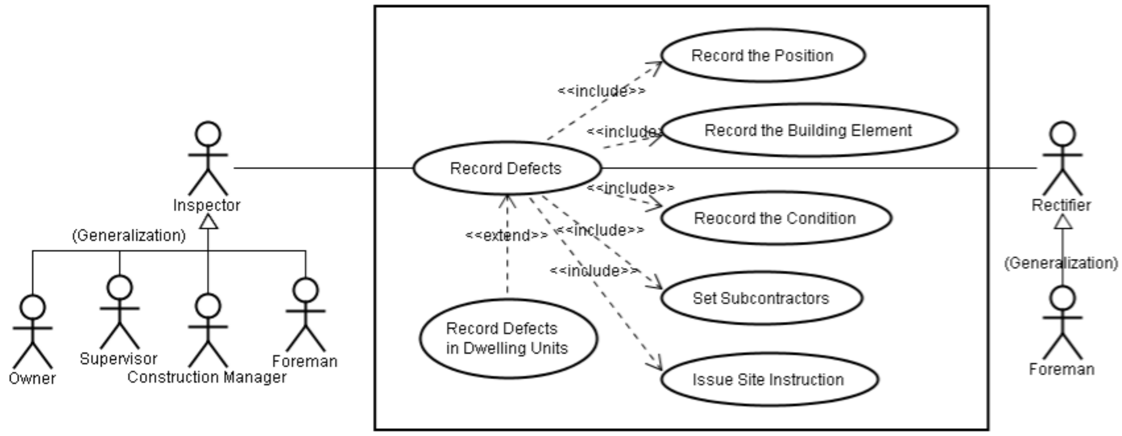

Figure 3: Use Case Diagram of Mobile Computer Management System

The second category is the description of system from the dynamic view point. The data exchange in the system and the state transition of the system are described as the behaviour of system. Activity Diagram basically indicates a flowchart. It makes clear of the flow and sequence of sub works. It usually sets the lane for the persons concerned. The lane makes clear each role in the inspection. Moreover, works in the diagram can be classified by the type of content such as decision making and data input. This classification is related to the scope and role of computer system. Figure 4 shows Sequence Diagram. It focuses on the message flow. The related subjects are the sender and receiver on messages. They are the actors such as an inspector and the parts of the system. This diagram is also related to the scope and role of computer system.

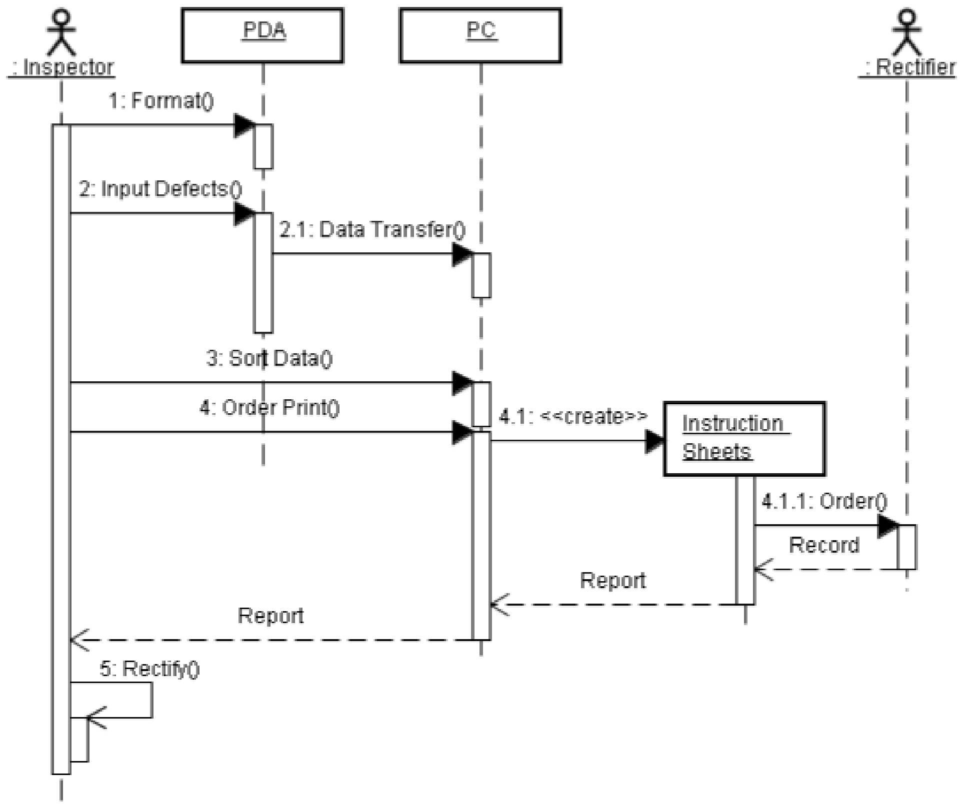

Figure 4: Sequence Diagram

The authors recognize the graphical user interface (GUI) as the important object of design pattern for EUC. It is familiar to both end users and system developers. The left sequence diagram in Figure 5 shows the message flow around GUI model in the inspection system. This model, which the authors have arranged for EUC, has five properties. The first one is the name of design pattern such as pattern-A and pattern-B, which is just for the identification. The second one is the type of control of system component such as the list and the scrollbar. In this case, this means a tool in data input. The third one is the type of access to GUI such as the selection of item and the direct input of information. The forth one is the type of data such as Integer, String and Boolean. The fifth one is the number of system component. The type of data is related to the control and access. For instance, the selection of an item from the list is suitable for the input of an item. The use of scrollbar is suitable for the input of numerical data, especially by construction managers with gloves out of doors in construction site. As Sequence Diagram shows the message flow, the input and output in the system becomes clear. The content of this GUI model is also familiar to both end users and system developers. Therefore, this flow can be designed by the collaboration of end users and system developers. Once GUI models are established, the development of actual GUI is easy and doesn't need much time because the model, design pattern, has designed the detail of the specification in advance. The right one in Figure 5 shows the development of actual GUI in the system.

The third category is the description of system structure from the static view point. Figure 6 shows Class Diagram of the inspection system. Class Diagram is a graph of classifier elements connected by their various static relationships [10]. The diagram shows the structure of elements and the relation among the elements in the system. The information of the inspection for buildings is composed of inspection information, building information, drawing information and defect information. The information has the properties. The diagram also shows the relation between the actors and the system. The description of overview of organization including the actors and the system will be able to become a tool for the description of business model. Figure 7 shows Deployment Diagram of the inspection system. First, it expresses the component of hardware. Processors are PDA and PC. Secondly, it also expresses the structure of the software including the relation the software and the operating system.

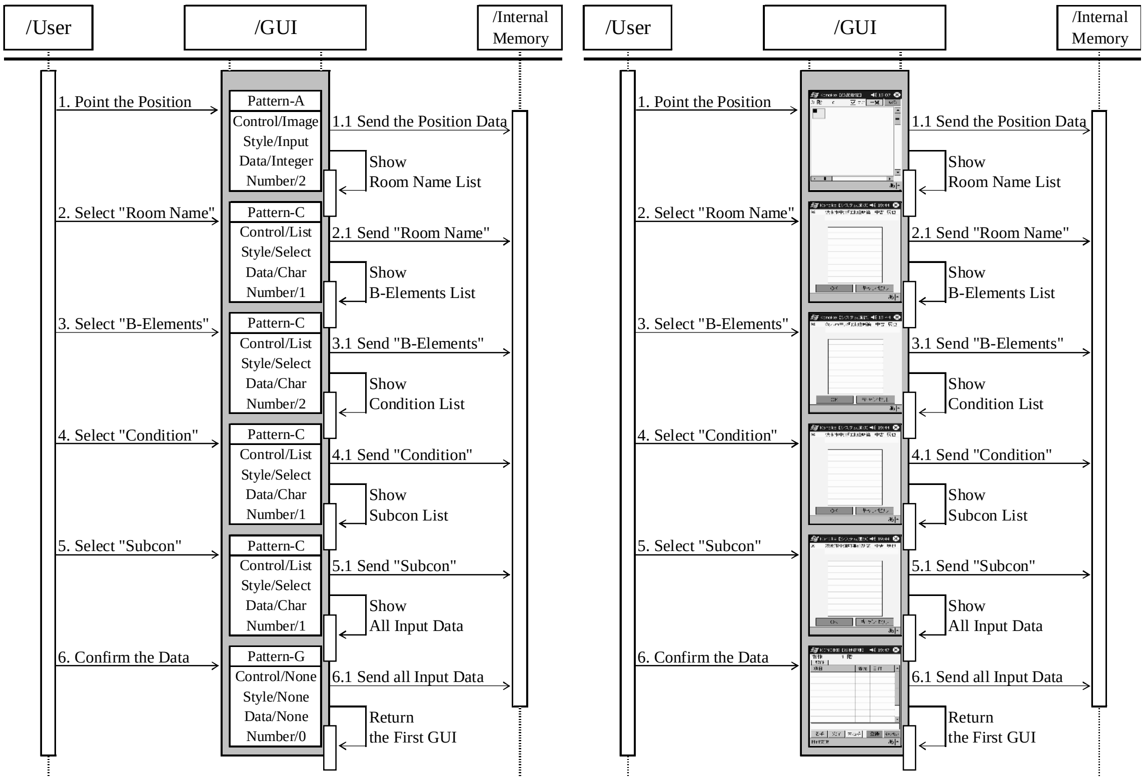

Figure 5: From User Interface Model to Real Graphical User Interface

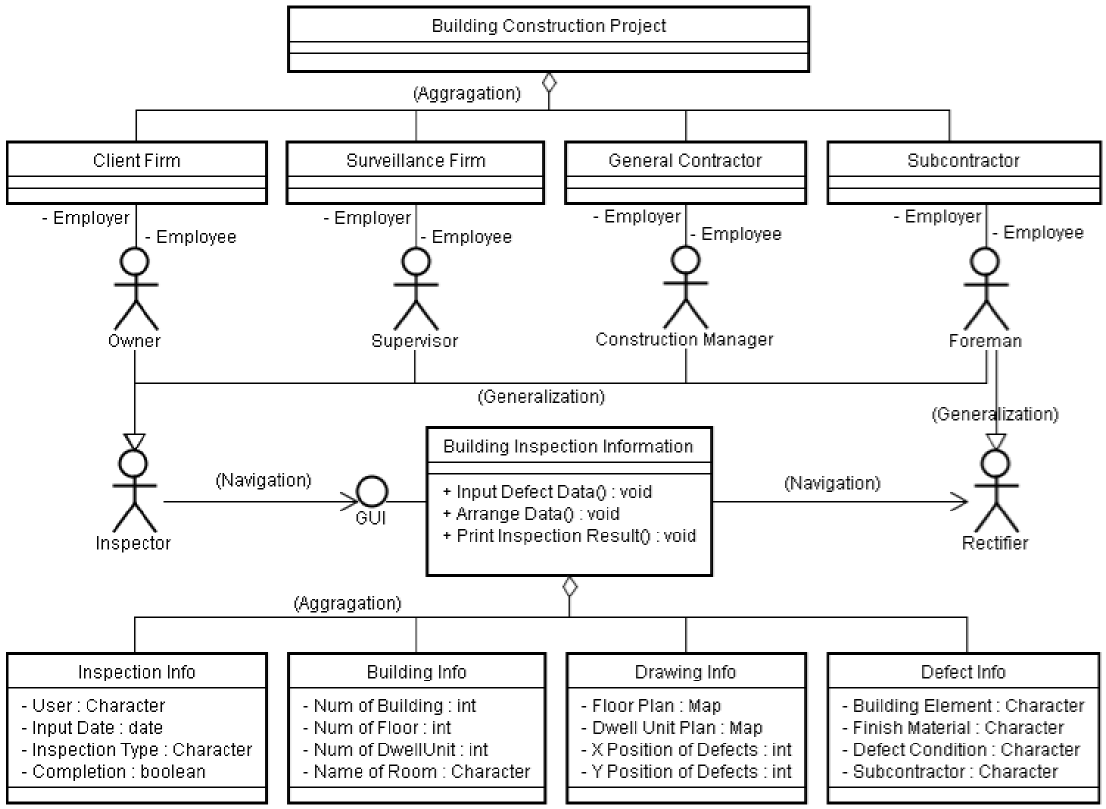

Figure 6: Class Diagram of Mobile Computer-Aided Management System

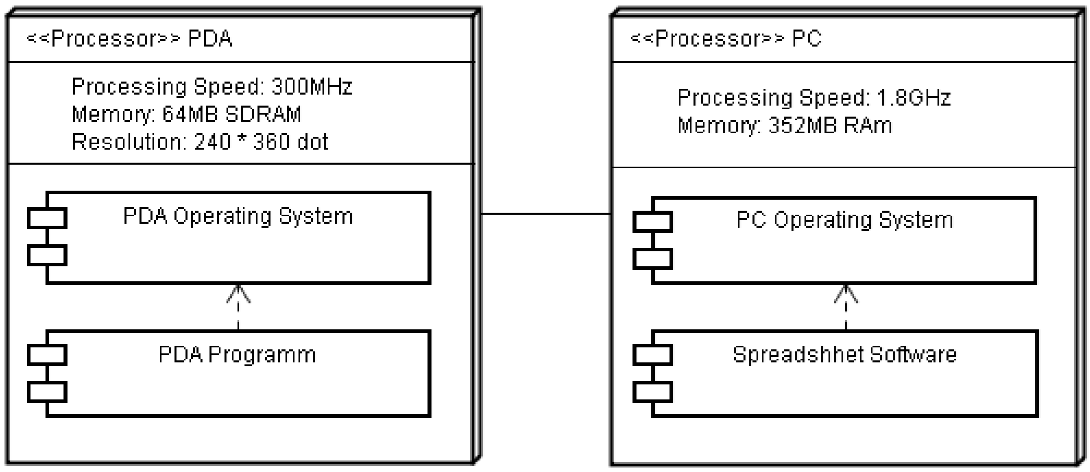

Figure 7: Deployment Diagram of Mobile Computer-Aided Management System

4.2 CASE 2: Schedule Simulator for Repetitive Construction Work

Figure 8 shows Use Case Diagram of Schedule Simulator [5]. The meaning is as follows. The system is an interactive one. Construction managers use the system for their own construction planning. They set up the system and get the answer. The planning of cycle schedule with the simulator is composed of three sub works: “set a construction plan”, “get the schedule” and “evaluate the schedule plan”.

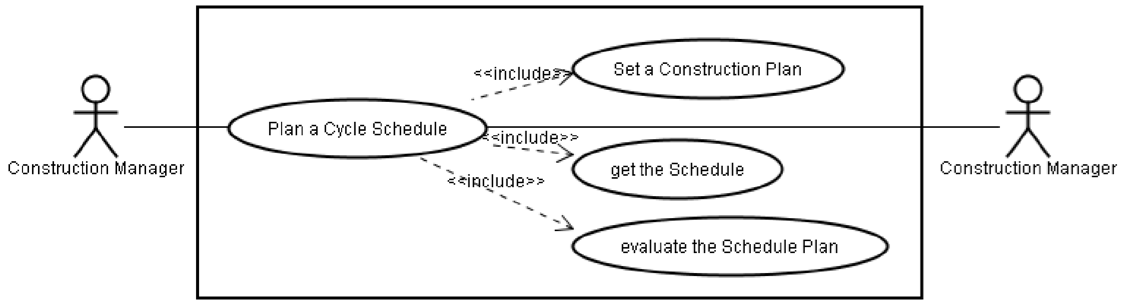

Figure 8: Use Case Diagram of Schedule Simulator

Figure 9 shows Class Diagram of the system. The meaning is as follows. Class in the system is divided to two categories: the planning and analysis, and the scheduling. The former has three classes: Plan, Database and Plan Analysis, and the latter has three classes: Relationship, Schedule and Graph. Figure 10 shows Deployment Diagram of the system. Spreadsheet software takes charge of the category of planning and analysis. Scheduling software takes charge of that of scheduling. The graphical user interface is directly connected with the spreadsheet software. End users use the function of the scheduling software by way of the spreadsheet software.

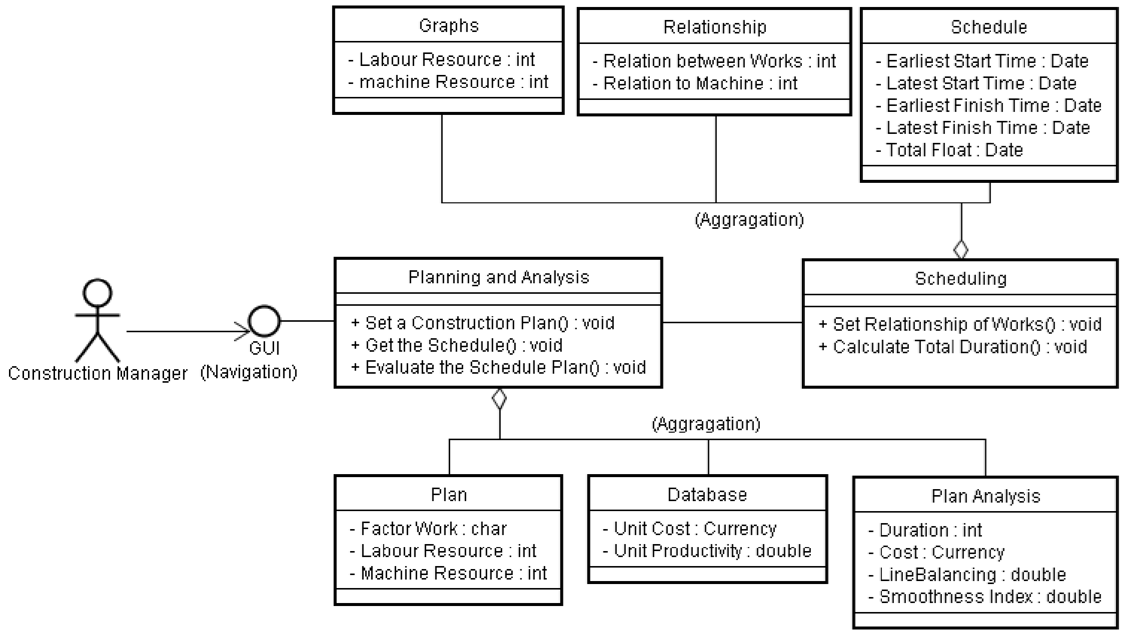

Figure9: Class Diagram of Schedule Simulator

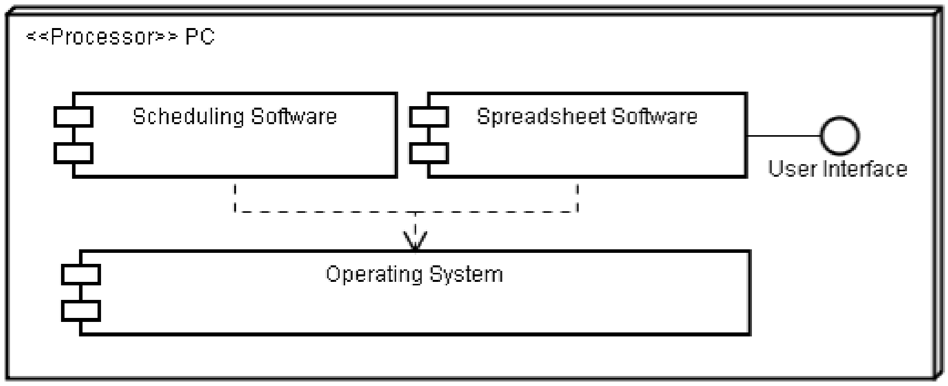

Figure 10: Deployment Diagram

4.3 CASE 3: Long Term Repair Planning and LCC Estimation System

Figure 11 shows Use Case Diagram of Long Term Repair Planning (LTRP) System [6]. It shows that construction managers and equipment engineers use the system, and that the owner and facility managers get the result. The system is composed of making a long term repair time table, and calculating the annual expense.

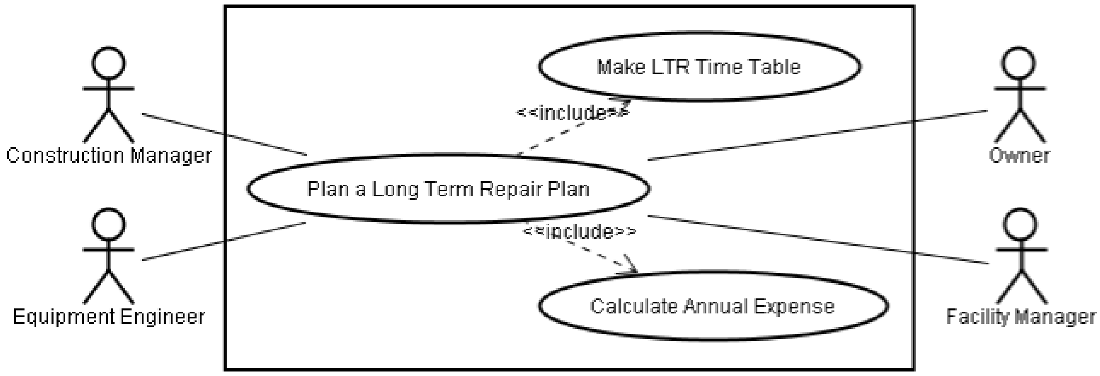

Figure 11: Use Case Diagram of Long Term Repair Planning

Class Diagram in figure 12 shows the structure of the systems: LTRP System and LCC Estimation System. These systems hold the data of cost and repair cycle for buildings in common. The diagram also shows the users. Sequence Diagram in figure 13 shows the message flow between users and LCC Estimation System, and that between the system and the database.

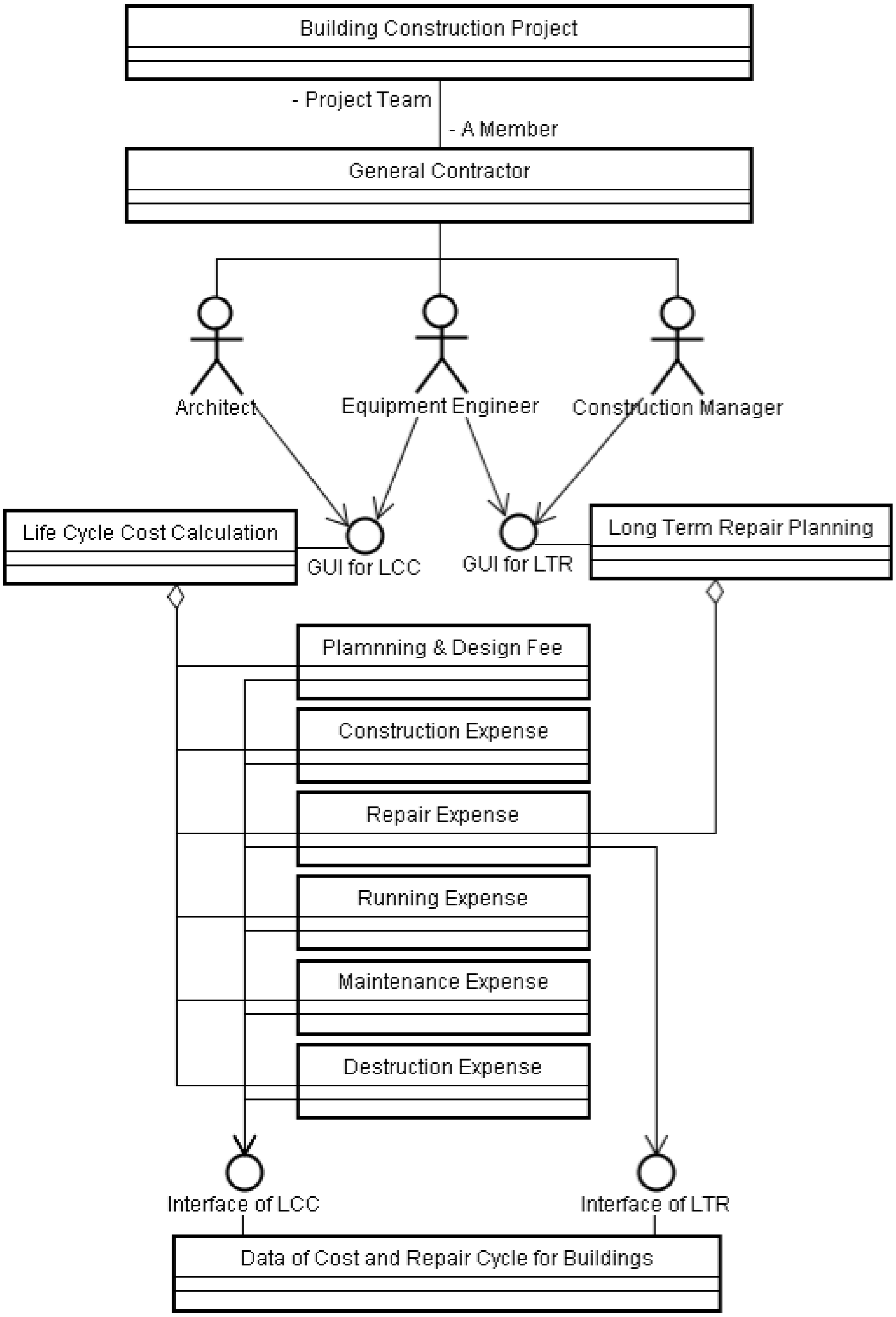

Figure 12: Class Diagram of LTR&LCC System

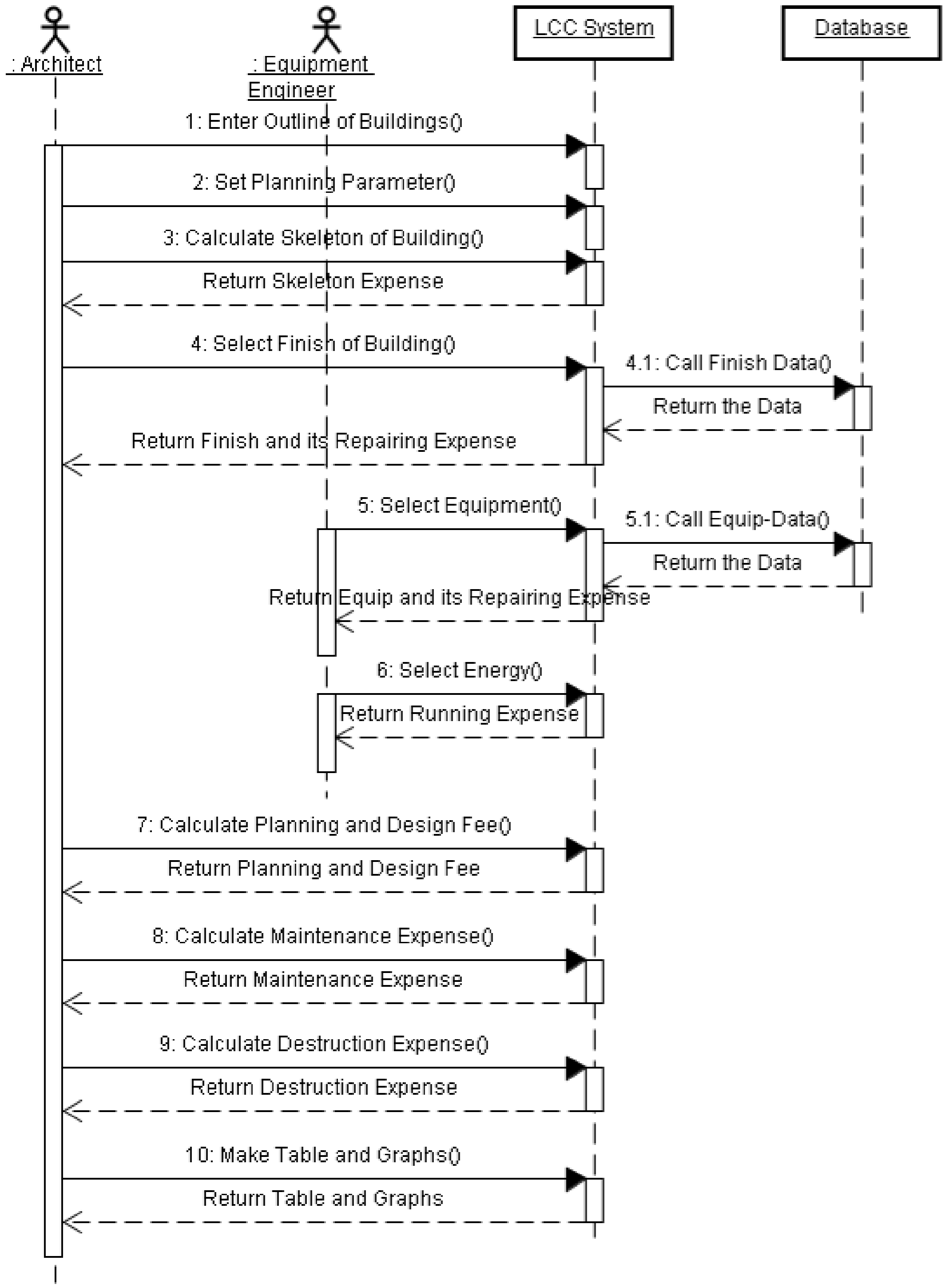

Figure13: Sequence Diagram for LCC

5. How to Evaluate Management System with UML

The introduction of IT systems usually aims the improvement of productivity and/or the extension of the function in the system. Therefore, end users and system developers must estimate the change, examine the effect, and evaluate the new system carefully. The tool for them is necessary. There is some possibility in the description of the system with UML.

5.1 Analysis of Shorter Working Hours and Working Saving

UML is a graphical language for visualizing, specifying, constructing, and documenting the artefacts of a software-intensive system [10]. Therefore, it can express the difference between systems visually. Figure 14 shows sequence diagrams of two models about the inspection work. Model 1 is the traditional way with paper sheets for both the data input and the rectifying order. Model 2 applies Mobile Computer-Aided Management System for inputting the data and making the order sorted by subcontractor. The comparison shows that the working hours and volume of inspectors decreases at the transition from Model 1 to Model 2. Moreover, Model 2 holds the data and creates the inspection sheet as a digital form. This means the door open to the further development. For instance, the analysis of the defect data is possible. All stakeholders will be able to hold the result in common through the network.

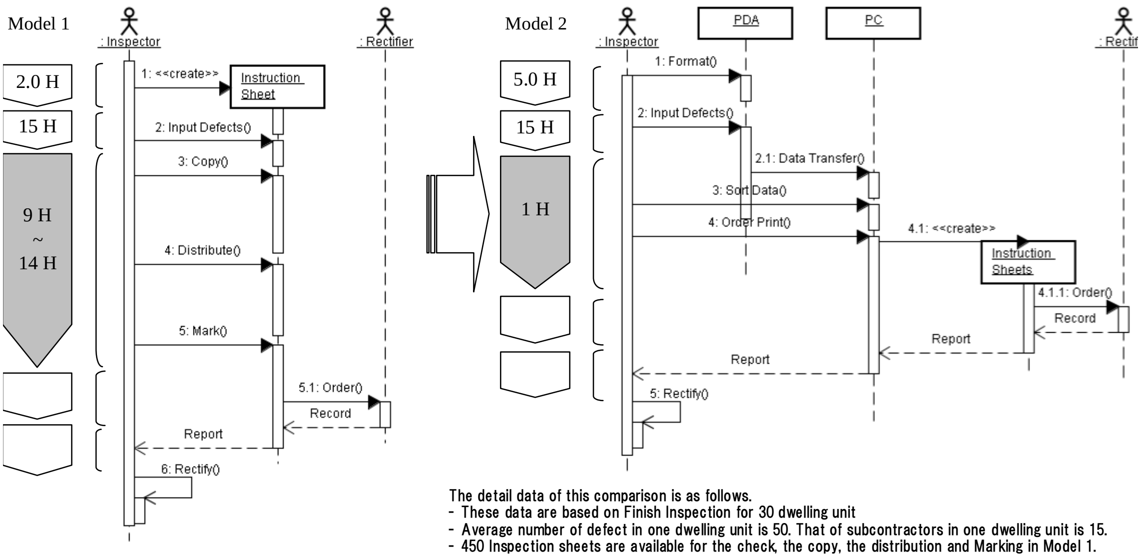

Figure 14: Comparison of models with Sequence Diagram

5.2 From Project-based Analysis to Company-based Analysis

Not only project-based analysis but also company-based analysis is necessary in the improvement of work because the work out of project such as the development of the system and the maintenance of database exists. The consideration of added value of systematisation with IT is important. So, the description of business model has been more important [1, 9]. The enlargement of the description scope will improve the precision of the evaluation.

6. Conclusions and Discussion

This paper describes the methodology of the description and evaluation of management system with UML. Especially, the authors aim the information system based on EUC and design pattern at a target. EUC is the approach from the viewpoint of organization, and design pattern is that from the viewpoint of computer system structure. Both are the mechanism to realize the diverse and rapid design of information system.

First, the paper shows the function of diagrams and the order of their use. The paper demonstrates the description of three systems with UML. Use Case diagram can show the use case of the systems. Sequence diagram can show the data flow in the system. Class diagram can show the organization of actors and information in the system. Deployment diagram can show the composition of hardware and software in the system. The paper shows the description of the actual systems and confirms the function of UML as a useful tool to describe the diverse of computer system.

Secondly, the paper proposes the user interface model in sequence diagram. The model is the key in the communication between end users and system developers because end users can give their opinion to the user interface. Moreover, the authors propose design pattern for the model. It makes it easy for end users to approach the model. Once the model is established through their discussion, system developers can develop the system easily and rapidly because design pattern has designed the detail of the specification in advance. In Mobile Computer-Aided Management System, the authors have actually derived some subsystems with design patterns: the inspection system, the progress monitoring system, the position check system, and the checklist and reference system. The paper indicates that EUC and design pattern are useful for the project-based development of computer system corresponding to project management for construction, and gives demonstrations.

Finally, the paper shows the comparison of two sequence diagrams as the evaluation of the system with UML. The one shows the traditional way with paper sheet for the inspection work. The other shows the application of Mobile Computer-Aided Management System. The comparison indicates the difference of data flow clearly. However, sequence diagram doesn't show the work volume. The authors add the information of necessary time for factor process. As a result, the diagram makes clear of the shorter working time by the introduction of the computer system. The evaluation of computer system needs the company-based analysis. More extension of UML is necessary. Marshall, Erickson and Penker have extended the function of UML for the description of business model [1, 9]. On the other hand, UML has spread as a tool for the description of computer system in actual business. The authors have tried to extend UML from the viewpoint of the evaluation of computer system in business. The authors expect that this result compensate the gap between at the tool level and at the business level.

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ICT in Construction and Facilities Management

ICT today is maturing fast and is seen as a key enabler for the better planning, monitoring and control of construction and facilities management activities. It has gone beyond the simple functional purpose of scheduling projects or estimating costs. In fact integrated ICT systems are being used to manage the complete building lifecycle. The use of product models in the form of complete building information models are but one step in this direction.

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