A FRAMEWORK FOR EXPLORING ICTM IMPACT ON BUILDING DESIGN AND MANAGEMENT APPLIED TO A HOSPITAL DEVELOPMENT PROJECT

Proposing ICTM to Building Design and Management for Information Consistent Control of Construction and Service Robots

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Abstract: The field of building design is complex, and the successful interplay between iterative and interdependent processes, roles and actions can be seen as a foundation of developing good architectural design solutions and building projects. Over the years, the development of ICTM (Information- and Communication Technologies Management) has led to several changes in the AECFM (Architecture,Engineering,Construction, Facility Management)- industry. The main topic of this paper is to explore expected and perceived benefits and challenges from the use and implementation of IFC (Industry Foundation Classes)-based 3D product model. Special attention is hereby paid to the architect's work and interactions in the building design process, since this defines the economic success of creating real estate. A better overview and understanding of these issues can be crucial for ensuring good architectural design and information consistent management of building projects. This paper focuses especially on four essential, interdependent and iterative aspects of the building design process: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. The framework is furthermore based on the suggestion of three hierarchical levels: the micro-(individual), the meso (group/project)- and the macro-level (AEC-industry). The framework aims to support the exploring and analyzing of data collected in order to gain better understanding and overview of the complex relationship between ICT and building design and management, and to achieve a well structured and consistent information environment as a prerequisite for construction and service robot applications.

Keywords: building design process, building design management, IFC-based BIM, ICT impact, robotics

1. INTRODUCTION

A fundamental pillar of a successful building project is a good design process. The field of building design is complex, and the successful interplay between iterative and interdependent processes, roles and actions can be seen as a foundation for developing good architectural design solutions and for defining the economic success of creating real estate. Over the years, the development of ICT (Information and Communication Technologies) has led to several changes in the AEC industry and the participants involved in the different phases in a building project's lifecycle face ICT related benefits and challenges on several levels. Both working processes and role definitions are affected [1].

Much research of today focuses on the development of new and improved ICT. The topic of this paper is how the use and implementation of ICT impacts on the building design process. Special attention is hereby paid to the architect's work and interactions in the early phases of a building project. A better overview and understanding of this topic can be crucial for ensuring good architectural design and information consistent management of building projects.

This paper is based on a framework for exploring the ICT impact on building design and management [2]. The

framework aims to support the exploring and analyzing of data in order to gain better understanding and overview of the complex relationship between ICT and building design and management, and to achieve a well structured and consistent information environment as a prerequisite for construction and service robot applications. This framework focuses especially on four essential, interdependent and iterative aspects of the building design process: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. The framework is furthermore based on the suggestion of three hierarchical levels of operations and actions within the building design process. The **micro-level** comprises individual and cognitive processes, as for instance the creative and reflective processes in the head of the individual architect [3],[4]. The **meso-level** covers the mechanisms within a group, for instance the architect's interaction with other designers and consultants within the design team. The **macro-level** comprises tasks and mechanisms on overall AEC-level level (Fig.1).

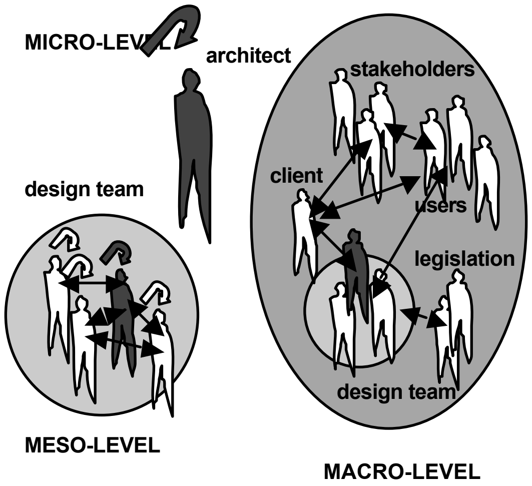

Figure 1. The three hierarchical levels

An ICT impact matrix, built up on the four selected design aspects and the three hierarchical levels, summarizes the explored key benefits and challenges regarding ICT implementation and use. The framework and the ICT impact matrix aims to support the exploring and analyzing of both theory and practice, in order to gain better understanding and overview of the complex relationship between ICT and building design and management in order to achieve a well structured and consistent information environment as a prerequisite for construction and service robot applications.

The purpose of this paper is to illustrate how this framework has been used to explore several architects' experiences due to use and implementation of ICT in a large hospital development project in Norway; the AHUS project. The paper focuses especially on the experiences made from the use and implementation of a 3D product model (building information modeling or BIM) based on IFC (Industry Foundation Classes) and intelligent objects. An ICT impact matrix [2] at the end of the paper summarizes the key points from the exploration and the implications for building design and management for an information consistent environment will be discussed.

2. INTRODUCING THE AHUS PROJECT

The new Akershus University Hospital (AHUS) is a major hospital development project in the suburbs of Oslo, Norway. The new hospital buildings comprise a total floor space of 116.000 m2 (fig. 2). After an architectural competition and several revisions, a final main outline of the project was presented in May 2003, and this outline became the basis for further design development and detailing. Full operation is planned during the autumn 2008 [5]. The architect suggested early to implement a 3D object model (BIM) based on IFC. The client's "go" for this suggestion, made the AHUS project to what Khemlani [6] calls "*a front runner in Norway in the use of IFC-based BIM*". The project is divided into five main building parts, with their own teams of architects and consultants. The 3D object model has to a different degree become implemented in the five building parts. Only the architectural team developing and planning the front building uses the 3D object model to (almost) its full extent. This paper focuses on this front building part (2.500m2), which contains different public hospital services. The modelling of the front building started autumn 2004, and in the spring of 2005 the 3D object model was "completed", a little later as expected. This paper represents a "cut" of the running project (May 2005), made at the end of the design process, shortly before the front building project was going to be handed over to the contractors and the production of the building started.

Figure 2. The AHUS project and the front building

There are four ICT cornerstones in the front building project. Firstly, the 3D product model (AutoCad ADT 2004) which: Given the huge size and complexity of the project (…), the main focus of the use of the 3D product model was to keep track of all the objects—rooms, components, fixtures, furniture, and equipment—not just during design and construction but throughout the project lifecycle [6]. This paper focuses mainly on the implementation and use of this 3D product model. The 3D product model is a computer model based on three-dimensional objects containing "intelligent" information about for instance materials, qualities, prices etc. All building project information should be gathered in this one model, and "traditional" drawings as plans, sections etc. can directly be generated from it. Thus, there are no parallel illustrations of building parts comprised on different drawings and documents

Secondly, in a document database (ProArc) all drawings and documents was to be archived and distributed, no parallel document archiving was allowed. Thirdly, a room database containing room lists, equipment lists etc. represented the users programme and requirements (dRofus). And finally, e-mail was an important tool in the everyday project communication.

Three IFC R&D projects were partly are implemented and tested within the planning of the front building at the time the interviews were carried out. An IFC Model checker (Solibri) can check the consistency of the 3D object model through intersecting objects, doubles- and clash-detection etc. Another project is the linking of the room database with the 3D object model, with the possibility to check deviations between the users' requirements due to rooms and equipment, and what is actually integrated in the object model. In Mai 2005, this project was partly implemented. The last project was to transfer object information to Facilities Management (FM) systems (Bakkmoen, BuildingSMART conference in Oslo, 31.05.-01.06.2005).

3. INTRODUCING THE INTERVIEW RESPONDENTS

The presented exploration of the project is based upon open ended interviews with four architects carried out Mai 2005. All of the interview respondents were involved in management tasks on different levels in the project. Their perception of the project processes, participants, and the use and impact of ICT, can deviate from how something really happened. Three of the architects worked for the architectural firm, one of them represented the client.

The presented data from the interviews are intended to give a rough picture of ICT-related expectations, benefits and challenges on all levels regarding the four design aspects, thus illustrating how the framework could be applied for exploring a real-life project. Therefore interview respondents were selected representing experiences perceived from different levels, views and positions within the front building project. One of the respondents was a frequent user of the 3D product model, without a direct influence on the implementation and development of the model. This was the responsibility of the other two respondents from the architectural firm, who both administrated and facilitated the implementation of the model in the front building team and on project level. The last respondent had no special knowledge about how to use or develop the technology, but as a client he has strong and obvious interests in a successful implementation leading to a successful building project.

4. MACRO-LEVEL: THE NORWEGAIN AEC INDUSTRY AND THE IMPLEMENTATION OF ICT

With the aim to ensure interoperability and efficient information exchange between different ICT systems, IAI (International Alliance of Interoperability, also called buildingSMART) was founded in 1995 [7]. IAI is the key actor behind the development of IFC (Industry Foundation Classes), which shall ensure a "system-independent" exchange of information between all actors in the whole life cycle of the building . From feasability and investment analysis to briefing and maintenance of building.
Intelligence acquisition from investment decision, to rentabilty and serviceability, buildability and and reuseability will reduce the friction between planning phases (especially between planning and production) and roles which lead to delays and misunderstandings, often resulting in increasing building and maintenance costs. One of the visions is that all participants should work with a common model throughout the whole life cycle of the project. The borders between the traditional phases and role definitions in a building project will blur and merge, allowing information and experiences from production and building maintenance to be fed forward into the design phase of the building project. A challenging issue regarding this issue to define which information is necessary for making the best decisions on every stage in the project.

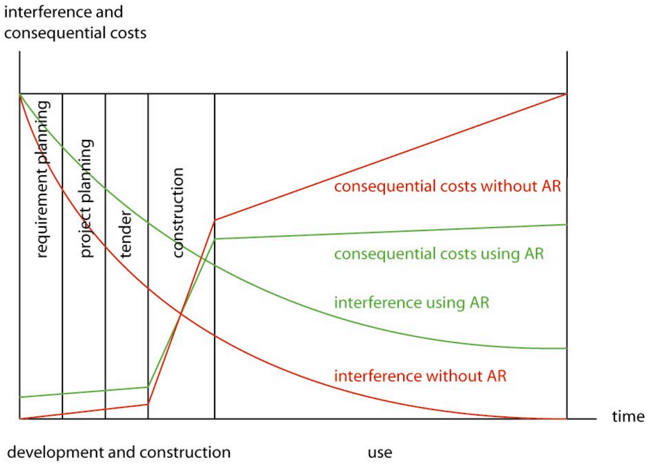

Figure 4.1:Interference of building investments
The use of a 3D product model support the capturing of (explicit) knowledge, for instance can the information embedded in the 3D products be seen as a storing of information, which can be reused in other projects. One of the respondents from the architectural firm would welcome an evaluation of the project after completion. Such an evaluation of the experiences made in the AHUS project could support capturing valuable (explicit) knowledge and competence, thus becoming a sufficient starting point for benchmarking, programming and designing new building projects. The POE (Post Occupancy Evaluation) method, developed by Prof. Preiser of Cincinatti University, USA, can be helpful in the future.

In discussions about the implementation of IFC-based BIM and according to the interview respondents, the emerging challenges linked to contractual issues regarding definition of responsibility and roles, and cultural issues regarding different working methods and ways of generate and evaluate solutions, communicate and making decisions, are "hot" topics.

The Norwegian Chapter of IAI is an important driving force behind the development of IFC-based BIM in the Norwegian building industry. The AHUS project is the first Norwegian project in this scale where this quite new technology has become implemented. Through the key positions of one of respondents both in the Norwegian IAI and the AHUS project, an interplay between the visions defined on the macro-level and the experiences made in the project, both individual (micro-level) and in the building design group (meso-level) was made possible.

The potential of the technology for ensuring project material consistency and quality was one of the triggering factors behind the decision of implementing IFC-based 3D product model in the AHUS project, especially regarding the crucial transition of data between the planning and the construction stage in the project. This issue was far more important than the potentials regarding realistic 3D visualization, which was regarded as a nice side-effect of the technology.

Another motivating aspect behind the implementation was the knowledge building effect; to collect experiences and build up competence around the implementation and use of this still quite new and untested technology within the AEC industry. Both the client organization and the architectural company are convinced that IFC-based 3D product models will become the major planning tool in building projects within few years.

Finally, the potential of the IFC-based 3D product model to facilitate interoperability; an uncomplicated, transparent and efficient exchange of information between the different actors and systems involved in the AHUS project, was another essential motivation behind the implementation.

5. MESO-LEVEL: USE AND IMPLEMENTATION OF ICT IN THE AHUS PROJECT DESIGN TEAM

In the AHUS project, there are defined several formal structures for communication and decision-making. Regularly there are arranged meetings for different purposes (every 1-2 weeks). The front building planners meeting is the operational instrument of the project and of the design team. Every decision regarding the design and development of the front building is made here. In addition to the responsible persons from the different building planning disciplines (architects and consultants), there were also participants representing the users and the client. The extensive degree of user participation required also another important forum for design related issues; the user meetings taking place autumn 2004.

Although every communication between the architects and the other consultants theoretically should include the client, informal communication within the design team was usual and to some degree also wanted. All respondents emphasized the advantages of the collocated situation, with the opportunity to build up a common understanding and culture, and to exchange information and make ad hoc decisions in an uncomplicated and fast way.

The 3D product model was not used directly in the formal meetings. Evaluation of the project development and decision-making was based on views or cut-off drawings (2D) generated from the model, partly projected on a screen using a beamer. Once a week cut-offs of the 3D object model were made available in the document database. Every relevant and up to date drawing or document was easy and fast accessible, which the respondent representing the client regarded as a huge advantage of ICT in order to better could follow, control and evaluate the development of the planning. However, he perceived the 3D product model itself being a black box to which the client has no directly access, unless he has special competence in handling this technology. In this project, this drawback could be compensated by the collocated situation, since the client could easily get information from informal face-to-face meetings with the architect and the other consultants.

In both the formal and the informal design team meetings the pen, sketch paper and physical models were still central tools supporting ad hoc solution generation and decision-making. In the meetings with the user, however, the 3D product model became a valuable support for preparing discussion and decision-making material. Around 1000 unique rooms on total project level made a huge amount of drawings necessary as basis for the discussions and decisions. All these drawings (sections, plans and elevations) were generated directly from the 3D model.

The implemented IFC version did not allow rendering of the objects. It was not possible to generate realistic visualizations and walk-throughs directly in the 3D model environment, which could have been useful for more dynamic and interactive presentations of design solutions in e.g. the users meetings, thus supporting the decision-making process However, the 3D product model of the front building had at the time of the interviews reached a stage where calculations and simulations regarding indoor climate, energy consumption etc. could have been possible. But according to the respondents the model was too “heavy” to use and change. Therefore, to work real time in the 3D environment in meeting situations demonstrating e.g. “live” simulations was not an issue since this would have required more rapid simulations or visualizations of the change consequences. An underestimated issue became the need for more powerful computer processors. The object model files were far heavier than the traditional line-based 3D models; an experience regarded as much useful for developing better file structures in future projects.

Although one of the main aims behind building up an IFC-based 3D object model was the issue of interdisciplinary and interoperability, at the time of the interviews only the architects worked directly with the 3D product model. The other consultants used the 2D cut-offs and dwg-files as their base of planning. The cut-offs and the dwg-files were accessible in the document database. However, tentative and informal drawings were often exchanged between the architects and the other consultants using e-mail instead of the document database.

The elements received from the consultants, for instance columns and slabs from the structural engineers, the architects partly “transformed” to fit into the model. Since the architects thus themselves generated 3D objects from other consultants’ elements, they felt, according to one of the respondents from the architectural firm, that they better could control the consistency of the 3D model and its data.

6. MICRO-LEVEL: THE INDIVIDAUL USE OF ICT IN THE AHUS PROJECT

The individual architect worked within a 2D user environment, dragging and dropping 3D objects. According to one of the respondents, this way to “draw” should be easier as the traditional drawing with lines, and

normally no special competence of the every day operator was necessary as long as pre-defined objects were accessible. However, till then, there were no pre-defined library of objects and building elements available. Every intelligent and IFC exportable object had to be defined "from scratch". Both defining and changing these objects meant time consuming processes within narrow time limits. There were not many architects within the project having the required competence for such tasks. This leaded to bottlenecks in the planning and loss of valuable time. One of the respondents and users of the technology, indicated the danger that planners could be tempted to avoid improving changes in stressed project periods. Furthermore, she pointed out that the lacking time and recourses to learn and be up-to-date partly resulted in an inefficient use of the rapidly developing ICT tools. The implementation of the model required that the architects working with it continuously had to extend their competence concerning the use of the software, which was difficult to operate, not intuitive and parametric.
In the building team, one person was full time involved with programming and building the 3D product model.

Both respondents involved in design tasks only to a limited degree uses the 3D product model in the individual generation and visualization of design solutions. According to one of them, she first made some rough sketches with pen and paper, before she transformed the idea into computer generated drawings. She tested her design ideas traditionally in 2D computer environment, using lines, not objects. Transforming the 2D lines into 3D objects was made later, partly resulting in a 3D model not completely based on objects. Both respondents saw the lack of time recourses and the "heavy" operating of the model as the main barrier of using the 3D model directly for visualization and testing of design ideas. Furthermore, in order to produce consistent data and information, much discipline and effort was required from the technology user.

Table 1. *The ICT impact matrix – examples benefits and challenges from using IFC-based 3D product model in the building design process*

	Macro-level	**Meso-level**	**Micro-level**
Generation of design solutions	**benefits:** - design generation based on life cycle knowledge **challenges:** - understanding the creative processes - technical competence required	**challenges:** - model not intuitive and parametric, heavy	**benefits:** - reuse of solutions - pre-defined objects **challenges:** - model not intuitive and parametric - much competence required - time-consuming - implementing object-oriented working method - predefinition of products
Communication	**benefits:** - interoperability - less communication friction - merging of borders between planning, production and maintenance **challenges:** - contractual issues/definition responsibilities - cultural issues/different working cultures	**benefits:** - better access to consistent and updated information **challenges:** -different working cultures - lack of trust regarding quality of documents received from other disciplines - redefinition of working methods	**benefits:** - better access to consistent and updated information - potential of generating ideas in virtual reality - rapid production of consistent project material **challenges:** - not intuitive and parametric - rough hand-sketches the basis for the ideation
Evaluation of design solutions	**benefits:** - testing virtual building before physical building **challenges:** - degree of detail - info overload	**benefits:** - potential of real-time simulations - potential better coordination (e.g. clash-control) **challenges:** - time-consuming - not intuitive	**benefits:** - precision - "visual" control of complex esthetical issues **challenges:** - time-consuming
Decision-making	**benefits:** - decision-making based on consistent information - reduction of uncertainty **challenges:** - definition of which info is necessary - info overload	**benefits:** - consistency and precision of decision material - reduction of uncertainty **challenges:** - bias relation technical and esthetical aspects	**benefits:** - consistency and precision of decision material - reduction of uncertainty **challenges:** - presentation taking focus from content of design

In the future we want to consider investor, user, tenant on an ultra level and intuitive brain wave triggered design on a nano level.

7. DISCUSSION AND OUTLOOK

The ICT impact matrix (Table1), which is based on the three hierarchical levels and the selected four design process aspects, summarizes some of the experiences made due to the use and implementation of ICT in the AHUS project. According to the interview respondents, one of the aims was to ensure consistency in the planning material and to achieve a more efficient exchange of information, especially regarding the crucial transition of information between planning, construction and building services and maintenance. However, much time, competence and effort are invested in modelling and programming, partly caused by the lack of pre-defined objects.

The model is "heavy" and difficult to use regarding the normal design process day. But all respondents, also the every-day users of the 3D object model, were aware of what they perceive as essential benefits of using the ICT tools in this project, such as better control of rooms and equipment, the generation of building descriptions, the quantity take-off etc. Especially when it comes to the construction phase of the building, the key persons behind the ICT implementation hope to “reap the fruits” of the many participants’ effort and commitment.

This paper has illustrated how a framework for exploring the ICT impact on the building design process can be applied to a hospital development project in Norway. The tentative impressions of the frameworks’ adaptability on practice, is the potential for supporting and guiding the collecting, analyzing and presenting of the empirical data.

Regarding the project presented in this paper, the approach helped keeping overview of actors and processes, and their experiences due to use and implementation of ICT. There are of course still several aspects to be further developed and clarified, especially regarding the definition of the levels and the understanding of the interactions between them and the four design aspects. For extending the empirical basis, further case studies and interviews will be carried out.

The use of IFC-based 3D product models is still quite new and untested in real life building projects. In the AHUS project, they are still facing many “children diseases”, regarding for instance technical limitations and user behaviour. In practice, there are still many challenges to be handled before they can be turned into solutions, which the experiences made in the AHUS project, indicate.

However, the further development and testing of ICT and IFC-based 3D product models in building projects could close the loop between planning and operation through for instance the feeding crucial POE data into the early building phases. A consistent information environment could open up for an area which until now has been paid little attention in at least the European AEC industry – the application of construction and service robots.

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REFERENCES

[1] Wikforss, Ö. (2003) *Byggandets informationsteknologi. Så används och utvecklas IT i byggandet,* Svensk byggtjänst, Stockholm.

[2] Moum, A. (2005) "ICT and the Architectural Design Process - Introduction of an ICT Impact Matrix," in *ICT in Construction and Facilities Management*, A. S. Kazi, ed., VVT - Technical Research Centre of Finland and RIL - Association of Finnish Civil Engineers, pp. 2-13.

[3] Lawson, B. (2006) How Designers Think, The Design Process Demystified, 4 edn, Architectural Press, Oxford.

[4] Schön, D. A. (1991) The reflective practitioner how professionals think in action, Ashgate, Aldershot.

[5] Public website, http://www.nyeahus.no, Accessed Mai 2006

[6] Khemlani, L. (2005) Prefabrication of Timber Buildings based on Digital Models: A Perspective from Norway, AECBytes. Analysis, Research, and Reviews of AEC Technology, Electronic Journal http://www.aecbytes.com/feature/Norway_prefab.htm, March 2005.

[7] Public website, http://whttp://www.buildingsmart.com/ Accessed May 2006.

[8] Preiser, Wolfgang (2001) Post Occupancy Evaluation, Cincinati University , U.S.A.