

Anita Moum

Exploring Relations between the Architectural Design Process and ICT

Learning from Practitioners' Stories

Thesis for the degree of Philosophiae Doctor

Trondheim, August 2008

Norwegian University of Science and Technology
Faculty of Architecture and Fine Art
Department of Architectural Design and Management



NTNU

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ISBN 978-82-471-1121-5 (printed version)
ISBN 978-82-471-1122-2 (electronic version)
ISSN 1503-8181

Doctoral theses at NTNU, 2008:217

Printed by NTNU-trykk

summary

The overall aim of this thesis is to contribute to knowledge on the current situation in practice by investigating relations between the architectural design process and Information and Communication Technologies (ICT) in real-life projects. There is a growing need for more knowledge on what happens when new technologies are implemented and used in the practice of architectural design. We lack a comprehensive understanding and overview of non-technological factors, as well as of the relationships and interdependencies embedded in the encounter between the practice of architectural design and ICT. Two research questions are formulated. Firstly, what are the factors affecting the implementation and use of ICT in the practice of architectural design? Secondly, how do the implementation and use of ICT impact the work and interactions of practitioners involved in the architectural design process?

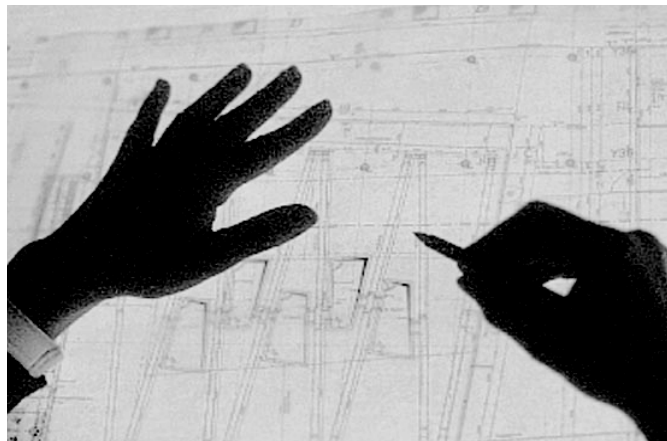
Several actions have been undertaken to address the research aim and questions. Firstly, a descriptive and holistic framework has been developed for exploring both literature and real-life situations. The main elements of the framework are related to two dimensions of architectural design practice. First, there is the process dimension and the focus on four design process aspects or tasks; the generation of design solutions, the communication, the evaluation of design solutions, and decision-making. Second, there is the level dimension, representing different social constructions embedded in a building project, which again is embedded in the context of the AEC industry. Three levels are proposed; the micro-level (the individual practitioner), the meso-level (the design team), and the macro-level (the overall project). Two framework tools have been established; the 'ICT impact matrix' and the 'multi-level factor model'. The framework and its tools have been applied to three further actions related to qualitative case studies of four real-life projects; one of these as the main case, and the other three as reference cases. These three actions, where particular attention is paid to the work and interactions of the architects and engineers in the design team, and to the implementation and use of technologies supporting 3D object-based modeling or Building Information Modeling (BIM), are: the identification of enablers and barriers affecting the implementation and use of these technologies, the exploration of relationships between these enablers and barriers, how these relationships affect the implementation and use, and finally, the exploration of the role of these new technologies and tools in the work and interactions of the practitioners involved. Together with passive observations and desk research, open-ended interviews are the main source of evidence. More than thirty respondents from the building projects are interviewed, in addition to several experts from practice, research or academia.

An important feature of the research is to consider both the situations observed at the different levels in the building projects and their context. Here the focus is on international or national R&D efforts for ICT integration in the Architecture-Engineering-Construction (AEC) industry. Further key features are the 'digging-broadly' approach to the problem field manifested by the holistic framework, and the detailed and reflective 'digging-deep' exploration of real-life situations identified by its application. Together with an elaborative and narrative 'storytelling' technique, the framework and its tools serve as the main vehicles for analyzing, organizing, and reporting on the data compiled from the case studies.

The identified factors affecting the implementation and use of technologies supporting 3D object-based modeling or BIM in the four examined projects can be related particularly to three main areas; firstly, to the skills and behavior of the project participants when it comes to adapting to new tools and related work methods; secondly, to the affordance of the tools with respect to the complexity of the work and the interactions of its users; and thirdly, to the tasks and interactions embedded in the practice of architectural design. This thesis reports on several enablers and benefits, particularly with respect to the development, control, coordination, and communication of geometrically and functionally complex design solutions. However, a number of barriers and challenges were observed, which still have to be tackled. Many of them can be related back to the lack of skills and to the shortcomings of the tools, and in all the projects, efforts were put into handling the effects of these in part foreseen factors. Nevertheless, a number of the barriers and challenges arose out of the complex and iterative nature of the architectural design process and the individual and collective tasks to be performed by its actors. 'The wheel of tasks, tools, and skills' is provided as an illustration of the relation between the implementation efforts, the three main fields of enablers and barriers, and the experienced benefits and challenges from use in the real-life projects. Understanding and balancing upstream and downstream interrelations between the factors in this wheel, which are placed on different levels, and in the projects' context, is recognized as crucial for the implementation and use of the new technologies in the architectural design process, particularly with respect to balancing the strategies and aims for ICT implementation against the experiences from adaptation and use in the practice of architectural design, and the 'tasks, tools, and skills'.

The contribution of the research is threefold, providing; firstly, the holistic framework for exploration and description of real-life practice – and the framework tools for analyzing and organizing complex and qualitative findings; secondly, a comprehensive and multilayered overview of factors and relations affecting the implementation and use of ICT in the practice of architectural design; and thirdly, case-study narratives and design-team stories as 'stand-alone' examples from current practice. Altogether, this thesis is a detailed and reflective documentation of current and 'established' practice and serves as a basis for future research and learning from real-life situations.

foreword



Sometimes rather small and seemingly unimportant situations can change the direction of one's whole life. In my case, this situation took place in the kitchen of a good friend in Oslo about five years ago. At that time I could look back on almost ten years' experience of working with architectural design and management of several large-scale and complex building projects in Germany. I was happy about being an architect, but I was also concerned about the negative trend with respect to the working conditions in and the influence of the architectural profession, surely coloured by the bad times and regression in the German AEC industry since the mid-nineties. Additionally, my profession was being more and more confronted with the spin-off effects of the rapid development of new communication and information technologies. In 1993, as I started in my first job as an architect, my colleagues were using felt pens and sending the drawings by mail or fax. Ten years later, we all had our own computers; 2D CAD was the everyday tool for drawing production, and information and plans were exchanged by e-mail or a project web. Similar to most of my colleagues, I was happy about the new tools and their support as we could rapidly change and exchange project material and visualize our ideas. However, I also experienced the clients' increasing expectations to speed up processes and integrate new requirements and changes, even extremely late into the process. After a while I felt the rising need for better understanding of how the implementation and use of the new digital tools impact our working day. At that time we were rather suffering

from the challenges than enjoying the benefits. However, I could see that the new digital tools had unutilized potential in supporting our efforts to create good architecture and real estate. Nevertheless, this potential was playing a rather secondary role. The most important issue was to deliver the required performance within mostly too tight time schedules and budgets. A colleague of mine used the following metaphor to describe the situation; in facing the challenge to cut down a whole forest of trees within as short time as possible, we are not able to take our time to sharpen the blunt ax. Thus, getting back to the kitchen in Oslo, when I sat there and expressed my frustration about this situation, my friend suddenly asked whether I had considered writing a PhD. This suggestion triggered the decision I made half a year later; to sharpen my blunt ax and take a step back from practice. Throughout the next years' journey into the exciting world of research there is an array of people who have shared their experiences and knowledge with me, and who have supported and nurtured my work and writing. To all of these I owe my deep gratitude!

At first I want to thank the main advisor of this work, Tore Haugen - for his belief in this project, for the opportunities he has given me and for his support in the ups and downs throughout the entire process. He has allowed me the freedom to find my own way, as well as contributed with his wisdom and advice as I was facing critical crossroads and decisions. I am furthermore grateful to the co-advisors Birgit Sudbø and Bjørn Otto Braaten, for many fruitful discussions and helpful feedback. A particular thank to co-advisor Thomas Bock, for sharing his visions with me and for offering me a base camp at his department at the Technical University in Munich.

My sincere thank to the many practitioners and researchers who have sacrificed their time in order to give me insight into their experiences and knowledge, for their interest and feedback. To all I have interviewed; this thesis could not have been written without your stories! Geert Stryg, Klavs Holm Madsen, Ernst Eberg, Rudolf Juli, Kjell Ivar Bakkmoe and Steen Sunesen - thank you for your help and support in coordinating my visits! I also want to thank Arkitektstudio, C.F. Møller Architects, Henning Larsen Architects, Obermeyer Planen + Beraten, Ramboll Denmark, SINTEF Building and Infrastructure, Statsbygg and Svingen Arkitekter for their permission to use their material in this thesis.

Many thanks to the Centre for Real Estate and Facilities Management and my colleagues there for the support and backup. Furthermore, I want to acknowledge the Competitive Building program and Brian Atkin, for introducing me to the rules of scientific research and to the leading edge of the Nordic IT. I moreover want to thank; Geir Hansen, Grete Vintervoll, Hannu Penttilä, Håkon Gissing, Knut Einar Larsen and Terje Tollefsen, as well as my PhD colleagues at NTNU, my colleagues at the Department of Architectural Design and Management and my colleagues at br+i in Munich, for their feedback and friendship. It has been wonderful to be a part of a these inspiring teams. I am grateful to Ad den Otter, Armando Trento, Christian Koch, Gunnar Næss, Ole Jonny Klakegg, Ole

Jørgen Bryn, Lee Anderson, Markus Peter, Rasso Steinmann, Stephen Emmitt, Timo Hartmann, and the many other researchers and experts who have taken their time for meeting me; for their valuable comments and for being available for fruitful discussions at different points in this process.¹

I owe my deep gratitude to Antje Junghans, Reidunn Rustad, Siri H. Blakstad and Tor G. Syversen for their helpful, critical and valuable comments to the last drafts of this thesis - thus triggering the essential final phase of necessary improvements and clarifications. Many thanks also to John Anthony, Gilbert Salim and Tomas Vassdal for proofreading and for helping me with their linguistic expertise, and to Berit Ingvaldsen for the transcriptions of the Norwegian interviews. I also want to acknowledge my many ex-colleagues; working together with these practitioners, whether architects, engineers, clients, contractors and users, has provided me with valuable experiences. Without these experiences I would not have been able to approach the complexity of the topic!

The decision to start with this PhD was the starting point for a life in and between Trondheim and Munich. This would not have been possible without the support of the Faculty of Architecture and Fine Art at NTNU, and their interest in international collaboration. I am furthermore grateful to my Norwegian family and friends for their hospitality and friendship throughout the long and dark Norwegian wintertimes. And finally, Klaus - without your love, understanding, patience and your acceptance of this two-country situation with all its drawbacks, I would not have been able to write this thesis in the first place!

Anita Moum, Trondheim/Munich, June 2008

1. Lists of persons interviewed are provided in Appendix A.

list of publications

This thesis includes three primary publications (journal articles), which are reproduced in the Chapters 4-6. Two secondary publications (conference papers) are appended.

PRIMARY PAPERS - INCLUDED

paper I (reproduced in Chapter 4)

Title: A framework for exploring the ICT impact on the architectural design process

Moum A (2006). Published in: ITcon, Vol.11, Special Issue: The Effects of CAD on Building Form and Design Quality , pp. 409-425, <http://www.itcon.org/2006/30>

paper II (reproduced in Chapter 5)

Title: What did you learn from practice today? Exploring experiences from a danish R&D effort in digital construction

Moum A, Haugen T and Koch C (2007). Submitted May 2007 to *Advanced Engineering Informatics* (revised version in regard to the first review round)

paper III (reproduced in Chapter 6)

Title: Design team stories. Exploring intedisciplinary use of 3D object models in practice

Moum A (2007). Submitted December 2007 to *Automation in Construction*.

primary paper I is an extended version of the conference papers:

Moum A (2005). ICT and the architectural design process - introduction of an ICT impact matrix. Published in: Kazi AS (ed) ICT in Construction and Facilities Management. VVT and RIL, Finland. pp. 2-13.

Moum A (2005). A three level approach for exploring the ICT impact on the building design process applied to a real-life project. Published in: Scherer RJ, Katranuschkov P and Schapke S-E (eds) Proceedings CIB W78 22nd Conference on Information Technology in Construction 2007. TU Dresden, Germany. pp. 669-676.

primary paper II is an extended version of the conference papers:

Moum A, Haugen T and Koch C (2007). Stretching the trousers too far? Convening societal and ICT development in architectural and engineering practice. Published in: Dong A, Vande Moere A and Gero JS (eds) Proceedings of the 12th International CAADfutures conference, Sydney. Springer Science, Dordrecht. pp 331-344.

Moum A, Haugen T and Koch C. (2007). What did you learn from practice today? Exploring experiences from a danish R&D effort for digital construction. Published in: (Rebolj D, ed) Proceedings 24th W78 Conference Maribor 2007, Bringing ITC knowledge to work. pp. 239-246.

SECONDARY PAPERS - APPENDED

conference paper a

Title: A three level approach for exploring ICT impact on architectural design and management applied to a hospital development project

Moum A (2005). Published in: Proceedings of the CIB W096 Architectural Management, Designing value: new directions within architectural management, DTU Lyngby, Denmark, November 2-4, 2005 (Emmitt S and Prins M, eds). pp. 83-92.

conference paper b

Title: 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.

Moum A and Bock T (2006). Published in: Proceedings of 23rd International Symposium on Automation and Robotics in Construction (ISARC), Tokyo, Japan, October 3-5, 2006. pp. 107-112.

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abbreviations

AEC	Architecture-Engineering-Construction
BIM	Building Information Model/Building Information Modeling
CAD	Computer Aided Design
CAAD	Computer Aided Architectural Design
HVAC	Heating, Ventilating and Air-Conditioning
FM	Facilities Management
IAI	International Alliance of Interoperability
ICT	Information and Communication Technology
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
R&D	Research & Development

1 introduction

“Pre-tuning”: The point of departure of this thesis is the need for a more comprehensive understanding of what happens in practice when we implement and use new technology. Four real-life projects have been explored to gain insight into the relations between the complex and iterative architectural design process and Information and Communication Technologies (ICT). Particular attention is paid to the work and interactions of the architect in the design team, and the implementation and use of technologies supporting 3D object-based modeling or Building Information Modeling (BIM). Key features of the research are both the broad approach to the problem field manifested by the development of a holistic and descriptive framework and the detailed and reflective exploration of real-life situations identified by its application.

1.1 research background

“The architect must be able to do two things; understand what people need and build houses.”¹

The architects asked at the start of this research project about what they saw as their main responsibility and contribution to the design process, especially mentioned two points: first, creating good architecture, and second complying with the contract conditions and requirements of the clients, users and building authorities. The first point is related to the product, the second to the processes leading to it. Architects traditionally play distinct and important roles in the architectural design process (Gray and Hughes 2001). Their highly complex, sophisticated and in part tacit skills (Lawson 2006) make them suitable for several tasks and roles – from being design specialists, translating the many project constraints and information into physical form, to being involved in management tasks where they lead, coordinate and administrate the design process. Architects are, however, not alone in their efforts to create successful buildings and real estate. Cuff (1991) describes design as a social construction. Behind the seemingly simple quotation above is a highly complex universe where predictable and unpredictable interactions, interrelations and interdependencies between actors and processes create our physical environment.

1. The author's free translation into English of: “Architekten müssen zwei Dinge können; verstehen was Leute brauchen und Häuser bauen”, as said by Professor Kohler from TU Karlsruhe (ifib) in an interview April 2006. According to Kohler, this was originally said by Dr Francis Duffy, the founder of DEGW.

the practice of architectural design meets the digital world

More than thirty years ago the architects and other practitioners involved in the architectural design process faced an entirely new situation due to the new and rapidly expanding Information and Communication Technology (ICT) industry. They have, however, been slow to adapt the new technologies in their work and interaction. Compared to other industries, the Architecture-Engineering-Construction (AEC) industry is lagging behind when it comes to the successful implementation and use of ICT (Gann 2000, Wikforss 2003a). Even though there were high expectations as to the potential of the new technologies to enhance growth and to improve processes, the productivity status of the AEC industry is still an issue of concern in many countries.

With the new millennium and the growing awareness within the industry as to the potential of the new technologies, more and more powerful industry stakeholders have participated in research and development (R&D) projects to encourage and promote the integration of ICT in practice. In recent years an array of international and national joint efforts and alliances have been introduced (Bazjanac and Kiviniemi 2007).² These initiatives support 3D object-based modeling and Building Information Modeling (BIM). The integration of these technologies is expected to lead the AEC industry into a new era characterized by better communication and exchange of architectural design information between project actors involved in all phases of the building's life cycle.³

big bangs, challenging gaps, square pegs and horseless carriages

The CAD director in a major international company explained to me in an interview that the major theoretical problems and visions addressed by the many R&D efforts are eventually turned into smaller and more practical problems in their building projects.⁴ According to him, the basic problem architects and other practitioners have is how to deal with new digital tools within a project where there is much work to be done and drawings to be produced. Although his company is a key actor in an international industry consortium for integrating building information modeling in the AEC industry, and they are very enthusiastic about implementing new technology, the practitioners

2. For instance, in Denmark, Finland, Norway and the USA, to mention a few. Descriptions of some R&D initiatives will be provided in Chapter 2.4; A shift in focus from technology development to implementation, and in Chapter 5.3; Integrating ICT in the AEC industry: Some international and national R&D efforts.

3. At an international information seminar on the Industry Foundation Classes (IFC) and the International Alliance of Interoperability (IAI) in Oslo on June 15 2004, it was suggested that the implementation of IFC-based BIM was, in practice, triggering a paradigm shift in information handling and communication across actors and phases throughout the whole life cycle of a building. The seminar was organized by the IAI Forum Norway in co-operation with Foreningen Næringselendom (FNE) and the Norwegian Society for Facilities Management (NBEF).

4. Based on an interview I conducted during a visit to HOK (San Francisco) in March 2007.

involved are constantly running into practical problems that make it easy to fall back into traditional ways of working.

This story from practice indicates several challenges arising out of what Wikforss (2003) calls a big bang between the traditional AEC industry and the rapidly developing ICT industry. Some of these challenges are related to the above-mentioned practical issues. Others are related to the complex nature of the still not fully understood architectural design process. According to Kalay (2004:199) “the synthesis of design solutions is characterized by uncertainty, unpredictably, the joy of discovery, and the frustration of fruitless explorations. It has fascinated, baffled, and challenged designers, researchers, and philosophers for at least 2,500 years.” Chastain et al. (2002) describe two paradigms of problems related to the encounter between the practice of architectural design and the digital world. They call the first paradigm trying to put ‘a square peg in a round hole’, which describes the problem of adapting new technology to current practice, indicating a mismatch between the designers’ tasks (holes) and the tools applied (pegs). This mismatch or gap might be caused by a failure to understand the designers’ tasks, or by the replacement of traditional tools with new ones that have the wrong affordance.⁵ They call the second paradigm ‘the horseless carriage’, which characterizes “the shifting perception of a practice as it transforms in relationship to a new technology” and where “the task of transportation is described through the lens of a previous technology – even though the practice of travel had changed” (Chastain et al. 2002:239). The tools used by the architects are changing with the development of new technologies, but without reflection on how this affects the practice of architectural design.

The story relates in a wider context to an observation made by several researchers (for instance Gibbons et al. 1994, Schön 1991); there is a gap between the professional knowledge established in research and academia and the actual demands of real-world practice. Heylighen et al. (2005, 2007) question the traditional one-way flow of knowledge from research and academia to practice. They call for more focus within academia on ‘unlocking’ and using knowledge embodied by architectural design practice. Schön’s (1991) famous description of how studio master Quist supervises and reviews the work of one of his architectural students is one example which illustrates that by studying real-life situations, more understanding can be achieved; in this case about what he calls a reflective conversation within architectural design.

1.2 research problem, aim and questions

A crucial question arising out of these observations of trends and movements within the industry and research is how the adoption of new technologies affects the development

5. Affordance: “The term, coined by psychologist James Gibson, describes a potential for action, the perceived capacity of an object to enable the assertive will of the actor.” Chastain et al. (2002:238).

of good architectural design solutions and real estate. What happens with the complex universe of interactions and interdependencies between processes, roles, and actions that are an integral part of the architects' and other practitioners' daily work? Research dealing with ICT related to the AEC industry has been dominated by a focus on the development and improvement of new software and hardware systems, and on technology related to issues of implementing these in practice. Wikforss and Löfgren (2007:337) criticize that current research "has not resulted in a comprehensive understanding of how new technology works (...) if we consider human, organizational and process-related factors in addition to purely technological factors."⁶

The point of departure for this work is the growing need for more knowledge on what happens when new technologies are implemented and used in the practice of architectural design. We lack a comprehensive understanding and overview of non-technological factors, as well as of the relationships and interdependencies embedded in the encounter between the practice of architectural design and ICT. This statement of the problem is the basis for formulating the following aim:

To contribute more knowledge on the current situation in practice by investigating relations between the architectural design process and ICT in real-life projects.

Such knowledge could be valuable for improving implementation and use of ICT in future building projects. Furthermore, it could contribute to a 'two-way' knowledge flow between research and practice, and serve as the basis for further investigation of ICT implementation and use in the AEC industry. Two research questions are defined to address the aim and to investigate the research problem:

RQ 1: What are the factors affecting the implementation and use of ICT in the practice of architectural design?

RQ 2: How does the implementation and use of ICT impact the work and interactions of practitioners involved in the architectural design process?

To clarify the intention behind these questions some of the words and terms used will be briefly explained here. First there is **ICT**; Information and Communication Technologies. In the widest context of this work, the term ICT is limited to computer-based tools and devices which are applicable to the practice of architectural design.⁷ The empirical part of the research focuses especially on technologies supporting 3D object-

6. The authors relate this problem to research on collaborative communication within the industry.

7. For instance: design systems and tools, server- or web based databases, network technologies and advanced visualization technologies (derived from Wikforss' description of four strategic categories of technologies, 2003b:104).

based modeling or BIM.⁸ **Implementation** of ICT means activities putting the use of ICT into effect. The term **use** relates to how the actors involved in the architectural design process practice ICT in their work and interactions; individually and within a discipline, and collectively and across the disciplines. The expression **practice of architectural design** is used to emphasize that this research deals with the architectural design process related to practice and to situations in real-life projects. From an overarching view, **practitioners** are here actors involved in the AEC industry. The main focus is, however, architects and their interactions with other actors involved in the architectural design process.

1.3 overview of research objectives, focus and methodology

Six research objectives are related to the investigation of the two research questions. This section gives an overview of these objectives and the focus of the research, as well as the methodological strategies and instruments applied. A detailed description and discussion of the research design, process and methodology is provided in Chapter 3.

1) Developing a descriptive and holistic framework for exploring the implementation and use of ICT in the practice of architectural design.

How should the research questions be approached? How can the implementation and use of ICT in the practice of architectural design be explored? How can a more comprehensive understanding and overview of the research topic be achieved? These were the initial questions that revealed the need for a holistic framework.⁹ The research problem can be approached and examined from different points of view. In this thesis the problem is examined from the perspective of an architect. The main idea behind the framework mirrors the architects' holistic approach to problem identification and solving, and their ability to synthesize and coordinate bits and parts into a whole without detailed knowledge about each of these. The development of the framework is based on reviews of relevant literature and research, as well as on observations of practice. The main elements of the framework are related to two dimensions of architectural design practice. First, there is the process dimension and the focus on four design process aspects or tasks; the generation of design solutions, the communication, the evaluation of design solutions and decision-making. Second, there is the level dimension, representing different social constructions embedded in a building project. Three levels are proposed; the micro-level (the individual practitioner), the meso-level (the design team) and the macro-level (the overall project).

8. This comprises for instance; 3D modeling tools, IFC (or other standards for information sharing), applications such as viewers and clash detectors and IFC. See also the Glossary appended to the thesis.

9. Holistic: "of or pertaining to holism; characterized by the tendency to perceive or produce wholes". Oxford English Dictionary.

2) Establishing framework tools that provide an overview of factors impacting the implementation and use of ICT.

Based on the main framework elements, different tools and models are introduced to provide an overview of the factors affecting the implementation and use of ICT. These tools contribute to an operationalization of the exploration of relations between the architectural design process and ICT.

The **ICT impact matrix** is introduced as a tool for organizing the findings from literature and studies of practice. The matrix provides an overview of key benefits and challenges from using ICT in the architectural design process, related to all four design aspects and all three levels. A **benefit** from use can be quantitative and measurable (e.g. cost and time savings) or qualitative and hard to grasp (e.g. more shared understanding). The term **challenge** describes a demanding situation or task due to the use of ICT (e.g. the need to make decisions earlier in the process).¹⁰ The matrix is used to organize both benefits and challenges explored in current literature, and those perceived by the actors involved in real-life projects. The **multi-level factor model** provides an overview of enablers and barriers affecting the implementation and use of ICT in the architectural design process. The terms enablers and barriers are used to describe some key premises for implementation and use of technology in the studied building projects. An **enabler** supports and facilitates implementation (e.g. extra time and money available), while a **barrier** impedes implementation and use (e.g. the users' lack of skill).

3) Evaluating the framework's applicability in real-life projects.

As the main outline of the framework took form, it was applied to two pilot case studies of real-life projects for further improvement and development.¹¹ The framework and its tools have evolved and improved throughout the entire research process. The framework has been presented at several workshops, seminars and conferences, and it has been discussed with an array of researchers and practitioners.

The three objectives above relate to how to address the research questions. The next three objectives are focused more on the effort to find the answers. The framework is here applied to the collecting, exploring, and reporting of data from qualitative case studies of one main and three reference case studies of ongoing or just completed building projects. These projects are middle- to large-scale European projects regarded as 'front-

10. I realize that the term 'challenge' is not the antonym of 'benefit'. However, it is not my intention to draw any hasty conclusions about the effects of ICT on the design team members' work and interactions. What appears to be a disadvantage in one situation or according to one person could be perceived as an advantage in another. The word challenge implies that something is questioned without necessarily making a judgment as to whether something is bad or not.

11. These case-study results and the experiences of applying the framework on the AHUS project are reported in conference papers a and b, which are enclosed with this thesis.

runners' in their countries when it comes to implementing and using new technologies.¹² The main case and object of investigation is the design team involved in the new Icelandic national concert and conference centre in Reykjavik. Furthermore, reference studies have been undertaken of the new Akershus university hospital, of the Tromsø university college (both in Norway) and of a Audi production plant in Germany. The purpose of these reference studies is to provide empirical data that will open a discussion on the findings of the main case in a wider context. Open-ended interviews with more than thirty architects, engineers and clients involved in the architectural design and management of these projects play an important role in the exploration of the research problem. Further sources of evidence are direct observations of design team meetings, and studies of project documents and artifacts.

The case studies focus on technologies supporting 3D object-based modeling or BIM. More specifically, they focus on the implementation and use of these technologies superlaid to the four design process aspects and activities, as for instance visualization, simulation, consistency controls, data exchange, generation of drawings and take-offs. In the case studies, the focus is limited, moreover, to the meso-level and the work and interactions taking place in the design team. The objects of investigation are the 'traditional' design team actors; the architects and the main engineering disciplines (building structures, HVAC and electrical systems). Their interactions with, for instance, the contractors, the building authorities and the users have only been regarded on the overall level, based on the stories told by the architects and the engineers.

4) Identifying enablers and barriers affecting the implementation and use of technologies supporting 3D object-based modeling or BIM in the practice of architectural design.

5) Exploring relationships between the identified enablers and barriers, and how these relationships affect the implementation and use of 3D object-based modeling or BIM in the practice of architectural design.

All the four studies projects are connected to national or international R&D programs for promoting the integration of ICT in the AEC industry. Key persons in these programs are at the same time involved in the projects studied, either as managers or coordinators of the implementation and use of the new technologies. The strategies and aims established in the R&D initiatives, and the efforts to bring these into real-life situations, are likely to affect the situation in the projects studied and the experiences made. The focus of objectives four and five is therefore on identifying enablers and barriers, both placed on different levels in the studied projects, and in their context; here the R&D initiatives.

12. To the best of my knowledge and according to the respondents who were asked about the situation in their countries regarding the implementation of technologies supporting 3D object-based modeling or BIM.

The identified enablers and barriers are organized by using the multi-level factor model. In the next step, some key relationships between the identified factors and the implementation and use of ICT in the projects are discussed.

6) Exploring the role of 3D-object-based modeling or BIM in the work and interactions of the practitioners involved in the architectural design process.

What are the processes, strategies and routines within the building projects related to the generation of design solutions, communication, evaluation of design solutions and decision making? How do the architects and the engineers use the tools to perform these tasks? What do they find are the main benefits and challenges from this use? What are the enablers facilitating or barriers impeding this use? These were some of the concerns underpinning this last task. The related key findings are explored and reported by using a narrative technique. Factors placed in the relation between initiatives and strategies on the macro-level, the processes within the design team and on the meso-level, and the individual experiences on the micro-level are interweaved into five design-team stories.

A key feature of this research is the interplay between the broad and holistic approach of the framework, and an elaborative and 'digging-deeper' strategy for detailed exploration of the situations identified by its application. The framework, as well as the research questions and tasks, serves as an important vehicle in finding focus and delimiting scope

1.4 delimitations of scope

Generally, the scope is limited to the current situation in the AEC industry and to the investigation of real-life projects representing 'established practice' within architectural design, by which I mean projects following the widespread procedures within today's AEC industry.¹³ An investigation of the change of architectural design practice resulting from the development of ICT falls outside the scope of this paper. The choice to study real-life projects also limits the scope of this research to the actual status of practice, both with respect to which technology is used, and how it is used. Thus, the practical influence of initiatives within current research related to, for instance, standardization of building objects and information handling is not investigated in this work.¹⁴ Such efforts are still in an early phase, and even in the investigated real-life 'front runners', their implementation and use are limited. Although the projects studied in this sense lag behind the latest technological innovations, the knowledge generated from investigating actual and real-life project situations is regarded as highly valuable for preparing the ground for the further development and implementation of the technological 'hot topics' from university and industrial research.

13. Manifested by legislation, professional societies and organizations, guidelines regulating the definition of project phases or what is to be performed by the actors involved, common procurement models etc.

The current situation in the practice of architectural design regarding the implementation and use of ICT can be viewed from a number of perspectives. This work pays particular attention to process issues embedded in the practice of architectural design, and how these relate to the implementation and use of ICT (architectural-process-practice-related view). Discussions and investigations based on specific organizational theories, business development theories or system theories fall outside the scope of this work (organizational or system-theory related view), as do also investigations of how ICT impacts the roles of the different project actors. Moreover, descriptions of technological specifications and functionalities, and discussions of how these should be further developed and improved are not provided (technology related view).

1.5 structure of the thesis

This is a paper-based thesis comprising three journal articles and several conference papers.¹⁵ The three journal articles, or primary papers, are directly reproduced and integrated in the thesis in each their own chapter. These three main papers establish the foundation and main empirical body of the work. Due to the paper format, these three chapters are individual in nature; they are independent strands of the rope establishing the totality of the thesis.¹⁶ Their integration affects the structure of the thesis as some repetition of content appears (especially in the descriptions of background, context, framework and methodology). Furthermore, the reproduced papers have been written at different stages in the research process, which results in some variance in the use of terms and wording. This mirrors the process of improvement and development and does not affect the validity of the research. These are unavoidable side-effects of the paper-based structure.

The thesis is divided into nine chapters which relate to each of the elements and stages of the research. Figure 1-1 provides an overview of the thesis and its content. **Chapter 1** briefly presents the research background and some key observations from current

14. A central feature of the BuildingSMART initiative and the work of the International Alliance of Interoperability (IAI), is the effort to standardize object classifications and establish libraries with pre-defined objects (IFC and IFD), and “standardizing” the flow of information (IDM). The further development and implementation of these initiatives in the industry is likely to affect the architectural design process. The issue of standardization is important and controversial, and especially among architects questions are raised as to whether these trends will negatively impact creative freedom and innovation. An exploration of these issues falls outside the scope of this work. Nevertheless, they are also likely to become ‘hot topics’ in the future AEC industry. See Chapter 9 and the recommendations for future research.

15. All papers included in this thesis or appended to it have already been submitted or published in international journals or conference proceedings. The second journal paper (Chapters 5) was still under review for the journals when this thesis went to press. The journal paper reproduced in Chapter 6 has been through the first review round. Both are expected to be published by the end of 2008.

16. The ‘strand and rope’ analogy is borrowed from Charles Peirce, the ‘founder of pragmatism’.

practice and research, as well as the research problem, the overall aim and the research questions. Furthermore, the chapter provides an overview of the research objectives defined to answer the research questions, and of the methods and strategies applied. Finally, some key limitations of the research scope are outlined. **Chapter 2** describes the frame of reference for the discussions and explorations to be undertaken in the succeeding chapters. The purpose is to clarify which understanding of the architectural design process and ICT this research is founded on. **Chapter 3** deals with the research design and strategies, describes the research process and the methodological tools, and ends with a discussion on the validity and reliability of the work. **Chapter 4** reproduces primary paper I. Here the outline of the framework is introduced and discussed, along with a demonstration of its application in a pilot case study. **Chapter 5** reproduces primary paper II. This paper explores enablers and barriers related to the strategies, requirements and guidelines formulated in the Danish national public-private 'Digital Construction' program and experiences of implementing one of its digital foundations, the '3D Working Method' project, in the main case – the New Icelandic national concert and conference centre in Reykjavik. Furthermore, the relations between these identified enablers and barriers are discussed. **Chapter 6** reproduces primary paper III, which goes further into the main case and presents five design team stories about the interdisciplinary use of 3D object models in the architects' and engineers' work and interactions. **Chapter 7** reports from the case studies of the three reference building projects, while **Chapter 8** examines an extract of the findings from the main case study and the three reference studies. **Chapter 9** discusses the synthesis between the research questions and findings and offers a reflection on the research activities, particularly the development and application of the descriptive and holistic framework. After presenting the work's key contributions, the chapter rounds off the thesis by looking at the implications of the findings for practice and providing recommendations for further research.

Due to the broad and practice-related approach, this thesis could be interesting for readers with various agendas and backgrounds. The thesis summary and the short description of content introducing each chapter provide a quick overview of what this thesis is about, and which parts could be interesting to various parties. The dark grey 'boxes' in the thesis overview suggest chapters and sections which might be especially interesting for readers in the practical field.



Figure 1-1. Overview of thesis structure and content.

Exploring relations between the architectural design process and ICT

2 frame of reference

This chapter explains the frame of reference and the background of the research design, descriptions, explorations and discussions presented throughout the next chapters of this thesis. The intention is to clarify the underlying understanding of the architectural design process and the current status within ICT development. The first part deals with various features of the practice of architectural design, and impacting trends. The second part provides a brief overview of the development of ICT as well as the current status of ICT implementation and use in the AEC industry. The chapter concludes with a description of the role of information and knowledge. The frame of reference is based on explorations of relevant literature and research activities, as well as observations of current practice.¹

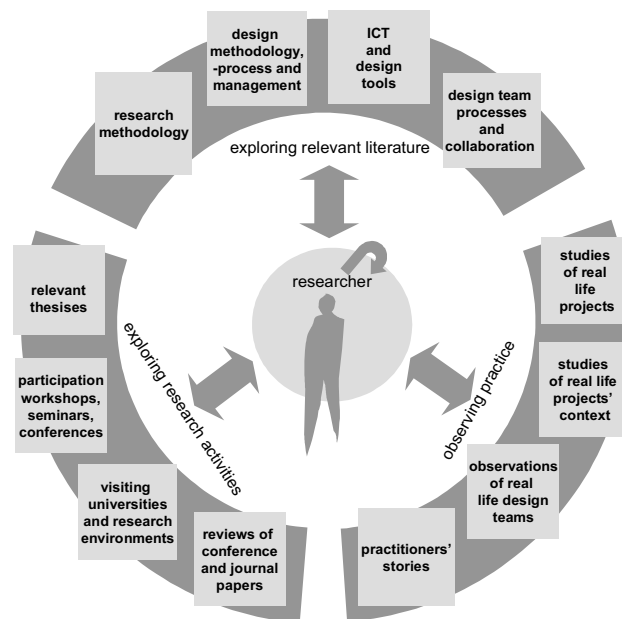


Figure 2-1. The research project's frame of reference.

1. "The frame of reference can be local, as in the specific relationship between the observed object to other objects in its vicinity; or it may be global, as in the relationship between the object and its overall context." Kalay (2004:95-96).

“The synthesis of design solutions is characterized by uncertainty, unpredictability, the joy of discovery, and the frustration of fruitless explorations. It has fascinated, baffled and challenged designers, researchers and philosophers for at least 2,500 years.” Kalay (2004:199).

The practice of architectural design and the roles and tasks of the actors involved has evolved over centuries and decades. Societal, political, economic and technological development and movements have formed the practice of architectural design and the AEC industry we know today. The quotation above indicates that this evolution has been followed by countless attempts to tackle the challenge of explaining, understanding and mastering the processes behind our built environment.²

Providing a complete picture of all theories and approaches to the architectural design process, or of all studies and initiatives related to the development and implementation of ICT worth mentioning, would over-extend the scope of this work. The intention here is to highlight some of the elements establishing this work’s frame of reference to deepen the understanding of the architectural design process and the current status within ICT development, which underpins the explorations and discussions in the chapters to follow.³

2.1 the architectural design process

In the introductory chapter the architectural design process was described as a complex universe of predictable and unpredictable interactions, interrelations and interdependencies between actors and their actions. This understanding relates to observations of the practice of architectural design made by such researchers as Kalay (2004), Lawson (2006) and Schön (1991). Kalay (2004:13) refers to design as a cyclical relationship between two paradigms; design as problem solving, where the designer attempts to produce solutions to ill-defined problems, and design as puzzle making, where design is seen as a process of discovery where given parts are synthesized into a new and unique whole. Lawson (2006:49) describes the design process as “a negotiation between the problem and solution through the three activities of analysis, synthesis and evaluation,” and challenges the comprehension of the design process as a sequence of activities. Schön (1991) characterizes design practice as a reflective dialogue between the designer and the design situation.

2. An overview of the role of the architect through history is given by, for instance, Barrow (2000) and Symes et al (1995). An overview of the evolution of theories related to design methodology is given by for instance Lundequist (1992b).

3. Moreover, several references to relevant literature and research projects are given in each of the three main papers.

The features of the architectural design process described above are closely related to cognitive processes and design thinking. Some features are, however, also given by regulating external factors. Examples of these are (highly simplified):

- The delivery of design information and project material to the client; the building authorities and contractors are regulated in phases, each presenting a higher level of detail and information depth, and each to be approved by the stakeholders before moving on to the next phase.⁴
- The time and performance related definitions of these phases are mostly specified in the project contracts. These might also be regulated by guidelines or regulatory demands on the national level.⁵
- The architectural design process is situated between the statement of the brief (more or less defined) and the start of the building production (Fig. 2-2).
- In practice, one project phase does not follow the other in a pure sequential process. Limited time resources, tough project budgets and the contractual models call, for instance in the main case study, for an overlap of the phases (Fig. 2-2).

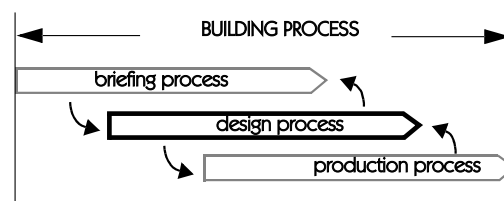


Figure 2-2. The building process and its three main phases – which are again divided into an array of sub-phases (based on an illustration in ‘Samspillet i Byggeprosessen’, Haugen and Hansen (2000:10)).

Bearing the two above-mentioned groups of features in mind, the practitioners involved in the architectural design process must deal with an interplay between highly iterative, unpredictable and non-linear activities on the one hand, and regulated and linear activities on the other.

4. For instance; the outline design phase, the scheme design phase and the consultants’ detailed design phase (Gray and Hughes 2001). Or in Denmark: conceptual design, design proposal and detailed design. In Germany: the ‘performance phases’ (Leistungsphasen 2-5); Vorentwurf, Entwurf, Genehmigungsplanung, Ausführungsplanung.

5. Different countries have different definitions of the required performances of each of these phases. For instance, in Norway, the AY (ArkitektYtelsler), and in Germany, the HOAI (Honorarordnung der Architekten und Ingenieure).

trends impacting the current practice of architectural design

The actors involved in the current AEC industry and the practice of architectural design have several interrelated trends and movements to deal with, for instance:⁶

- Increasing focus on collaboration and integrated design (Elvin 2007).
- Specialization of the actors as a consequence of the increasing complexity of both processes and products. For instance, in Germany we see growth of companies specializing in developing building facades, or in climate concepts.
- Increasing focus on sustainability and 'green architecture'.
- Increasing focus on the building life cycle, and on the management and maintenance of building facilities.
- The growth in building stock with the need for rehabilitation and modernization.
- A professionalizing of the client role; from the single building client-user, to the professional developer of multiple building projects.
- Globalization and internationalization, new market situations and the free flow of labor.
- And not to forget, the trend which motivated this work in the first place: the development and increasing availability of ICT tools and devices.

2.2 the growth of new technologies: a brief overview

Ivan Sutherland's development of the Sketchpad program at MIT in 1963, the introduction of the first PC from IBM in 1981, the establishment of the hypertext language HTML and the emergence of the internet era at the end of the 80s are some of the milestones of technological development and R&D efforts preceding the range of tools and devices available within the AEC industry today.⁷ In his overview of the development of key technologies, Eckerberg (2003:168) refers David C. Moshella's chronological description of different eras: the system-centered era (1964-1981: development for big companies), the PC-centered era (1981-1994), the network-centered era (1994-2005: the growth of the internet and collaboration technologies) and the content-centered era (2005-2015: user/customer focus). Kalay (2003) describes three generations of digital design tools. The

6. In the northern and central part of Europe.

7. According to Kalay (2004:65), with Sketchpad, "Sutherland and his mentor, Steven A. Coons, thus invented both the modern concept of computer-aided design and the tools to implement it."

first generation of tools was introduced as 'building design systems' centered on architectural objects and intended to support the design. The second generation of tools comprises more general drafting and modeling systems, focusing on the representation of the buildings. The products of this generation include the 2D design tools used by most actors involved in architectural design today. According to the IT barometer 2007 (Samuelson 2007), around 90% of the architects and 75% of the engineers/technical consultants in Sweden are using 2D design tools. The third generation of design tools comprises knowledge-based design systems enabled by the development within object-oriented programming, artificial intelligence and database management (Kalay 2003:65-74). Kalay (2003:70) argues that the second generation of tools represents a 'dumbing down' of the first generation's ambitions. Instead of making the tools more 'intelligent' and specialized, as in other industries, the focus of the AEC industry-related technological development was, until recently, on producing general software packages supporting drafting and rendering (Kalay 2003).

The technologies particularly focused on in this work, the tools supporting 3D object-based modeling or Building Information Modeling (BIM), originate from the 'third-generation' efforts within university and industrial research. The following will examine the development and implementation of these technologies in the AEC industry.⁸

2.3 technologies supporting 3D object-based modeling and BIM

For an overview of the history of 3D object-based modeling and BIM, here are some key milestones.⁹ According to Howard and Björk (2007), the first research dealing with product modeling took place as early as the 1970s. However, the development of this technology gained momentum with the start of the ISO STEP (Standard for the Exchange of Product Data) standardization project in 1985 and with several European and German research projects into the mid-1990s (Junge and Liebich 1997).¹⁰ The knowledge gained from these projects served as the basis for the industry consortium International Alliance

8. An explanation of the technological terms and how they are used in this work is given in the 'Glossary of technical terms' at the end of this thesis. Here for brief clarification: '3D object models' and '3D product models' can be regarded as more or less the same (Interview with Professor Richard Junge March 2007, and with Dr. Thomas Liebich December 2006).

9. For readers interested in a detailed description of the development and technical specifications of 'third-generation design tools', 3D object models and BIM, see for instance: B.-C. Björk's book from 1995 'Requirements and Information Structures for Building Product Data Models', C. Eastman's book from 1999 'Building Product Models: Computer Environments Supporting Design and Construction', Kalay (2004:71-74) and Tarandi (2003:253-299). The first two books are not listed under the references as the review of technical specifications falls outside the scope of this thesis. However, in the literature reviewed for gaining an overview of the development and general features of the technology, these two books are referred to as primary literature for detailed descriptions of product models.

10. For instance; COMBI (1993-1995), an EU-sponsored project involving, for instance, Professor Richard Junge (involved in the STEP-ISO group) and Dr. Thomas Liebich in Munich, as well as the TU in Dresden (according to Dr. Liebich in an interview December 2006).

for Interoperability (IAI) which in the mid-1990s took over product modeling standardization for the AEC industry. The IAI is the prime mover behind the development of the Industry Foundation Classes (IFC). From the end of the 1990s, Finnish research activities, for example the VERA program (VERA 2006), were important catalysts in the IAI's efforts to develop the IFC. Today, the IAI is a worldwide consortium comprising a wide array of research and development efforts.

a shift in focus from technology development to implementation

In the first years of the new millennium, the limited adoption of these technologies in practice, the rising concern about productivity in the AEC industry, and industry stakeholders' increasing awareness of the new technologies' potential triggered a shift in focus from technological development to implementation. The Finnish ProIT (Product Data in the Construction Process) program initiated in 2002 (ProIT 2006), and the Danish 'Digital Construction' launched in 2003 (EBST 2005), are both examples of R&D programs on the national level, where powerful actors in both industry and research have combined forces to stimulate the integration of the new tools, whereas the ROADCON project, initiated in 2002, is an example of a European research initiative which attempted to develop a strategy for implementing ICT in the AEC industry (Rezgui and Zarli 2006). At the same time, the program for the international IAI conferences focused more and more on stakeholders perceived to have the power and ability to implement the developed standards and technologies (Fig. 2-3). In June 2005, the IAI introduced the brand 'BuildingSMART', the label for the growing efforts in several countries, among them Norway, to integrate technologies supporting 3D object-based modeling and BIM in their AEC industries.



Figure 2-3. Live demonstration of interoperability at the international Building Smart Conference in Oslo June 2005 (Photo downloaded from www.iai.no).

visions about a new era in the AEC industry

“Throughout the history of architecture, the essential building representation has been drawings. Innumerable books review how drawings and sketches are relied on in architect’s thinking and creative work (...). The replacement of drawings with a new base representation for design, communication, construction, and archiving of buildings is a revolutionary and epoch-making change, in both architecture and in the construction industry generally. This change alters the tools, the means of communication, and working processes.” Eastman (2006).

There are many visions, aims and expectations connected to the development and implementation of technologies supporting 3D object-based modeling and BIM. First, in the famous ‘Islands of Automation in Construction’ (Fig. 2-4), a group of researchers in Finland illustrated, the vision of a ‘land-raising’, where the new technologies connect the islands of automation into one big island, without the borders between planning phases and roles which today are a source of communication friction, delays and misunderstandings (Hannus et al. 1987).

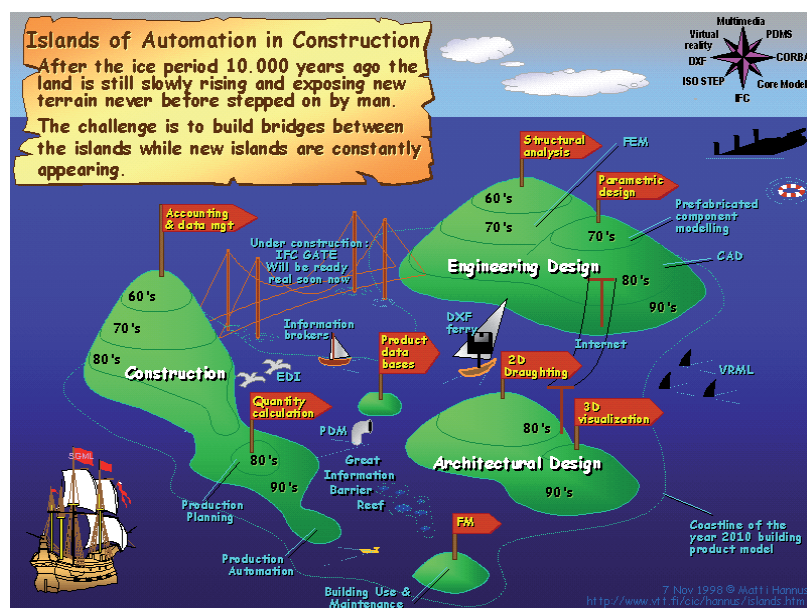


Figure 2-4. Islands of Automation in Construction (Hannus et al. 1987).

The ‘building information circle’ (Fig. 2-5) illustrates the vision of BuildingSMART; a consistent and smooth flow of information across all involved actors and throughout the entire life cycle of a building based on three pillars. The first pillar, the Industry Foundation Classes (IFC), defines how to share or exchange building information. The second,

the International Framework for Dictionaries (IFD) defines what building information is to be shared or exchanged. And the third, the Information Delivery Manual (IDM), defines which building information to share or exchange at what time (SINTEF Building and Infrastructure 2007). On many occasions the figure has been referred to in conferences and seminars arranged by the IAI and BuildingSMART. In a presentation of the Norwegian BuildingSMART project (Sjøgren 2006) the technologies supporting 3D object-based modeling and BIM are expected to “reduce uncertainty and improve decision making in the building life-cycle” to solve the “Babylonian confusion in the AEC industry”. The presentation claims that 25-30% of the construction costs in the current AEC industry are incurred due to communication errors and loss of information as a result of, for instance, the need to re-enter and re-create the same information several times in different systems and software before the building is handed over to its owner.

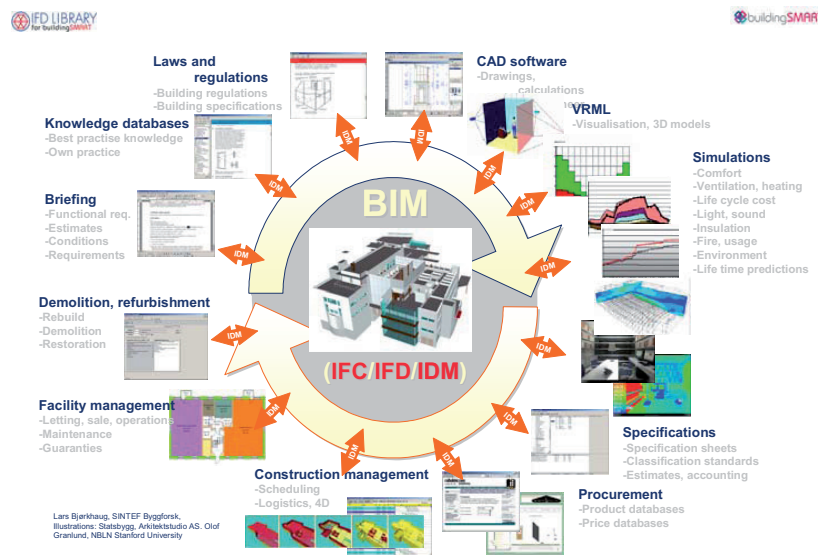


Figure 2-5. The 'building information cricle'. (Illustration made by Lars Bjørkhaug, SINTEF Building and Infrastructure, Olof Granlund, LBNL, University of California, Stanford University). Downloaded from: <http://buildingsmart.byggforsk.no/blog/index.php/2008/02/29/a-building-information-circle-from-us-to-you/>

Another expected effect of implementing these technologies is the 'front-loading' of design efforts (Fig. 2-6), enabled by the potential of the technologies to support earlier concretization of design solutions and decisions making. Typically, the peak of design efforts is placed in the detailed design phase, where design changes result in increased costs. By front-loading these peak and design efforts into an earlier phase in the building process, the design solutions can be changed without the same negative effects on costs.

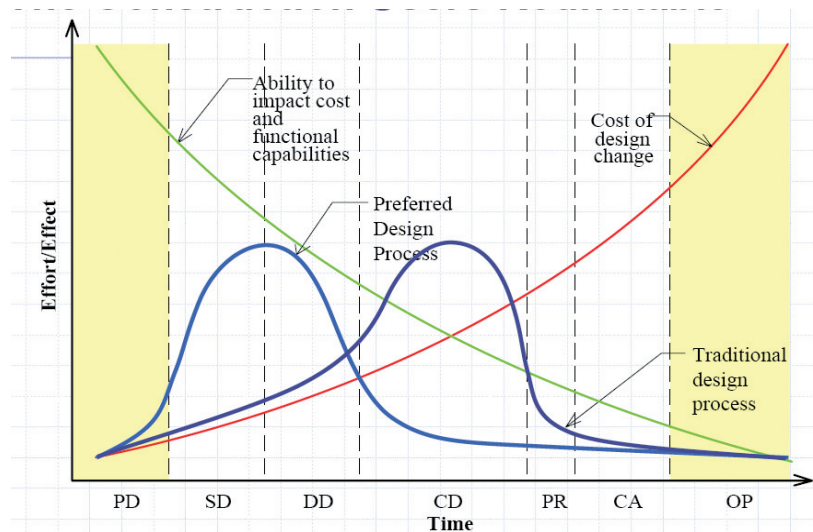


Figure 2-6. Preferred design process or 'front-loaded' process (Courtesy: IAI). Presented at the international Building Smart Conference in Oslo June 2005, by Norbert Young, FAIA.

visions meet reality 2007: enthusiasm and critical voices

Since this research was initiated in 2004, the visions and expectations related to the technologies supporting 3D object-based modeling and BIM have caught the attention of an increasing number of stakeholders in various countries. As a result, pressure on the actors involved in the architectural design process to implement and use these technologies has been growing. Paper II reports from Denmark, where from January 1 2007 a regulatory client directive was issued, requiring the use of 3D object models in public building projects with building costs exceeding 40 million Danish kroner (approx. 5.3 million). In May 2007, one of the Norwegian public clients, Statsbygg (the Directorate of Public Construction and Property Management), announced their intention to demand the implementation and use of IFC compliant BIM in all their projects from 2010 (BuildingSMART 2007).

Alongside the increasing focus on implementation, there appears to be a growing interest among several research communities in the experiences gained from practice. The international CIB W78 conference, held in Maribor, July 2007, was entitled; 'Bringing ITC knowledge to work'.¹¹ Several papers dealing with industry experiences and challenges were presented and discussed in one of its workshops (for instance Khanzode et al.

11. A CIB workgroup dealing with "Information technology in construction", involving several researchers engaged in BIM/IFC/3D product model development. CIB = International Council for Research and Innovation in Building and Construction.

2007, Samuelson 2007, Simondetti 2007). In the same period, Wikforss and Löfgren (2007:338) described:

*“After ten years of IFC development, its adoption and use in the construction industry is still marginal. The ambitious approach of IAI may have focused too much on the model based world instead of the real one, leaving IFC as a theoretical model specification or an academic exercise rather than a useful industry standard for professionals in practice.”*¹²

Several online journal platforms reported (and are still reporting) on the current status and discussions both within the AEC and the ICT industry, for instance, AECbytes (<http://www.aecbytes.com>) and Project Controls Online (<http://www.projectcontrols.com>). In some rather critical articles published by the latter, Laiserin (2007a, 2007b) pointed out the necessity ‘to separate hype from reality’ in the current discussions on BIM. Mario Guttman’s reflection on ‘Things I do worry about’ in an AECbytes article entitled ‘buildingSMART – get over it’, summarizes this selection of ‘sentiment indicators’ in 2007:

*“To begin with, the BIM discussion has created a misconception that exchanging information is something like gathering nuts, where the bigger the bag we can toss over the fence at the end of the day, the better. In fact, controlling the flow of information is a very important reason for the traditional divisions of professional responsibility. My responsibility as an Architect requires that I be very careful in how I provide information and how it is used by others.”*¹³

2.4 relations between the architectural design process and ICT and the role of information and knowledge

*Data - Information - Knowledge - Understanding - Insight - Wisdom*¹⁴

This information ladder, which was introduced by Norman Longworth, describes the stages in human learning, where a learner makes his or her way up the ladder to construct ‘wisdom’ at the highest level from ‘data’ at the lowest level.¹⁵

12. They refer here to the former Nordic chairman of the IAI. Their reference: Kiviniemi (2006): Ten years of IFC development - Why are we not yet there? CIB W78 keynote lecture, in the Proceedings of the Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montreal.

13. AECbytes Viewpoint #17 (August 09, 2005), http://www.aecbytes.com/viewpoint/2005/issue_17.html (retrieved March 2008)

14. Oxford English Dictionary defines “data” to be: “1) facts and statistics used for reference or analysis. 2) the quantities, characters, or symbols on which operations are performed by a computer. Information is “1) facts or knowledge provided or learned. 2) what is conveyed or represented by a particular sequence of symbols, impulses, etc.” Knowledge is: “1) information and skills acquired through experience or education. 2) the sum of what is known. 3) awareness or familiarity gained by experience of a fact or situation.” (<http://www.askoxford.com>, retrieved March 2008).

15. From Wikipedia (http://en.wikipedia.org/wiki/Information_ladder, retrieved March 2008).

Information and knowledge are two terms which are used repeatedly in different contexts throughout the last chapters and for this reason merit some attention here.

The entire building process and the interactions between actors and processes (including the four design-process aspects focused on in the framework), can be said to rely on the generation, interpretation, distribution, coordination, management, and storage of information (Emmitt and Gorse 2003:20, Gray and Hughes 2001). Bearing in mind the buildingSMART visions, the expectations for ICT and the technologies supporting 3D object-based modeling and BIM are closely related to their potential for processing and storing a vast amount of information. The investigations to follow focus on design information, with which I mean information about the physical building; both related to its geometry, and to its attributes and properties (properties and qualities of the objects). Information is based on data communicated by neutral media, and must be interpreted by the human receiver to become knowledge. Information can thus contribute to gaining knowledge, but information is not knowledge, and it does not communicate knowledge about how it should be interpreted (Lundequist 2003:363).

Knowledge is a highly complex subject examined by such disciplines as psychology and philosophy. In the context of this work, I will only point out some of its general features. Griffith et al (2003) describe three types of knowledge. Explicit knowledge can be articulated, and is thus accessible to others (for instance objective knowledge based on facts). Implicit knowledge is knowledge which is hard to grasp, but which can be 'transformed' into something which can be articulated. Tacit or 'silent' knowledge cannot be put into words and plays an essential role in the work and interactions of the actors involved in the practice of architectural design. Tacit knowledge can be described as a kind of 'feeling of' (Schön 1991) and can be expressed, for instance, by experience-based, intuitive and unconscious habits, routines and actions. This knowledge embodied by the practitioners involved in architectural design is hard to grasp and unlock, for computer systems and also for researchers.

"Even now after some thirty years of working on design research, I realize that there is much I know about the design from practicing the process rather than studying it. Perhaps this remains not only the greatest single failing but also the inherent fascination of the field. We have still not fully explained that most magical of all conjuring tricks, the design process." Lawson (1997:308).

Exploring relations between the architectural design process and ICT

3 research design and process

The first part of this chapter introduces the approach and strategies underpinning the research design. The purpose of the research is described as mainly explorative, and the research design has been developed by using a flexible strategy. Whereas the scope and research questions have been defined through a long process, the decision to apply a case-study strategy was made early, based on the initial aim of the research and the desire to better understand and learn from the current status of practice. The main criteria for selecting one main and three reference cases are described, as well as the criteria for selecting the interview respondents. Qualitative and open-ended interviews are the main sources of evidence. The second part of the chapter provides an overview of the research process; from preparing to conducting and documenting the case studies and interviews, to analyzing the data collected, to the reporting of the findings and the processes. A narrative technique, matrixes, tables and figures are the vehicles for communicating complexity. In the third part of the chapter, a discussion of the validity and reliability of the findings is provided, as well as a description of the actions undertaken to ensure the quality of the research. A reflective approach is applied to ensure the consistency of the research design and the quality of the findings.

PART I: research approach and strategies

3.1 investigating practice

The first chapter introduced several problems, trends and movements within the current AEC industry and related research. One of the problems pointed out is the gap between knowledge established within research and the actual demands of practice. This observation deserves more attention before going further into the descriptions of research approach and strategies.

Schön (1991) criticizes the limited ability of traditional research to address the actual complexity and uncertainty of practice.¹ He suggests that “we may also consider science as a process in which scientists grapple with uncertainties and display arts of inquiry akin to the uncertainties and arts of practice” (Schön 1991:49). Gibbons et al. (1994) point to increasing societal and cognitive pressure and the resulting shift within knowledge pro-

duction, introducing the terms 'mode 1' (traditional knowledge) and the co-existing 'mode 2' knowledge. The key features of mode-2 knowledge are that it is diverse, heterogeneous and transdisciplinary.² Mode 2 is furthermore characterized by "a constant flow back and forth between the fundamental and applied, between the theoretical and practical" (Gibbons et al. 1994:19). Schön, with his reflective approaches, Gibbons et al., with their mode-2 knowledge production, and Heylighen et al. (2007), with their call for a two-way flow of knowledge, present different though related views on the need for a stronger focus within research on generating and unlocking knowledge embedded *in practice about practice*.

This need is also mirrored in the formulation of the main aim, here repeated: to contribute more knowledge on the current situation in practice by investigating relations between the architectural design process and ICT in real-life projects. The investigation of real-life situations encounters an array of challenges and pitfalls which have influenced the choice of research approach, strategies and methodological instruments. Unlike a laboratory setting, where variables can be controlled and their causal relationships can be tested, the real world represents a research arena that is impossible to control and for which there is no full overview. "In real-world practice, problems do not present themselves to the practitioner as givens. They must be constructed from the materials of problematic situations which are puzzling, troubling, and uncertain" (Schön 1991:40). Reviews of literature and recommendations by reputable researchers as to how to approach and carry out studies of real-life situations have provided a good overview and support for developing the research design (for instance Yin 2003, Kvale 1997, Robson 2002).

1. In his book "The reflective practitioner" Schön (1991) argues for a shift from the traditional model of Technical Rationality to Reflection-in-action. He sees Technical Rationality as the heritage of Positivism: "It seems clear, however, that the dilemma which afflicts the professions hinges not on science per se but on the Positivist view of science. From this perspective, we tend to see science, after the fact, as a body of established propositions derived from research" Schön (1991:49).

2. Gibbons et al (1994:5) describe four central characteristics of transdisciplinarity: "It develops a distinct but evolving framework to guide problem-solving efforts. This is generated and sustained in the context of application and not developed first and then applied to the context later by a different group of practitioners. (...) Though it has emerged from a particular context of application, transdisciplinary knowledge develops its own distinct theoretical structures, research methods and modes of practice, though they may not be located on the prevailing disciplinary map. (...) unlike mode 1 where results are communicated through institutional channels, the results are communicated to those who have participated in the course of that participation and so, in a sense, the diffusion of the results is initially accomplished in the process of their production (...) transdisciplinarity is dynamic. It is problem-solving capability on the move (...) Mode 2 is marked especially but not exclusively by the ever closer interaction of knowledge production with a succession of problem contexts".

3.2 research purpose and strategy

Finding out what happens when implementing and using ICT in the little understood and complex world of architectural design is, according to Robson (2002), a typical feature of research with an exploratory purpose. The explorative nature of the research is furthermore underpinned by the two research questions, starting with a 'what' and 'how', and several of the six related research tasks. Although the research is mainly explorative, it also contains several important descriptive elements. The explorations are based on descriptions of the observations made in the case studies and on a body of narratives which describe persons, events and situations.

The research process is based on two main co-existing phases where the second phase evolved out of the first (Fig. 3-1).

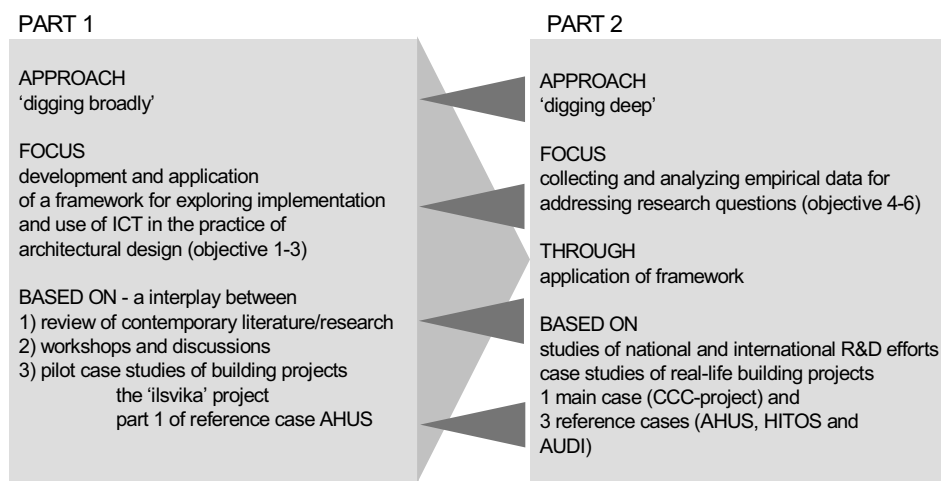


Figure 3-1. The two main phases of the research process.

The two research phases are characterized by different approaches to the research problem. In the first phase, a 'digging broadly' strategy was used in order to gain an overview of the field and to identify important findings and relationships, both embedded in the situations observed and in their setting or context. In the second phase, an elaborate and 'digging deep' strategy was applied to achieve a more detailed understanding of the phenomena revealed in the first phase (Fig. 3-2).

The complexity of the research topic required an overview and previous knowledge about the field before the research questions and tasks could be appropriately defined. Additionally, the new insights gained throughout the empirical part called for a regular check of the need to adjust the question, tasks or the research design itself. By following

what Robson (2002) calls a flexible and qualitative design strategy, the research design has evolved in the interplay between the two main phases.

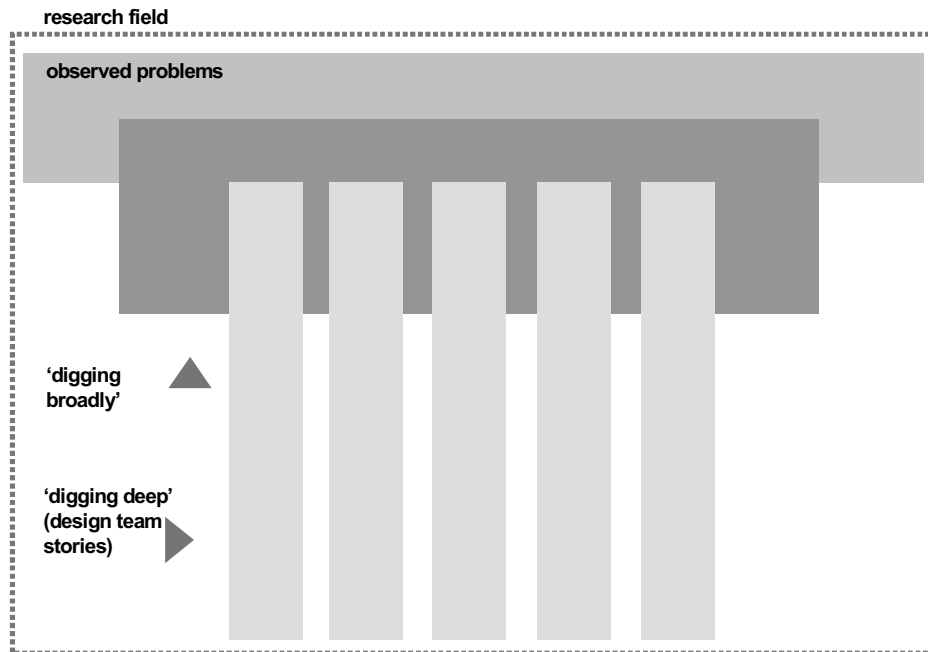


Figure 3-2. The 'digging broadly' and 'digging deep' strategy.

3.3 the case study as a research strategy

Bearing in mind the main aim and the research questions, a case-study strategy for investigating the real-life projects and for establishing the main empirical body of the work has been applied.³ Yin (2003) defines the case study as a research strategy arising out of the need to understand complex phenomena and to "retain the holistic and meaningful characteristics of real-life events" (Yin 2003:2). His recommendations on how to conduct case-study research have been an important reference and guidelines throughout this work.

understanding the context of the projects studied

Schön emphasizes the importance of considering the problem setting or context when solving real-life problems; "the process by which we define the decision to be made, the ends to be achieved, the means which may be chosen" (Schön 1991:40). Investigating a

3. Case-based research strategies and methodologies are applied by several research and academic groups dealing with processes and problems related to the AEC industry today. For instance: CIFE at Stanford University (Fischer and Kunz 2004) and Design, Technology and Management at the Harvard Graduate School of Design (Professor Spiro Pollalis).

case as a part of a context is a central feature of the case-study strategy (Robson 2002, Yin 2003).

In order to understand what is going on in the building projects studied, it has been important to understand some of the contextual aspects which impact the phenomena and situations observed, which relates to the first research question; what are the factors affecting the implementation and use of ICT in the practice of architectural design? Particular attention has been paid in these contextual studies to the international or national R&D initiatives for integrating ICT in the AEC industry linked to the studied projects.

qualitative vs. quantitative case-study approaches

"... quite recently, increasing recognition of the value and appropriateness of qualitative studies has emerged. This may perhaps be in acknowledgement of the potential for such methodologies to get beneath the manifestations of problems and issues which are the subject of quantitative studies, and thereby, to facilitate appreciation and understanding of basic causes and principles, notably, behaviours." Fellows and Liu (2003:91).

The quotation above describes some typical features of a qualitative approach which are here found to be important for responding to the problem statement, to repeat; we lack a comprehensive understanding and overview of non-technological factors, as well as of the relationships and interdependencies embedded in the encounter between the practice of architectural design and ICT.

Whereas it was a natural step to adopt a case-study strategy, the question of whether the qualitative data needed to be supplemented by data collected with quantitative methods called for careful considerations. Generally, it is possible to combine qualitative and quantitative approaches within case-based research (Yin 2003, Johansson 2005). For example, during the data-collection phase, I considered undertaking a questionnaire-based survey with the key actors involved in the main case study to strengthen the findings addressing the first research question. The first argument for not doing so was that such a survey would not provide deeper insight into the situations studied than already provided by using the qualitative methods. The second argument was related to a side effect of studying new and untested technology, and of investigating real-life practice; there is an array of factors and relations embedded in the project, or in its context, influencing the situations studied which are unlikely to be recognized and revealed by a survey. To undertake a time consuming survey was therefore regarded as having too little effect within the limited timeframes of a PhD research project. Instead, this time was spent on carrying out three qualitative case studies in addition to the main case study.

aim of the case studies

The aim of the case studies has been twofold: Firstly, to support the development of the framework and the research design, and secondly, to gain access to the information required to address the two research questions. Particular attention was thus paid to:

- The strategies, ambitions and expectations related to the implementation of technologies supporting 3D object-based modeling and BIM (both within the project and its context).
- The role of these technologies in the daily work of the architects and engineers.
- The project actors' experiences from implementing and using the technology (perceived benefits and challenges).
- The architectural design process (e.g. tasks, routines, work methods, strategies, aims - with focus on the four selected design process aspects).
- The project network and relations between the actors.

selecting the cases

As indicated in the introductory chapter, one main and three reference case studies of middle- to large-scale building projects have been conducted (Fig. 3-3).⁴ One important criterion for selecting the building projects was that they should be good arenas for learning and for accumulating knowledge about how technologies supporting 3D object-based modeling or BIM work in practice. The main common denominator of the projects is that they all are, or were, trying to implement and interdisciplinarily use new technology in real-life project situations. Other important criteria were that they should be ongoing, or just completed, they should be situated in Europe and they should be connected to current R&D initiatives and programs on the national or international level for integrating ICT in practice (the context of the case).

Both Norway and Denmark, where three of the four selected projects are situated, are countries that are putting much focus on the national level on the broad integration of ICT in the AEC industry. Germany, where the fourth project is located, might be regarded as the cradle of the ideas behind IFC and 3D product modeling. Several international R&D projects are still today connected to German research and academic groups. At the time, the main part of the four case studies had been carried out (2005-2006), all of them were 'front runners' in their countries due to the implementation and interdisciplinary use of 3D object models and BIM (to the best of my knowledge). Finland and the USA are examples of other countries which today represent interesting arenas for finding building projects fulfilling the criteria described. However, due to the limited

4. A more comprehensive description of the projects can be found in Papers I-III (Chapters 4-6) and in Chapter 7.

resources of the PhD project, several practical considerations were also among the criteria for selecting the projects.

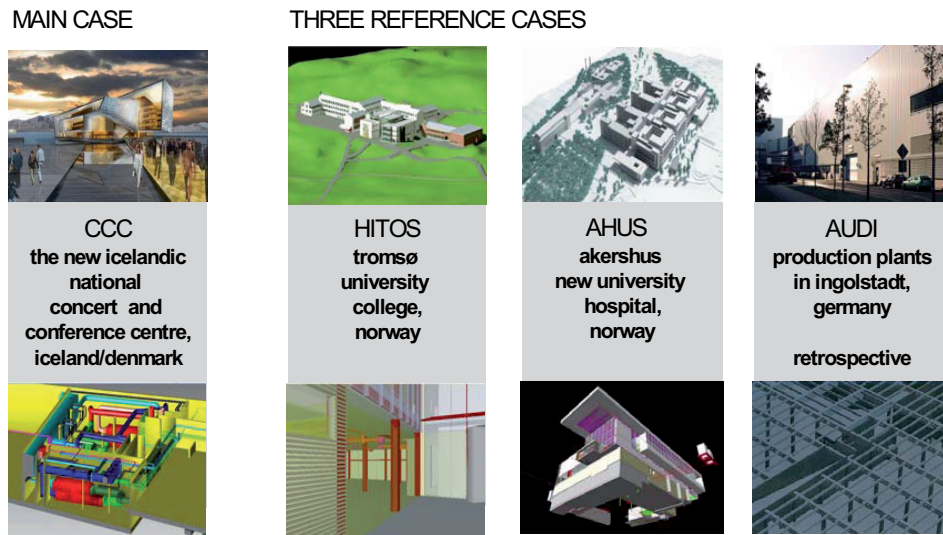


Figure 3-3. The four main case studies carried out 2005-2007. Additionally, there was carried out a small test case study of the 'Ilsvika housing estate' project in Trondheim spring 2005 .

The purpose of carrying out three reference case studies in addition to the main case study is twofold. Since the four case studies were carried out more or less parallel to each other, the lessons learnt in the reference studies were used to improve the questions, strategies and focus of the main case study. Moreover, the extension of the empirical data basis by three reference projects enabled me to view the findings of the main case study in a broader context in the final synthesis and concluding discussions.

case-study design

What would be the most appropriate case-study design for the purposes described above? Each of the case studies is a complete single case based on what Yin (2003) calls an embedded single case study design. The different units of analysis embedded in the project are placed on different levels; from the overall project level (macro-level), to the design team level (meso-level), down to the individual level (micro-level). One important issue was not to lose sight of the relations between the units of analysis; for instance by focusing too much on a subunit level without returning to the larger units of analysis. The framework has here played an essential role, since it contributes to obtaining an overview of the units of analysis related to different levels and tasks within the architectural design process.

The main case has been investigated at different points in time and thus it can be regarded as a longitudinal case. Since this building project was one of the first projects using inter-

disciplinary 3D object modeling within its context, it also represents a unique case.⁵ Additionally, its uniqueness is characterized by its function, by the ambition of creating an architectural highlight, and by the 'best practice' knowledge embodied by the recognized actors involved. Furthermore, the building project's links to the national R&D program 'Digital Construction' made it a unique case for investigating the relation between the project and its context. This uniqueness was among the criteria for selecting this project as the main case. Nonetheless, several of the observed situations were predicted to be present in the reference cases as well, thus they can be regarded as representative.

Yin (2003) recommends basing the case study on multiple sources of evidence. The main empirical body of this work is based on data collected from five different sources; interviews, documentations, archival records, direct observations and physical artifacts. The subtitle of the thesis; 'Learning from practitioners' stories', indicates the important role of the interview.

learning from practitioners stories

"If you want to know how people understand their world and their life, why not talk to them? (...) The qualitative research interview attempts to understand the world from the subject's point of view, to unfold the meaning of peoples' experiences, to uncover their lived world prior to scientific explanations." Kvale (1996:1).

Kvale (1997) describes the interview as an arena for knowledge production, where the interview is literally an 'InterView'; an interchange of viewpoints between two persons who are conversing on an issue of mutual interest. Obtaining access to knowledge embodied by the key actors involved in the building projects was regarded as crucial if I were to address the research questions and gain valuable insight into not very visible and explicit processes and events. For this purpose the open-ended (or semi-structured) interview was found to be the most appropriate approach since it enables an informal and conversational interview situation guided by a pre-defined set of issues to be dealt with. The interviews which were carried out with the project actors can also be compared to what Holstein and Gubrium (1995) call an 'active interview', where the interviewer plays an important role in actively guiding the interview, by reacting to the precedence and restraints emerging throughout the situation.

selecting the respondents

To answer the research questions, the group of respondents had to provide insight both into the factors affecting the implementation and use of ICT (strategies, aims, visions) and into the impact of the technologies on the work and interactions of actors involved in

5. Yin's five rationales for single case studies (2003:40-42): the critical case, the unique or extreme case, the representative or typical case, the revelatory case and the longitudinal case.

the architectural design process (e.g. experiences from use). The respondents interviewed were therefore key actors involved in the real-life building projects, in the design process context or in both (Fig. 3-4).

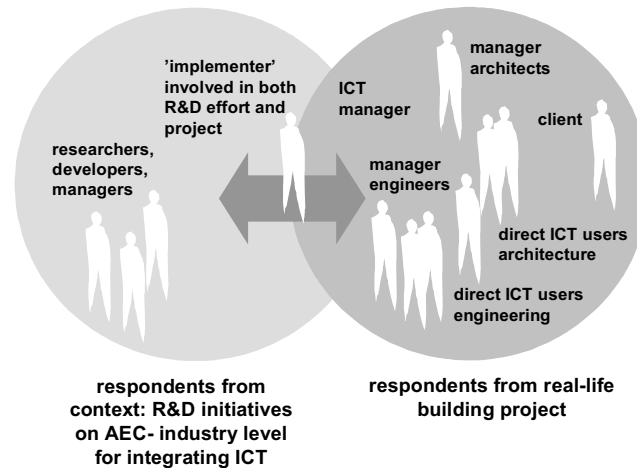


Figure 3-4. The interview respondents.

The contextual respondents were, for instance, involved in international and national R&D initiatives or in academic research groups. The respondents selected from the building projects represented various disciplines and positions; architects and engineers involved in both design and management, actors responsible for coordinating and managing the implementation and use of ICT, and actors representing the client. Although the respondents involved in management did not directly perform design tasks or use the technologies studied, through their 'silent design development' they were influencing the process, the flow of information and the interactions between the different designers.⁶ Project and design managers were therefore regarded as valuable sources of information about the aims, and about the technology and process-related strategies, whereas the designers and draftsmen provided information about the role of the technologies in their work and interactions.⁷ The respondents' different points of view and perspectives thus together provided a good picture of the architectural design process and the implementation and use of ICT within the building projects; from the AEC industry level, to the overall project, down to the individual user of the technology

6. According to Gray and Hughes (2001), the term 'silent design development' was introduced by Dumas and Mintzberg.

7. The focus of this work is on the implementation and use of ICT in order to perform tasks related to architectural design, and to explore how the impact of ICT on the tasks of the manager beyond 'silent design development' falls outside the scope of this.

3.4 strategies for reporting the research process and results

The complexity of the topic has also required considerations as to how to capture and make the knowledge explicit in a way which can be understood by other researchers and practitioners. How should the flow of knowledge from practice to research be supported?

storytelling

“The story format provides a dense, compact way to deal with and communicate the complex reality of a real-world building project, while respecting the interrelated nature of events, people and circumstances that shaped its conception.” Martin et al. (2005:35).

Heylighen suggests together with Martin (Martin et al. 2005) that storytelling is a vehicle for communicating the knowledge embedded in practice. Martin et al. have used this technique actively within teaching, where students have carried out case studies of building projects by establishing what they call ‘Building Stories’. The aim of their case studies was to explore “the knowledge embodied by the best practices of significant architectural firms” (Martin et. al 2005:36).

This narrative technique has here been used to capture and communicate the essence of the data collected into different stories. They represent detailed elaborations of situations and factors identified by using the framework. Each story represents a ‘spot’ on significant bundles of findings and relations addressing the research questions. The stories attempt to interweave and communicate complex case-study findings in an understandable way. In addition to being the basis for the further explorations and discussions presented later in this thesis, the stories are also regarded as contributions in themselves to a repository of knowledge about real-world practice.⁸

figures, tables, matrixes and models

Figures, tables, matrixes and models are actively used to simplify and visualize processes, decisions, relationships and findings throughout entire thesis. The intention is to support the overview and understanding of key aspects of the work. Examples are, for instance, the framework tools and the figure underneath (Fig. 3-5) which attempts to illustrate the research process. The figures, tables, matrixes and models enhance the overview and understanding of the ‘big picture’, whereas the storytelling technique provides deeper insight into particular relations and situations.

8. Flyvbjerg (2004) points out that good case studies are narratives in their entirety, whereas summaries and generalizations may fail to communicate important relationships and the contextual value of the study.

PART II: the research process

As a consequence of the strategies and approaches chosen, the research process has been iterative and cyclic, rather than linear and straightforward. Figure 3-5 illustrates the relation between the data collection, the analysis, the framework and the structure of the thesis. The following section describes the main elements of this research process.

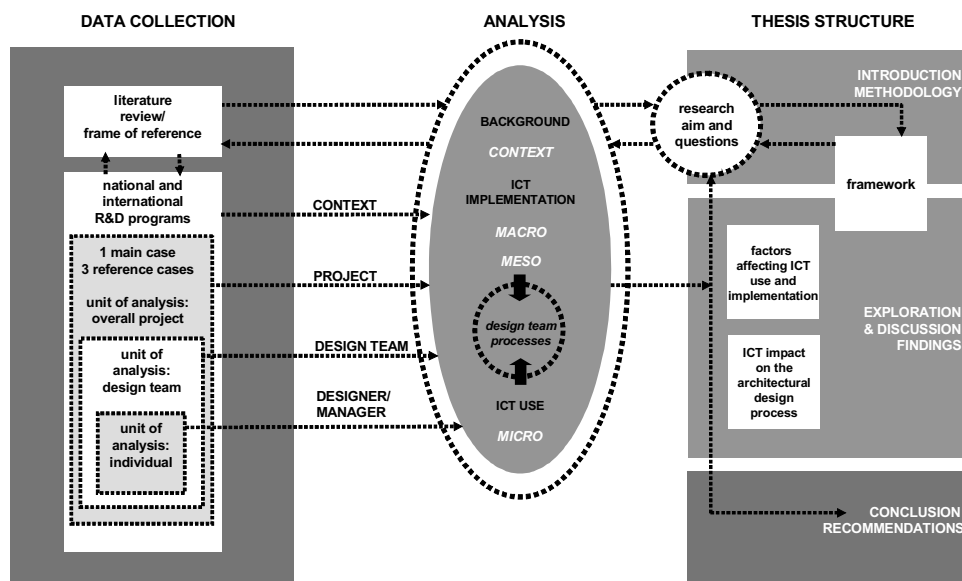


Figure 3-5. The research process.

3.1 preparing the case studies

"The case study, like other research strategies, is a way of investigating an empirical topic by following a set of prespecified procedures." Yin (2003:15).

According to Yin's (2003) recommendations, the case studies were carefully prepared by establishing a case-study protocol. Key elements of the protocol are an overview of the field procedures and the purpose and questions of the case study.⁹ The case-study protocols have guided the data collection, they have helped to ensure the reliability of the studies and they have been used to introduce the case study to key persons involved in the projects. Furthermore, and based on the aim of the case study and the research questions, an interview guide was developed (Fig. 3-6).

9. The case-study protocol made for the main case study can be found in Appendix B.

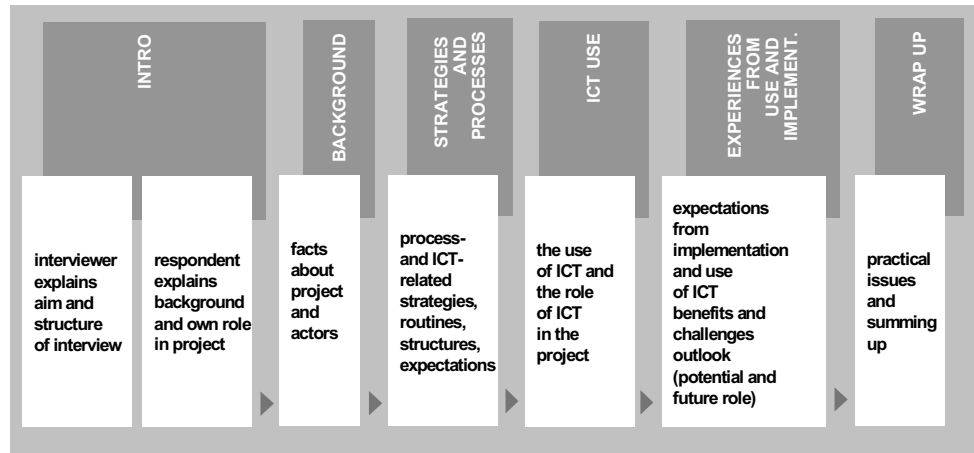


Figure 3-6. The interview guide. Simplified version which was included in the case-study protocol of the main building project.

The research topic has generally been met with much interest and enthusiasm by the persons contacted and interviewed. Their openness and willingness to give access to relevant documents and to sacrifice their time for interviews have been encouraging indications about the relevance of the research topic. Nevertheless, the time these actors have for activities not directly related to the building project is at a premium. Thus, both in respect to the case-study actors and to the issue of reliability, it was important to maintain professionalism and to follow some formal procedures; distributing the case-study protocol to the key actors involved, getting the project managements' official 'green light' for conducting the case study, sending reports and paper drafts to the respondents for their comments and acceptance before submission or publication, getting permission to use project material, quotations and photos, making agreements about the degree of anonymization etc.

A pilot case study of the IISVika housing estate project in Trondheim conducted in April 2005, and the first part of the AHUS case study carried out May 2005, have played an important role in testing the case-study design, the interview guide and the first outlines of the framework.¹⁰ The experiences gained in these initial case studies were presented and discussed in a workshop with experts from research and practice, and at international conferences.¹¹ These discussions established a valuable basis for conducting the main case study.

10. The IISVika case study was based on one interview with the design manager of the architectural team.

11. The findings are reported in secondary papers a and b, which are appended to this thesis.

3.2 conducting the case studies

Table 3-1. Overview of the data collected from the case studies of the four building projects.

	MAIN CASE	REFERENCE CASES		
	CCC-project	HITOS-project	AHUS-project	AUDI-project
amount of interviews	20	8	10	7
interview rounds	1: end conceptual design phase June 2006 (3) 2: end design proposal September 2006 (10) 3: detailed design June 2007 (6) 4: detailed design October 2007 (1)	1: after completed conceptual design November 2006 (7) 2: update June 2007 with design manager (1)	1: end detailed design May 2005, shortly before delivery to contractors (4) 2: construction phase/start IFC project November 2007 (6)	1: after completed project, December 2006-February 2007
respondents	11: design managers (2) architects (2) engineers (4) IT-coordinators (3)	8: clients (2) design manager(1) architects (2) engineers (3)	6: clients (2) architects (3) engineers (1)	6: clients (1) architects (2) engineers (2) IT-manager (1)
other sources of information	project material observation of 3 meeting types 'guided tours' in front of computer	project material 'guided tours' in front of computer	project material 'guided tours' in front of computer	project material 'guided tours' in front of computer

interviews

All the interviews were carried out in the respondents' locations, with the exception of one interview which had to be made by phone. The open-ended interview with one respondent at a time was the most common situation. In some of the reference case studies two persons were interviewed at the same time. Conducting such group interviews in the informal setting of the open-ended interview was a positive experience. In several situations the two respondents staked out and developed narrative territories together; a comment from one respondent leading to the further reflections and reasoning by the other. In the main case, the respondents were interviewed two to three times over a one-year period, which enabled a better impression of the consistency of their experiences and an overview of the design development.

The interview guide was what Holstein and Gubrium (1995) call an advisory and a conversational agenda in the interview situation. How actively the interview situations had to be conducted varied from interview to interview. Firstly, the different positions and backgrounds of the respondents called for different questions. A project manager can

provide one type of information, the designer another. Moreover, some respondents needed only some rough keywords to tell their stories, others required very focused and clear questions. In the attempt to 'unlock' the knowledge embodied by the inter-viewees questions were also asked to encourage reflections on their actions. Several of the respondents explained after the interview situation that putting their experiences and lived world into words was useful as they became more aware of their experiences and what they had learnt throughout the project.

Handling the active role of the interviewer was challenging and required both training and a high level of concentration. Two challenges arising from the open-ended interviews have been considered carefully. The first was the possibility that the respondent might react reflexively to the questions; meaning answering what he or she might believe the interviewer wants to hear. Reasons for such reflexive reaction might be that they have not understood the reason for asking a specific question, that the questions require more reflection and knowledge than the respondent can provide due to his or her actual experience and background or that they generally want to get out of the situation as soon as possible. The issue of reflexivity was, however, not found to be a problem in the conducted interviews. Perhaps due to the practice-related nature of the questions, most respondents had very clear opinions about the issues questioned. The open-ended and active interview situation also enabled an adjustment of the questions due to the respondents' reactions. Personally, I found it positive to give the respondent full attention throughout the entire situation, avoiding looking into papers or writing notes, which I believe might have distracted the respondent and disturbed the conversational atmosphere in the interview situation. Additionally, it seemed that my practitioner background encouraged the respondents to share their experiences with me in a 'from-colleague-to-colleague' setting based on a mutual understanding of the topic. A second challenge was to appropriately deal with leading questions. Leading questions can reduce reliability but they can also enhance it (Kvale 1996:158). I used leading questions, for instance, to verify whether my interpretation of the respondent's answers was correct or not.

All interviews (both with project and context actors) have been audio-recorded and transcribed. The first interviews were transcribed word for word. Throughout the research process a 'transcription light' technique was developed, where dead ends, repetitions and empty fill words without meaning were excluded. Thus the time-consuming transcription process was speeded up and the readability of the text was improved. However, these adjustments were made carefully so the meaning or the content of the respondents' comments were not interfered with. Together with the audio-recordings, the transcriptions establish the 'raw' interview data which have been used for further analysis and explorations. All transcriptions have been e-mailed to the respective respondents, and they have also been given the audio recordings on request.

direct observations

In the main case, three types of meeting were observed (Fig. 3-7). All these observations have been documented and analyzed. It was important not to interfere with the discussions and actions taking place, thus no comments or questions were raised throughout the meeting situation, and a periphery observation position outside the action area of the participants was chosen. Some of the observed issues were discussed afterwards in interviews with the respondents who participated in these meetings.



Figure 3-7. Snapshot from a workshop observed in the main case June 2006 (author's photo).



Figure 3-8. Visiting the architectural company (Henning Larsen Architects) involved in the main building project (author's photo).

To conduct the interviews, the companies involved were visited, which gave the opportunity to obtain an impression of the workplace, and the meeting and social space of the project participants (Fig. 3-8). Together with the interviews this impression was useful in understanding how the project actors were working and interacting.

studying documents and archival records

The documentary information base from the building projects and their context comprises different websites, minutes from meetings, descriptions of R&D projects and agreements, CAD manuals and project manuals, and also project documents (e.g. plans, sections, 3D renderings, screen dumps perspectives and so on) and project presentations. To gain an overview of the project structure and the phases, I examined charts and lists illustrating responsibilities, positions and relations between the actors, as well as time schedules.

physical artifacts

To better understand the use of 3D software and applications, after the main interview situation some respondents were asked to demonstrate the main functions of these tools on their computers. Throughout these 'guided tours' screen dumps were made and integrated in the transcriptions of the tours, and these became important visual aids in the analysis work. The 'guided tours' triggered the respondents to reflect further on their perceived benefits and challenges from use; a very valuable supplement to the outcomes of the main interview situation.

3.3 analyzing the empirical data

To understand the 'blackbox' between the raw data and the research findings, the next section will describe the data analysis process.

The analysis and interpretations of the empirical data collected from the four building projects are firstly based on the understanding of the practice of architectural design and of the emerging technologies as described in Chapter 2, and secondly on the application of the holistic and descriptive framework (Fig. 3-9). The focus is on the different units of analysis (from the context of the project down to the individual designer), as well as on the relations between them. The findings from the three additional cases provided a valuable reference when it came to analyzing and discussing the data collected from the main case study.

the reference for analysis

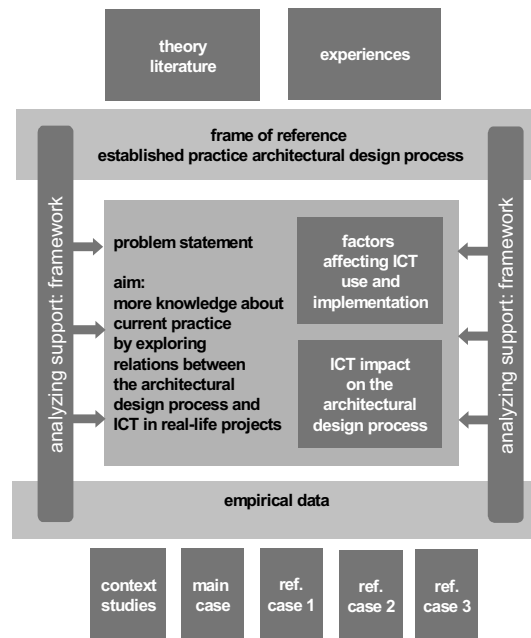


Figure 3-9. The analysis process and its frame of reference.

analyzing the interview material

Through my active role in the open-ended 'InterViews', the first part of the analytical process already took place in the interview situation. The transcriptions and audio-recordings were structured and analyzed in the following steps:

- By marking and pre-coding key comments and sections in the transcriptions (manually or digitally), a first overview of the large interview material was established and a clarification for further structuring was made (Fig. 3-10). A distinction was made between essential and non-essential passages, 'hard' facts and 'soft' facts. Furthermore, the text was coded according to different topics (derived from the aim of the case study and using the levels and tasks defined by the framework).
- The 'hard facts' were analyzed and summarized into case-study descriptions and tables. Examples of 'hard' facts are: information about project size, its background, the project organization and the software systems.
- The 'soft' facts in each interview were analyzed by applying the framework tools. The ICT impact matrix was, for instance, the basis for further cross-interview structuring and bundling (Fig. 3-11). The findings were also allocated in 'specialized' matrixes

dealing with key relationships or stories. Examples of 'soft' facts were: information about work methods and processes, perceived benefits and challenges by using technology and so on.

46	r: ja, det er dem jeg sitter med og liker i // (39-30) det er det vi kommuniserer ut av huset, som folk skal ikke på vår 3d modell kommuniserer selvsels også ut, men ikke annet enn til rambøll de er de eneste, det er ikke noe presentasjon i det.	
47	a: noe som blir sett på som en fordel, er en tidligere forståelse av bygningen og av koordinasjonen av fagene. kommentarer?	
48	r: det er en god kontrollfunksjon i det, men den liest ikke hos meg, den ligger hos de folk, som sitter med mer snevære problemer, de store fagmodellene blir lagt sammen, og det er bitte konstaterer der det er problemer, og kommuniserer det videre, kanskje til meg, eller til den som må vite det.	
49	a: temaet kreativitet og forholdet arkitekt og ingeniør, du fortalte at dere har vært bevisste på å knytte dem med inn i beslutninger for å få en dialog rundt ideer og løsninger, men at det har vært problematisk, har det forandret seg?	
50	r: jeg vil si, ja kanskje, det er knyttet til den enkelte ingeniør, hvor åpne de er, som arkitekt så snakker man om at alle muligheter og dører er åpne, vi skal ikke beslutte oss ennå, og det har ingeniørene svart ved å forholde seg til, det er noen bedre til enn andre, noen på dette prosjektet, og flere enn jeg har opplevd tidligere, som er gode til å være med, men som jeg alliert og utrykk for seg, det er noen som nesten føler ubehag med å være med i denne dialogen, selv om de har gjort dette de siste 25 år og har meget erfaring, også med å samarbeide med arkitekt, vet ikke om det er blitt bedre, det fungerer egentlig fint nok, mulig det er blitt bedre i forhold til det jeg har uttrykt tidligere, det kan godt være, i har et ille godt samarbeid, i har en fin forståelse // og står sammen utad sett, i har få konflikter bakda is, det er godt.	
51	a: ser du noen forskjeller på dette prosjektet når det gjelder avvikling av prosesser i forhold til andre? mer overlapping, forskyvninger, beslutninger på andre tidspunkt?	
52	r: i kan rose oss selv på dette prosjektet for å ha vært på forank med mange ting // det er i bruk av i sitter 20 mann på prosjektet, og over halvdelten har vært med å tegne konserthuset uppsala, og operaen, har vært igjennom noen av de samme problematikker før, det er kanskje bedre gang man gjør det her // (44-44) men vet hva som kommer av problemer, og man er kanskje bedre til // å ta diskusjonen tidligere, enn kanskje i har gjort på denne type prosjekt før fordi dette prosjektet er så komplekst, mange ting å forholde seg til, vi er ok på forank i forhold til både på operaen og uppsala, det er helt klart fordi der sitter folk som vet hva det handler om, det er en gevinst, generelt i forhold til andre prosjekter, som ikke er konsert- eller operahus, er det noen prosjekter hvor man kanskje har vært enda bedre, fordi det er mindre komplekse bygninger, det er nemmere, men dette prosjektet ligger over midlet, prosessmessig, hvordan beslutningene blir tatt og hvordan det henger sammen.	
53	a: det gjelder da arkitektsiden, men i forhold til framdriften i hele prosjektet?	
54	r: ...den ligner alle de andre, men framdriften har vært ganske utmerkert, en relativt god framdrift.	

Figure 3-10. Snapshot from the data-analysis process: pre-coding transcriptions.

ign-team						micro-level/individual user					
	resp	pos	story-rel.	ben+chall.	barriers/enablers	comments	resp	pos	story-rel.	ben+chall.	barriers/enablers
linear engineers are... they are dividing the... floors etc...	gs1	26	3 and 8			education engineer. has been vvis-department leader for 5 years in ramball (administrative), now ramball's project manager for the ccc-project, which is the biggest project in the company.	gs1	5, 14	0		
in 3d model, the... changes his... model.	gs1	60	3 and 8			main responsibility/aim: best possible use of 70.000 hours or 50 man years. to ensure that ramball delivers the agreed performance within agreed time, for agreed quality and costs.	gs1	18, 22	0		
upload digital 2d... sketches with... 3d. not possible... architect does not	gs1	61-68	10			shortcoming for user of program: there is no "intelligent" (parametric) connection between model and the necessary system diagrams: within structures: modeling and calculations not connected.	gs1	142-144	13	interop	shortcomings in software, lack of
structural drawings and	gs1	70	7	inconsistency by parallel 2d and 3d		fear of losing job and influence because of new technology.	gs1	180	7		barrier: fear of users
architectural 3d... is not the task of... and solving	gs1	74-78	10	challenge: more work for architect	barrier: architect has no 3d model	still shortcomings for users in software. ramball has suggested ideas and problems the vendor were not aware of themselves. the software cannot handle all aspects of the size and complexity.	gs2	16			challenge: techn. shortcomings
and to build up model,	gs2	28-30	10		barrier: no 3d from arch.	in the meantime, most of structural engineers have attended 3d courses: now able to handle simple parts of program.	gs3	27	7		enabler: more part. have attended courses
king with 2d, and... would be better to work... hope for future:	gs2	42	10	challenge: exchange	barrier: different levels of 3d modeling	challenge: not possible for single user to work online. eg the structural engineer must wait until next day (for updated viz-file) in order to see if still fit with other disciplines. source of uncertainty.	gs3	31	0		challenge: techn. shortcomings
engineers level... they are working also in... confusing and... north facade.	gs3	7, 9	4		barrier: different methods arch and eng						
ence files: then even... pon.	gs3	11, 13	3		?						
parts of planning must... geometry of the... ent, however, the... ly decided upon... ering company... ves gradually... le changes bigger in... a work?	gs3	13, 15	3		barrier: different working methods. poor capability of 3d tool for re-design and changes.						

Figure 3-11. Snapshot from the data-analysis process: allocation of findings in matrix.

The broad and holistic approach of the framework, on the one hand, and the elaborating and 'digging deep' strategy for detailed exploration of the situations identified by its application, on the other, required different data analysis techniques. In the 'transformation' process from the transcriptions and the large text into table or matrix form meaning condensation was used; "long statements are compressed into briefer statements in which the main sense of what is said is rephrased in a few words" (Kvale 1996:192-193). Additionally, there has also been a translation process; from the original languages (Norwegian, Danish or German) into English. Furthermore, since the tables and matrixes are based on different topics and levels, a meaning categorization has also been undertaken by the coding and the allocation of different parts of the interviews into different categories. The 'transformation' process from the transcriptions, partly via the tables or matrixes, to the story format, can be compared to what Kvale calls narrative structuring. In this structuring process, the many scattered stories told by practitioners representing different views and backgrounds have been interwoven into some few rich, condensed and coherent stories. These stories or narratives can be regarded as "open-ended answers to the questions in the case-study protocol" (Yin 2003:103).

PART III: ensuring the quality of the research

Real-world projects and the practice of architectural design represent a research arena which can be compared to what Yin (2003:42) calls a “swampy lowland where situations are confusing messes”. Robson (2002), Yin (2003), Flyvbjerg (2004) and Kvale (1997), who I have referred to several times in this chapter, argue that the findings from qualitative research and case studies of practice represent valuable contributions to scientific knowledge. They emphasize, however, that there are many pitfalls which can result in a ‘wishy-washy’ study, and point to the particular importance of having a research design and case-study procedures that guarantee the necessary scientific rigor, validity and reliability. Throughout the entire research process much effort has been spent on ensuring the validity and reliability of the findings.

3.1 validity and reliability of the research design

There are four tactics for testing the quality of the research design which are common for most social sciences (Yin, 2003). Three of these are relevant for this explorative and descriptive study: construct validity, external validity and reliability.¹²

Table 3-2. Case-study tactics for three out of four design tests. Illustration derived from Yin (2003:34).

TESTS	CASE STUDY TACTIC	PHASE OF RESEARCH IN WHICH TACTIC OCCURS
construct validity	<ul style="list-style-type: none"> • use multiple sources of evidence • establish chain of evidence • have key informants review draft of case study report 	data collection data collection composition
external validity	<ul style="list-style-type: none"> • use theory in single-case studies • use replication logic in multiple-case studies 	research design research design
reliability	<ul style="list-style-type: none"> • use case study protocol • develop case study database 	data collection data collection

12. Yin (2003:34) summarizes the three tests as follows: Construct validity; establishing correct operational measures for the concepts being studied. External validity; establishing the domain to which a study's findings can be generalized. Reliability; demonstrating that the operations of a study, such as the data collection procedures, can be repeated with the same results.

the construct validity of the research

As indicated by the table above, three strategies for ensuring the construct validity of the research are recommended. The first is to use multiple sources of evidence. The purpose of collecting data from five sources of evidence (documentations, archival records, interviews, direct observations and physical artifacts) has here been twofold. In some situations one source provides supplementary information for another. In other situations, the different sources highlight the same phenomenon from different angles. This “converging on the same set of results or findings” (Yin 2003:83) enables data triangulation. Since the interviews establish the main part of the empirical body, it has also been an issue to enable triangulation based on the interview data. This has been particularly important because the respondents’ answers cannot be regarded as objective and unbiased (Yin, 2003). The interview respondents’ perception of an event or situation can deviate from how something really happened, and their stories must therefore be analyzed with care. Two tactics have been used to enable data triangulation and respond to this limitation of the interview. Firstly, many respondents were selected from the same case, each representing different views and backgrounds. Secondly, the key respondents were interviewed on two to three different occasions, which provided a better impression of the consistency of their attitudes and experiences.

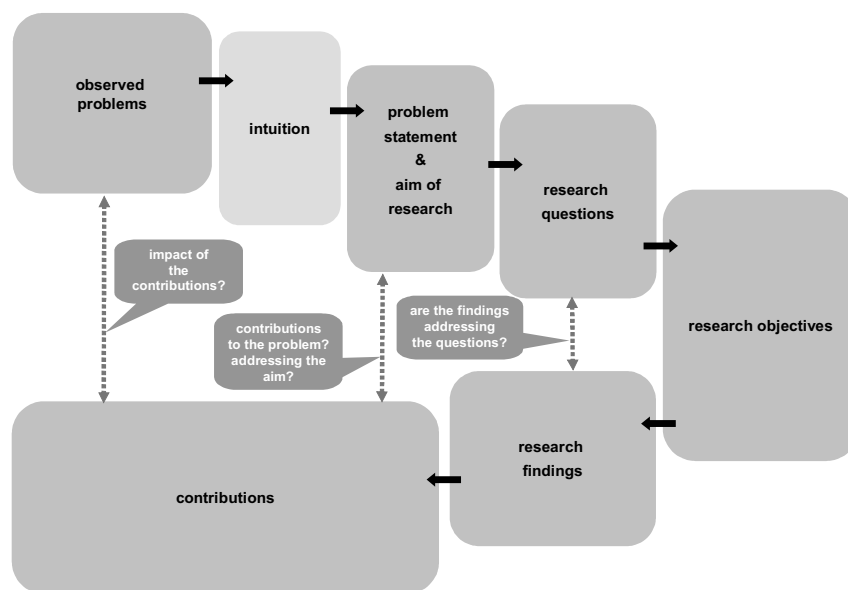


Figure 3-12. The ‘horseshoe’ approach for checking the consistency of the research design.

The second strategy for establishing construct validity was to ensure a chain of evidence. One of the challenges in using the flexible design strategy is to establish coherence

between the main elements of the research design; the problem statement, the aim and research questions, the tasks and the methods applied, the findings and the conclusions. Regular checks were made throughout the entire process of the internal consistency between these research-design elements. Do the findings actually address the research aim and questions? Do the findings impact the observed research problem? Placing the different research-design elements with their content in a 'horseshoe' constellation has here been particularly helpful in checking their relationships (Fig. 3-12). This idea and the illustration above are derived from the 'Horseshoe research method' developed and applied by the Center for Integrated Facilities and Engineering (CIFE) at Stanford University, which I visited in April 2007. This academic research center works with issues related to virtual design and construction of AEC industry projects (CIFE 2008).

The third strategy for ensuring the construct validity is to let key informants review the case-study reports. It has therefore been important to inform the respondents about the progress of the study and its results. Both Papers II and III have been sent to key respondents for their feedback on the use of the raw data and on the interpretations presented in the papers. These 'reviewers' have positively confirmed that these papers are good reports on the project situation according to the topics investigated.

the external validity of the research

"The formal generalization is overvalued as a source of scientific development, whereas 'the force of example' is underestimated." Flyvbjerg (2004:425).

The research here seeks to contribute more knowledge on and comprehensive understanding of the implementation and use of ICT in real-life projects. An array of factors and relations have been revealed and explored in the real-life projects by using various methods and techniques. To enable a statistical consideration of this huge amount of relevant variables related to the studied phenomenon and its context an impossible number of cases would have been required. Yin (2003) points out that case studies rely on analytical generalization, where "the investigator is striving to generalize a particular set of results to a broader theory" (Yin, 2003:37). How is the domain to which the findings can be 'generalized' established in this work?

Each of the case studies can be regarded as a 'complete' and single study based on their own 'converging lines of evidence'. The intention of conducting four case studies is not to directly compare the data collected to generalize findings or to achieve data triangulation. The case-study constellation must therefore not be confused with what Yin (2003) calls a multiple case-study design. Each project represents highly complex arenas of different and uncontrollable variables and relationships through their different functions, project structures and contractual models. Nonetheless, due to their common denominators and the application of the framework and the same strategies and procedures for data collection and analysis, some of the findings of the main case study were

predicted to be and actually were similar to the findings generated from the reference studies.¹³ This enabled what Yin (2003) calls replication logic, which is one of the recommended strategies for ensuring an external validity, however, here, not in the sense of direct data comparison, but as an empirical reference for discussing and strengthening the significance of the main case findings.

Johansson (2005) describes another interesting view on generalization which can be related to this work. He points out the important role of the research audience in what he calls an abductive mode of reasoning. The main focus of the investigator is here put on understanding the case, while the audience is undertaking the 'naturalistic generalization'; it applies the knowledge made explicit by the investigator on other actual problem situations by making appropriate comparisons.

the reliability of the research

Ensuring the reliability of the research shall contribute to less errors and biases in a study and enable other investigators to arrive at the same findings (Yin, 2003). The case-study protocol and the careful documentation of the case-study procedures has been one way of achieving this. This chapter has provided an overview of the procedures, the approaches and the research instruments applied. Additionally, a broad array of supplementary documentation is available through a case study database, comprising, for instance, the case-study protocol, the interview transcriptions, archival records and project material.

3.2 quality assurance throughout the process

In addition to the strategies described above, the work has been actively checked throughout the entire research process to strengthen the validity, both for an external audience and for my personal critical reflections.

workshops

In December 2005 I arranged a workshop at NTNU with nine experts from both research and practice.¹⁴ Here the research design and the descriptive framework were presented, together with a demonstration of their application for exploring the impact of ICT on the architectural design process in one of the reference cases; the AHUS project (May 2005). In the discussion part of the workshop, the participants gave their feedback and comments. Their comments confirmed the relevance of the problem statement, and they welcomed the idea of the descriptive and holistic framework. Addition-

13. Yin calls this 'literal replication' (similar results predicted), as opposed to 'theoretical replication', which is to select case studies predicting contrasting results for predictable reasons (Yin, 2003:47).

14. More info about the workshop can be found in Appendix A.

ally, some steps were discussed that could sharpen the focus of the further work. This workshop has been video-recorded.

other expert arenas for discussions and feedback¹⁵

The research design and parts of the findings have also been presented at several international conferences and seminars. This was a good opportunity to obtain feedback on the work from other researchers in the field, as well as to get an overview of relevant activities in other research environments and academic groups. Short visits to other universities, academic groups and AEC companies regarded as leading in their fields have been undertaken to obtain deeper insight into some of these research activities and to receive comments on the relevance of the problem statement, and on the approaches and strategies applied. Some of these universities and companies were visited during a trip to the San Francisco Bay area in 2007. Reports have been made from all trips to other universities and companies.

All papers included in this work have been reviewed by two or three experts, with the exception of Paper III, which is still in the review process. Papers I and II are extended versions of conference papers, thus they have even been through a double review process. For instance, the framework concept has been introduced at several international conferences.¹⁶ Two of these conference papers (Moum 2005a, 2005b) became the basis for Paper I, which is re-produced in Chapter 4.

reflective research(er)

Schön (1991) introduces the terms 'reflection-on-action' and 'reflection-in-action' to describe important mechanisms in the practitioners' daily work, and he points to the important role of such reflection in research as well. The reflective approach has been an important vehicle for ensuring the quality of this research. Firstly, for a regular and critical checking of the consistency of the research design and process I use 'reflection-on-action'. Moreover, the writing process itself and the development of visualizations of process and findings were important arenas for explorations and discussions of the data collected; 'reflection-in-action'.

15. Lists of persons interviewed, conferences and seminars attended and visits to other universities and companies are provided in Appendix A.

16. At the 11th CIB Joint International Symposium 'Combining Forces, in Helsinki 2005, the first paper presenting the outline of the framework (Moum, 2005b) was awarded as 'best paper' in the group of research papers dealing with 'ICT in Construction'. One of the reasons given was the scientific committee's approval of research projects going beyond only having a focus on technological aspects.

3.3 the issue of objectivity and the role of the researcher

“Do case studies contain a subjective bias? ... The fourth of the five misunderstandings about case-study research is that the method maintains a bias towards verification, understood as a tendency to confirm the researcher's pre-conceived notions, so that the study therefore becomes of doubtful scientific value.” Flyvbjerg (2004:428).

Flyvbjerg points out a controversial assumption within qualitative research; the more objective the researcher, the higher the scientific value. Undoubtedly, being objective is an important virtue of the researcher, as personal opinions and worse, prejudices, can contaminate the findings and the subsequent conclusions. It has also here been vitally important to strive for the objectivity needed to ensure the rigor and reliability of the research. The state of absolute objectivity can, however, hardly be achieved, as every researcher is of a particular gender, age and nationality, and is part of a cultural, political, economic and social context. These factors also created the glasses through which the world and research phenomena were viewed in this work.¹⁷

This has required particular awareness on two issues. Firstly, I had to be aware of the glasses I wore. What impact did they have on my interpretations and the decisions I made, and how did the learning and extension of knowledge throughout the process impact me? The second issue has been to be candid so the reader can be aware of the person behind this work and the glasses through which this research issue has been viewed. The issue of objectivity has thus, on the one hand, required reflection and sensitivity due to the validity and the reliability of the work. On the other hand, my background and experiences from practice have been helpful in conducting and dealing with the complexity of this work in the first place. Robson (2002) points to the importance of such previous knowledge in gathering the appropriate information and asking the relevant questions.

17. Fellows and Yin (2003) emphasize the importance of considering the impact of the context or the environmental factors on the research.

Exploring relations between the architectural design process and ICT

4 paper I

a framework for exploring the ICT impact on the architectural design process¹

SUMMARY: 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. A better understanding and overview of how ICT affect on the complex mechanisms within the early stages of the planning process can be seen as central to achieve project success. This paper presents a framework for exploring the ICT impacts on the architectural design process, focusing on ICT benefits and challenges regarding four essential design process aspects: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. The framework is founded on the suggestion of three hierarchical building project levels, the micro (individual)-, meso (group)- and macro (overall)-level. Several benefits and challenges of ICT regarding the four architectural design process aspects are explored and the outline of an ICT impact matrix summarizes the key points of the exploration. Furthermore, the paper gives an example of how the framework could be applied to a real-life project for supporting the exploration of how ICT impact on the architectural design process in practice.²

4.1 introduction

A fundamental pillar of a successful building project is a good design process. The field of architectural 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 building projects. Over the years, the development of ICT (Information and Communication Technologies) has led to several changes in the AEC industry. The network technologies, advanced visualization tools and CAD (Com-

1. This is the first of the three main articles in this paper-based thesis. The article has been published in the international 'Journal of Information Technology in Construction' (ITcon) in May 2006.

2. 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. Sincere thanks goes also to Jørund Andreas Kjærem from Svingen Arkitekter AS, for giving interesting answers to many questions.

puter Aided Design) are some examples of ICT, which represent powerful potential of facilitating change and improvement. The participants within the building design process face ICT related benefits and challenges on several levels. Both working processes and role definitions are affected (Berg von Linde 2003, Sundell 2003, Wikforss 2003a and 2003b).

Much research of today focuses on the development of new and improved ICT. The main topic of this paper however, is how the use and implementation of ICT today impact on central issues in the architectural design process. Special attention is hereby paid to how the implementation and use of ICT affect on the architect's work and interactions. A better overview and understanding of these issues can be valuable for ensuring good architectural design and management of building projects.

This paper presents the outline of a framework for exploring the ICT impact on the architectural design process. The framework focuses on four essential aspects of the architectural design process: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. Furthermore, the framework is based on the suggestion of three hierarchical levels: the micro- (individual), meso- (group) and macro (overall)-level (Fig.4-1). These three levels and the four design aspects are the main components in an ICT impact matrix (Fig.4-2), which has been developed as a tool" for summarizing the explored ICT-related benefits and challenges.

In the first part of this paper, after a brief explanation of the framework and the motivations behind it, examples of contemporary research and literature regarding the ICT-related benefits and challenges within the four selected design process aspects of the framework will be explored. The ICT impact matrix summarizes the key-points of this exploration. In the part two of the paper, an example will be given to demonstrate how the framework and the ICT impact matrix could be used to explore and summarize the ICT impact on a real life project. This practical example is based on an interview with an architect involved in a housing estate project in Norway. Finally, after a tentative discussion of the frameworks adaptability on practice, the further steps will be described.

The presented framework establishes the fundament of a research still in progress. This paper is based on conference papers presented on the CIB 2005 Joint Symposium 'Combining Forces' in Helsinki (Moum 2005b) and on the CIBW78 2005 conference 'IT in Construction' in Dresden (Moum 2005a).

4.2 outline of a framework for exploring the ICT impact on the architectural design process

To explore the ICT impact on the architectural design process is a huge undertaking. In order to support the exploration and analysis of the multiple and complex amounts of information collected from both theory and practice, a framework has been developed.

The framework focuses on four central aspects of the architectural design process; the generation of design solutions, communication, the evaluation of design solutions and decision-making. The starting point for selecting these four aspects is the crucial role of decision-making in the architectural design process. A decision can directly impact on both the architectural design process and the product, in the form of a new requirement, a "green light" for further development of a design idea or a refusal of a suggested solution. Decisions are made on different levels and by different actors. The architect will make his decisions about which design solutions are worth being put on the paper. The client will be responsible for the crucial decisions regarding which proposed architectural design concept should become the foundation of further development. Making good decisions in such cases relies heavily on the individual designer's or the design group's ability to generate design solutions in the first place. 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' into something that can become the conceptual fundament of the building project (Lawson 2006). But also the ability to communicate good design solutions is a crucial issue. Communication is in much literature emphasized as a key to success and good decision-making on several levels in the architectural design process (Emmitt and Gorse 2003, Kalay 2004, Lundequist 1992c, Schön 1991). The communication and interaction between the building process actors, each representing different interests and experiences as basis for evaluation of the proposed design solution, can essentially impact the decisions made and the further development of the architectural design solution. Furthermore, decisions are made based on the decision-makers' or other participants' evaluations of for instance the design solution's quality or its consequences for the design as a whole. Through the last decades, there have been many attempts to explain what is really going on in the architectural design process (Lundequist 1992b). There are many different approaches regarding design methodology and the relationship between different design process components and aspects. The ambition behind this framework is not to establish a new comprehension of the design process, and also not to re-introduce the sequential understanding characterizing the first generation of design theories in the 1960s (Lundequist 1992b). The four selected design process aspects; the generation of design solutions, communication, the evaluation of design solutions and decision-making, are central issues in the literature explored. They seem in a dynamic and iterative interplay, to together form a central part of the process of design.

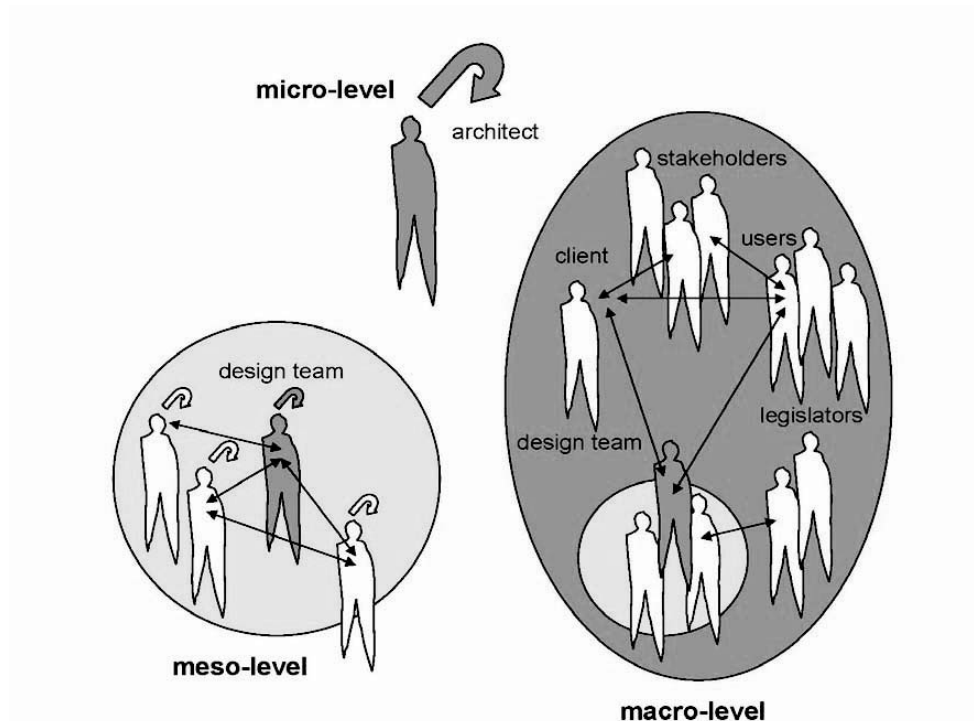


Figure 4-1. The three hierarchical levels.

	Macro-level	Meso-level	Micro-level
Generation of design solutions			
Communication			
Evaluation of design solutions			
Decision-making			

Figure 4-2. The ICT impact matrix.

The framework is furthermore based on the suggestion of three levels of operations and actions within the architectural design process; here called the micro-, meso- and macro-level (Fig. 4-1). The micro-level focuses on individual and cognitive processes, for instance the architect's individual development of design solutions. The designer's con-

versation with the design situation (Schön 1991), or what Kalay (2004) calls ideation or an intra-process role of communication are examples of micro-level processes. The meso-level covers the mechanisms and processes within a group. The interaction between the architect and the other consultants within the design team illustrates actions on the meso-level. The design team is a part of an overall context. The macro-level comprises processes on overall level.

To use levels as a possibility to structure and organize different issues is a usual approach within several areas. Yin (2003:31) describes four different levels of theory; individual theories (e.g. cognitive behaviour, individual perception), group theories (e.g. work teams, interpersonal networks), organizational theories (e.g. inter-organizational partnerships) and societal theories (e.g. marketplace functions, international behaviour). Emmitt and Gorse (2003:44) refer to Kreps, who divides human communication into four levels: 1) intrapersonal communication (thought process of one person), 2) interpersonal communication (communication between two), 3) small-group communication and 4) multi-group communication (enables different groups to coordinate efforts). The terms micro, meso and macro are used in different settings, for instance within communication theories (see example <http://www.tcw.utwente.nl/theorieenoverzicht/>).

Based on the four selected design process aspects and the three hierarchical levels, an ICT impact matrix is suggested as a 'tool' for summarizing and giving overview of the key points explored (Fig. 4-2), both regarding theory and practice. The lines between the different levels and design aspects in the illustration should rather be understood as a 'translucent' and 'breathing' layer between interdependent elements than fixed borders between rigid categories. A puzzle could be another appropriate metaphor for describing the complexity imbedded in the matrix.

Until now, there has not been found literature or research which applies this kind of framework for exploring the ICT impact on the architectural design process. The development of the presented framework is based on the review of contemporary literature, on experiences from design and management of building projects and on workshops and discussions with actors from both research and practice. The framework and the ICT impact matrix are in this paper presented as a possible approach for exploring theory and practice, in order to gain a better understanding and overview of the relationship between ICT and the complex field of the architectural design process.

PART I: a literature-based exploration of the ICT impact on four essential aspects of the architectural design process

4.1 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 (Lundequist 1992b). The first generation of design methodologists' focus on the design process as something sequential and linear, was to be challenged. Lawson (2006) 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, and it 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 (Lawson 2006). The designer operates in a virtual world, a constructed representation of the real world in practice (Lundequist 2003, Schön 1991). 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 (Lawson, 2006). However, the first generation's 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 (Lundequist 1992b), still have some relevance. One vehicle of achieving these early aims, although with other means, could be ICT.

computer aided design or drafting

The generation of design solutions is still perhaps the area, in which the ICT has gained less foothold (Lawson 2005). The CAD systems used within the design process, support drafting and modelling rather than special design attributes and analytical capabilities, and have not changed the task of drafting or modelling (Kalay 2004). 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. There are also developed computer programmes better suited to support the designers sketching act than the traditional CAD-programmes. For instance SketchUp, which on the software website is described "as the pencil of digital design" (<http://www.sketchup.com/>). But can CAD support the generation of the design solution itself? Or is the computer what Lawson (2005) calls a draughtsman? 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.

ICT as a design partner

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 to combine them to alternative solutions in much shorter time than the human being can. A research project at the ETH in Zürich, called "KaisersRot" (Fritz 2002), 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 these 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 (Wikforss 2003b). 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. 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 (2003) 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 (2003b) 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 (Kalay 2004). A design agent can make a designer aware of inconsistency regarding building legislation, for example the minimum height of a staircase handrail. Thus, ICT would develop from being a tool to becoming a design partner. Lawson describes in one of his recent articles a vision about a web-based, learning and pro-active creative design partner role (Lawson 2005). 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.

new design methods

The development and implementation of 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 (2004) 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 influence on the working methods (e.g. 3D product model), although such tools could offer obvious benefits.

4.2 communication within the architectural design process

The successful planning and realization of a building project depends heavily on the success of communication on many levels. Schön's (1991) description of the designer's conversation with the drawing, or what Kalay (2004) 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. 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 (Kalay 2004). Figure 4-3 attempts to illustrate the relations between interdependent and iterative processes.

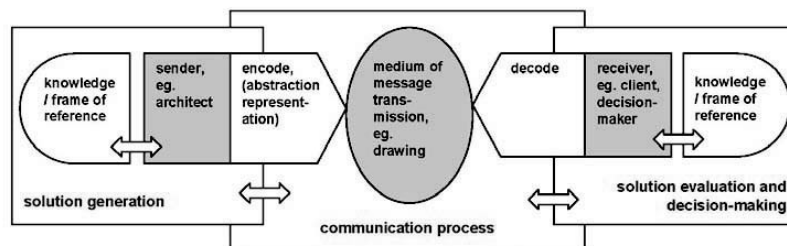


Figure 4-3. Illustration of the relations between the four selected architectural design aspects.

Failed communication can cause conflicts and misunderstandings, and negatively influence the building project, if not recognized and solved at an early stage. 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. The architect can assume that the client knows which totality an abstraction represents, for example the door symbol in a plan drawing. 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 (Griffith et al. 2003). Wittgenstein's language game theory is one illustration of this problem area (Lundequist 1992a). 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 (Lundequist 1992a).

the designer's conversation with the design situation

Schön (1991) 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." (Schön, 1991:140). 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 often illustrate a variety of metaphors, and contain a high degree of uncertainty? Until now, the answer seems to be no.

network technologies and collaboration

Successful teamwork is based on shared understanding. If the participants have similar background and a common base of experiences, with the opportunity to learn about each other over time, to communicate, share information, and to develop a team spirit, this will be ideal conditions to ensure a shared understanding of goals and tasks (Hinds and Weisband 2003). However, within a building design team, this will not always be the case.

The importance of collaboration is growing, as globalization and increasingly complex technology and products require more teamwork. 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 (Lawson 2006). Participants with different backgrounds, preferences and experiences try to achieve a common goal. Barrow (2000) 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" (Barrow 2000:272-273).

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, as they support information exchange independent of geographical and organizational borders. Collaborative design and communication within a virtual instead of collocated situation inherits many new possibilities, but also 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 (Duarte and Snyder 2001). 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.

information access and distribution

The network technologies make an easy and fast access to and distribution of information possible. This has been a benefit within the building project and has, according to Schwägerl (2004), contributed more to accelerate the design processes than the CAD tools. The development of the data base technologies (server or internet-based), has been an important support of handling the huge amount of documents and drawings within a building project. A pool of documents and drawings is accessible to the different project 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 (Berg von Linde 2003). 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 and the attention of the receiver is becoming an important resource (Davenport and Beck 2002).

communication standards and 3D product models

Another influential trend within ICT is the development of communication format standards between different programs and systems, in order to achieve interoperability. An example of such a standard is the Industry Foundation Classes (IFC) (Ekholm 2003, Kiviniemi 2004, Tarandi 2003). The development of communication standards is one of the fundamentals 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 modelling (BIM). Such models are based on the definition of objects (products) containing so-called intelligent information (Ekholm 2003, Tarandi 2003). The main objects, such

as doors and windows, are standardized. According to Fekete (2003), 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 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 (Kiviniemi 2004, Wikforss 2003a). From the model 'traditional' drawings can easily be generated, and the density of information can be controlled.

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' (Gray and Hughes 2001), illustrating which participants dominate the different planning stages of the design process, could change. 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' (Hanus et al, 1987) illustrates the current construction sector as many separate islands in a big construction sector ocean. The use of ICT, in this case the 3D product model, contributes to a 'land rising', where the many small islands 'melt' to one big island. As a consequence, the traditional borders between roles or planning stages would blur and change. The separate bits of the planning process are melting and compressed to a conglomerate. 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 work and interactions of the architect?

4.3 evaluation of design solutions

The architectural design process is in addition to the measurable, quantitative and conscious based on the qualitative, intuitive and tacit (Kiviniemi 2004, Lawson 2006, Lundquist 2003). 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?" (Lawson 2006:63). Lawson (2006) emphasizes further that a crucial skill of the designer is to balance qualitative and quantitative aspects.

'almost real'

ICT offer a most powerful support of evaluation. Through simulation and highly realistic visualizations it is possible to get an impression of the 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 (Wikforss 2003b). However, there can be a conscious or unconscious mismatch between the intention of the sender and the interpretation of the receiver (Lawson 2006).

These tools usually require the presence of something to evaluate, and a level of precision often not feasible in the early stages of design. Lawson (2006) characterizes the temptation of too early precision as the design trap of over-precision, which can become a creative process impediment. Until now, the generation of 3D models as a 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 (Lawson 2006). 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 (Kiviniemi 2004).

information overload

We do not know much about how the human being handles and edits information (Lundquist 2003). 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 and organizing of information (Berg von Linde 2003). 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?

4.4 decision-making within the architectural design process

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 (Gann 2000). An important skill of the designer is to juggle

with several ideas at the same time, without forcing a premature precision or decision (Lawson 2006). 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 (2003b) emphasizes the importance of enough time for maturing in the planning- and decision process. There must be enough time available to reflect on and understand the consequences of different solutions and decisions. He emphasizes further that ICT tools, e.g. the 3D product model, must allow a step-by-step precision.

Obviously, it is easier to make a decision if every uncertainty is eliminated. The use of ICT supports the storing and capturing of previous project experiences, as well as the reusing and modifying of 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 (2003) sees a possible conflict between the established experience and the will to innovate. 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 offer 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 (2003) ICT support 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.

4.5 ICT benefits and challenges regarding four aspects of the architectural design process: summary

The first part of this paper has presented a broad and literature based range of different ICT impacts on the architectural design process. The ICT impact matrix (Table 4-1) summarizes some of the explored and discussed ICT related benefits and challenges within generation of design solutions, communication, evaluation of design solutions and decision-making.

Exploring relations between the architectural design process and ICT

Table 4-1. The ICT impact matrix summarizing the key points of the explorative literature review.

	Macro-level	Meso-level	Micro-level
<p>Generation of the design solution</p> <p>Examples ICT: CAD, VR, sketching programs, design-agents etc.</p>	<p>Benefits:</p> <ul style="list-style-type: none"> Advanced visualization tools as VR a possible trigger of innovation and "evolutionary" architecture. <p>Challenges:</p> <ul style="list-style-type: none"> 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. 	<p>Benefits:</p> <ul style="list-style-type: none"> Supporting the development of collaborative design. Advanced visualization of design idea possible. <p>Challenges:</p> <ul style="list-style-type: none"> Interaction between individual and group design generation – "cybernetic architecture". 	<p>Benefits:</p> <ul style="list-style-type: none"> 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. <p>Challenges:</p> <ul style="list-style-type: none"> Computer systems requiring too much precision. Complicated user surfaces can disturb the mediation of creative processes. ICT should support step-by-step precision.
<p>Communication within the design process</p> <p>Examples ICT: 3D product models, databases, network technologies (e.g. Internet, e-mail, WorldWideWeb) etc.</p>	<p>Benefits:</p> <ul style="list-style-type: none"> Better access to and distribution of information within building projects – more transparency. Interoperability on overall level. "Land-rising" within construction sector – more transparency – foundation for collaboration. <p>Challenges:</p> <ul style="list-style-type: none"> Redefinition of roles, responsibility and planning stages Misunderstandings due to represented decision material (intention not like interpretation). New communication and collaboration culture. 	<p>Benefits:</p> <ul style="list-style-type: none"> 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. <p>Challenges:</p> <ul style="list-style-type: none"> Less social presence and info richness than F2F can lead to misunderstandings and conflicts. Different knowledge reservoirs within design team – source of conflicts. From push to pull of information. 	<p>Benefits:</p> <ul style="list-style-type: none"> Better access to information for the individual. <p>Challenges:</p> <ul style="list-style-type: none"> 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?
<p>Evaluation of the design solution</p> <p>Examples ICT: 3D product models, simulation tools (e.g. cost, time, climatic aspects), 4D models etc.</p>	<p>Benefits:</p> <ul style="list-style-type: none"> Almost real world simulation and visualization, early recognition of conflicts and problems. <p>Challenges:</p> <ul style="list-style-type: none"> How to judge and measure the quality of a design solution? Information overload and loss of focus and overview. 	<p>Benefits:</p> <ul style="list-style-type: none"> Almost real world simulation and visualization support coordination within design team – early recognition of conflicts and problems. <p>Challenges:</p> <ul style="list-style-type: none"> Simulation or visualization of only building parts – loss of overview and total quality. Information overload and loss of focus and overview. 	<p>Benefits:</p> <ul style="list-style-type: none"> Almost real world simulation and visualization, early recognition of conflicts and problems. <p>Challenges:</p> <ul style="list-style-type: none"> Information overload – loss of overview and focus for the important.
<p>Decision-making within the design process</p> <p>Examples ICT: 3D product models, simulation tools (e.g. cost, time, climatic aspects), VR, 3D modeling tools, network technologies etc.</p>	<p>Benefits:</p> <ul style="list-style-type: none"> Decision material more consistent and real-world like – reduction of uncertainty Reuse of previous experience easier -reducing uncertainty. <p>Challenges:</p> <ul style="list-style-type: none"> 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? 	<p>Benefits:</p> <ul style="list-style-type: none"> Decision material more consistent and real-world like – reduction of uncertainty. <p>Challenges:</p> <ul style="list-style-type: none"> Realistic visualization and simulation forces too early decision within design team? 	<p>Benefits:</p> <ul style="list-style-type: none"> Decision material more consistent and real-world like – reduction of uncertainty. <p>Challenges:</p> <ul style="list-style-type: none"> Realistic visualization and simulation forces too early decision? Obstruction of the creative processes and parallel lines of thought?

PART II: the framework applied to a real life project for exploring the ICT impact on the architectural design process - an example

This part two of the paper illustrates how the presented framework could be used to explore the ICT impact on a real life project. The intention is to establish a foundation for further discussions and considerations regarding the framework's application to real life projects, since the next step of the research would be to carry out case-studies of building projects. The example presented here is based on an interview with one of the key architects in a housing estate project in Trondheim, Norway. His experiences regarding the use of ICT in the architectural design process within this specific project have been explored on all three hierarchical levels.

4.1 background and context of the project

Trondheim is a middle-sized old university town in Norway. On a site directly by the waterfront, the development of a housing estate, including a home for elderly people, was started in 1998.



Figure 4-4. The housing estate project (Courtesy: Svingen Arkitekter AS).

The client, a professional organization, offered services within project development, real estate, contracting and module manufacturing. These different client departments played different roles during the building process. The client commissioned in 1998 a middle-sized architectural company from Trondheim to negotiate with the building authorities. These negotiations resulted in a development plan which became the starting point for

the further development of the architectural design. The housing project was divided into four stages of construction, in the size from 850 to 6400 square meters usable area (total 22.000 square meters). The design of the first construction stage started in 1999, the whole project was completed for sale in 2002.

Within the design process, the construction stages had own groups of architects. The interview respondent was the design manager from the architectural side, responsible for two of the four stages. In addition he kept the overview of the project in total to ensure the transfer of experience between the different construction stages. He was also involved in the development of the architectural design. Thus, he could give a good overview of processes and actors on all three levels. It should be emphasized that the respondent gave answers reflecting his attitudes, experiences and interpretation of a situation, process or action, which can deviate from how something really happened.

4.2 the use of ICT

In this specific project, the CAD-programme VectorWorks was the architects' basic tool for generating 2D-drawings and 3D visualizations. The architects working with the development and design of the project used this CAD program as a 2D tool only. 3D models of some parts of the project were made of a specialist within the architectural company. These 3D models became the basis for the generation of realistic visualizations, Quick-Time movies and 'walk-throughs'.

Originally, the client wanted to use a project-web system for documentation and file exchange, which would have been quite unusual and innovative at that time in the Norwegian AEC industry. These plans were stopped as the main person behind this idea left the client organization. Instead more 'traditional' ways of documentation and information exchange were used. E-mail thus became the main network technology supporting communication and exchange of data. The exchange between the architect and the client organization was based on pdf-files, the communication with the consultants and the manufacturer on dwg-files.

This project could be seen as a typical example regarding the use of ICT in a middle-sized building project around year 2000 in Norway.

4.3 exploring the ICT impact on the macro-level design process

The client organization and the building authorities were defining the overall constraints, requirements and aims, which essentially impacted on both the design process and the design product.

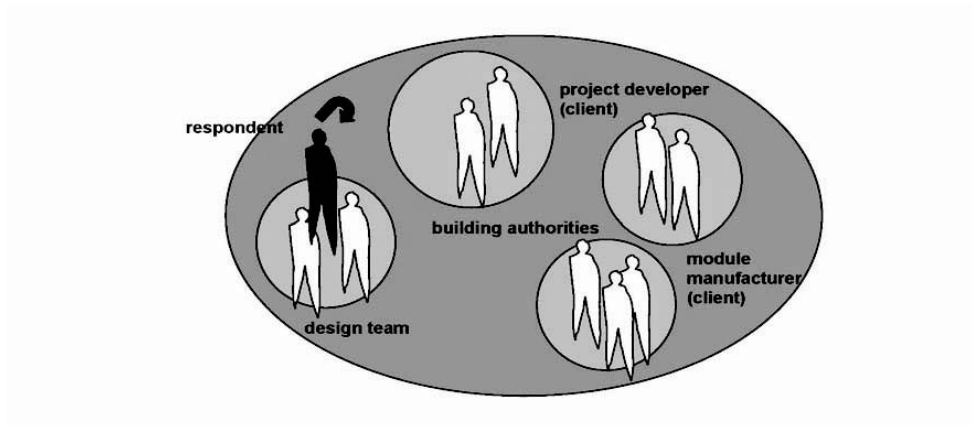


Figure 4-5. Macro-level actors.

A key requirement of the client was to apply a pre-fabricated module-based building system. These modules were to be produced by the manufacturing part of the client organisation, which gave the client an essential controlling and evaluating position regarding production related aspects. The intention behind requiring a module-based project was to reduce the construction time of the project. According to the respondent, the short construction time of two years for the whole project was made possible thanks to ICT.

In order to ensure more decision-making certainty regarding the constructability of the suggested design solutions as early as possible, the client required the manufacturer to contribute with his knowledge already in an early design phase. The client's requirements became thus the driving force behind a 'blurring' of the border between design- and production aspects. ICT however, became the facilitator of this "blurring" phenomenon.

The communication and data-exchange between the architect and the manufacturer was mainly based on the use of e-mail. The manufacturer evaluated the constructability of the suggested solutions, based on the architects' precise CAD-generated 2D drawings. This was one of the circumstances making the architects digitalize their ideas very early in the design process (which eventually also complicated the complex solution and problem finding process, see micro-level section). In addition; with the integration of traditionally later actors and actions in the design process, conflicts occurred. According to the respondent, the main communication problem general within this building project was inherited in the communication between the architect and the manufacturer, since the areas of responsibility for the design were not clearly defined. According to the respondent, the conflicts mentioned above could have been avoided with more face-to-face contact between the manufacturer and the architect.

The use of ICT in this project did not lead to central advantages due to accelerating the processes in the first stage of the construction. However, after the cumbersome development of the first stage, the module based details and solutions generated here could easily be re-used, modified or improved in the following construction stages. ICT supported this transfer of information in an efficient way and accelerated the processes regarding all selected four design aspects. The respondent perceived the last construction stage as the best one, due to both building and process. However, the fact that the actors involved remained mostly the same throughout all the construction stages is another issue not to be overseen. The tacit knowledge, routines and experiences built up from collaboration and design, embedded in the head of each individual actor, were probably valuable issues in order to reduce the time necessary for planning and construction in the later stages of construction.

Another benefit of ICT was, according to the respondent, the realistic 3D visualization and simulation of design solutions or problems. For example, the daylight situation was from the building authorities regarded as a critical issue, leading them to require special precautions with negative impact on the architecture and the building costs. To prevent this, the architect used ICT generated daylight simulations in order to convince the building authorities that his suggested design solutions could offer a satisfactory situation for the future users.

The architect also used this way of presenting ideas deliberately to influence the client's decisions. The communication between the architect and the client followed a quite traditional pattern regarding generation and evaluation of design solutions and decision-making. The architects often generated their ideas 'at home' in their office, and spent considerable time in making convincing and illustrative presentations of these ideas (especially to underpin visual issues). Based on these presentations, with or without the physical presence of the architect, the client made his decision about the further development of this idea. The respondent's experience was that the ICT-generated realistic 3D visualizations helped making the qualities of the design solutions better understandable and visible. ICT supported the communication of difficult understandable design issues, which perhaps otherwise would have let the client or the building authorities make their decisions based on 'wrong' pictures in their head, or even misunderstandings.

4.4 exploring the ICT impact on the meso-level design process

In the early design process, there were not many actors participating in the traditional design team (comprising architects and consultants from the engineering disciplines). The architectural company handled themselves the schematic mechanical and electrical services in the early design phases, which is not an unusual situation in Norwegian small- and middle sized projects (2000). The main reason for the late appearance of most of the consultants was according to the respondent the fee- and contractual situation. As the

mechanical and electrical consultants finally joined the process, as both planner and manufacturer of the technical systems, the main design concept was almost fixed. The respondent emphasized several times the drawback of this situation, since the knowledge of these participants would have been a valuable contribution within the development of the design concept, especially in the first construction stage.

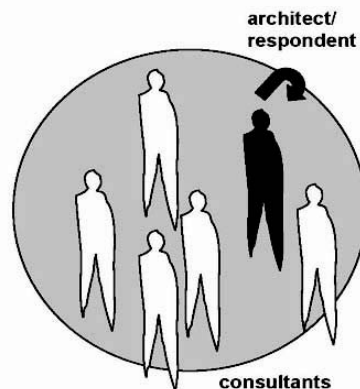


Figure 4-6. Meso-level actors.

The information, which was not exchanged face to face within regular design team meetings (finally taking place towards the end of the design process), was communicated using telephone, fax or e-mail. Most consultants were using AutoCad as CAD system. The respondent mentioned that some of the consultants, after receiving the dwg-files from the architect, redrew the computer-generated drawings from scratch with their own CAD system. This resulted in double work and inefficiency. A part of this problem can probably be found in some actor's mistrust in the correctness of drawings generated by another computer system (or by the architect), another perhaps in old habits and traditional data exchange patterns between the architects and the consultants.

4.5 exploring the ICT impact on the micro-level design process

In the beginning of the design process, the architect was sketching with pen and paper. But very early the hand-sketches had to be transformed into computer-generated drawings. As described in the macro-level section, the project was to be built up on a pre-fabricated modular system. This modular system was adapted to for instance accommodation units, facades and construction systems. As soon as the sketch of a design solution was put on the paper, its potential as a repetitive element had to be tested and evaluated. For this purpose, the architect 'transformed' his hand sketches into computer-generated 2D drawings. These computer-generated drawings, not the hand-drawn sketches, were used as the basis for communication, evaluation and decision-making.

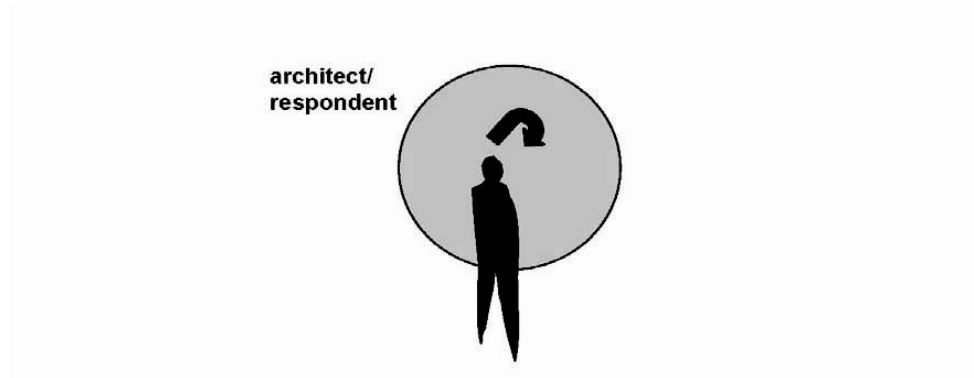


Figure 4-7. Micro-level actor.

For the individual architect, the computer supported drafting and modelling, but not the generation of design ideas itself. Here rather traditional tools as pen and paper supported the architect's conversation with the design situation. The computer became however a valuable support for testing and evaluating the generated design ideas' ability to fit into and underpin the modular system. Thus, in this project, ICT was more a tool for drafting and evaluation than a partner supporting the generation of design solutions. The respondent perceived the time available and used for sketching and modelling by hand as too short, which is an interesting issue. According to him, this could negatively have influenced the quality of the design solutions. The step from the rough sketch to the precise drawing was perhaps made too fast. Premature decisions were eventually forced, without enough time for the ideas to mature or enough time for testing out more of the "balls" the architect can 'juggle' with in the sketching act.

The ICT impact matrix (Table 4-2) attempts to summarize examples of ICT related benefits and challenges on all three hierarchical levels in this specific building project.

Table 4-2. The ICT impact matrix summarizing some examples of ICT benefits and challenges in the real-life project.

	Macro-level	Meso-level	Micro-level
Generation of the design solution	<p>Benefits:</p> <ul style="list-style-type: none"> • ICT supported modular system planning/design. <p>Challenges:</p> <ul style="list-style-type: none"> • ICT supported modular planning, which led to early integration of production aspects in the design process – not enough time for the creative processes? Negative effect on architectural quality? 	<p>Benefits:</p> <ul style="list-style-type: none"> • ICT supported modular system planning/design. <p><i>little design solution generation activity – late involvement of consultants</i></p>	<p>Benefits:</p> <ul style="list-style-type: none"> • ICT supported modular system planning/design. <p>Challenges:</p> <ul style="list-style-type: none"> • Early integration of production constraints – • Short time available for free sketching
Communication within the design process	<p>Benefits:</p> <ul style="list-style-type: none"> • ICT supported early communication with manufacturer. • ICT supported the communication of esthetical aspects which would have been difficult to explain only with words. <p>Challenges:</p> <ul style="list-style-type: none"> • Blurring border between planning and production, • Unclear definition of responsibility resulted in misunderstandings, • Misunderstandings could have been avoided with more face-to-face contact 	<p>Challenges:</p> <ul style="list-style-type: none"> • Consultants re-drew architect drawings (VectorWorks) with own system (AutoCAD) – double work – mistrust in technology and "old habits" regarding data exchange within the design-team? <p><i>little communication activity – late involvement of consultants</i></p>	<p>Challenges:</p> <ul style="list-style-type: none"> • ICT not used as an "interactive" design partner – ICT a drafting tool.
Evaluation of the design solution	<p>Benefits:</p> <ul style="list-style-type: none"> • Realistic and real-world like 3D visualizations and simulations supported the evaluation of e.g. day-light situations and esthetical aspects. • Early evaluation and control regarding constructability of solutions possible. 	<p><i>little evaluation activity – late involvement of consultants</i></p>	<p>Benefits:</p> <ul style="list-style-type: none"> • ICT supported the testing of the design solutions ability to fit into modular system. <p>Challenges:</p> <ul style="list-style-type: none"> • Too early transforming of ideas into accurate and precise computer generated drawings for evaluation and testing?
Decision-making within the design process	<p>Benefits:</p> <ul style="list-style-type: none"> • Decision material more consistent and real-world like – reduction of uncertainty. • Reuse of previous solutions/knowledge - reducing uncertainty. • ICT allowed architect to indirect influence on client's decision-making (conscious use of 3D visualizations to emphasize architectural quality in decision-making material). <p>Challenges:</p> <ul style="list-style-type: none"> • Forces too early decision not representative for the factual status of project? 	<p>Benefits:</p> <ul style="list-style-type: none"> • Reuse of previous solutions/knowledge - reducing uncertainty. <p><i>little evaluation activity – late involvement of consultants</i></p>	<p>Benefits:</p> <ul style="list-style-type: none"> • ICT supported architect's decision-making due to the design solutions ability of fitting into the modular system – • Reuse of previous solutions/knowledge - reducing uncertainty. <p>Challenges:</p> <ul style="list-style-type: none"> • Too early decisions regarding which ideas to be further developed? Not allowing the "juggling" with several ideas and parallel lines of thought?

4.6 a tentative discussion of the framework's adaptability on practice

The project example above illustrates how the framework can be used to explore and organize data collected from an interview. Based on this example, some issues concerning the adaptability of the framework on a specific building project can be tentatively discussed.

The main support of the framework has in this example been its support regarding the collecting, analyzing, structuring and presenting of the empirical data. The framework helped keeping overview of actors and processes, and the interview respondent's experiences due to the use of ICT. However, there are several challenges to be handled in the further development of the framework's adaptability on practice.

One of these challenging issues is the definition of the three hierarchical levels. Macro-level comprises in this practical example the processes on overall project level. On the meso-level, the experiences regarding the traditional design team (architects and consultants) have been explored. And on micro-level, the attention was paid to how the individual architect used ICT. In this specific project and according to this definition, it could be discussed on which level the collaboration between the client and the architect was actually taking place, on the macro- or on meso-level. Dependent on the contracting and partnering forms, 'new' actors can participate in the traditional design team, for instance the contractor, the manufacturer and the client.

In order to allow a more dynamic approach to the borders between the participants and the role-definitions within a building project, a less overlapping definition of the macro- and the meso-level could be considered in the further research. In the theoretical part of this paper, the benefits and challenges explored and summarized on the macro-level was of general and overall character. 'Transferred' to a practical situation, the macro-level could represent mechanisms and processes outside a building project. According to such a definition, an example of mechanisms on macro-level could be the Danish public-private initiative called Digital Construction (Det Digitale Byggeri) which, on a national AEC-industry-level, among others aims to establish a coherent set of rules for the implementing and working with BIM in building projects (www.detdigitalebyggeri.dk). Thus, the meso-level would comprise the (group) processes taking place within a building project, including all 'project-specific' participants who are taking part in the architectural design process and in the design team.

Another important issue is to handle the relationship between the different components in the framework. The architectural design process is multi-dimensional and interactive, based on an interconnectedness of different factors. As already emphasized, the intention behind the framework is not to force elements of the architectural design process into rigid boxes. Each of the framework's components could be seen as a piece in the puzzle of architectural design. Probably much of the dynamic in the architectural design process can be found in the interfaces between the three hierarchical levels and the four selected design aspects, each of them impacting on the other.

Another experience worth to be considered in further research, was made in the interview situation itself. It became soon clear that using the ICT impact matrix as a direct guideline in the interview situation was of little help. It was difficult to separate between

the four design process aspects, especially due to the partly unconscious cognitive processes on the micro-level. There was also challenging to spontaneous handle all the 'specialities' and the irregularities in the project. Both resulted in a freer interview form, leaving the more structured interview guide beside. However, the framework itself helped the interviewer to keep the big picture and not get lost.

4.7 conclusions

This paper has presented a framework for exploring the ICT impact on the architectural design process. Several literature-based key points regarding the ICT-related benefits and challenges within the four selected design process aspects: the generation of design solutions, the communication, the evaluation of design solutions and decision-making, have been explored and finally summarized in an ICT impact matrix. Further the paper has given an example of how the framework could be applied to a real life project, followed by a tentative discussion regarding the framework's adaptability on practice and the challenges for further research and development.

The presented framework could represent one possibility to approach the wide range of ICT impacts on the complex field of the architectural design process.

This paper reports on an early stage in a research, which aims to gain knowledge about how the use and implementation of ICT today impact on the architectural design process, with a special eye on the architect's work and interactions. The presented framework establishes the fundament of the first part of this research, in which the relation between ICT and the architectural design process is viewed from a broad scope. A 'top-down' approach has been chosen as a starting point of this research in order to gain understanding and overview of the field as a whole before 'diving' into a limited research scope. In the second part of the research, the focus will be narrowed to how the implementation and interdisciplinary use of BIM (Building Information Modeling) impacts on the design team, especially on the architect's work (micro-level) and his interactions with the consultants from the engineering disciplines (meso-level). The main emphasis of this second part will be to carry out and analyze multiple case-studies of building projects in e.g. Norway, Denmark and Germany. The framework presented in this paper is supposed to guide the design of these case-studies, and to support the data collection, analysis and the comparing of data from different cases. The application of the framework to the multiple case-studies, could take form of what Yin (2003) calls table shells: "These are the outlines of a table, defining precisely the rows and columns of a data array - but in the absence of having the actual data. In this sense, the table shell indicates the data to be collected, and your job is to collect the data called forth by the table. Such table shells help in several ways. First, the table shells force you to identify exactly what data are being sought. Second, they ensure that parallel information will be collected at different

sites where a multiple-case design is being used. Finally, the table shells aid in understanding what will be done with the data once they have been collected." (Yin, 2003, p. 75)

Throughout the development of the research, a dynamic interplay between the 'general' first part with its development of the framework and the 'dive' in the second part will take place.³

3. The reference list of this paper is integrated in the list at the end of this thesis. The acknowledgements are included as a footnote at the first page of this chapter.

5 paper II

WHAT DID YOU LEARN FROM PRACTICE TODAY? exploring experiences from a danish r&d effort in digital construction¹

SUMMARY: The Architecture-Engineering-Construction (AEC) industry has been slow in turning the potential of Information and Communication Technologies into greater efficiency and productivity. This is a phenomenon which can be observed in many countries, and in Denmark this issue has been recognized as a major problem for the further development of the AEC industry. The public-private and nationally funded R&D program 'Digital Construction' was initiated in 2003 to establish a common platform for exchanging digital information and stimulating digital integration in the Danish AEC industry. This paper reports on the lessons learned from developing strategies, demands and guidelines in the 'Digital Construction' program and from adapting one of its 'digital foundations', the '3D Working Method', to the design process of the large-scale building project 'The Icelandic National Concert and Conference Centre'. The explorations are based on a process evaluation of the R&D program and a qualitative case study of the building project. The paper reports on identified factors enabling or hindering the adaptation, as well as on the benefits and challenges experienced from using and exchanging 3D object models according to the '3D Working Method'. The paper concludes that the adaptation has been successful due to the initial ambitions of the project actors. Nevertheless, there are still many challenges to be overcome. The findings indicate that the introduction of the '3D Working Method' to the real-life project depended on the success of balancing an array of the factors identified across the R&D program and the different levels within the building project. These indicate three especially crucial balancing acts; first, the power of the 'implementer' versus the expected risk and benefits of implementation, second, the strategies and guidelines within the program versus the resources for learning and the organizational traditions for using digital tools, and third, the level of ambition versus the skills of the users and the potential of the technology to

1. This is the second of the three main papers included in this thesis. The chapter is a reproduction of the revised version of the paper submitted to the international journal 'Advanced Engineering Informatics' in May 2008.

address real-life practice. Mastering these balancing acts requires a broad understanding of the project and its context. The findings from qualitative and holistic studies as presented in this paper are valuable for building such understanding, and for further learning and improvement regarding strategies for integrating ICT in architectural and engineering practice.²

5.1 introduction

Information and Communication Technologies (ICT) are commonly linked to future prosperity and growth in a number of European countries. Nevertheless, compared to other industries, the Architecture-Engineering-Construction (AEC) industry lags behind when it comes to the successful implementation of ICT and in turning the potential of the new technologies into greater efficiency and quality (Gann 2000, Wikforss 2003a). The productivity status in the AEC industry described in the Latham report in 1994 (Latham 1994), still gives rise to concerns. Several international and national initiatives and consortia working on the integration of ICT into the AEC industry have emerged in recent years (Bazjanac and Kiviniemi 2007). In Denmark, the national R&D program 'Det Digitale Byggeri' (Digital Construction), co-funded by public and private sources, was initiated in 2003 to establish a common platform for exchanging digital information and stimulating digital integration in the Danish AEC industry (EBST 2005). While the R&D program came to an end in March 2007, it has been followed by an ongoing implementation effort, which started in 2005.

Where Tom Paxton's old song 'What did you learn in school today' refers to the slow and insufficient learning of children, the contemporary AEC industry has to learn at a much faster pace and at a rate beyond the single project's timescales. Learning becomes ubiquitous and large scale R&D programs, as well as real-life practice, are contexts we need to learn from. This paper presents the findings from an overarching exploration of the strategies, demands and guidelines formulated in the 'Digital Construction' program, as well as the lessons learned from applying one of the program's digital foundations, the '3D Working Method', to a real-life project – the new Icelandic National Concert and Conference Centre in Reykjavik (CCC project) (Fig. 5-1). The focus is on factors affecting the adaptation of the '3D Working Method' to the work and interactions of the project actors. Particular attention is paid to non-technological factors, which are recognized as crucial by several researchers (Rezguy and Zarli 2006, Wikforss and Löfgren 2007) and by the actors involved in the 'Digital Construction' program. The paper explores enablers and barriers from the national R&D program level down to the individual architect or engineer involved in the real-life project, as well as the benefits and

2. Acknowledgements: The authors would like to thank all interview respondents and contact persons involved in the R&D programs and building projects described and explored in this paper.

challenges experienced from using and exchanging 3D object models according to the '3D Working Method'.

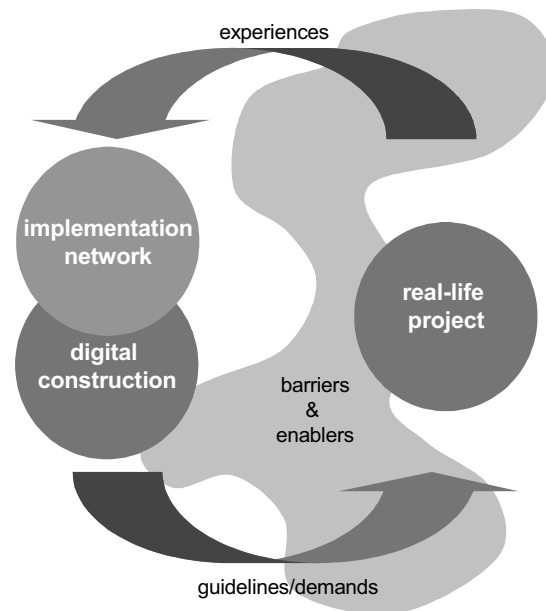


Figure 5-1. Exploring the relationship between the R&D program and a real-life project.

After a brief description of the methodological issues, some examples of international and national initiatives for integrating ICT in the AEC industry are provided as background for the further exploration of the Danish context. The first part of the exploration deals with the structures, visions and strategies developed within 'Digital Construction' and specifically within the '3D Working Method' part of the program. In the second part, the focus is on the CCC project, and on the design team actors' adoption of the '3D Working Method' in six activities related to 3D object-based modeling. The final discussion interweaves the findings from the program and the building project with the main lessons learnt from adapting the '3D Working Method' to real-life practice.

5.2 method

To explore the complex, iterative and unpredictable arena of the AEC industry and architectural and engineering practice, we need an approach that enables broad and holistic insight into the topic. The exploration of the 'Digital Construction' program is based on the results from a qualitative process evaluation which has followed the development of the program over a period of about four years by an independent evaluation panel, where two of this paper's authors have played a major role. Seeing the Danish 'Digital Construction' program from a process evaluation point of view gives us the possibility to evaluate the dynamic development of the program (Patton 1990 and 1998, Van

de Ven et al. 1999). Initiated by EBST (The National Agency for Enterprise and Construction, a Danish public agency under the Ministry of Economics and Business), which is the host of the program, the evaluation started in the winter of 2004. Since the program was launched in late 2003 and ran up to the summer of 2007, the process evaluation has been documented in four intervention and status notes on the program's progress, in addition to a final report (Koch and Haugen 2006, Koch et al. 2007). The process evaluation is based on an array of methods; interviews, participant observations and desk research. Forty-nine interviews have been conducted, comprising biannual interviews with project managers from EBST and project managers representing the various active development consortia within the program, the surrounding learning network and so on.

The exploration of the experiences of implementing 'Digital Construction' in the CCC project, build on the findings from a qualitative case study which has been carried out as a part of a PhD project with the title 'Exploring relations between the architectural design process and ICT – Learning from practitioners' stories' (to be completed in the summer of 2008). The empirical data have been collected from several evidence sources, a strategy recommended by Yin (2003) to ensure the construct validity of the qualitative study. The findings presented in this paper are generated from twenty semi-structured and open-ended interviews (Kvale 1997) conducted in 2006-2007 with eleven architects and engineers involved in building design and project management. To gain broad insight into the studied project beyond the subjective world of the single respondent, project actors have been selected who represent different backgrounds, experiences and points of view. Further sources of evidence are; passive observations of three different kinds of design meetings, 'guided tours' on computers with the users of the 3D tools, observations of the workplace of the design team as well as investigations of project material. The brief glimpses into other national and international initiatives for integrating ICT in the AEC industry are based on open-ended interviews with key actors involved, as well as on desk research.

A descriptive and holistic framework developed for gaining a better overview and understanding of the implementation and use of ICT in real-life projects has been applied as an instrument for organizing and analyzing the results of the process evaluation and the case-study data. The framework is grounded on two dimensions of design practice. First, there is the process dimension. The framework focuses particularly on four central design process aspects; the generation of design solutions, the communication of design solutions, the evaluation of design solutions and decision-making. Second, the framework is based on the level-dimension, where three levels representing different social constructions in a building project are suggested; a macro-level (overall project), a meso-level (the design team) and a micro-level (the individual architect/engineer). These three levels are again embedded in the context of the AEC industry, in this paper represented by the national Danish R&D program (Fig. 5-2). A detailed description of the framework

and a demonstration of its use in a Norwegian pilot project can be found in the paper 'A framework for exploring the ICT impact on the architectural design process' (Moum 2006).

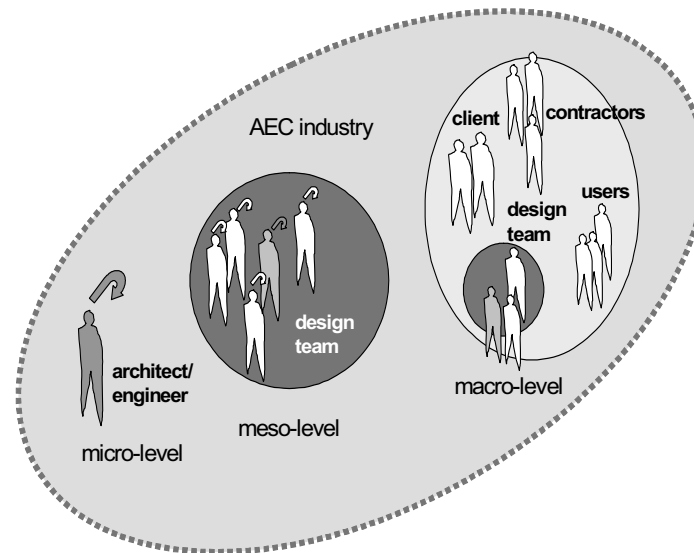


Figure 5-2. Three project levels embedded in the AEC industry context.

We recognize that through using an Icelandic building project as a case examining the implementation of the Danish national program, the exploration is limited to the internal part of the design process and the Danish design team actors, whereas a full evaluation would also encompass the interactions with external actors, such as the Danish state acting as client. Nevertheless, the CCC project's organizational structure and scale, the geometrical and functional complexity, the ambitions of creating an architectural landmark and several economic and managerial related aspects make it an exceptional arena for exploring factors affecting the implementation and use of the '3D Working Method' part of 'Digital Construction' in architectural and engineering practice. At the time the case study was carried out, to the best of the authors' knowledge, the CCC project was one of the first ongoing large-scale building projects in Denmark where all main actors in the design team were attempting to work with and exchange 3D object models according to the '3D Working Method' in a real-life and ongoing project situation.

The structuring framework, the many sources of evidence, and the rigor of the case study and process evaluation procedures, were important vehicles for ensuring the construct validity and reliability of the presented findings. Gathering empirical data from a single case study and a limited part of the large-scale and complex 'Digital Construction' program, results, however, in limitations with respect to generalization and the external

validity of the findings. Nevertheless, we consider the findings of this and similar qualitative studies as being valuable contributions to further learning and improvement. Quoting Flyvbjerg (2004:425); 'The formal generalization is overvalued as a source of scientific development, whereas "the force of example" is underestimated.'

5.3 integrating ICT in the AEC industry: examples of international and national R&D efforts

With the aim of ensuring interoperability and efficient information exchange between various ICT systems, International Alliance of Interoperability (IAI) was founded in the USA in 1995 (IAI 2006). IAI is the key actor behind the development of IFC (Industry Foundation Classes); an open standard for a system-independent exchange of information between all actors in the whole life cycle of the building. The program for the international IAI conferences over the last four years indicates a change in focus; from being development-of-technology oriented, to being implementation oriented. Consequently, the IAI introduced the new brand 'BuildingSMART' in June 2005. The ROADCON project (2002-2003), funded by the European Commission, is an example of a European research initiative with focus on developing a strategic roadmap for implementing ICT in the AEC industry (Rezguay and Zarli 2006).

The Finnish Vera Technology Program, which was funded in 1997, became a central stakeholder in the IAI's efforts to develop the IFC as an international product model standard (VERA 2006). Five years later, after this program came to an end, the Confederation of the Finnish Construction Industries initiated the ProIT project – Product Model Data in the Construction Process (ProIT 2006), which focused on developing strategies for implementing 3D product models in the Finnish construction industry. The program was based on a joint effort between research and the construction industry. Guidelines for architectural and engineering design were developed and 3D product modeling was tested in several pilot projects. Finnish promoters of the ProIT project pointed out in 2005 that Finland can benefit from being a small country (ProIT information DVD 'Product modelling as the basis for construction process', released 2005). Compared to many larger countries, it is easier to bring the prime movers together and combine forces in the implementation of new technology. This situation has also probably been a good starting point for the R&D initiatives in Norway (and as we shall see later, for the Danish 'Digital Construction' program). The Norwegian BuildingSMART project is a joint venture involving actors from both industry and research who have recognized the potential of introducing information exchange with IFC compliant 3D object models throughout the entire value chain of the building process. Several R&D projects are under development, partly on the international level (Sjøgren 2006, BuildingSMART 2006); for instance the IFD project (Information Framework for Dictionaries), the IDM project (Information Delivery Manuals), and the efforts regarding electronic submission to planning authorities. This last project is based on the experiences gained in Singapore,

where CORENET was introduced in 2002 as a public e-submission system (CORENET 2006). One of the implementation arenas for the BuildingSMART technology was the Norwegian pilot building project Tromsø University College, also called the HITOS project (Statsbygg 2006). Here the public client, Statsbygg (The Directorate of Public Construction and Property), required and supported the implementation of IFC-based Building Information Modeling in the project's conceptual design phase.

These are only selected examples of international or national efforts for integrating ICT, not representing a complete picture of all international or national initiatives worth mentioning. There are also several interesting individual building projects using 3D/4D tools or BIM, for instance reported on by CIFE at Stanford University (Khanzode et al. 2007). Our intention is here to provide brief glimpses into some trends as a background for the further exploration of the Danish R&D program. Comparing the Danish situation with the experiences gained from other R&D programs falls outside the scope of this paper, but would be an interesting subject of further research. An important point to be mentioned here is that there has been a particularly active exchange of experiences with the other Nordic countries throughout the development and implementation of the Danish 'Digital Construction'. Nevertheless, the authors interpret the Danish R&D program as strongly embedded in and characterized by the Danish institutional set up. A limitation of the present contribution is that the characteristics of this and how it impacts the program have not (yet) been developed further. A possible reference for investigating these aspects is Bang et al in Manseau and Seaden (2001).

5.4 digital construction, a public development program in denmark

visions and strategies of the program

One important feature of the 'Digital Construction' program is the belief in the client power of the state. The program has undertaken a particular version of state-driven development, namely drawing on the power of the purchaser. It is hoped that through a targeted development program the Danish state can set a standard for digitalized tendering, programming, and classifying of building data, project webs and managing facilities. Three major professional state clients were envisioned as prime movers in the program process, and they cooperated with the consortia established in the program. The assumption was that the construction-sector actors will commit to developing a basis for a future legislated digital interaction with the public clients. Another main idea of the program has been to adopt existing generic software packages and configure them to support the developed guidelines and standards. Thus, the program focuses on using existing systems and improving the implementation and use of them rather than on the development of new ICT applications. The underpinning vision of the R&D program is the integration of ICT into major parts of the AEC industry, involving players from clients/

owners, architects, engineering consultants, general contractors, trade contractors and real-estate administrators. The program has used a consensual approach in combining forces and mobilizing AEC-industry players who were believed to be best able to drive and develop new methods and procedures to be used by the industry in the future. The mobilization was both direct, through involvement in the project, and more indirect, through a series of communications and dialogues which were intended to encounter stakeholders in the broader sector. The consulting engineers and architects have been the most active players in the program, more or less in alliance with the contractors. The property owners and facility management operators have not been that involved, even with respect to issues relating to facilities management. In this sense the program mirrors existing hegemonies in the Danish construction industry. Nonetheless, the establishment of proper and consensus-based strategies for implementing the solutions agreed upon in practice was an essential issue in the program. Bearing all this in mind, three main strategies have been defined (EBST 2006):

1. Provide a **digital foundation** for standards and methods to ensure that all players in the construction business are 'speaking the same digital language'.
2. Establish a set of regulatory **client demands**, which were issued by 01 January 2007 for public building projects
3. Establish a '**Best Practice**' base; a compilation of real-life projects demonstrating how the integration of digital solutions in real-life projects can promote greater efficiency in the work process.

An extension of strategy three was that the program included an effort to evaluate and communicate best-practice experiences from implementing and operating ICT in construction. The consortium responsible for this part of the program featured a handful of the major players among contractors and consulting engineers. The project ran into a number of problems; significantly it turned out to be very difficult to find best-practice examples. In December 2006, the 'best-practice' base of 'Digital Construction' included 17 cases, whereof five deal with 3D-issues, four with the project web and the rest with e-learning, commissioning, e-mail standards and other smaller ICT issues in construction. This base mainly represents cases with limited scope, focusing on smaller parts of the building process. The cases are rather derived from the developmental work of an experimental character within 'Digital Construction' than from well-documented 'best practice', as also noted by the program itself (Det Digitale Byggeri 2006).

the digital foundation

Over the spring of 2004, the 'digital foundation' of 'Digital Construction' was divided into four project proposals:

- Classification
- 3D Working Method
- Logistics and Process
- Building Items Chart (not followed up)

These projects reflect a delicate balance of interests. Object orientation has been 'secured' room through the '3D Working Method' project, while positions of a more pragmatic nature, as well as interests in favor of a 'document view', are secured space within classification. Moreover, 'Logistics and Process' represents an area that contractors are interested in. Broad participation was assured at workshops and was achieved as more representatives came from contractors than initially were mobilized. The design was challenged both internally and externally by website debate and in the program council. In May and June 2004, several elements were dropped to meet the overall budget. The remaining three projects (the first three bullet points) stabilized and all commenced before September 2004. The new classification has been developed and was being reviewed by external experts during the spring of 2007. The '3D Working Method' was finalized by the summer of 2006, with extensive material available on the public website and used in the case below. The result of the 'Logistics and Process' project was a proposal for the use of so-called 'production cards'; a tool for detailed scheduling at the building site inspired by latest planner/lean construction theories. Currently the results of this project will likely have little practical application. However, it is also likely that actors in the construction branch will continue the development of a production planning element of the digital foundation. In the next section of this paper we will look more into the '3D Working Method' foundation of the program and the experiences from implementing this concept in a real-life project's design team.

the 3D working method

The '3D Working Method' has been developed to provide a common coherent working method for all parties in planning and construction which will support the exchange and re-use of information throughout all phases of the process (bips 2006). Further formulated aims were (examples): working-process optimization and improved collaboration, improved quality and consistency of project material, clear definition of responsibility through common working-method principles, improved communication, and automation of sub-processes (e.g. consistency control and quantity take-offs). The '3D Working Method' concept is intended to match the building processes and technologies known today, and thus mirrors the common visions of the 'Digital Construction' program. One important step has been to develop a concept which enables future implementation of new and innovative collaboration scenarios and CAD technologies, for instance, from working with geometrical 3D models (without attributes data) to working with Building

Information Models (BIM), where all geometry, object attributes and specifications are integrated into a total building model.

Around 35 companies representing varying interests in the industry have participated (for instance architects, engineers, contractors, manufacturers, building authorities and clients). Their joint efforts have resulted in four 3D CAD (Computer Aided Design) manuals. The manuals can be downloaded from the public 'Digital Construction' website (the English version from April 2007 can be downloaded from this website: <http://www.bips.dk/Bips/Main/Mainpage.htm>):

- 3D Working Method (concept definition)
- 3D CAD Manual (practical guidelines for building the 3D model)
- Layer and Object Structures
- 3D CAD Project Agreement

Six main activities related to 3D object-based modeling throughout the design process are described and illustrated in the '3D Working Method' (Fig. 5-3); 1) drawing production (documentation), 2) exchange, 3) visualization, 4) control of consistency (model checking), 5) automated take-offs and 6) simulations.

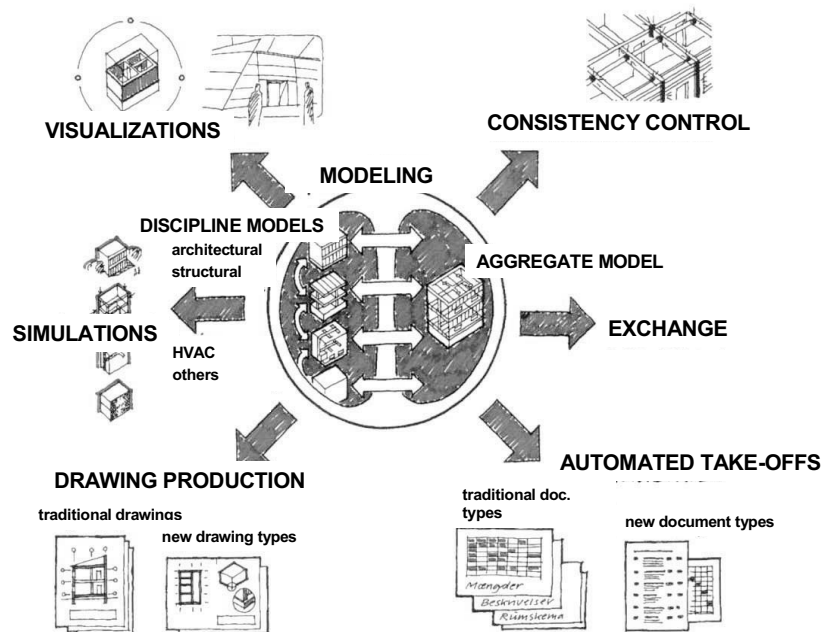


Figure 5-3. Illustration from the '3D Working Method' (Courtesy: bips 2006). Author's translation and comments.

The '3D Working Method' is based on the idea that each discipline will build, maintain and, most importantly, be responsible for their 3D discipline-specific object model (for instance architectural model, structural design model and so on). All necessary development and changes shall be undertaken in these discipline models. The discipline-specific models are also the basis for generating 2D drawings and take-offs. The exchange of the 3D object models between the disciplines is to be based on IFC or other appropriate file-exchange formats. The '3D Working Method' also suggests that the discipline models should be built according to seven information levels, following the evolving level of detail throughout the building process, and to gather these discipline models into an aggregate model. The decision as to which extent an aggregate model shall be integrated and used in a building project depends on the project-specific technical and financial possibilities to be clarified in the CAD agreement. From January 2007, the '3D Working Method' was made available to the Danish AEC industry as guidelines supplementing the regulatory client requirement for the use of 3D object models in public building projects when building costs exceed 40 million Danish kroner (5.3 million Euro) (EBST 2005).

5.5 the icelandic national concert and conference centre

The Icelandic National Concert and Conference Centre (CCC project), located in Reykjavik harbor is a prestigious public-private-partnership project, which aims for visibility in the international landscape of architectural and cultural highlights (Fig. 5-4 and 5-5, Table 5-1).

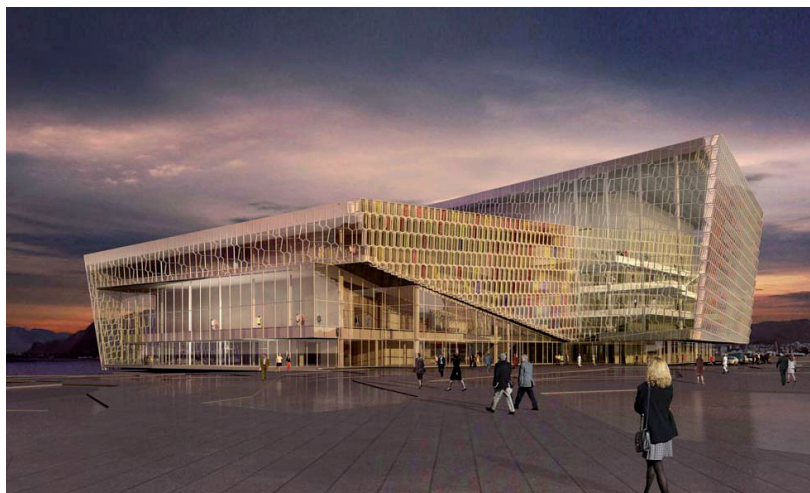


Figure 5-4. The CCC project in Reykjavik (Courtesy: Henning Larsen Architects. Exterior-rendering made by Eyecadcher).

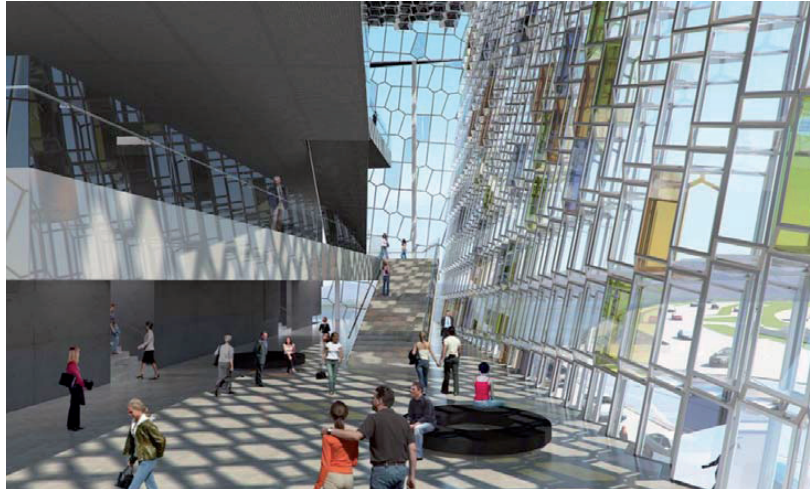


Figure 5-5. The CCC project in Reykjavik (Courtesy: Henning Larsen Architects. Interior-rendering made by Eyecadcher).

Table 5-1. CCC project: number and facts.

	CCC project
function	Concert and conference centre with parking garage
gross floor area	32.000 m2 (not counting the parking garage)
schedule	Competition: 2005 Design and construction: 2005-2009 Operational: around new year 2009/2010
project type	Public-private partnership
client	Portus Group
architect	Henning Larsen Architects, Denmark & Batteriid Arkitektar, local architect, Iceland
artist	Olafur Elisasson, Iceland/Germany
engineers	Ramboll Denmark AS, Denmark & VGK Hönnun HF, Rafhönnun HF, sub-consultants, Iceland
contractor	IAV, Iceland (design build) - the client of the design team

the background for implementing the '3D working method'

macro-level background: the overall project

The Icelandic client and the contractor are not part of the Danish AEC industry and therefore are not one of the target groups for the implementation efforts of 'Digital Con-

struction. Neither of these project participants was skilled in 3D object models or their use. Thus, the decision to implement the '3D Working Method' and to use 3D object models was not based on a client demand or on requirements defined in the contract. The transition from 2D CAD to 3D object-based modeling was thus to be undertaken within the existing time schedules and budget, and the financial risks connected to the implementation of the new tools had to be carried by the companies themselves. The implementation of the '3D Working Method' in the CCC project was initiated by the Danish engineering company, where one of the project actors was also involved in the 'Digital Construction' program and in leading the development of the '3D Working Method' project. As a consequence, the implementation of this 'digital foundation' of the 'Digital Construction' program was limited to the design team and the architectural and engineering companies located in Denmark. The prime movers behind the implementation appeared to be related to the companies' development and marketing strategies, on the one hand, and to 'Digital Construction's' need to collect experiences from practice, on the other. The CCC project was part of the 'best practice' strategy of the program, expected to inspire other actors in the industry.

meso-level background: the design team

The CCC project is functionally, technically and geometrically highly complex. The amount of non-orthogonal angles, tilting walls and roofs, and split levels, challenged the abilities of the design team. The interdisciplinary use of 3D object models was expected to play an important role in supporting the development of the complex design solutions and in smoothing the interactions between the design team actors. According to the project manager of the engineering team, this was an important factor which motivated the company to require all engineering disciplines to build and use 3D object models according to the '3D Working Method' manuals, however, with the limitation that the efforts of the design team should focus on handling the geometry-related aspects of building and exchanging the 3D object models. From the beginning, linking the design information and attributes to the objects was regarded as the next step on the ambition ladder.

In contrast to the engineering company, the architects felt the risk of going for full implementation of the technology was too high. They wanted to collect experiences and test the potential of 3D object-based modeling, but at the beginning of the design proposal the architects only agreed to build an architectural 3D object model as an 'add-on' to the traditional manual production of 2D CAD drawings. However, the importance of the 3D object model for the architectural design team increased during the project. In the autumn of 2006, the architectural company decided to extract all 2D drawings directly from the 3D object model in the detailed design phase (Fig. 5-6 and 5-7). Another important observation was the organizational differences within the design team, with respect to who is supposed to be skilled in CAD and 3D object-based modelling.

micro-level background: the individual architects and engineers

Neither the architects nor the engineers or draftsmen had previous skills in 3D object-based modeling (with few exceptions). The experienced engineers in the company traditionally do not use CAD. They develop their concepts and systems based on hand drawings, before draftsmen 'transform' this information into digital drawings or models. The architectural company requires that all architects involved in design are skilled in 2D CAD. According to the manager of the architectural team, this was also the aim regarding 3D object-based modeling. Throughout the design process, most of the architects and draftsmen were attending 3D CAD training courses. In the period from the design proposal phase to the detailed design, the number of architects using 3D object models as their main or supplemental tool increased to 50%. The majority of the engineers were still working with sketches, whereas all draftsmen were working with 3D object models. However, in the summer of 2007, and in the detailed design phase, some of the structural engineers were able to handle simple parts of the 3D modelling tools and the applications.

experiences from implementing the '3D Working Method': six activities

3D object modeling

Each discipline created their own discipline model by following the guidelines of the '3D Working Method' manuals and the 3D CAD Project Agreement. They used the software most appropriate for their specific needs (Fig. 6-7). In both the architectural and engineering companies, those with good skills in 3D object-based modeling and with a good overview of the requirements in the '3D Working Method' manuals held key positions due to the implementation and quality control of the main discipline models. The CAD operator in the engineering company assembled the various disciplines' models into an aggregate model.

An important issue inherited from the transition from 2D CAD to 3D object-based modeling is the ability to link design information to the objects (which together with the ability to define the parametric relation between the objects, leads to the popular term 'intelligent objects'). The extent to which the architects and engineers populated their discipline models with object information varied, and seemed to depend on; the availability of object libraries, the need to generate internal lists, including door lists, quantity lists, and the fact that the contractor did not require or use the information imbedded in the model. Thus, the 3D discipline models were 'complete' only in terms of the geometry of the building.

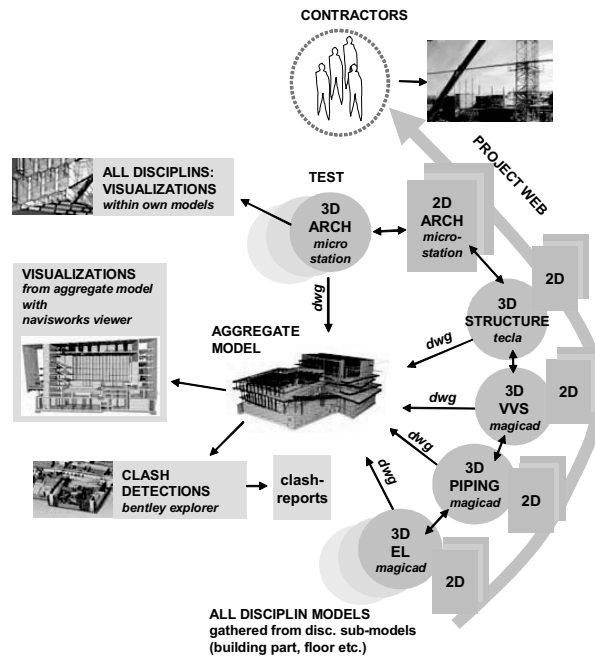


Figure 5-6. The 3D object model system, software and applications autumn 2006 (design proposal phase).

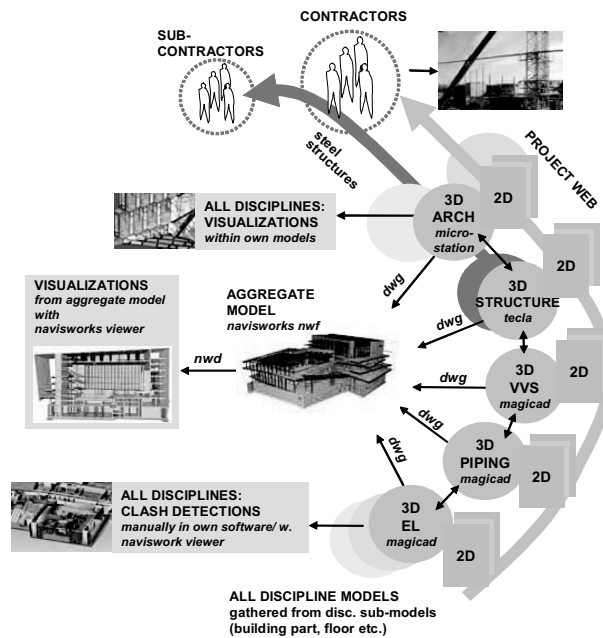


Figure 5-7. The 3D object model system, software and applications summer 2007 (detailed design phase).

The 3D discipline models' level of detail depended on such factors as the starting point of modeling, the software capacity, the skills of the user and the 2D based project delivery to the contractor. From the architectural 3D object model it was possible to generate 2D plans and room drawings to the scale of 1:200 – 1:50, as well as some details. The additional details needed for the manufacturers and the building site were produced manually in 2D. The seven information levels defined in the '3D Working Method' were not implemented in the CCC project. The detailed descriptions of these levels and the resulting impractical application for the design team actors were pointed out as explanations in some of the interviews. Nevertheless, according to the leader of the '3D Working Method' project, the information level in the concept definition could contribute to more awareness among the project participants as to the management and distribution of information throughout the project phases.

All interviewed respondents involved in the 3D object-based modeling reported that several challenges that arise when working with the software can be related back to the inability of the software to address the individual user's needs or to the complexity of the design process. One of the respondents from the architectural team explained that the 3D software's user-interface did not sufficiently support his efforts to generate design solutions, which made it necessary to also use traditional tools for the creative and intuitive part of the design development (for instance pen and paper and physical models). Throughout the design proposal and detailed design phase there was a continuous process of improving or modifying design solutions. According to the HVAC (Heating, Ventilation and Air Conditioning) team, implementing changes in their discipline models was a time-consuming affair, and in some cases this even forced them to rebuild parts of their models. These are just two of many examples. The respondents were aware that the challenges described above derived from the lack of skills and experience in using the software. From the beginning of the project, there has been close collaboration between the users and the software vendors or company internal software experts. Due to this, some of the technical shortcomings have been solved during the project phases, one by one. Nevertheless, according to several of the respondents, the improvement of the tools was more time consuming than foreseen at the beginning of the project.

drawing production

The client's review of the project phases and the project delivery to the contractor were based on 2D drawings, which also were the statutory documents of the project. Furthermore, 2D drawings were used as the basis for discussions in meetings, and in many cases also for the information exchange between the architects and engineers. Extracting 2D drawings from the 3D discipline models was time-consuming, especially for the architects and the structural engineers. The architect pointed out this activity as one of the most challenging parts of working with 3D object models. It was difficult to configure the gen-

eration, and the extracted drawings had to be supplemented manually with textual information and measurements. According to the leader of the steel structure team, about 12 hours were needed to convert one of their model files into a flat dwg-drawing. The steel structure team worked solely in a 3D environment, supplemented by hand-made sketches. They did not use or need 2D drawings for their daily work. The generated 2D drawings only contained 80% of the information actually embedded in the 3D models of the steel structures. The structural engineer's description of the project delivery of the steel structure systems points out what he perceived to be a promising future; the Chinese subcontractor was using the 3D object model to pre-fabricate the steel structures before shipping them to the building site in Iceland. Nevertheless, on the building site itself, the traditional 2D drawings had the main role.

exchange of 3D object model data

Each discipline imported model files with the object geometry from other disciplines as x-refs according to the '3D Working Method'. This method worked well for the various discipline models on the engineering side. However, the comments from both the architects and engineers, interviewed in the summer of 2006, point out several challenges related to the exchange of the data and information needed for the design development. Considering that at the beginning of the project the architects did not commit themselves to deliver a 3D object model, neither to the engineer nor to the contractor, the first upload of the architectural 3D object model into the aggregate model was not possible until near the end of the design proposal phase. Before then, the structural engineers had to build their discipline model based on the architectural 2D drawings. On the other hand, a complete set of 2D drawings from the structural 3D model was not generated until the end of the design proposal phase because the generation of 2D drawings from the structural model was a time-consuming procedure. Due to this, the architects had to 'transform' hand-sketches from the structural engineers into their architectural 2D drawings. Hence, both the architects and the structural engineers felt they had to do more work than necessary because of insufficient information delivery from 'the other side'.

The 3D model data exchanged digitally was limited to geometry aspects. The engineers and architects did not exchange the attributes and design information linked to their discipline model objects. According to respondents from both the architectural and engineering group, in most instances it was not necessary to acquire access to the discipline-specific object information in other 3D models. The information needed in addition to the object geometry was for instance exchanged in meetings, via e-mail and through hand-sketches. One interesting issue here was pointed out by one of the architects; receiving simple hand-sketches with the required information can in some cases be more convenient and efficient than getting complex, information-rich and heavy 3D model files.

3D visualizations

Different viewer applications were used to visualize the 3D object models. These model views allowed the observer to move and rotate the model and to cut through rooms (Fig. 5-8). These views were a representation of the geometry-related information only, without the possibility to carry out modifications. The engineers changed the viewer application in the autumn of 2006 because the first application was not able to handle the data size of the aggregate model (Fig. 5-6 and 5-7). Because of the poor rendering abilities of some of the 3D modeling software, for instance, the architects used specific rendering applications for making photorealistic visualizations of the building envelope and the effects of daylight and reflections.

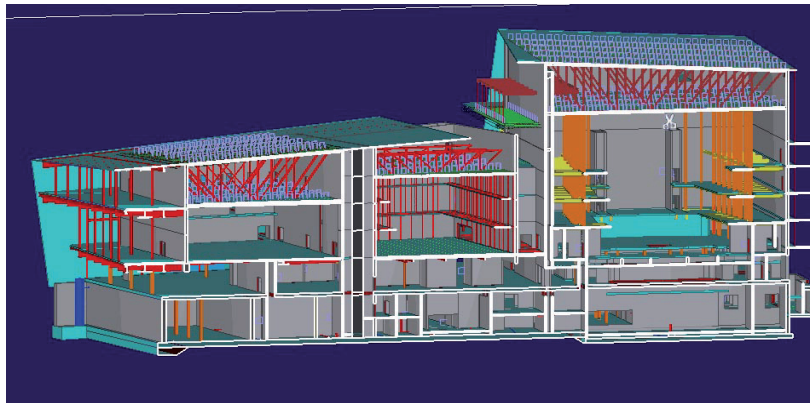


Figure 5-8. Visualization/view of structural systems. (Courtesy: Ramboll Denmark AS).

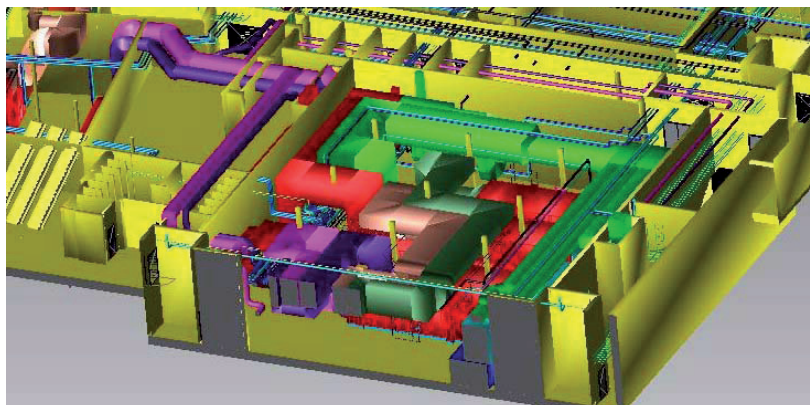


Figure 5-9. View of merged HVAC and structural model (Courtesy: Ramboll Denmark).

The interview respondents in the engineering company pointed to the improved understanding and control of the building geometry and the geometrical relations between the different disciplines as substantial benefits gained from working with 3D object models. Through the 3D visualizations of the complex geometry, clashes and conflicts could be recognized and solved earlier (Fig. 5-9). One respondent involved in the architectural façade group pointed out that developing and communicating the complex building envelope would have been nearly impossible without using a 3D object model as support for solution generation, communication and evaluation. The aggregate model has also contributed to improving the communication of project intentions to external actors. In the autumn of 2006 the engineers presented and demonstrated their visualization file of the aggregate model in a design meeting with all key actors of the project, which was helpful for project participants with difficulties in interpreting traditional 2D drawings. Nonetheless, in most cases the 3D object model was not used directly or real-time in meeting situations. This would require skills of the users and software not available in this project.

consistency control

According to the managers of both the architectural and the engineering teams, the 3D object models have been helpful when it comes to interdisciplinary coordination; for instance between the architecture and structural systems, or between the ventilation components and the load-bearing elements. In the autumn of 2006, the engineering team tested an application for automated clash detection and the generation of clash reports from the aggregate model. However, after the test phase, the engineering company declined to take this application further since it was not usable in practice. A large amount of the automatically detected clashes in fact did not represent actual geometrical conflicts, and too much time had to be invested in filtering real from non-real clashes. One consequence of this was that the design team members were manually and visually checking the consistency of their own discipline models and against the other discipline models. According to the operator of the ventilation model, the draftsmen from all the engineering disciplines worked together to make visual checks of the project material in front of a wall projection of the aggregate model. The aggregate model did not play an important part in the daily work of the draftsmen and designers. The views from the aggregate model were rather used by those design team actors who did not master the 3D models. One of the design team actors from the engineering team commented on the limitations in such views in controlling measurements and testing information. Generally, a great deal of the consistency control of the project material was still based on reviewing and checking the 2D documents for two main reasons: the lack in 3D skills of the actors responsible for approval, and the 2D drawings were the statutory project documents.

automated take-offs

Since the contractor did not use or require the 3D object models for the project delivery and for his quantity take-offs, the architects and engineers only used this functionality of the 3D object models to a limited degree. The architect generated lists of building elements (doors, walls and so on) and floor areas. The electrical engineers generated quantity lists of some electrical components to control quantities and costs. These lists were in most cases only used internally by the various design team groups. Nevertheless, the architects' generated door lists have been used for tendering, and in June 2007 the HVAC group considered the delivery of some lists of quantities for tendering. Another exception was that the engineering team developing the steel constructions generated quantity take-offs from their discipline models and delivered these to the contractor. This team seems to have utilized the opportunities provided by their discipline 3D model the best. According to one of the respondents involved in the international IAI, the steel construction domain is generally found to be in a leading position with respect to software development and use.

The 3D modeling software used by the HVAC team has an embedded module for automated calculations. In June 2007 this module was tested to calculate the cooling loads. However, according to the project manager of the engineering group, as there is no certification from the software vendors guaranteeing that the results of the calculations are correct, the risk of completely relying on these calculations was still considered to be too high. The project manager considered the software to be more like a black-box, where it is not possible to control what happens between feeding in the necessary data and the output results. Furthermore, with the growing amount of information and the increasing geometrical complexity in the early stages in the project (a consequence of the 3D object model), quality assurance was even more challenging. The structural engineers still had to carry out their calculations with other software systems as their 3D modeling tools did not provide this functionality.

simulations

Simulations based on the 3D object-models were not utilized in the CCC project. As in the case of the structural calculations, the main technical barrier here was also the lack of interoperability between the simulation software and the 3D modeling software. The project manager of the engineering team clearly emphasized that carrying out simulations was not part of the ambition of this project.

Figure 5-10 illustrates the activities of the '3D Working Method' concept which have been carried out in the CCC project's design team.

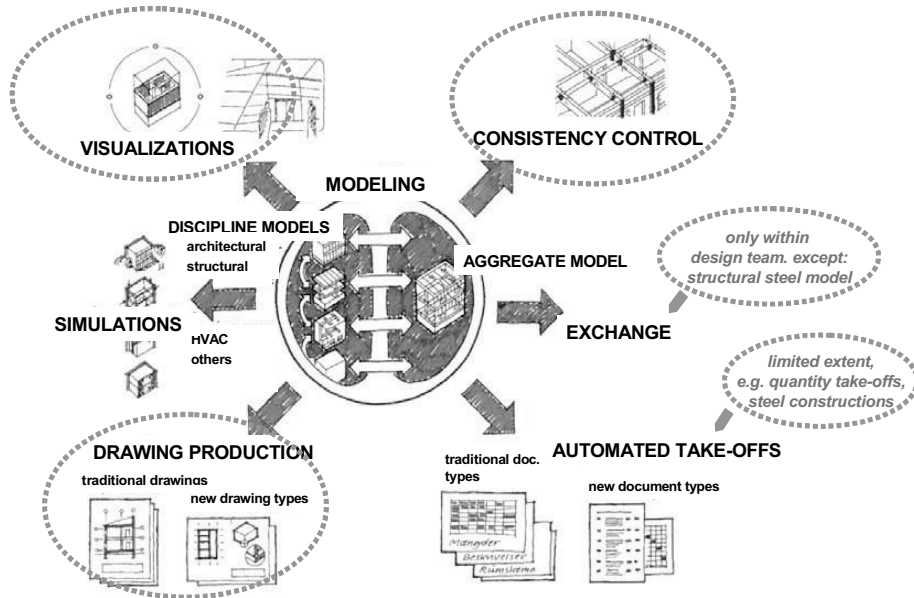


Figure 5-10. Illustration from the '3D Working Method 2006' (Courtesy: bips 2006). Author's translation and comments (Situation in project until June 2007).

5.6 lessons learned from the danish digital construction

Figure 5-11 provides an overview of the various reported barriers and enablers, and the perceived benefits and challenges from using 3D object models in the CCC project's design team. Some of the key relationships and factors affecting the implementation of 'Digital Construction' and the '3D Working Method' in the CCC project are discussed below.

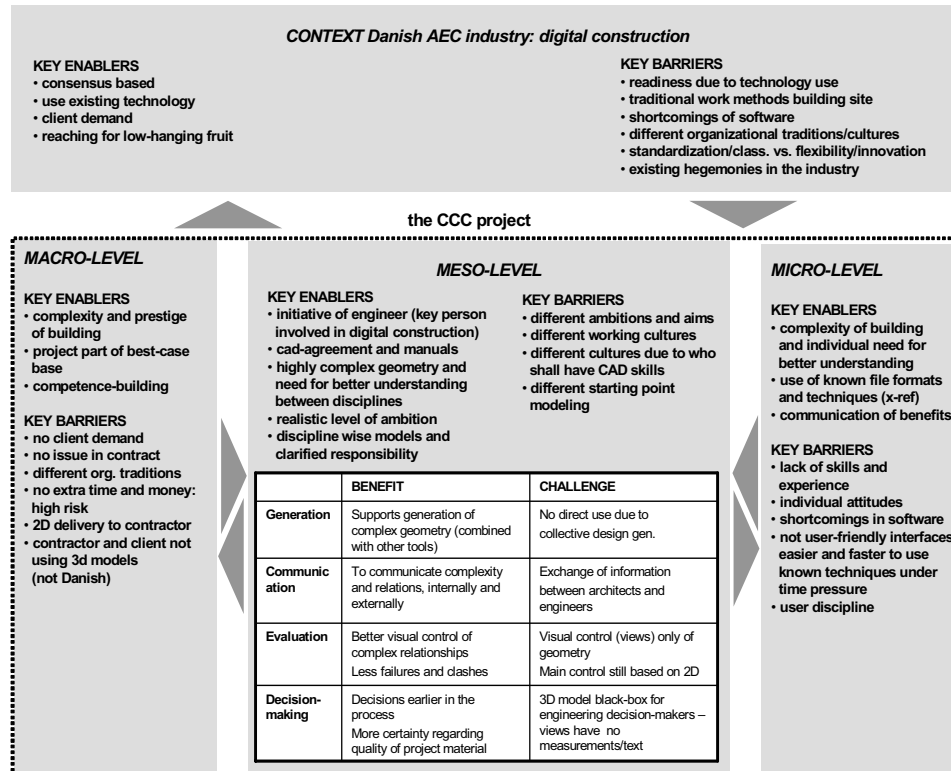


Figure 5-11. Key enablers and barriers affecting the implementation and use of 3D object models in the CCC project.

the power of the 'implementer' and the distribution of the technology

One of the main strategic enablers for integrating ICT in the Danish AEC industry is the involvement of the (public) client as the 'implementer' and the one demanding use. However, in the case of the CCC project, the initiative for introducing and testing the '3D Working Method' and 3D object models came from the engineering company – it was not a client demand. This mirrors the situation in the program generally, where the architects and engineers were the most active players. The main consequence of this situation was a limited distribution of the technology among the project actors as the '3D Working Method' was only adapted by the Danish actors in the design team. Thus a number of further interactions (for instance with the client or the contractor) in the building project could not reiterate the 'Digital Construction' intentions. A further consequence of this situation was the 2D-based project delivery to the contractor and the client, which crucially affected each architect's and engineer's utilization of the 3D object models and the related activities. The degree to which they applied the '3D Working

Method' seemed to depend crucially on their 'implementers' and what they perceived to be the benefits, challenges and risks of working with 3D object models.

The initiative of the engineering company, the belief in this technology becoming the future main tool of design and production and the expected benefits from processing the complex geometry of the building were thus important enablers for the adoption of the '3D Working Method' in the design team. The project manager of the architectural team pointed out the importance of communicating the benefits from 3D object-based modeling to all levels in the project organization, from the overall project down to the individual users of the tools. The fact that the companies had to carry the risk of negative consequences for the project's costs and timescales was, on the other hand, an essential barrier for the architect's full implementation of the '3D Working Method' already at the beginning of the project. The variances of technology implementation within the design team resulted in several challenges in building and exchanging the discipline models.

the guidelines for working and the resources for learning

The implementation of '3D Working Method' and its guidelines and manuals enabled a degree of shared understanding of how to build and exchange the 3D models. Until they attended a kick-off meeting where the '3D Work Method' was presented in the engineering company, the project participants were sceptical to the decision to implement interdisciplinary use of 3D object models in the project. According to the project manager of the engineering team, the clarity of the concept regarding responsibilities and the discipline-specific models were factors that increased the acceptance of the design team and thus enabled implementation. One challenge especially affecting consistency of the 3D models was to ensure the actors' discipline in building and exchanging the 3D models according to the 3D CAD manuals and guidelines.

One barrier to the implementation of the 3D Working Method project was the different organizational attitudes as to who should be skilled in 3D object-based modeling. Younger engineers indicated a generation shift, where not only draftsmen but also engineers are able to work with 3D CAD. Nonetheless, if this situation is to be changed, it will, according to the project manager of the engineering team, take time. This was seen as one of the greatest challenges in the engineering company regarding the future implementation of the '3D Working Method'. In addition to being a generation-dependent issue, raising 3D CAD skills and competences is also a question of educational and organizational policies and strategies, both inside and outside the company. A number of training and support measures are set up in the so-called 'Implementation Network' to support the implementation of the '3D Working Method' part of 'Digital Construction' in the Danish AEC industry (Implementeringsnetværket 2007). However, in 2007 this network did not play a direct role in the CCC project. Nevertheless, the 3D software courses arranged throughout the design phase within the engineering and architectural

company taught most of the design team members a certain level of basic knowledge. One barrier, however, and here especially for the architects, was the limited time available to learn and test the new technology. One situation which again was interrelated with barriers on other levels; the fact that the architectural companies were hesitant to undertake full implementation, that no extra time or money was made available for implementation, and that the decision to work in a 3D object-based way was not based on a client demand or contractual requirements. However, the project manager of the architectural team stated that the architects have come further with implementation than expected at the beginning of the project. The project manager of the engineering team pointed positively to the observed steep learning curve among both the architects and the draftsmen. Within the engineering company, the experience of the CCC project was communicated to other teams, thus enabling the actors in new projects to start on a higher skill and competence level.

In the autumn of 2007, an extended version of the '3D Working Method' will be available for everyone in the Danish AEC industry. In addition to the 3D section, there is now also a part comprising the 2D-based working method. According to the IT manager in the engineering company, these extended manuals will be implemented as the new company-wide CAD standard.

the level of ambition and reaching for 'low-hanging fruit'

Some of the parties involved in the program have felt that implementing existing ICT systems in the AEC industry is more of a conservative rather than visionary and innovative approach, and this has been an area of controversy in regard to the development of the 'Digital Construction' implementation strategies. Research at architectural schools, universities and applied science units is putting great effort into developing more innovative concepts and technologies. The readiness of the AEC industry, the current abilities of the technologies and the expected non-technological barriers were, however, among the arguments for choosing the perhaps moderate level of ambition and aiming for 'low-hanging fruit'. In the CCC project the project managers decided from the beginning to have a realistic ambition level which should reflect this 'reaching-for-the-low-hanging-fruit' strategy, the skills of the project participants, the shortcomings of the technology and the limited implementation by the design team. There was an awareness among the interviewed actors that not all the aims defined in the '3D Working Method' could be fulfilled in the CCC project. Making simulations based on the 3D object models, extracting automated take-offs for tendering and production, or exchanging design information linked to the objects, were not within the ambition of the project (exceptions were seen as positive add-ons). Several of these activities would have required IFC or otherwise compatible software, and were felt to comprise the next step on the companies' steep learning curve in relation to the adoption of '3D Working Methods'. In the long run, the key persons behind the implementation expect technology- and skill-related barriers to

be turned into enablers. Although there were only minor expectations as to cost or time savings in this specific project, the actors involved hope to reap a good harvest from the lessons learned that can then be applied in the next projects, and, all in all, to raise their competitiveness within the Danish AEC industry. In the summer of 2007, all large-scale projects within the engineering company were based on 3D object modeling. In the architectural company, the second '3D-based' building project was under development.

5.7 conclusions

This paper has explored and discussed issues focused on implementing and using the '3D Working Method' part of the 'Digital Construction' program in the CCC project. The first experiences from implementing the '3D Working Method' concept into this specific building project indicate a large number of benefits of 3D object-based modeling, especially due to the indispensable support of developing, coordinating and controlling the complex geometry of the building. Generally, we can conclude that the implementation of the '3D Working Method' in the CCC project has been successful in the sense that these benefits address the aims and ambitions stated by the architects and the engineers at the beginning of the project. Nevertheless, this paper has also shown that there are still many challenges to be dealt with before all aims and visions formulated in the 'Digital Construction' program and the '3D Working Method' can be actualized.

The findings reported on in this paper imply that the introduction of a national based ICT platform into real-life projects depends on the success of balancing an array of factors placed at different project levels and in the project context. The discussion above especially points out three such balancing acts which have impacted the adoption of the '3D Working Method' in the CCC project. The first is the power of the 'implementer' versus the perceived risk and the expected benefits of implementation for the overall project, the design team and the individual user. The second involves the strategies and guidelines defined in the program versus the resources the individual has to learn and test new technology, and the organizational traditions for using digital tools. And the third is the level of ambition versus the potential of the technology and the skills of the project actors in using the technology and in adapting to new working methods and processes.

From January 2007, the Danish state has provided stronger impetus for moving towards the integration of ICT in the Danish AEC industry, and will probably also strongly encourage 3D object modeling in the future. Thus, in Denmark, as also for instance in Norway and Finland, powerful players have got the ball rolling. The challenge is to foresee how the ball will perform as it makes its way further into the AEC industry and down into architectural and engineering practice. The first experiences gained in Denmark represent a valuable basis for further development of strategies and aims for ICT integration within the AEC industry and for creative practice. Mastering the balancing acts arising out of the relation between the establishment of national R&D strategies for ICT inte-

gration in the AEC industry, and their implementation in real-life practice, is crucial and requires a broad understanding of both the project and its context. The qualitative methods and the holistic framework applied to the analysis and interpretation of the compiled empirical data is one possible approach to building such an understanding. As this paper is being written, the first Danish public clients are now providing projects where the results of the program will be tested in full scale. More than 50 projects are on the way. Thus, again remembering Tom Paxton's song; building knowledge is crucial and a matter of time. The Danish 'Implementation Network' (Implementeringsnetværket 2007), based on new funding and launched in late 2005, will ensure and support the further implementation of the program and its solutions after the R&D program's end in March 2007. The Danish 'Digital Construction' story continues.³

3. The reference list of this paper is integrated in the list at the end of this thesis. The acknowledgements are included as a footnote at the second page of this chapter.

6 paper III

DESIGN TEAM STORIES exploring interdisciplinary use of 3D object models in practice¹

SUMMARY: This paper explores the interdisciplinary use of 3D object models by design teams. Based on a qualitative case-study of the ongoing building project New Icelandic National Concert- and Congress Center (CCC-project) in Reykjavik, the paper presents five stories about different challenging or beneficial situations from using 3D object models. The implementation of such technology in the CCC-project, is connected to strategies and guidelines formulated in the Danish public-private R&D program 'Digital Construction'. 3D object-based modeling and related activities are expected to play an important role in supporting the design development and in the smoothing of interactions between the actors and the processes in the project. The case-study, which was carried out 2006-2007, is based on twenty semi-structured interviews with architects and engineers involved in design and management, together with observations of design meetings and desk research. A qualitative, descriptive and multi-level framework for exploring the ICT impact on the architectural design process has been applied for analyzing and organizing the data collected. Based on the identified barriers hindering the team from using the technology as intended, or enablers facilitating a successful use, the five design team stories throw light on complex issues inherited in the relation between the design team processes and the technology. The following situations are explored: developing complex geometry, achieving shared understanding, handling the painful processes of change, formalizing processes within a dynamic design environment and handling the relation between design and production. The paper demonstrates that the use of the descriptive framework, together with the story-telling technique for communicating the findings, can contribute to a better understanding of the implementation and use of 3D object models in design teams.²

1. This is the third of the three main articles in this paper-based thesis. The article has been submitted for the first review in the international journal 'Automation in Construction' in December 2007.

6.1 introduction

“Design is a complex process that continues to grow in complexity because of the dramatic increase in specialist knowledge. There are now many contributors to the design of a project from a wide variety of organizations. This gives rise to design processes that consist of a continual exchange and refinement of information and knowledge. Even the most experienced design teams can fail to manage this complex process and supply information at the wrong time and of the wrong quality to members of the production team.” Gray and Hughes (2001:1).

This paper explores the interdisciplinary use of 3D object models by a real life project's design team. Gray and Huges (2001) indicate in the quotation above, the challenging task to manage collaboration and design in order to achieve good architectural design solutions and economic successful one-off real estate. The building design teams' efforts are crucially based on a successful interplay between iterative and interdependent processes, actors and actions (Lawson 2006, Lundequist 2003). Cuff (1991) considers in her studies of architectural practice, design as a social construction, where buildings are collectively conceived. A whole range of more or less predictable issues impact on the design team members' individual and collective efforts. These issues are placed on many levels, from Architecture-Engineering-Construction (AEC) industry level, down to the level of the individual designer. Different trends in the society, as for instance globalization and the increasing concerns about sustainability and environmental issues have contributed to raise the complexity of the design process even more. The focus on integrated practice and on collaboration, where specialized participants with different backgrounds, preferences and experiences try to achieve a common goal, is growing within both research and practice (Barrow 2000, Beyerlein et al. 2002, Elvin 2007, Haymaker et al. 2006, Kalay 2004 and 2006, Matsushima 2003). At the same time, the productivity status in the AEC-industry described in the Latham report in 1994 (Latham 1994), still gives raise to concerns. A substantial part of the building costs can be related to failures on the building site, which again in many cases are the result of poor interactions within and outside the building design team. The implementation of Information and Communication Technologies (ICT), as for instance 3D object models or Building Information Models (BIM), together with the product model standard IFC (Industry Foundation Classes), are expected to improve this situation through supporting design related work and collaboration (IAI 2006). Still, compared to other industries, the AEC industry has been a laggard regarding the successful implementation of such technologies. In order to “push” the

2. 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 feedback from advisors and colleagues. Sincere thanks also to all interview respondents and contact persons involved in the CCC-project; without their willingness to sacrifice their valuable time and to openly share their experiences and thoughts with the author, this paper could not have been written in the first place!

implementation in practice, powerful national and international players in the AEC-industry are combining their forces for stimulating integration in all phases of the buildings life cycle (BuildingSMART 2006, Det Digitale Byggeri 2006, ProIT 2006). The implementation of ICT is expected to impact on both working processes and role definitions (Berg von Linde 2003, Sundell 2003, Wikforss 2003a and 2003b). Based on these new trends and movements in the AEC-industry, there is an increasing need for a more comprehensive understanding beyond the purely technology-oriented issues, which until recently have been the main focus of research and development (Amor et al. 2007, Wikforss and Löfgren 2007).

The aim of this paper is to gain knowledge about the interdisciplinary use of 3D object models in practice. The first lessons learnt by design teams in pioneer projects from implementing new and untested technology is a valuable source for building up such understanding. By applying a qualitative, descriptive and multi-level framework (Moum 2006) and a story-telling technique, the paper attempts to reveal and communicate central aspects inherited in the complex relationship between technology use and the architectural design process. The paper presents five design team stories about different challenging or beneficial situations from using 3D object models. These stories are based on a qualitative case-study of the new Icelandic National Concert and Congress Centre (CCC-project) in Reykjavik (Fig. 6-2 and 6-3). Special attention was hereby paid to the interactions between the architects and engineers due to central tasks within the design process. The stories are throwing light on barriers hindering the team from using the technology as intended, or enablers facilitating a successful use, even beyond the borders of the design team.

The paper is structured as follows. After a short section about the methods used, the CCC-project and the background for implementation and use of the 3D object models is briefly introduced. In the main part of the article, the five design team stories are told, each including a summary and a short discussion. Finally the paper provides a short conclusive discussion of the approaches and methods applied, and the implications for further research.

6.2 method

The findings presented in this paper are based on a qualitative case-study (Yin 2003) of design team practice. Twenty semi-structured interviews (Kvale 1997) have been carried out in 2006-2007 with architects and engineers involved in building design and management. The respondents are representing different backgrounds, disciplines and positions in the project organization, and their stories together with observations of design meetings and desk research, provide a good overview of how the design team is working and interacting. An overview of the methods, amount of interviews, and when they were carried out is given in Table 6-1.

Table 6-1. An overview of the data collection in the CCC-project.

	CCC-project
interviews	20
interview rounds	1: end conceptual design phase June 2006 (3) 2: end design proposal September 2006 (10) 3: detailed design June 2007 (6) 4: detailed design October 2007 (1)
respondents	11: design managers (2), architects (2), engineers (4), ICT- and CAD coordinators (3)
other sources of data	Project material Observation of 3 meeting types "Guided tours" in front of computer

A descriptive framework has been applied for conducting the case-studies and for analyzing the data. The framework has been developed for analyzing and understanding the ICT impact on the architectural design process. It is based on the suggestion of three hierarchical project levels embedded in the AEC-industry context (Fig. 6-1); a macro-level (overall project), a meso-level (the design team) and a micro-level (the individual architect/engineer). The framework focuses furthermore on four central design process aspects; the generation of design solutions, the communication, the evaluation of design solutions and decision-making. A thorough description of the framework can be found in Moum (2006).

The findings of the case-study are interwoven in five design team stories. Martin et al. (2005) arguments that:

"The story format provides a dense, compact way to deal with and communicate the complex reality of a real-world building project, while respecting the interrelate nature of events, people and circumstances that shaped its conception". Martin et al. (2005:35).

The five stories explore central design development issues placed in the dynamic relation between initiatives and strategies on overall project level (macro-level), the processes within the design team (meso-level) and the individual experiences from using digital 3D design tools (micro-level).

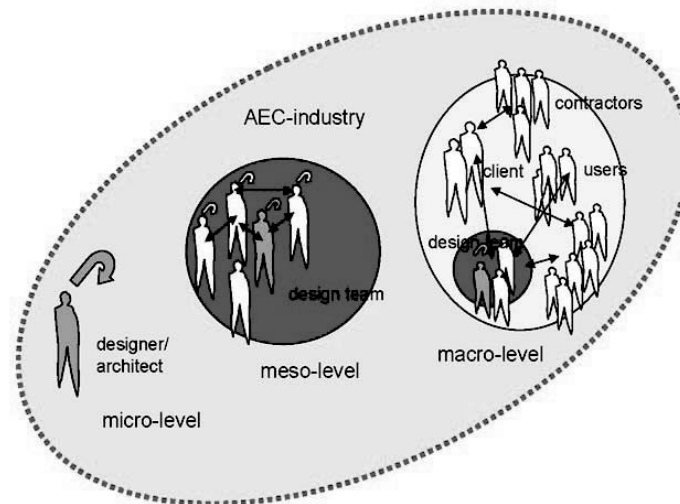


Figure 6-1. The three project levels embedded in the AEC industry context.

The intention by telling the five stories is not to provide the reader with a complete picture of all actual relevant issues due to the use of 3D object models within the design team. The design team stories should be read and understood as 'glimpses' or 'spotlights' into a highly complex reality, each indicating areas which should be investigated in further research.

6.3 introduction of the CCC-project

The Icelandic National Concert and Conference Centre, located in the harbor of Reykjavik, is a prestigious public-private-partnership project aiming to make Reykjavik visible in the international landscape of architectural and cultural high-lights. On the web-site of the Portus group (the client), the architectural and artistic concept is described with the following words:

"The concept of the building is to create a crystalline form with a variety of colours dependent on the surrounding nature, giving the viewer a continuous feeling of sensuous change. The building stands alone as a monolith, reflecting the varying sky both in intensity and colour depending on the time of day, the weather and the season." (retrieved September 2007 from: <http://www.portusgroup.is>)

The concert and conference building with the parking garage is functionally, technically and geometrically highly complex. The amount of non-orthogonal angles, tilting walls and roofs, are some of the geometrical aspects challenging the abilities of the project organization. Several of the design team stories presented in this paper, are related to the

development of the building envelope, called the Quasi-brick façade (Fig. 6-2 and 6-3). There are many actors involved in the design development of this large scale project (Table 6-2). This paper focuses on the collaboration between the architectural and the engineering company in Denmark.



Figure 6-2. The CCC-project in Reykjavik, Iceland (Courtesy: Henning Larsen Architects. Rendering made by Eyecadcher).



Figure 6-3. The CCC-project in Reykjavik, Iceland (Courtesy: Henning Larsen Architects. Rendering made by Eyecadcher).

Table 6-2. Numbers and facts of the CCC-project.

	CCC-project
function	Concert- and conference center with parking garage
gross floor area	32.000 m ² (without parking-garage)
schedule	Competition: 2005 Design and construction: 2005-2009 Operation: around new year 2009/2010
project type	Public-private partnership
client	Portus-group
architect	Henning Larsen Architects, Denmark & Batteriid Arkitektar, local architect, Iceland
artist	Olafur Elisasson, Iceland/Germany
engineers	Ramboll Denmark AS, Denmark & VGK Hönnun HF, Rafhönnun HF, sub-consultants, Iceland
contractor	IAV, Iceland (design-build) - the client of the design team

the background for implementing 3D object-based modeling

Key-persons within the engineering company have been playing an important role in the Danish public-private R&D program 'Digital Construction' and in the development of one of its foundations; the '3D Working Method' project (2003-2007). The aim of the program has been to establish a common platform for interchanging digital information and to stimulate digital integration in the Danish AEC-industry (EBST 2006). These same key-persons initiated the implementation of 3D object-based modeling in the CCC-project's design team. The relation between the R&D project 'Digital Construction' on national level and its implementation in the CCC-project is thoroughly explored in Moum et al. (2007). The implementation of 3D object-based modeling in the CCC-project is thus based on the initiative of the engineering company, not on a client demand or on requirements defined in the contract. The step from 2D CAD to 3D object-based modeling had to be undertaken within the existing time schedules and budget. Based on this situation and on different organizational traditions, the architectural and the engineering company initially had different aims and ambitions regarding the degree of implementation.

Although the architectural company since several decades holds an influential position both in Denmark and internationally, they still are (similar to other architectural companies) quite low tech due the use of digital 3D design tools for design development. Specialists within the company are making highly impressive renderings and animations for

sale purposes. Until the start of the CCC-project and the initiative of the engineering company, the main digital tool for all architects involved in design development was 2D CAD. In June 2007, six months before the end of the detailed design phase, about 50% of the architectural team members were working 3D object-based. Based on their lacking skills in 3D modeling, the architectural company initially perceived the risk of a full implementation as too high. To build up a complete architectural 3D object model of the whole building was therefore only an 'add-on' to the architects' traditional manual production of 2D CAD drawings until the end of the design proposal phase autumn 2006 (Fig. 6-4 and 6-5). Still, as we shall see in the five design team stories, the 3D object model has from the beginning played an important role for the architects' design development of the complex building envelope.

The engineering company on the contrary, stated already from the beginning the aim that 3D object-based modeling shall replace 2D CAD in all engineering disciplines involved in the CCC-project. However, not the engineer, but the draftsman is the one who is responsible for the 3D object modeling. According to the project manager of the engineering group, the long term aim in the company is to change this organizational tradition; in the future also the engineers shall be able to build up and use the 3D object models.

the interdisciplinary use of 3D object models

Each design team discipline has built up and maintains discipline-specific 3D object models according to the Digital Construction's '3D Working Method' manuals (bips 2006, Moum et al. 2007). 2D drawings and other take-offs are generated from these discipline models. 3D object models from other disciplines are imported as external references (x-refs). The CAD responsible in the engineering company gathers the different discipline models to a common model³, which is the basis for generating 3D visualization files and during autumn 2006, even clash reports (see example, a competition animation presenting the CCC-project: <http://www.portusgroup.is>).

Figure 6-4 and 6-5 illustrates the development of the 3D object model system from summer 2006 to summer 2007.

3. Comment: the 'common model' in this Paper III is called the 'aggregate model' in Paper II.

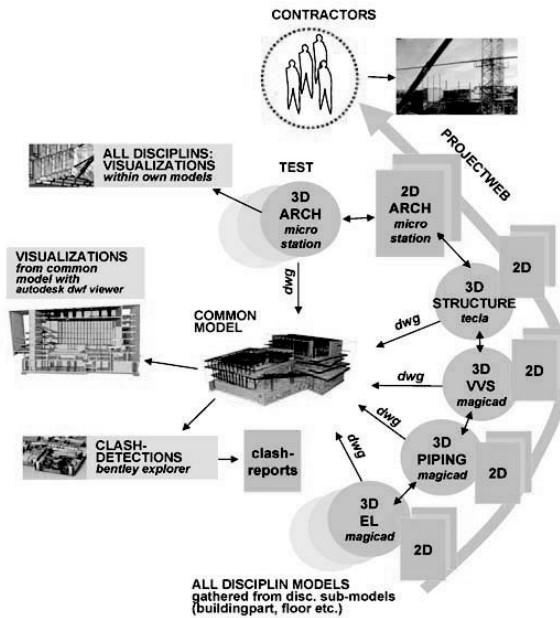


Figure 6-4. The 3D object model system, software and applications autumn 2006 (design proposal phase).

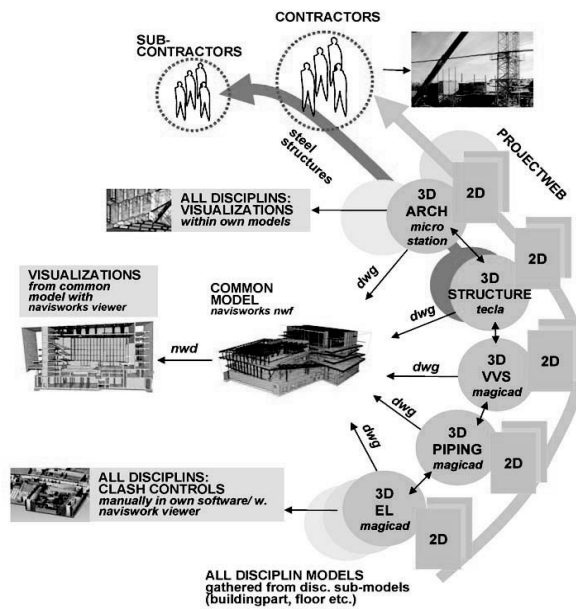


Figure 6-5. The 3D object model system, software and applications summer 2007 (detailed design phase).

An important issue inherited in the step from 2D CAD to 3D object-based modeling, is the possibility to connect textual information to the objects, which together with the parametric relation between the objects, leads to the much used terms ‘intelligent objects’ and Building Information Model (BIM). Since the CCC-project’s discipline models to some extent are populated with object information, the term BIM can be used to describe them. However, since the project’s model concept is primarily placed in 3D object-based CAD, and the ambition and the main priority of the engineers and the architects is to build up ‘complete’ 3D models in the sense of the building geometry, the term ‘3D object model’ is used in this paper.

The interdisciplinary use of 3D object models in the CCC-project is expected to play an important role in supporting the development of the complex geometry, in the reduction of geometry-related failures in the project material, and in the smoothing of interactions between the actors and the processes. The five stories told in the next section are dealing with the benefits and challenges from generating, communicating, evaluating and deciding upon geometry.

the hierarchical meeting structure in the project

The main fora for formal communication and decision-making are three different meeting types, based on a clear hierarchical meeting structure (Table 6-3).

Table 6-3. The hierarchical meeting structure.

	participants	purpose	frequency	media
DESIGN MEETINGS	Project-/ design managers from client, contractor, architects/engineers.	Decision-making regarding cost- and schedule issues.	Every second week.	Paper prints, sometimes powerpoint.
WORKSHOPS	Project-/ design managers from architects/engineers and contractor.	Problem identification, strategy definition.	Weekly and when needed.	Paper prints, physical models, sometimes powerpoint.
WORK MEETINGS	Designers from architectural and engineering companies.	Design development, problem solving.	When needed. Often in the prolongation of the workshops.	Sketches, paper prints, physical models.

6.4 design team stories

The 5 design team stories presented in this section are exploring the following beneficial and challenging situations from the interdisciplinary use of 3D object models within the design team:

- its support and its limitations regarding the development of complex geometry
- its contribution to building up shared understanding both within and outside the design team
- its role in the painful processes of change
- the challenge of formalizing processes in dynamic design environments
- the interface between design and production; blood, sweat and tears from generating 2D drawings and a happy story about shipping pre-fab steel from China.

Figure 6-6 provides an overview of some key findings from the qualitative case-study, which are interwoven in the stories to come.

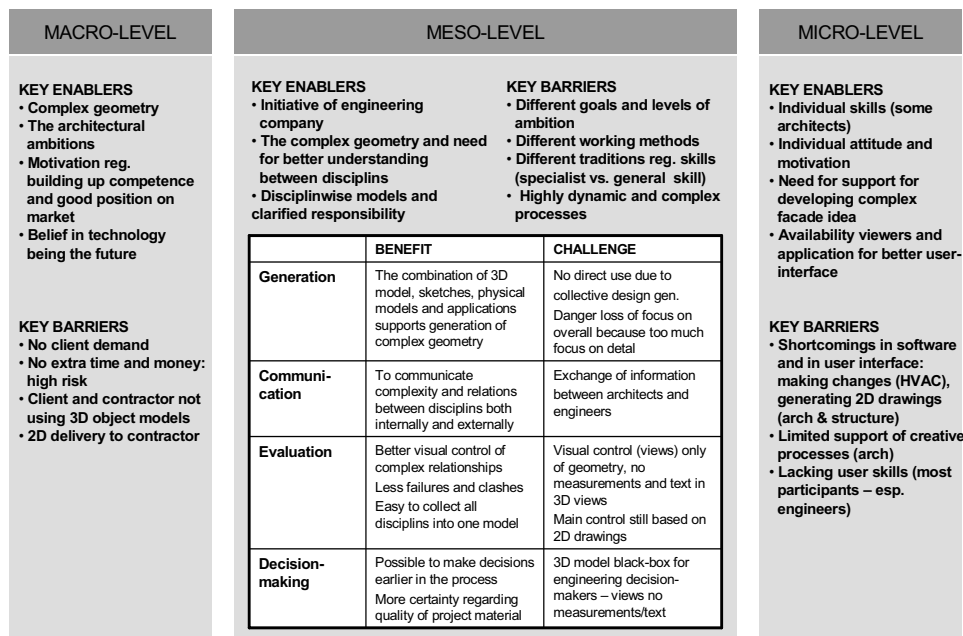


Figure 6-6. Illustration of key benefits and challenges from using 3D object models, and barriers and enablers influencing this situation.

STORY 1: developing complex geometry

Throughout the last decades there has been considerable effort to describe and explain the design process and the generation of design solutions. The first generation of design methodologists' focus on the design process as something sequential and linear in the 1960s, has long been challenged (Lundequist 1992a). Lawson (2006) emphasizes that there is no clear distinction between problem and solution, analysis, syntheses or evaluation in the design process. Schön (1991) describes the design practice (e.g. sketching)

as a conversation or reflective dialogue between the designer and the design situation or design issue. As indicated in the introduction, there is an increasing focus on collaboration and collective design. Barrow (2000) introduces in his thesis 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." Barrow 2000:273.

There are different models for developing and managing design. Gray and Huges (2001) refer to Dumas and Mintzberg and their four management models, where at least two are relevant for the design team situations described in the following story. Firstly, the dominated design (leading function); an 'over the wall' approach, where one team takes charge to impose the design realization on the other. Secondly, the co-operative design (interactive functions); an approach based on teamwork, interaction among the actors and the spontaneity of their organizations.

This first story focuses on how the architects and the structural engineers develop the geometrically challenging building envelope. It describes and discusses how they are working and collaborating, and which role the 3D object model is playing in the design team's individual and collective efforts.

architects' and engineers' design development and the role of the 3D object model

The around 20 architects working with this project are comprised on several sub-teams each responsible for different areas of the building. A two-person team was responsible for designing the building envelope during the design proposal phase. The philosophy of the architectural design manager is to allow the groups some freedom in initiating and driving the design forward. This mirrors the flat hierarchy in the company due to design generation, where every voice uttering an interesting design idea gets heard. The development of the building envelope is based on a continuous interplay between individual working, informal discussions with the group neighbor or with the team managers, initiated spontaneously when needed. The not unexpected support of the 3D object model due to the development of the Quasi-brick façade is stated by most of the respondents, independent of discipline, position or task. Quoting one of the architects developing the building envelope (September 2006):

"...Not even in my dreams I can imagine how we could have developed this façade manually. We would then have no precise opinion about what we are developing (...) I have experienced that a detail at the foot of the building (...) triggered a chain reaction affecting the whole façade (...) I have no possibility to overview my problem complexity in a 2D drawing."



Figure 6-7. Workplace of one of the architects (Author's photo).



Figure 6-8. HLA's office (Author's photo).

According to the design manager of the architectural team, the geometric rules behind the single Quasi-brick are simple, but by combining and adding them, it gets hard to over-view the geometry (September 2006):

"...all the same how much you try to control and understand [the problem], you are not able to solve it by using a pencil or simple 3D models. You can get an impression of the scale and the geometry. But when you starts with reflections

and mirroring effects (...) sometimes you gets surprised how far it [the expression] is from the reality. It is more complex than you expect."

However, one of the architects designing the building envelope, points on the 3D software's limitations in supporting the creative processes where the first ideas are taking form. He developed his ideas based on a rapid back and forth between hand-sketches and its testing in the 3D model. Furthermore, he perceived the connection between the design generation and the hand-made sketch being more intuitive than between the design generation and the 3D object model. There are still too many technical software requirements to be considered. Since also the rendering ability of the 3D model software is rather poor, advanced rendering programs are used. By seeing the effects of the design solution on reflection and mirroring effects in such renderings, the respondent sometimes decided to reject or re-design a solution. In this sense he emphasized that the quality of the software impacts on the design generation process. Altogether, the architects are using several tools in addition to the 3D object model in order to support their development of the building envelope; physical models, hand-sketches, and software applications, dependent of the task and the problem to be solved (Fig. 6-9 and 6-10).

The 3D object model has supported the rapid achievement of a high level of precision and detail of the Quasi-brick façade, at least in parts. One of the respondent from the architectural team commented here on what he sees being a danger inherited in this software ability; the temptation to dive into and focus too much on details, making the 'think big', which is important for rejecting or improving overall concepts, difficult.

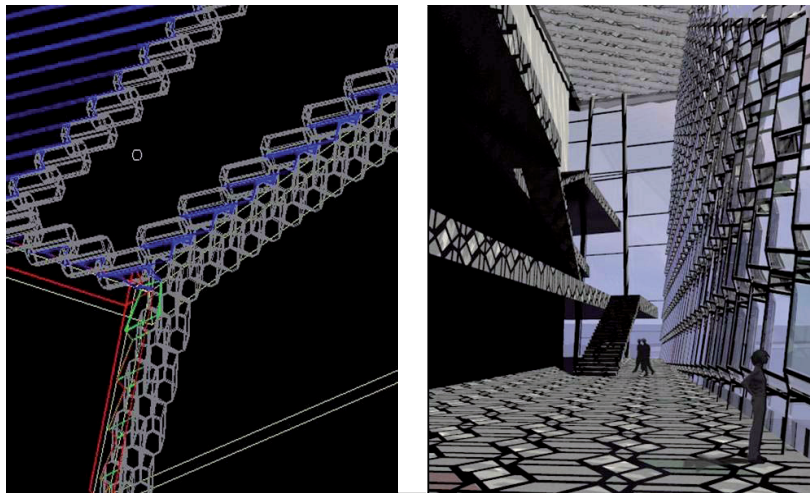


Figure 6-9. Left: Using 3D CAD for controlling geometry. Right: Using rendering software for controlling reflections (Courtesy: Henning Larsen Architects).

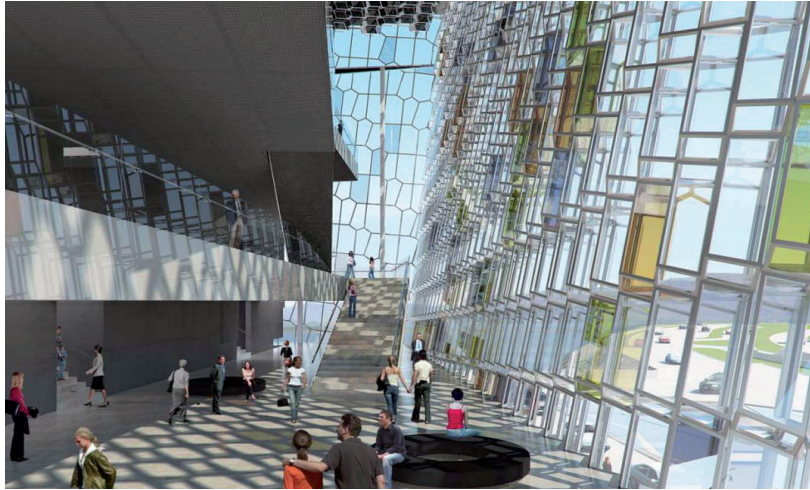


Figure 6-10. Advanced rendering for presentation and public web-site (Courtesy: Henning Larsen Architects. Rendering made by Eyecadcher).

Also the engineers' working day is based on a dynamic interplay between individual working and informal discussions. However, there is a clear hierarchical structure within and above the teams, defining who is developing the main concepts and deciding the technical parameters (mostly experienced engineers), and who is testing out and drawing/modeling the solutions (mostly draftsmen). The engineers are typically developing concepts and technical parameters by hand sketches. These are handed further to CAD-skilled draftsmen as soon as the design generating 'ping-pong' process between for instance the steel construction engineers and the architects has come to an end.

The responsible for designing the piping systems pointed on two interesting situations emerging from this engineer-draftsman system. Firstly, she perceived the delay between her sketching and the draftsman's testing and further development of her idea in the 3D model as something disturbing her individual design development process. This situation became even more challenging, since the human resources for modeling were limited and leading to periods of waiting for available draftsmen. Thus, a rapid back and forth between hand-sketches and its testing in the 3D model was not possible. Secondly, in order to feed the draftsmen with the information necessary for their modeling task, she felt she had to make decisions before her ideas were thought through and developed properly. These two situations could partly have been solved in the case this respondent would be able to handle the technology herself. Nevertheless, she pointed on what she perceives being a challenge by the engineers modeling themselves; the temptation of focusing too much on detail by using modeling tools, could lead to a loss of overview of the overall systems and concepts. One of her colleagues, pointed on the contrary on the necessity to merge the separate worlds of the engineer and the draftsman into one.

According to him, the user of the software should both master software- and engineering related knowledge. This would be especially useful in order to utilize modeling tools with integrated simulation and calculation modules. However, this would require more user friendly software interfaces than today.

collaborative design generation and the role of the 3D object model

The architects designing the building envelope are closely interacting with the engineers developing the steel structures of the building. The leader of this engineering team, describes the collaborative design development the following way:

"...we sometimes arrange small workshops where we discuss different issues in the building (...) then we go home and make some calculations and sketches which we send to the architect (...) Then the architects say; no, this is not what we want (...) it is a ping-pong; back and forth, back and forth, slowly getting closer to a solution."

In a "Quasi-brick" work meeting observed by the author, the architects and the engineers were developing cost saving alternatives of the Quasi-brick roof system in a highly interactive and cooperative setting. It seems that the collaboration between the architects and engineers in order to develop the building envelope is based on a mix between the "over the wall approach" (the architects initiate a solution, which in the next step is tested by the engineers) and cooperative design development (Figure 6-11 and 6-12: impressions from the Quasi-brick work meeting June 2006).



Figure 6-11. The engineer explains the architects one of her ideas using a physical model (Author's photo).

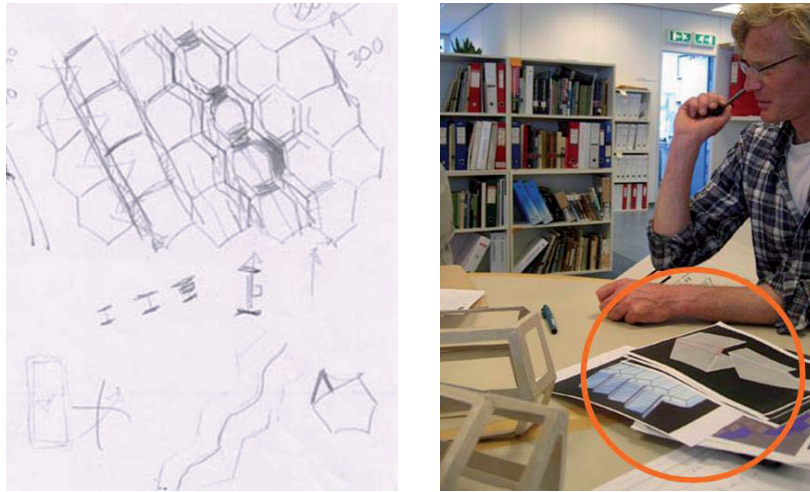


Figure 6-12. Left: One of the hand-sketches made during the meeting (Courtesy: Henning Larsen Architects/Ramboll Denmark). Right: The architects brought with them some paper plots from their 3D model (Author's photo).

The 3D object models have not been used directly for supporting the dynamic generation of design solutions in a meeting situation during the conceptual design or the design proposal phase. The participants in the work meeting referred to above were discussing highly complex geometrical relationship between the facades and the roof based on very simple hand-drawings made parallel with the 'generation - evaluation - decision-making' cycle. In addition, they were actively using a physical model and some computer generated sketches (from the architects) made before the meeting (Fig. 6-11 and 6-12).

summary and discussion

The respondents in the CCC-project are describing the development of the design solutions as a 'ping-pong' process between the architect and the engineer. The media used for collaborative design generation are rather traditional. Here the 3D object model is only playing an indirect role, as it is not used directly in meeting situations where architects and engineers together are developing design. In the work meeting situation described in this story, some aspects and challenges were recognized late, forcing the participants to re-think about the solutions agreed upon earlier in the meeting. A real-time use (means: testing out ideas directly in the 3D model, immediately seeing the consequences of the changes) of the architects Quasi-brick model, could have visualized central challenges already at the beginning of this meeting.

The architects are using several tools for supporting their design development, depending on the situation. Although the 3D object model (alone or with rendering applications) is playing a crucial and positive role in the architects' individual development of the com-

plex geometry, the technology has limited abilities for being the actual medium of the 'design conversation'. The architects are using the 3D object model rather for testing and evaluating the design ideas and the consequences of changes, than for creative sketching. In the case of the engineers, the 3D model plays an even more limited role in their individual design development. Since they have no or minor skills in using CAD, a second party (the draftsman) is involved in the testing and evaluation part of the creative cycle.

Another challenge indicated in this story, is the tightrope act between the appropriate level of detail for controlling and developing the complex geometry, and the abstraction needed for creative freedom; allowing change and improvement in a stage where a design solution still has not reached enough maturity. Lawson (2006) characterizes the temptation of too early precision as the design trap of over-precision. According to Lundequist (2003) we still do not know much about how the human being handles and edits information. However, the use of the 3D object model in the CCC-project has supported the control of relationships and consequences of change. This leads us to the next story, which deals with the communication, coordination and understanding of complex geometry.

STORY 2: achieving shared understanding

Communication is in much literature emphasized as a key to good collaboration and teamwork (Cramton and Orvis 2003, Emmitt and Gorse 2003, Kalay 2004, Lundequist 1992b). The communication and interaction between the building process actors can essentially impact the decisions made and the further development of the architectural design solutions. Successful collaboration and communication is crucially based on shared understanding of goals, tasks and the product to be developed (Griffith et al. 2003, Hinds and Weisband 2003). The ideal conditions for ensuring shared understanding are based on the participants having similar background and a common base of experiences, with the opportunity to learn about each other over time, to communicate, to share information, and to develop a team spirit (Hinds and Weisband 2003). However, this is mostly not the case in a building project. In the CCC-project, the actors involved are representing different backgrounds, experiences and interests, most of them working together for the first time. This story explores the role of the 3D object model in order to support the understanding, communication and control of complex geometry, both within and outside formal meeting situations.

understanding complex geometry

The work meeting situation described in the first story was taking place in the prolongation of a workshop, where among others the rain water drainage of the Quasi-brick roof was discussed. This discussion was triggered by the clients' concerns regarding maintenance, durability and cost of the roof. In the workshop, the strategies and directions for further development were defined. On the design meeting and workshop level in the

meeting hierarchy (Table 6-3) the focus lies on problem identification and strategy definition, not on design generation or problem solving, which is the main purpose of the work meetings. The participants in the work meeting situation described in story one have been intensively and directly involved in the design development for months. The workshop participants (mostly with decisions-making responsibility) however, are attending without the same detailed knowledge and understanding of the complex building geometry. The project manager of the engineering team described an experience he shares with most of the project participants (June 2006):

“... I do have problems with participating in [some workshop] discussions, because I cannot understand and overview the geometry in such a complex building (...) one [design meeting] topic has been the [rain] water drainage from the roof, and I was simply not able to understand where the rainwater would flow when it hits the roof (...) here it would have been enormously good to have a 3D model. Since 2D is flat, you lose some information. It would have been great to use the 3D model and a projector, where you can turn the building around, seeing the rain water flow in the wrong or correct direction.”

the role of the 3D object model in formal meeting situations

The project manager quoted above clearly recognizes the potential of the 3D model for enabling a better and shared understanding of the complex geometry and the related problems in a meeting situation. However, in summer 2007 this technology still played a limited role in supporting formal communication. Similar to the work meeting situation described in the first story, the basis for discussions, problem identifications and decision-making within the workshops and design meetings, are paper prints of 2D drawings, excerpts from the 3D model, hand- and computer generated sketches and physical models (Table 6-3). Nevertheless, autumn 2006 the engineering company presented views of their 3D models and demonstrated the possibilities for easy 3D navigation in front of all key actors of the project in a design meeting setting (Fig. 6-13). According to the project manager, this was a success and a breakthrough in order to communicate the very complex interplay between the different disciplines in a visual and easy understandable way. This enabled the project participants with difficulties in interpreting traditional 2D drawings, a better understanding of the building. Still, he perceived this event rather being a demonstration of 3D skills and the status of the design development and coordination, than something actually impacting on the clients' decision-making process. Additionally, two respondents pointed out that the use of the 3D model would not be feasible in all meeting situations. According to them, the usefulness of the 3D model should be considered due to the meeting type, the agenda and the participants' knowledge about the process and the building. A third respondent expressed even his concern that using 3D object models in some meeting situations could mislead the decision-makers to focus on irrelevant details.

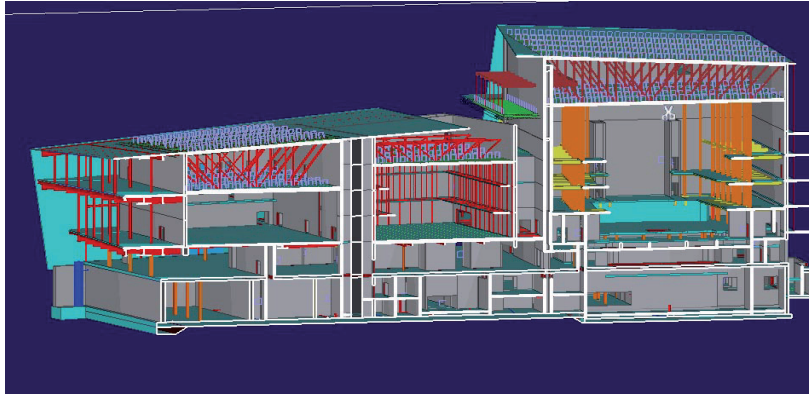


Figure 6-13. 3D view of structural model (Courtesy: Ramboll Denmark AS).

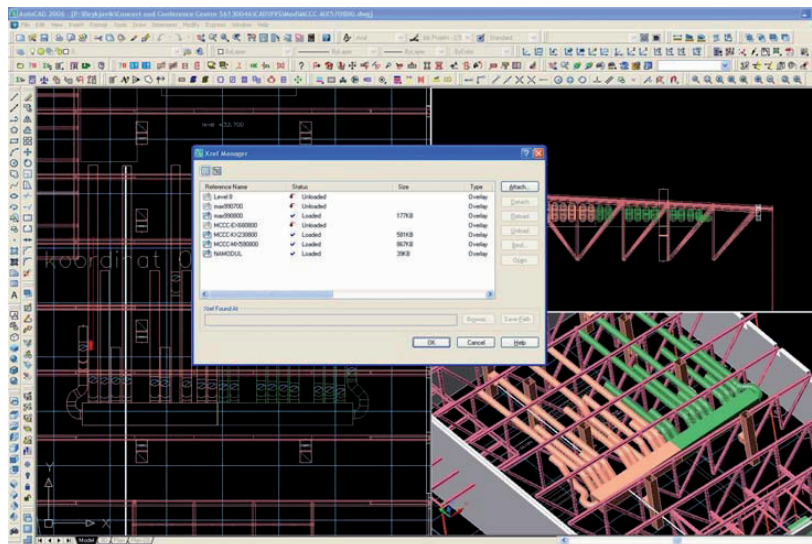


Figure 6-14. Screen environment of ventilation draughtsman (Courtesy: Ramboll Denmark).

improving coordination, control and communication

Whereas the potential of 3D object model and viewer applications for achieving shared understanding has not been fully utilized in formal meeting situations, substantial benefits have been harvested in the daily work internally within the design team. There seems to be a general agreement among the respondents that using the 3D object model and its viewer applications (viewers) has supported the understanding and the control of the building geometry and geometrical relations between the different disciplines. Through the 3D representation of the complex geometry, clashes and failures could be recognized and solved earlier. Thus, uncertainty could be reduced and errors avoided already

at an early stage of the building project. The individual designers (engineer or architect) are making their visual checks of the design solutions directly within their own discipline model. By importing model-files from other disciplines, they are able to recognize eventual conflicts between for instance the ventilation pipes and the load-bearing structures. Figure 6-14 shows the typical screen environment of the HVAC draftsman. In some cases the draftsmen from all engineering disciplines are together making visually checks of the status and consistency of the project material in front of a wall projection of the 3D model.

Altogether, the use of 3D object models and viewer applications within the design team has been helpful in order to achieve a shared understanding and to support communication regarding the needs and the intentions of each discipline:

“If I deliver flat and hard technical 2D drawings [to the consultants], they would have to imagine the spatial situation where (...) a column is horizontally affected by the façade (...) This [situation] I can present in ONE picture, perhaps two or three (...) It would have required ten [2D] drawings (...) In this case it is a fantastic tool of communication, since you get an overall overview of this situation.” One of the architects developing the Quasi-brick façade, September 2006.

Figure 6-15 illustrates some of the attitudes of the respondents involved.

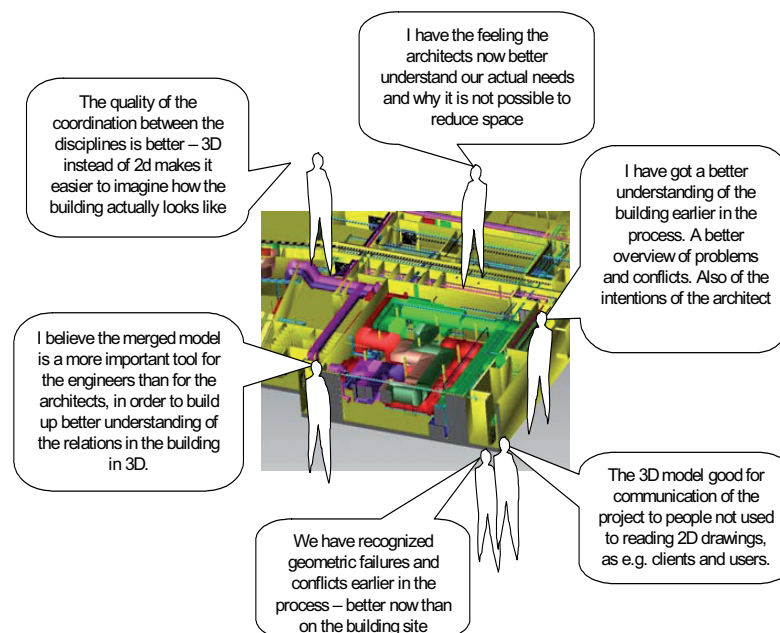


Figure 6-15. Shared understanding is perceived as a key benefit among design team members. The bubble-text is fiction, but based on comments in interviews (Screen-dump from common model: courtesy Ramboll Denmark).

summary and discussion

The interdisciplinary use of the 3D object models seems to have essentially contributed to building up a shared understanding of intentions, needs and geometrical relations among actors representing different backgrounds, interests and positions. Through 3D visualizations, an impression of the building project can be provided before it is finished. According to the architects and engineers interviewed, this is a key benefit from using 3D object models within the CCC-project, in addition to the crucial support in developing the complex geometry of the façade, as described in the first story. However, the 3D object models are still with very few exceptions used directly in formal meeting situations for explaining or testing design solutions or for recognizing problems. There is clearly awareness among some of the design team members about the potential of the 3D object model technology in order to support some meeting situations. A real-time use of the 3D object model could for instance provide an immediate testing and overview of change consequences. This would require both highly skilled users and rapidly responding software. In the case of the CCC-project, neither the technology nor the skills are available today.

Nevertheless, the 3D object model's contribution to building up shared understanding has been successful in the sense that the benefits achieved address the aims and ambitions stated by the architects and engineers in the beginning of the project

STORY 3: The painful processes of change

"The designer has a prescriptive rather than descriptive job. Unlike scientists who describe how the world is, designers suggest how it might be." Lawson (2006:112).

In the beginning of the design process, the architect, the engineer or the client do not know exactly how the building will look like, what are the problems to come or even what are the requirements to be fulfilled. Lawson (2006) describes the design process to be a simultaneous learning about the nature of the problem and the range of the possible solutions. This story describes how the architects and the engineers handle the changes inherited in the development of the 'Quasi-brick' façade.

the development of the Quasi-brick facade

The development of the building envelope has been a long and in periods a painful process. In the course of the further development of the architectural competition's Quasi-brick idea, the concept turned out to be too expensive, and there were several technical and architectural challenges due to rain water drainage from the roof, or to the joints between the Quasi-brick system and the conventional facades (Fig. 6-16, left).

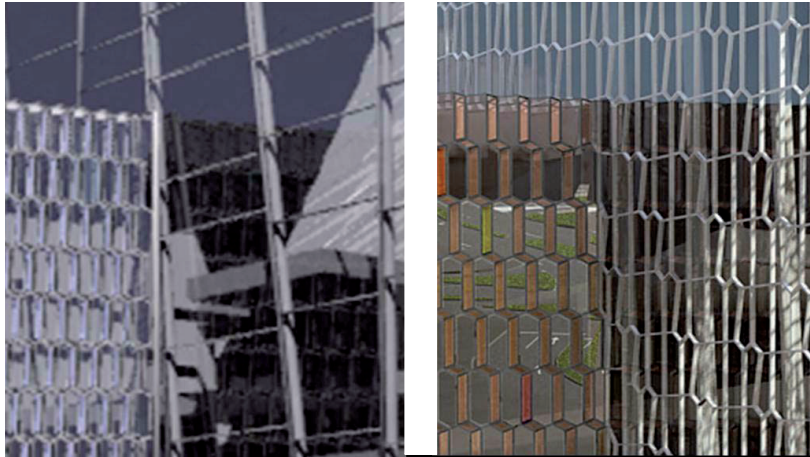


Figure 6-16. Left: Challenging joints between the Quasi-Brick facade and the conventional facades. (Courtesy: Henning Larsen Architects). Right: the new design solution: The Cut-quasi-brick facade (Courtesy: Henning Larsen Architects. Rendering made by Eyecadcher).

The decision-making mechanisms influencing this process were highly complex and non-linear, taking place on all levels in the project organization. Many interests were to be regarded; the expectations of the Icelandic tax payers, cost-, sustainability-, usability and durability aspects, architectural and technical quality, to mention some. In order to find compromises satisfying all actors involved and to solve the many challenges inherited in the original idea, the facades developed rather slowly. According to one of the architects, at some point in the process, the clarity and conceptual strength of the idea started to blur. The breaking point in the Quasi-brick story came toward the end of 2006. The architects presented together with the artist a new approach to the client; by “cutting through” the 3D quasi-brick façade, they got heterogeneous but still logical “2D” façades based on so called ‘Cut-quasi-bricks’ (Fig. 6-16, right).

different cultures of change handling

The respondents emphasized the good collaboration between the architects and the engineers, but they also expressed some frustration created by the situation described above:

“...We are not in the creative phase anymore, now we are in the production phase. And there we do not want to face new problems, solutions and thoughts (...). But there still turn up new requests and things which are not clarified. This should have been completed half a year ago. It is hard, to continuously make changes and investigate new things, when we at the same time have to produce and produce.” Leader of the steel construction team, June 2007.

The project manager of the architectural team points on a cultural gap between the architects and engineers regarding the handling of design changes (September 2006 and June 2007):

"We normally say; when we make decisions, there are loops, getting smaller and smaller, but they probably never disappear in our attempt to find the optimal solution. The process among the engineers is linear. They can get frustrated about the architects' making changes, that things get re-designed. (...) Perhaps the architectural profession is more flexible regarding changes. We are used to doing last minute changes ourselves; in the case we get good ideas. Then the engineers often say no and stop; we are finished, we cannot change anything anymore. Here there is sometimes a cultural gap, since we all the time like to optimize. And then there have been all the changes we have no influence on, coming from outside (...) Of course, this leads to some frustration, but often this also motivate us."

He furthermore pointed on the engineers' need for more precise information and requirements in order to develop their design than the architect. In his reflections about this situation, he addresses additionally some other issues impacting on the engineers' attitude to design changes in a practical example. Due to the sight lines in the concert hall, the front edge of the concrete floor had to be changed. For the architect, this resulted in changing some lines in the model. For the structural engineer, this implied in addition to the geometrical changes, a re-calculation of the load-bearing system. In this and other re-design related situations, the engineers seem to be confronted with more time-consuming work than the architect.

Indicated by the engineer quoted above, the project schedule was an additional issue triggering painful processes of change. The scheduled mile stones should not to be affected by the uncertainty and the slow progress of the building envelope and the adjacent areas. Firstly, the load-bearing structures had to be fixed already summer 2006, in order to start with the fundamentals on the construction site in time. Secondly, in the detailed design phase the HVAC and electrical engineers must deliver their tender packages to the contractor six months later than the architects (the Quasi-brick façade has its own schedule). The project manager of the engineering team emphasized that both situations should not represent a problem, as long as the architects do not change anything which impacts on the engineering part of the planning. However, due to the time-consuming decision-making processes and the general maturation process of optimizing design solutions and requirements described above, it seems to be challenging to avoid such changes. In spite of some engineers' efforts to focus as long as possible on developing building parts with low risk for further changes (e.g. technical rooms), already shortly before the delivery of the HVAC and electrical tender package summer 2007, re-planning was expected to be inevitable.

The project manager of the architectural team compares the efforts of the design time with the juggling with many balls, where the challenge lies in catching the balls before it is too late. He explains that the understanding about which parts of the design development belongs to 'long' (possible to make changes late in the process) and 'short' processes, is central in order to handle the challenging situation described above.

the role of the 3D object model

Does the design team's use of the 3D object models relieve the painful handling of changes and re-design? Some of the expectations connected to the use of such technology are its potential to speed up processes and to enable rapid re-design. As described in story two, although the design team has used the 3D model actively in order to visualize the problems to be solved and decided upon, the technology has only to a limited degree impacted on the decision-making processes of the clients. According to the project managers, several expectations are still to be fulfilled in the CCC-project. One obvious reason is the lacking skills of the actors in working 3D object-based, another is the shortcomings of the software itself. Especially the engineers and draftsmen modeling the HVAC and electrical systems perceive doing changes in the 3D model as the biggest challenge in their daily work. The many changes emerging throughout the planning and the time consuming work to integrate them in the 3D object models, hindered these teams in delivering their complete detailed design package within deadline. According to one of the engineers involved, it is often easier to start modeling from scratch than to edit the existing model. Another issue mentioned was that since the 3D models are representing a higher level of detail earlier in the process (requiring more efforts and decisions of the actors), making changes implies an increasing amount of consequences to be overviewed.

summary and discussion

This story has illustrated that crucial changes during the design process in the CCC-project are triggered by many issues; for instance the architects' initiatives and driving force to improve and partly re-design solutions, or new requirements emerging within the client organization. The story has also described that the architects and engineers are handling the upcoming changes differently, due to different working methods, the different consequences of doing re-design, and the time schedule. Especially for the HVAC-team, the use of the 3D object models has rather made this situation even more difficult than it has 'relieved the pain'. An issue indicated in some of the interviews, is that the software often does not address the actual complexity of the design processes. However, it is likely that by improving the software and the user skills, the 3D object model will play a more supportive role in the rapid handling and integration of design related changes. The integration of calculation functionalities in the modeling tools, or the increasing interoperability between the 3D tools and calculation applications, are solutions which could support the engineers' change handling in the future. Additionally, the

potential of the technology in capturing explicit experiences from previous projects is likely to reduce uncertainty. Nevertheless, the project schedule's impact on the design development and the interactions between the architects and engineers seems to be a substantial non-technological aspect. One of the engineers perceived his experiences from twenty years ago as less painful; as the engineers started with their planning when the architects had 'settled down' their design development. However, different trends throughout the last decade have changed this situation. The CCC-project seems to be one of many building projects today, where the project participants are facing overlapping planning phases, leading to some of the challenging situations described above. Nevertheless, the ICT-responsible in the engineering company emphasizes that the overlap and merging of architectural and engineering design also represents a potential for achieving coordinated and harmonized design solutions.

This story about the painful process of change, indicates also another challenging contradiction; the need for maturing phases and time to think through and understand consequences on the one hand, and the striving for saving time and speeding up processes on the other. This furthermore indicates a 'tightrope act' between allowing innovation and creativity, and optimizing and formalizing processes, which leads us to the next design team story.

STORY 4: Formalizing processes in a dynamic design environment

Similar to most building projects, the CCC-project is organized in milestones and project phases, where the end of each phase results in a package of material. This package documents the planners' performance of the contract requirements, and is the basis for the client's "green light" for continuing to the next phase. This structuring of the design process into phases indicates a gradually and continuous development from something rough and very abstract to something precise and detailed. This seems to be the basis for the development of guidelines (bips 2006, ProIT 2006) suggesting how to build up and use 3D models in order to optimize and making processes and information flow more efficient, within and between planning phases and disciplines. This story addresses issues of formalizing design team processes within a dynamic design environment.

the dynamic switching between the levels of detail

Both the first and the third story describes a highly dynamic and non linear design development, where 'loop', 'cycle' and 'ping-pong' are terms used to describe the design development and the interactions between the architects and the engineers. The architects seem to rapidly switch between overall concept thoughts, down to detail and material considerations, back again to the consequences for the overall design and so on. Sometimes an idea about a detail turns out to become the generator of a next cycle. For instance; the idea of how to solve the joint between the Quasi-brick exterior wall and the roof can influence the whole building envelope system (see story 1). Paired with the

continuous optimization of the design ideas, or with new requirements from the client, such situations sometimes result in re-design or even rejection of solutions already agreed upon (story 3).

the use of geometrical simplifications; 'reference shells'

The architects developing the building envelope soon realized that to model the complete facades into detail would not only exceed the capacity of both the software and the user, but it would also be inefficient due to the data exchange with the engineers. In order to solve this issue, the architects simplified the façade into 'reference shells' (Fig. 16). The 'shells' are describing the surface of the building envelope and the interface between interior and exterior, but not the structural system or any details. Until the 'Cut-quasi-brick' idea and the 'go' from the client, these shells were the basis for the 3D model exchange with the engineers. The architects' partly very detailed 'Quasi-brick' model was mainly used internally for their design development and testing, as described in the first story. Not until the mid part of the detailed design phase (spring 2007), the geometrical information level in the "official" architectural 3D object model of Quasi-brick facade actually addressed the late design stage.

building up 3D object models according to pre-defined information levels

Initially, the initiators of the implementation of 3D object-based modeling in the CCC-project, considered that the 3D object models should be built up according to seven information levels defined in the Digital Construction's '3D Working Method' manuals (bips 2006). The purpose of these levels is to support and formalize the concretization of the design solutions throughout the design process, from the first ideas to the level of detail necessary for facilities management and maintenance of the building. Nevertheless, in the CCC-project it very soon became clear, that these seven levels could not be followed. The detailed descriptions of these levels and the general impracticability for the design team members were pointed out as explanations in some interview situations. The development of the level of detail in the different 3D discipline models in the CCC-project seemed to depend on for instance the starting point of modeling, the software capacity, the skills of the user and not at least on the fact that the delivery to the contractor was mainly to be based on 2D drawings and details. Still, an important observation made in the study of the project, was the non-linear concretization and development of design solutions (within the pre-defined project phases).

summary and discussion

The architects' improvement of their design solutions and the complex decision-making processes involving all project participants, are some of several factors leading to a dynamic design environment in the sense of being 'cyclic' rather than linear. Firstly, this story has described that there is a continuous and rapid switching between abstract and highly concrete level of details. Lawson quotes Robert Venturi saying;

" We have a rule that says sometimes the detail wags the dog. You don't necessarily go from the general to the particular, but rather often you do detailing at the beginning very much to inform." Lawson (2006:39).

He furthermore describes that there is no logical direction from the general to the particular within design thinking. The development of the building envelope seems to take place in a highly iterative and partly unpredictable design environment, where the design team works with different design solution versions and media simultaneously, representing different levels of detail and what Lawson (2006) calls 'parallel lines of thought'. This leads to the second point of this story; the need for simplifying information and geometry also in the later stages of the design process. And finally to the third point; to build up and exchange the 3D object models according to pre-defined levels of detail was perceived to be impracticable. The impact of the two former points on this latter is here an interesting issue.

Compared to a linear and straightforward development of design solutions, the processes described in this and the other stories indicate much effort and frustration, especially in the interactions between the architects and the engineers. Nevertheless, the development of the building envelope with its tiresome and two-steps-forward-one-step-back process and the up-and-down from the overall to the detail seems to have contributed to improving and optimizing the original idea. This leads us to what might be another challenging issue by implementing and using 3D object models in practice; to handle the relation between a dynamic design environment and the attempts of using the technology to formalize, control and master the architectural design process. How to formalize without losing the 'something' in dynamic design environments triggering improvement and innovation?

STORY 5: From design to production

As we have seen in the previous four stories, the interdisciplinary use of the 3D object models has both been a valuable support and a source of some frustration and extra work regarding the design team's efforts of establishing the fundament for good architectural design. The quality of the material delivered to the contractor is crucial for the further steps on the construction site and for the success of the project. On the other hand, tendering- and construction-related factors are affecting 'back' on the design team's work. Whereas the first story was about generating the design solutions, this last story to be told, is about handling the interface between design and production.

generating 2D from the 3D object model: blood, sweat and tears

Since none of the actors on the client side in the project organization is familiar with or using 3D object models, the statutory documents of the project are traditional 2D drawings. In the detailed design phase, all disciplines are using their 3D object models as basis for generating the required 2D sections, plans and facades (except details, which are pro-

duced manually with 2D). The respondents perceive the process of generating (or extracting) 2D drawings as time-consuming and as one of the biggest challenges in the project. According to the project manager of the architectural team, the configuration of the extractions and the necessary manually supplementing of information (e.g. text and measurements) on the generated 2D drawings impacts on their daily work in several ways (June 2007):

“We know that there is a benefit to work with 3D design. But it is also a big work load, at least right now (...) The process of making the extractions, costs much energy (...) With the 3D model, you must decide 1-1 ½ week before we deliver [the 2D drawings]. Then we must make a plan about who is supposed to do what, because the 3D model comprises several models (...) there are many people involved in delivering these extractions, and there are many things that can go wrong. (...) it has been blood, sweat and tears, every time we must deliver; it is very real and very frustrating.”

On a question asked later in the same interview, whether the use of the 3D model has impacted on the project progress, the respondent claimed:

“Yes, it has. Only these simple deliveries (...) in order to make plans and sections, there are now 5-6 persons involved (...) It is very heavy and more resources are required.”

Another respondent within the architectural team points on the limitation of the software in generating drawings with the graphical quality and readability required by the architectural company before delivery to client or contractor. Additionally, she perceives the fact that it is not possible to rapidly make 2D drawings for spontaneous needs and meetings, as challenging. According to her, better skills among all involved would improve the situation; now several project participants are not themselves able to go into the 3D model in order to get the information they need. Instead they must wait for the 2D drawings to be generated. Not only are the architects struggling with the generation of 2D drawings. Also the steel construction team perceives the generation of 2D drawings as a challenging task. Since the architectural drawings are the basis for most meetings and decision-making, the team developing the steel structures is not generating any 2D drawings until they are required to do so due to contractual project deliveries. Additionally, the team members are solely working with the 3D model, together with the necessary calculation software and with the traditional hand sketches. To work with 2D drawings is not part of their daily work.

a happy story about shipping prefab steel from China

The last story to be told in this paper is about using the 3D object model for pre-fabrication, which appropriately rounds up the experiences explored in this paper. The 3D object model of the steel structures has been sent (via the Icelandic contractor) to a Chinese subcontractor, who has supplemented the model with the necessary information

needed for production. Shop-drawings were then sent back to the engineers in Denmark, who controlled them carefully, before the steel elements finally were pre-fabricated. According to the leader of the steel structure team, the first ships with prefab steel from China are expected early autumn 2007.



Figure 6-17. Prototypes of 'Quasi-bricks' (Courtesy: Henning Larsen Architects).



Figure 6-18. Web-cam from the construction site in Reykjavik East Harbor (retrieved October 15th 2007 from the Portus-webpage: <http://www.portusgroup.is/video1.html>).

summary and discussion

On the one hand, the design team members are attempting to switch from a 2D based to a 3D object modeling based work method. On the other, they must still produce 2D

drawings since these are the statutory documents of the project. By generating the 2D drawings from the object models, it is expected that much work can be saved and that the amount of errors can be reduced which are related back to the need for entering or updating the same information comprised on a set of many 2D documents, can be reduced. Regarding the time saving issue, the first part of this story has described the generation of 2D drawings from the 3D object models being challenging, even negatively impacting on the time schedules and on the resources needed. The first steps towards a solution seem to be an improvement of the software regarding the generation of 2D drawings, and the improvement of the participants' 3D skills. However, a long term approach to "untie" this knot of challenges could be to strive for a situation where the 3D object models replace the need for 2D drawings throughout the whole building life-cycle. Although this situation already today could be imagined in the design process (however, we do not know how the exclusion of 2D drawings impacts on the maturing of design ideas and on communication), it still seems to be a long way to go until the 3D object model has replaced the role of the 2D drawings on the construction site. It is likely that the contractor will play a more active role due to the use of 3D object models in the future (at least regarding the bidding, the tendering and the construction management). This is also formulated as an aim in the Danish "Digital Construction" program. A crucial question however, is when and to which degree the 3D technology will be adopted by the building site's craftsmen. Some of the respondents in the CCC-project pointed on the possibility to use 3D printouts as a visual aid regarding complex geometrical relationships (e.g. the 'spaghetti' of pipes and ducts in technical rooms) on the construction site. However, they all perceive a complete switch from 2D to 3D on the construction site as rather unlikely within the next years.

Nevertheless, this last story points on a production field where the 3D object models can gain foothold in close future; the prefabrication of building components offers a fertile soil for linking the use of advanced 3D tools to design and production. Hereby new market situations and business models could arise, impacting on the whole value chain of building projects; from the existing hegemonies on AEC industry level, to contracting issues on project level, to collaboration forms on design team level, down to the role and work of the individual designer.

6.5 conclusions

The paper has presented five design team stories about different challenging and beneficial situations from the interdisciplinary use of 3D object models in the CCC-project. The stories have 'embraced' and explored interrelationships between a broad and complex array of case study findings (Fig. 6-6), in order to draw attention to and provide an overview of crucial issues and problem fields which need to be investigated and discussed in further research.

The paper has furthermore demonstrated that the multi-level and descriptive framework, applied together with a story-telling technique, can contribute to a more comprehensive understanding of the interdisciplinary use of 3D object models by design teams. The framework has supported the analyzing and organizing of the empirical data collected, and the story format has been helpful in the explorative writing process and in communicating the complexity of the situations studied. Not surprisingly, the stories indicate that the many shortcomings of the technology and the design team members' lacking skills in 3D object-based modeling are crucially impacting on their perceived benefits and challenges. However, the stories have also revealed central non-technological issues embedded in the relation between technology and process, affecting the design team members' daily work and interactions.

Although a single case-study has its clear limitations, studies of practice as presented in this paper could be a valuable source for learning and for gaining more knowledge about the relation between using 3D object models or similar technology, and the architectural design process. Building up such knowledge could be important in order to improve the effects of ICT on the design team members' individual and collaborative efforts in creating good architectural and real estate. This paper is one out of three papers together constituting a PhD project with the tentative title 'Learning from practitioners' stories - Exploring the relation between the architectural design process and ICT'. The next step within this research project is to discuss the findings presented in this paper in the light of experiences made in three other European building projects seen as 'front-runners' due to implementing and using 3D object models or BIM in practice.⁴

4. The reference list of this paper is integrated in the list at the end of this thesis. The acknowledgements are included as a footnote at the second page of this chapter.

7 reporting from the reference cases

This chapter reports on relevant findings from each of the three reference cases, which relate to the points explored and discussed in the main case. The first part of each case study report describes factors which affected the implementation of the technologies supporting 3D object-based modeling or BIM; the power of the 'implementer', guidelines for working and resources for learning, and the level of ambition. The second part of the reports presents brief glimpses into various design team situations for an impression of the role of the technologies in the project actors' work and interactions.

7.1 overview

At the time the four case-studies were carried out (2005-2006), all of them were pioneers building projects in their countries due to the interdisciplinary use of 3D object models or BIM in design teams¹. Based on this issue and several other common denominators, the main case and the three reference cases establish together an interesting ensemble for investigation. The two last chapters have provided a detailed insight into the implementation of new technologies in the main case. This chapter highlights some of the findings of the reference cases in order to establish a background for viewing the findings of the main case study in a broader context in the final synthesis and concluding discussions.² The three reference projects are interesting for several reasons. The experiences made in the HITOS project provide insight in implementing integrated BIM in the early phases of the building process.³ The AHUS project is particularly interesting regarding the role of IFC compliant 3D object models in the interface between design and production, as also in the coordination with the building users. The AUDI project is a good example of a project where also the client used 3D object models.

1. In real life projects not being demonstration projects. To the best of my knowledge. See also Chapter 3: Selecting the cases.

2. The large amount of data gathered from the reference cases, would have enabled the same level of detail as in the main case. Although the reference projects have been regarded with only some few pages in this final thesis, I must here again emphasize their crucial role in the development of the framework and the main case study.

3. For explanations of the technological terms and abbreviations used in this chapter, see the appended 'Glossary of technical terms'.

Exploring relations between the architectural design process and ICT

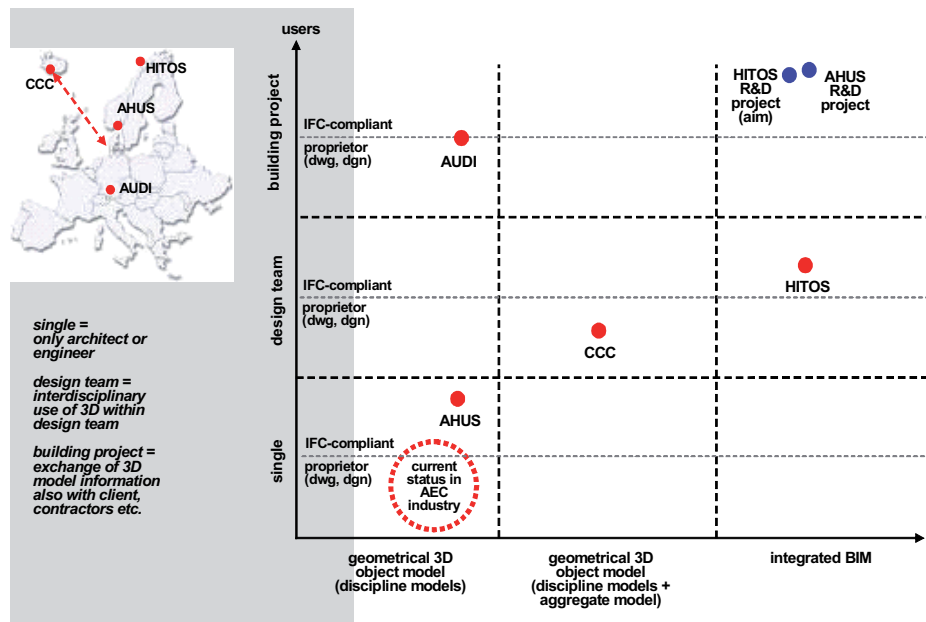


Figure 7-1. The four building projects and 3D object modeling/BIM- where are they? (qualitative indication).

Table 7-1. The four building projects: numbers and facts.

	CCC project (main case)	HITOS project (ref. case 1)	AHUS project (ref. case 2)	AUDI project (ref. case 3)
function	Concert and conference center with parking garage	University college	Hospital (focus: front building part)	Production plant for cars (offices and changing rooms included)
gross floor area	32.000 m2 (not counting the parking garage)	5.100 m2 (new buildings)	116.000 m2 (new buildings total) 2.500 m2 (front building)	25.000 m2 (hall N42) 13.000 m2 (hall N24)
schedule	Competition: 2005 Design and construction: 2005-2009 Operational: around new year 2009-2010	Conceptual design: 2006 (spring)	Competition: 2000 Conceptual design: 2003 Operational: 2008	Design and construction: 2004-2005 Operational: 2005 (N42), 2006 (N24)
client	Portus Group, Iceland	Statsbygg, Norway	Nye AHUS/ Helsebygg Øst, Norway	Audi, Germany
architect	Henning Larsen Architects, Denmark & Batteriid Arkitektar, local architect, Iceland	Arkitektstudio, Norway	C.F. Møllers Architects, Norway/Denmark	Obermeyer Planen + Beraten (architecture and structural systems)
engineers	Ramboll Denmark, Denmark & VGK Hönnun HF, Raffhönnun HF, sub-consultants, Iceland	Norconsult (structure and electricity) Sweco Grøner (HVAC), Norway	Multiconsult (structure), Sweco Grøner (HVAC), Cowi/ Interconsult (elt), Norway	FACT (HVAC and electrical systems), Germany

reference case 1: HITOS

The new university college in Tromsø (the HITOS-project) groups the department for engineering and economics with the department for teaching. The new buildings are extending the existing building block.

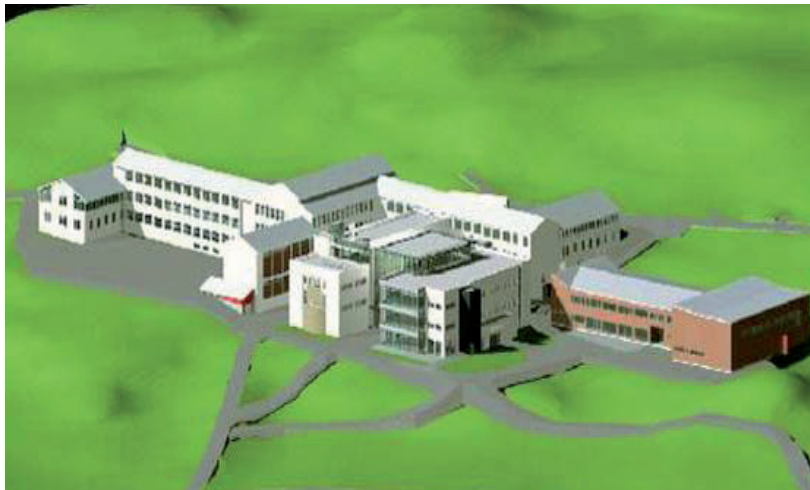


Figure 7-1. 3D view of exterior (Courtesy: Arkitektstudio/Statsbygg).

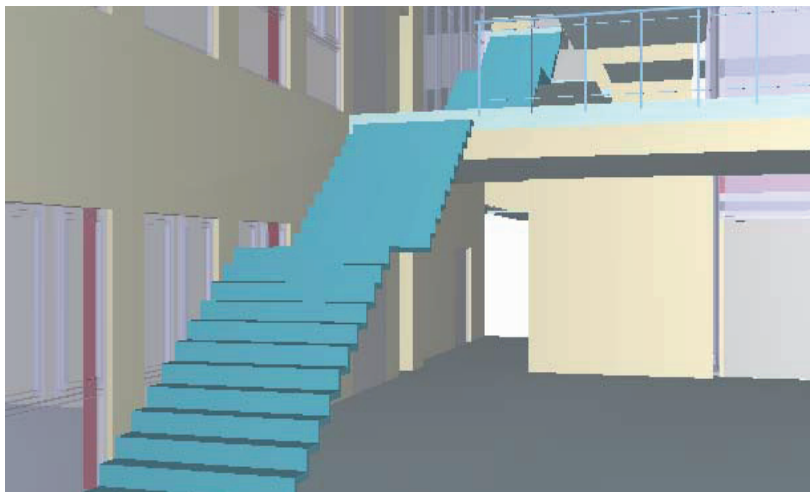


Figure 7-2. 3D view (screen dump) of interior (Courtesy: Arkitektstudio/Statsbygg).

7.1 the implementation of ICT in the HITOS project

the power of the 'implementer' and the distribution of the technology

The client of the HITOS project, The Norwegian Agency of Public Construction and Property, called 'Statsbygg', is a powerful actor in the Norwegian AEC industry and an important participant in the efforts on national level for integrating ICT in practice.⁴ They are responsible for building and maintaining a substantial part of the public building stock in Norway. 'Statsbygg' is today a major driver behind the implementation of BIM and IFC in Norway, and they are involved in R&D projects on both national and international level. Their efforts are based on the belief in the technology's potential to reduce errors in the design and construction process, and to enable cheaper and better buildings (BuildingSMART 2007).

One important feature of their implementation strategy is the 'doing it in real', where new technologies are tested, improved and evaluated within the context of ongoing real life projects. 'Statsbygg' selected the HITOS project as the arena for such learning-by-doing. All actors involved in the project, from architect to contractor, were demanded to implement and use technologies supporting BIM. The client established an R&D project to go along with (and to succeed) the ongoing building project. This R&D project was based on a close collaboration between the design team, the contractor, the software vendors and the Norwegian BuildingSMART group (BuildingSMART 2006). An additional feature of the 'Statsbygg' implementation strategy in the HITOS project, was their elimination of 'noise' and barriers in order to establish the best possible basis for driving the implementation forward. The scale of the HITOS project enabled an easier overview of the work and interactions of the project actors. Moreover, the contract enabled the actors to 'play with open cards' and to strive for the best solutions without defending positions and responsibilities. Furthermore, the commissioned design team actors knew each other well from previous building projects. Since several of these projects were college buildings, the team was familiar with the challenges related to the room program and to the functional constraints. And finally, particularly the architects and the HVAC engineers were trained in working with 3D object models. The architects started with geometrical 3D object modeling already in the mid 1990s.

guidelines for working and resources for learning

To build 3D object models was thus not new for most of the design team actors. However, their skills were limited in respect to for instance; to feed these discipline models with IFC-compliant information, to exchange of the models between design team actors,

4. The Norwegian BuildingSMART initiative; a joint venture of actors from practice and research. See also Paper II/Chapter 5: Integrating ICT in the AEC-industry: examples of international and national R&D efforts.

and to merge the various discipline models to an aggregate model. Through the R&D project, extra financial means and competence were available for testing and training. In order to improve the affordance and functionality of the implemented technologies, the architects and the engineers were collaborating closely with the software vendors and other key actors involved in technology development. To handle the resulting frequent upgrading through new software versions was perceived as being challenging. The ongoing project situation and the tight time schedules did not allow the actors much time for learning and experimenting. However, the project was stopped after the conceptual design, in order to await the government's approval for continuing to the next phase. Because of this break, more time could be spent on R&D activities related to the further improvement of the technologies. Moreover, the design team actors made first attempts in testing new ways of working. No working guidelines or manuals were available initially in the process. However, a report has been published on the experiences from working with IFC and BIM in the conceptual design phase (Statsbygg 2006).⁵ Additionally, the design team actors contributed (and still are) with their advice and experiences to the development of a BIM manual as well as three open international standards which are central parts of the BuildingSMART vision: the IFC standard, the IDM standard, and the IFD standard.⁶

the level of ambition

The original ambition was to test out integrated and IFC-compliant BIM as well as an array of related activities throughout the whole life cycle of the building; from programming to design, construction and the service and maintenance of the building (Fig. 7-4). Benefits in the terms of saved costs or planning time were not expected. In the ongoing project situation, the ambitions had to be adjusted to the tight time schedules and to the fact that 2D drawings were the statutory documents of the project. In the succeeding 'waiting period' the actors had the possibility to recapitulate parts of the design process and to test further features of the technologies on a limited part of the building. According to several respondents, the implementation required more time than expected. Although several shortcomings of the technology could be solved throughout the project, the client and the design team actors pointed out that the BuildingSMART visions cannot be achieved in one project alone. Many challenges must be turned into

5. The report focuses mainly on the benefits and problems regarding the technical shortcomings of the software.

6. For an explanation of the technological terms, see the appended Glossary of technical terms. The BIM manual is developed by SINTEF Building and Infrastructure. The HITOS team is contributing to the part about how to model, and how to implement the manual. The IFC standard has been further developed and extended throughout the project, and the experiences made in the HITOS project has been incorporated in the new IFC version (2x3). One of the respondents on the client side pointed on the challenge to decide which information shall be carried by the IFC standard, and whether IFC will be able to carry the information actually needed in the design and construction process.

solutions before IFC and BIM enable an operative working environment. The figure 7-5 illustrates the actual status in the conceptual design phase in 2006.⁷

By the end of 2007, the project participants were still awaiting the relevant authorities' approval for proceeding to the next phase. Thus, the use of BIM and IFC could not be tested in the detailed design and production phase. In the first months of 2007, the client decided therefore to continue and re-allocate the R&D activities to another arena; the university college in Bodø (Statsbygg HIBO). According to the manager of the design team, the HIBO project involves the same design team actors. The lessons learned in the HITOS project are the basis for the further R&D work and the overall aims and strategies have remained the same. However, in contrast to the HITOS project the R&D activities in the HIBO project are based on the simulation of processes in a project which has already been built.

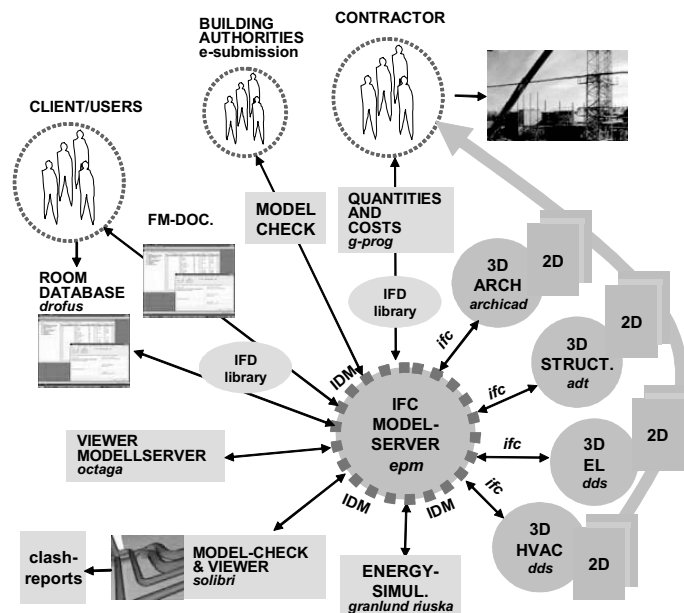


Figure 7-4. Integrated BIM in the HITOS project - the aim and vision.

7. The initial idea was to exchange IFC-compliant discipline 3D object models via a model server. To import or export data via the model server was however not a convenient solution in all situations. For instance, the HVAC and the electrical engineers exchanged information directly between their discipline models, since they were working with the same software. The architect carried out interdisciplinary model-checking activities directly within her discipline model. Thus, several 'shortcuts' were needed in order to efficiently could use of the tools in the daily work.

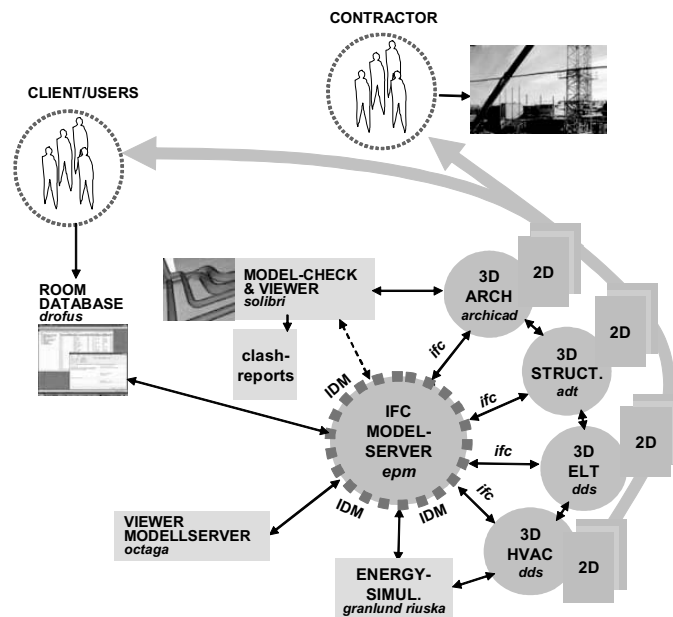


Figure 7-5. Integrated BIM in the HITOS project - status in the conceptual design phase.

7.2 the role of ICT in the design team's work and interactions

individual and collective development of design solutions

The architect responsible for the overall design described that he generated the outline of the design concept by sketching by hand. After the client and the users gave their approval for the further development of the main idea, the BIM operator (from the architectural team) started modeling. He emphasized his good experiences with this 'draftsman system'. Nevertheless, he pointed out that other and younger designers within the same company were more active users of different modeling software. He explained that he had observed two different tasks linked to 3D object-based modeling or BIM in the design phase. The first task, to build up the geometrical model, he saw as something closely related to the traditional tasks of the designer in the design process. The second task, to populate the 3D model with object information, he perceived being a 'foreign element' in the architect's efforts in developing design. He emphasized that to feed the models with information was a time consuming routine job which required a high degree of accuracy and discipline.

After the main concept had 'settled down' there was a continuous interplay between the design architect's further sketch-based development of the concept, and the 3D skilled architect's testing of these ideas in the model.⁸ The architectural model was established at first in the design team, and it became the basis for the engineers' discipline models.

Both the structural, HVAC and ELT engineers described that they attempted to clarify the main concepts (location technical rooms, main structural system, main shafts and pipes and so on) before they started to build their own models. They handed over hand-written information and sketches to the architect, who responded to their need for space and structures in their architectural model. The engineers' wait for the architectural model to reach a certain level of maturity, mirrored their practice from previous building projects. However, all respondents were aware that in order to enhance the potential of several BIM related activities (for instance interdisciplinary clash detections and simulations), they should start modeling as early as possible, and aim for a synchronous evolution of the discipline models' maturity and information richness.

achieving shared understanding and ensuring quality

The motivation for implementing and using the new technologies, was firstly to eliminate as many errors and conflicts as early as possible and secondly, to obtain an understanding of the building and its performance *before* it gets built. The respondents agreed that the key benefit from adopting IFC-compliant BIM was the improved interdisciplinary coordination and control. Through visualizations and clash detections, geometrical conflicts and errors were easily recognized. Figure 7-6 shows a conflict between the facades and the structural system.

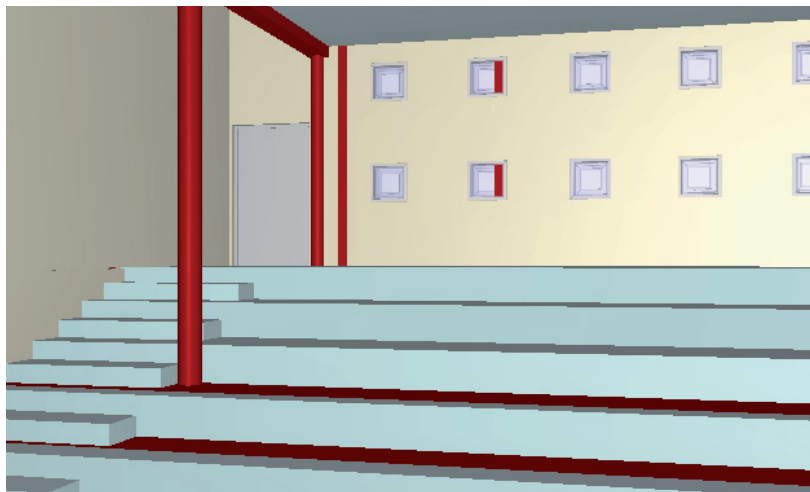


Figure 7-6. Supporting shared understanding. Screen dump: Clash detection between architecture and structural system, Microstation/Solibri (Courtesy: Arkitektstudio/Statsbygg).

8. Originally the BIM operator in the HITOS project was educated as a draftsman ('teknisk tegner'). However, due to 25 years experience from working in an architectural company, her role has been extended to involve design tasks, CAD coordination and administration.

Furthermore, the possibility to merge the different discipline models has contributed to the design team actors' shared understanding of architectural intentions, structural constraints and the need for space (Fig. 7-7). The positive effects of clash detections (within and between disciplines) increased as the different discipline models got more detailed and information rich in the R&D project. Although all respondents pointed out the importance of the new technology in achieving a shared understanding of the building, they also emphasized the crucial role of their shared experiences from previous college projects, and the face-to-face meetings in the initial phase of the project where they discussed and worked out the prerequisites and outline for the further design development.

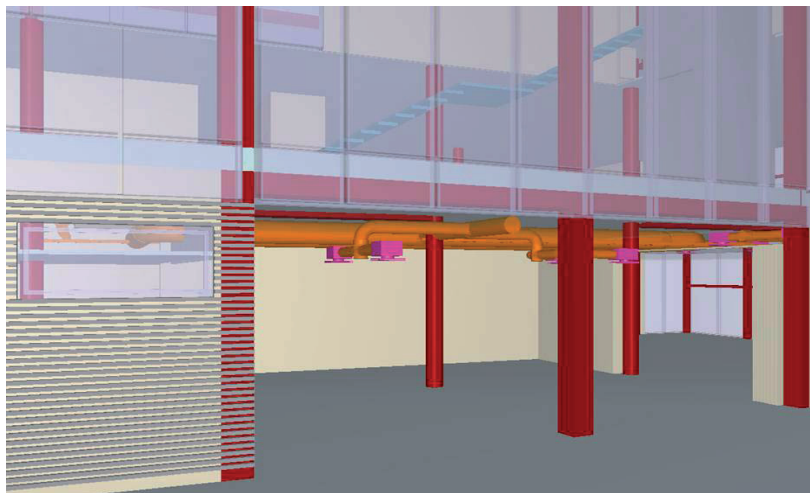


Figure 7-7. Supporting shared understanding. View of 3D model including architecture, structure and HVAC. Solibri/Archicad (Courtesy: Arkitektstudio/Statsbygg).

the role of the technology in formal meeting situations

Formal design meetings were arranged every second week, including both participants from the design team, the client and the users (10-15 participants). The importance of the new technologies in formal meeting situations increased with the evolvement of the 3D models. In the beginning of the project, the discussions and discussions were based on traditional paper prints and 2D drawings, whereas later in the conceptual design phase it became more usual to project 3D model views on the wall. The purpose of these meetings was to deal with overall design subjects, or to coordinate design solutions with the building users. According to several respondents, to show views and animations of the 3D models was highly useful in order to improve the building users' understanding of the design. The arena for collective design development and problem solving was the work meetings, which where taking place when needed. As the ongoing project situation came to an end and the R&D activities dominated the actors daily work, the traditional

design meetings were replaced by meetings on subjects emerging from the testing and using of the new technology. In these meetings, the tools were used real-time in order to for instance, demonstrate software-related problems.

calculations and simulations

According to structural engineer, one of the technology's greatest potentials for supporting his every day work would be an interoperability between calculating and modeling systems. However, a connection between the implemented structural modeling tool and calculation tools was not available and the structural engineers had still to do double work. In contrast, the leader of the HVAC team described that he could carry out parts of the calculations directly with the 3D modeling tool in the early phases of the project. Also the implemented 3D modeling tool for the electrical systems provided a functionality for calculations, which were to be tested shortly after the interviews were carried out in the autumn of 2006.

Initially in the project, energy simulations helped the design team actors to consider the design solution of the facades in respect to the use of materials and the requirements of the client. One of the interviewed clients emphasized the benefit of such early simulations for obtaining a better understanding of the design solutions' implications for the building operation and performance. The energy simulations worked well as long as they were based on early and simple versions of the architectural model. However, the simulation application was not able to handle the increasing complexity of the models later in the project. Another additional factor, which was pointed out in the interview with the HVAC and electrical engineer, was the need for engineering competence in order to evaluate the results of the BIM-related calculation and simulation activities.

Energy simulation as a BIM-related activity was to be further developed and tested in the follow-up project Statsbygg HIBO.

handling changes

The frequent need for re-design and change before the overall design concept reaches a certain level of maturity, was by the HVAC and the electrical engineer pointed out as a reason for their hesitation to start modeling in the early design phase. To model the HVAC and electrical systems requires more work and accuracy than to rapidly draw some lines on a piece of paper, and to change what has already been modeled is time consuming. The HVAC engineer explained that changes impacting, for instance, the location of a ventilation pipe, would not only require to modify of the pipe, but also to remodel and re-calculate the entire piping system.

the IDM project and the attempt to manage the flow of information

The original intention was that all exchange of information between the different actors involved was to take place via a model server. The role and functionality of this model server was a subject of discussion. According to the respondents, in the HITOS project the model server was used as an advanced project web or a repository for the discipline model data. The functionality of a model server is closely linked to the Information Delivery Manual (IDM) project. The different IDMs are surrounding the model server as a 'filter', controlling which info to be available for whom and when. The definition and implementation of the IDMs is intended to address the challenges related to the responsibility and ownership of objects and to the handling of the information flow between actors and projects phases. However, in the HITOS project the effect of the IDMs was limited due to the early stage of their development. To explore their impact on the design team's work and interaction falls therefore outside the scope of this work.

from user requirement to design to production

The building users gathered their room and equipment requirements in a room database (dRofus). The architects made some first attempts to import information from this digital room program into their model. The manager of the design team and the architects reported on several technical challenges, but emphasized the promising potential of such a link between program and design. Both in respect to the stronger involvement of the users in the early phases of the process, and the improved control of the relation between user requirements and design solutions.

Although the contractor tested out some features of IFC-compliant BIM due to tendering and pricing, the 2D drawings were the statutory documents and the basis for the project deliveries to the client and the contractor. According to the design team respondents, it was challenging to extract the required 2D drawings from the discipline models, because the information embedded in the objects could not easily be 'transported' to the 2D environment. The HVAC engineer commented that the software vendors seem to have focused more on developing a good 3D graphic than on the 2D representation of the models. The respondents emphasized generally the need for improving the quality and readability of the 2D drawings.

Exploring relations between the architectural design process and ICT

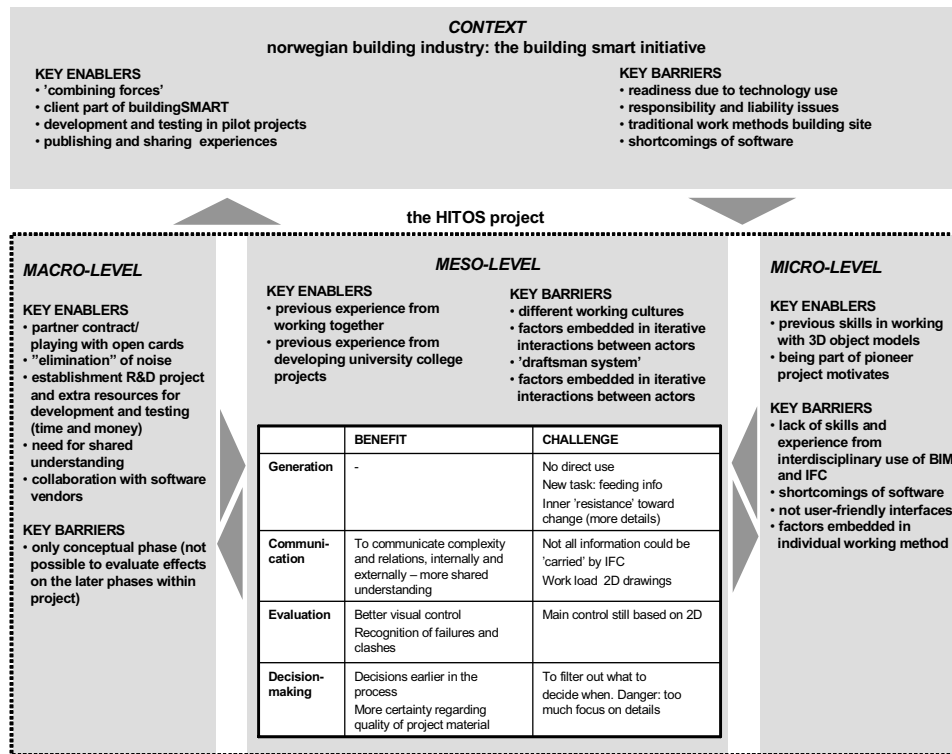


Figure 7-8. The multi-level model - overview of the identified enablers and barriers, and the experienced benefits and challenges within the design team.

reference case 2: AHUS

The new Akershus University Hospital (the AHUS-project) is a major hospital development project in the suburbs of Oslo, Norway (www.nyeahus.no).⁹



Figure 7-9. The hospital project (Courtesy: C.F. Møller Architects).



Figure 7-10. 3D rendering of the front building (Courtesy: C.F. Møller Architects).

9. The AHUS case is additionally and thoroughly explored and reported on in the appended two conference papers and the working paper.

7.1 the implementation of ICT in the AHUS project

“Nye Ahus, Akershus University Hospital is the largest in a series of new hospitals in Norway. Construction began in the spring of 2004; when completed in 2008, the hospital will be one of the most modern in Europe. The architecture is informed by a strong desire to put patients first – to create a friendly, informal place with open and clear surroundings which patients and their visitors will find welcoming.” www.cfmoller.com (retrieved January 2008).

The case study focuses on the front building part, which among others contains the main entrance, an auditorium and a canteen (Fig. 7-9 and 7-10).¹⁰

the power of the ‘implementer’ and the distribution of the technology

The implementation of the new technologies in the AHUS project was crucially based on some key persons knowledge, competence and enthusiasm. The suggestion to implement IFC-compliant 3D object-based modeling was made by the architects. One of the project managers of the architectural team was at that time (and still is) playing a key role in the Norwegian IAI. Additionally, around 2004 the development of the IFC standard had reached a level which caught the attention of many actors in the Norwegian AEC industry. The client’s approval for the architects’ suggestion, made the AHUS project to what Khemlani (2005) called “a front runner in Norway in the use of IFC-based BIM”. A project plan based on four different R&D projects was in 2004 agreed by all parties in the organization (Nye AHUS 2007). The four projects were:

1. Model-check of the 3D object models for consistency control (2004-2007).
2. Connection between a requirement/room database and the 3D object models (2004-2006).
3. FM documentation generated from the 3D object models (2007-2008).
4. The ‘IFC project’: to test the integrated BIM concept, IFC and a shared model server platform on the front building (2006-2007). The front building was seen as a good test object through its scale and solitaire position in the project, both in respect to the function and the schedule (the last building to be built). Include R&D project 1-3 (but only for front building part).

The two first R&D project were implemented in the entire ongoing project (although only by the architects). The third R&D project was not implemented, but was included in the fourth R&D project, the ‘IFC-project’. This ‘IFC project’ was detached from the daily business in the front building project. The client and the implementers were appre-

10. The architectural team designing the front building included three persons at the time the case study was conducted: two architects involved in design and management, and one person building the 3D model.

hensive about the possible risks related to the late implementation of new technology in an ongoing project situation. Among the factors which could negatively impact on the success of the project, were the many technological challenges to be solved, the uncertainties about the functionality of IFC and the lacking skills and experience of the different participants.

In the ongoing project, there was no extra time or sufficient finance available for implementing and using the new technologies. Another factor which was impacting their implementation, was their late introduction in the project. In 2004 the outline and main design concept was already fixed, and the structural and electrical engineers had based their planning on traditional 2D documents. This resulted in a situation where only the architects (and after a while also the HVAC engineers - they decided to switch from 2D to 3D based working in the detailed design phase) were actually working with 3D object models. Thus, in the ongoing project there were barely taking place any interdisciplinary activities related to IFC-compliant and 3D object-based modeling.

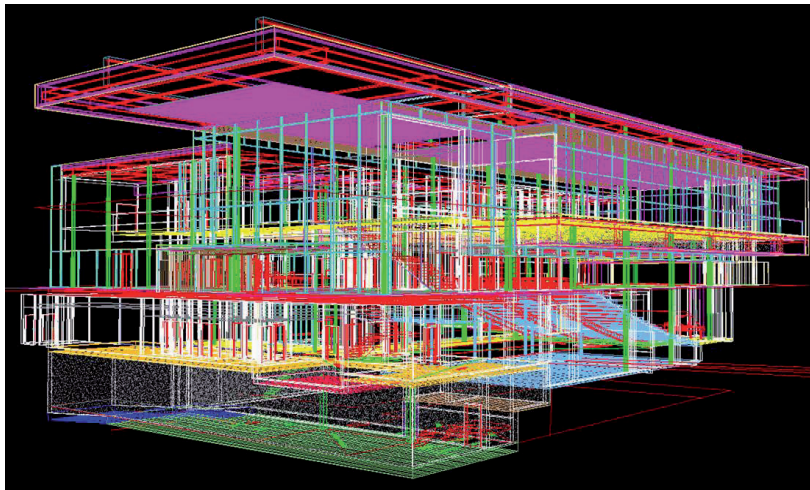


Figure 7-11. The architectural 3D object model of the front building in the spring of 2005 (Courtesy: C.F. Møllers Architects).

guidelines for working and resources for learning

According to several respondents on management level, an important motivation behind the implementation was to gain competence in using the new technologies. The 'IFC-project' should provide a good learning environment for training and testing activities related to 3D object-based modeling and IFC, independently of the requirements of the daily business. A report on the experiences made in this R&D project has been made available on the webpage of the Norwegian BuildingSMART initiative (Nye AHUS 2007).

Throughout the 'IFC project' it has been arranged several meetings where key persons from the AHUS and the HITOS projects exchanged their experiences. In addition, the experiences in the AHUS project are contributing to the development of several BuildingSMART projects, for instance the IDM and the IFD project.

The project participants had no previous skills in 3D object-based modeling. Within the architectural team the aim was that all architects should be able to handle the implemented tools. Training courses were arranged and manuals were distributed in order to stimulate learning and update skills. One of the architects in the front building team described that to handle the large number of information about how to use the continuously developing tools, was highly challenging within the tough project schedule. The limited time, which was available for learning and absorbing the information about software and applications, resulted in a limited utilization of the tools and in inconsistent 3D models. Both architects in the front building team emphasized that ideal working requires resources, which were not available in the ongoing project. Moreover, they emphasized the importance of communicating the overall benefits and expectations downward in the project hierarchy, as these might not be obvious for the daily users who are struggling with the many challenges related to the new technologies.

The architectural company won the major commission for Iceland's new university hospital in October 2005. The management of the architectural team hope that they can utilize some of the lessons learned. According to the project manager who was leading the implementation, the two most interesting subjects for further development in future projects would firstly be the visualization of user relevant aspects and secondly, the link between an equipment/room database and the BIM.

the level of ambition

The project director explained in an interview in November 2006 that the one of the aims of implementing the new technologies was to improve the collaboration and the interactions between the project participants. He expected furthermore that the technologies would enhance more discipline and precision in the design of the project, and reduce the amount of information entries, which he perceived to be the biggest source of error in the building process. By the production of more consistent project material, errors and failures on the construction site can be reduced. According to the project manager who was leading the implementation, to carry out and benefit from visualizations was not put particularly into focus, but regarded as a positive side effect. All respondents involved in management explained that no technology-related benefits were expected in terms of improved efficiency and productivity. To implement new technologies in the late design phases in an ongoing project was foreseen to be highly challenging.

However, the number of challenges emerging throughout the project was even larger than expected.

In the ongoing project the level of ambition had to address the tough project schedules, the lack of skills among the participants and the many shortcomings of the technology. The participants had to focus on the project delivery to the contractor and to the construction site. To detach the 'IFC project' from this situation enabled a different agenda and a higher level of ambition due to the implementation (Fig. 7-12). The leader of the 'IFC project' project described in November 2007 the following steps:

1. All disciplines shall build up a 3D object model.
2. To test the functionality of the model-server (import- and export procedures). To establish a merged model. To make interdisciplinary clash-detections in merged model. To make visualizations and simulations of the engineering disciplines.
3. To test 4D and interactions with the contractor (cost-estimates, building-description tools). To try out e-business and the generation of FM documentation (own model). To test the flow of information throughout all project phases.
4. To further test and develop the activities in step one and two. Then extend with: e-submissions/e-check, environmental aspects (connected to programming/briefing).
5. Evaluations and conclusions.

The Figures 7-12 and 7-13 illustrate the 3D object model system in the 'IFC project' and the ongoing project. The second part of this report focuses on the experiences made in the ongoing project situation (status 2006).¹¹

11. The data collection phase of this PhD project was completed in the autumn of 2006 (at the beginning of the 'IFC project'). According to the leader of the architectural front building team in June 2008, applications enabling visualizations, clash detections and model-checking were more and more adopted by the architects and engineers in the ongoing project situation (throughout 2007). He described that as a result, the number of errors and conflicts could be reduced. Moreover, the architectural company has in the meantime implemented these tools in further building projects.

Exploring relations between the architectural design process and ICT

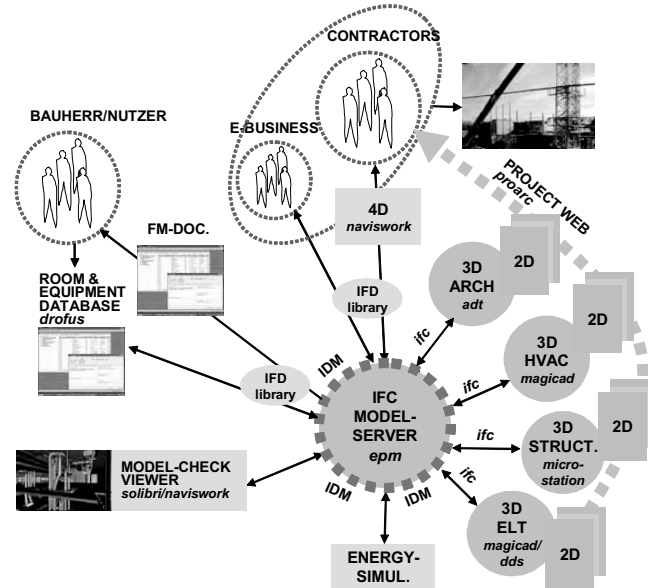


Figure 7-12. The 3D object model system, software and applications in the 'IFC project' (the aim).

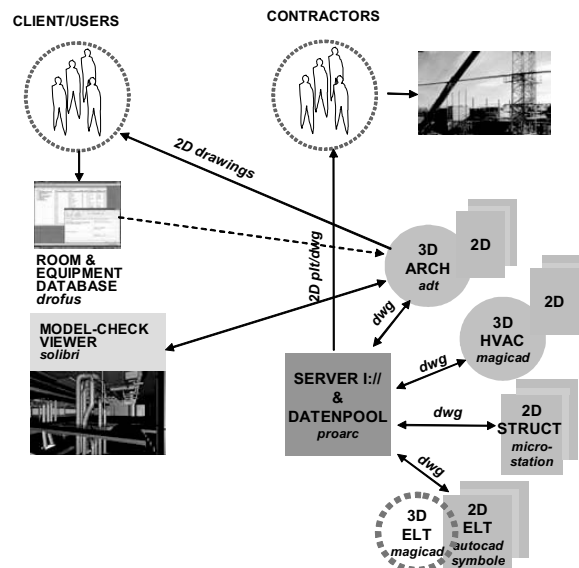


Figure 7-13. The 3D object model system, software and applications in the ongoing project (detailed design phase 2006).

7.2 the role of ICT in the design team's work and interactions

The situations that are described below presents 'glimpses' from the detailed design process (shortly before and some time after the involvement of the contractors). The architects dominated the working with IFC-compliant 3D object models in this period, and the 'glimpses' are mainly based on their stories.

individual and collective design development

The 'traditional' design tools, such as pen, paper and physical models, were still of major importance for the individual and collective design development in the front building team. One of the architects in the front building team explained that she first produced some rough hand sketches, before she made line-based 2D drawings of these ideas in the 3D object model. The accurate and precise nature of the computer enabled her early tests of her design ideas, which she perceived as a benefit. The transformation of the 2D lines into 3D objects was made later (by a third team member skilled in 3D modeling). This resulted in a 3D model not completely based on 3D objects. Furthermore, she was apprehensive about the consequences of the disappearing middle stage between the rough sketch and the detailed precise drawing. In the traditional '2D process', the designer generates several sets of drawings with evolving precision and detail. She questioned the importance of this traditional step-by-step process for the necessary maturation of the design ideas.

When she was working with the 3D object model, she was 'drawing' in a 2D environment by dragging and dropping 3D objects. According to the project manager who was leading the implementation, this was the general working method among most of the architects. She described furthermore that she to a limited degree used the 3D view in the model, which she found hard to handle and to navigate. However, she pointed on the support of these views in discovering geometrical conflicts (Fig. 7-14). Also the leader of the architectural front building team explained that he used the traditional tools in the creative part of his design development. This because he perceived the 3D modeling tools to be 'heavy' and not intuitive. As a further reason for his '2D thinking' he mentioned the 2D drawing-based delivery to the contractor. However, he perceived the 3D models as highly supportive in his attempt to visually control the most complex areas in the hospitality (e.g. the glass roof construction in the main traffic area). Nonetheless, such activities were rather the exception, because much effort and time was required in order to establish these visualizations. Both architects in the front building team pointed out the lack of time resources and the 'heavy' operating of the 3D object model as reasons for the limited use of the models in individual design development.

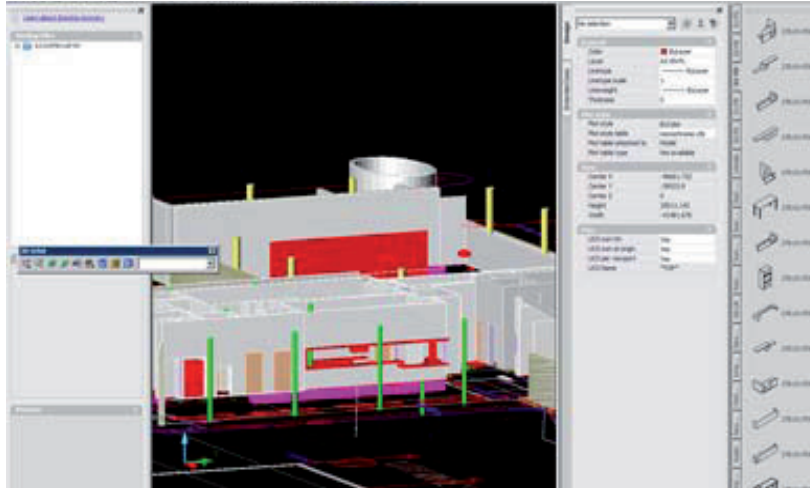


Figure 7-14. Screen dump from architectural 3D object model; view of the 3D environment (Courtesy: C.F. Møller Architects).



Figure 7-15. The physical 3D model was still an important medium for developing the AHUS project's front building (Authors photo May 2005).

The engineers used the 2D 'cut-offs' and dwg-files from the architectural model as basis for their planning. 2D information from for instance the structural engineers (columns and slabs) had to be manually added to the architectural 3D object model. According to the leader of the architectural front building team, a positive side effect of the resulting extra work was the good control of the consistency between the architectural and structural elements.

The main arena for collective design development was the informal meetings between the architects and the engineers. The fact that the architects and engineers were working in the same locations, enabled spontaneous face-to-face interactions. In the informal meetings, the participants used the traditional tools of design, such as pen, sketch paper and physical models (Fig. 7-15), to generate and evaluate design solutions. One of the architects saw no immediate need for using computer generated 3D visualization in such meetings, because all participants involved in the front building design team were experienced professionals who were used to 'think in 3D'. However, she emphasized that more intuitive and 'easy-to-handle' version of the technologies could be beneficial for meeting participants without this experience.

the role of the technology in formal meeting situations

In the overall project meetings, every participant brought with them their own laptop, which could be connected to the project database. In addition, 'cut-offs' and views from the model were projected on the wall with a beamer. An interesting aspect came up in the interview with the respondent representing the client. He perceived that the perfect and almost finished-looking drawings and illustrations, which were presented in these meetings, discouraged the meeting participants to suggest changes and improvements.

Table 7-2. The meeting hierarchy in the AHUS project (formal meetings).

	participants	purpose	frequency	media
OVERALL PROJECT MEETINGS	Client, users, project managers from architectural/engineering companies.	Decision-making, strategy related and administrative aspects in regard to the total project.	Weekly.	Individual laptops. Paper prints, sometimes cut-offs and views projected on the wall.
USER MEETINGS	Client, users, architects/engineers involved in design and management.	Coordination and decision-making in regard to the user requirements.	Frequently in the autumn of 2004.	2D drawings extracted from the 3D object models.
BUILDING PART MEETINGS	Clients, users, architects/engineers involved in design and management.	The operational instrument. Decision-making and development of design solutions.	Every second week.	Sketches, paper prints, physical models.

A key benefit from using the 3D object models was experienced in the coordination with the users. The 3D object model was highly valuable in the production and preparation of discussion- and decision-making material. Around 1000 unique rooms on total project level required resulted in a huge amount of drawings to be coordinated in the user meetings. All these drawings (sections, plans and elevations) were generated directly from the 3D object model. Thus time and efforts could be saved. In the user meetings the architects sometimes modified their model on a laptop while the decisions were being made. In the building part meetings, the participants brought 2D drawings printed out in

advance. The basis for discussions and design development was also here the pen, sketch paper and physical models.

achieving shared understanding and ensuring quality

A hospital is probably one of the most challenging building types when it comes to the complexity of technology, functionality and the substantial amount of user requirements. As described previously in this report, an important reason for implementing the new technologies was their potential to reduce errors and ensure consistency in the large number of drawings to be delivered to the client, users, and contractors. However, because only the architects were working with IFC-compliant 3D object models in the detailed design phase (and later the HVAC engineers), the implemented technologies played a limited role in the interdisciplinary coordination and quality assurance.

As mentioned previously in this report, the possibility to make visualizations based on the 3D object model was regarded as a nice side effect. Still, the architects could report on several positive experiences from using such visualizations in order to explain the intentions of their solutions to the clients and the users. One example given by one of the architects was to use 3D visualizations in order to support a discussion about the height of the window walls and the patients' visual contact with the outside of the building. Furthermore, he pointed out the huge potential of the technologies in order to build up a more shared understanding of the design solutions:

"It would be nice to put the virtual gloves and glasses on, to take the client by the hand and walk together with him through the building and decide which chairs shall be chosen for the virtual canteen, and how the acoustic should be handled in a specific room (...) they hear an echo, and through changing the material in real-time, they together can evaluate the effect in the virtual room. That would be ok. Then we could get a more experience-based understanding of success factors and the fundament of decision-making."¹²

handling changes

To modify objects in the model was, according to the leader of the architectural front building team, a time-consuming effort. Together with the tight time schedules and the limited resources, this resulted in several 'shortcuts' where the architects made the changes with 2D lines instead of modifying the objects. The definitions and modifications of objects were made by some few particularly skilled team members. According to the architects, because of the continuous need for changes and improvements of design solutions, this resulted in bottlenecks in the process. One of the architects was concerned

12. Based on comments in an interview May 2005. Author's free translation into English.

that these bottlenecks would make it tempting to avoid modifications in the first place, even if these would have improved the design solutions.

from design to production and the level of detail

The architectural 3D object model of the front building addressed the scale of 1:50. The details were made manually. The project manager who was leading the implementation, made the following distinction between the purpose of the traditional detail and the 3D model; the detail is providing the building site with instructions for the practical operations, whereas the 3D model is containing the information relevant for the quantities (how much wall, how many windows and so on). Nevertheless, the leader of the architectural front building team pointed on several challenges arising out of the information overlap between the 2D details and the 2D sections extracted from the 3D model. Since there was not enough time to update the sections due to other activities with higher priority, the details were more updated than the sections. This situation resulted in confusion among the contractors about where to look for the updated information. However, both respondents referred to above emphasized that to integrate the information related to the details directly in the 3D model, would not be a sufficient solution to this problem. Rather the 2D details could be linked to the 3D model as references.



Figure 7-16. The construction site of the front building, November 2006 (author's photo).

A further benefit pointed on by the architects, was the possibility to automatically extract the quantity take-offs was by one of the architects. A final point is related to the role of the 3D object models on the construction site. The instructions for construction were based on traditional 2D drawings. Nonetheless, the HVAC engineer reported on benefits from using 3D visualizations of the model (paper prints, Fig. 7-17) to communi-

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cate the complex 'spaghetti' of technical installations in the basement to the actors on the construction site (Fig. 7-17).

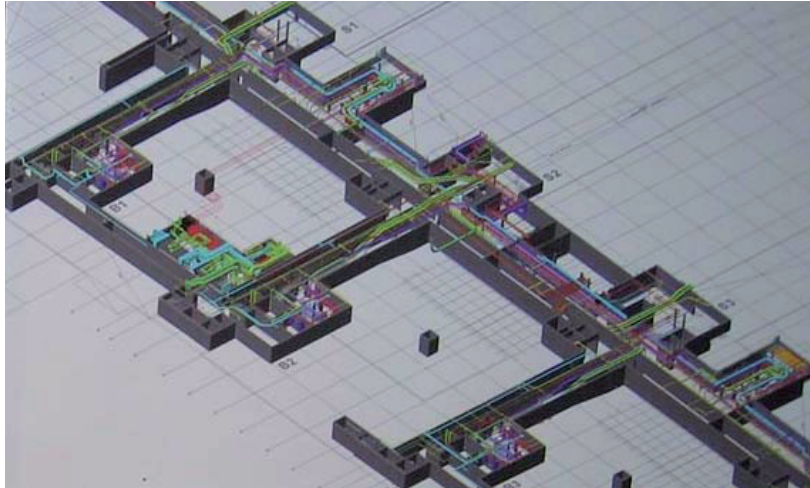


Figure 7-17. From design to production in the AHUS project. 3D views for illustrating service ducts and pipes (author's photos, November 2006).

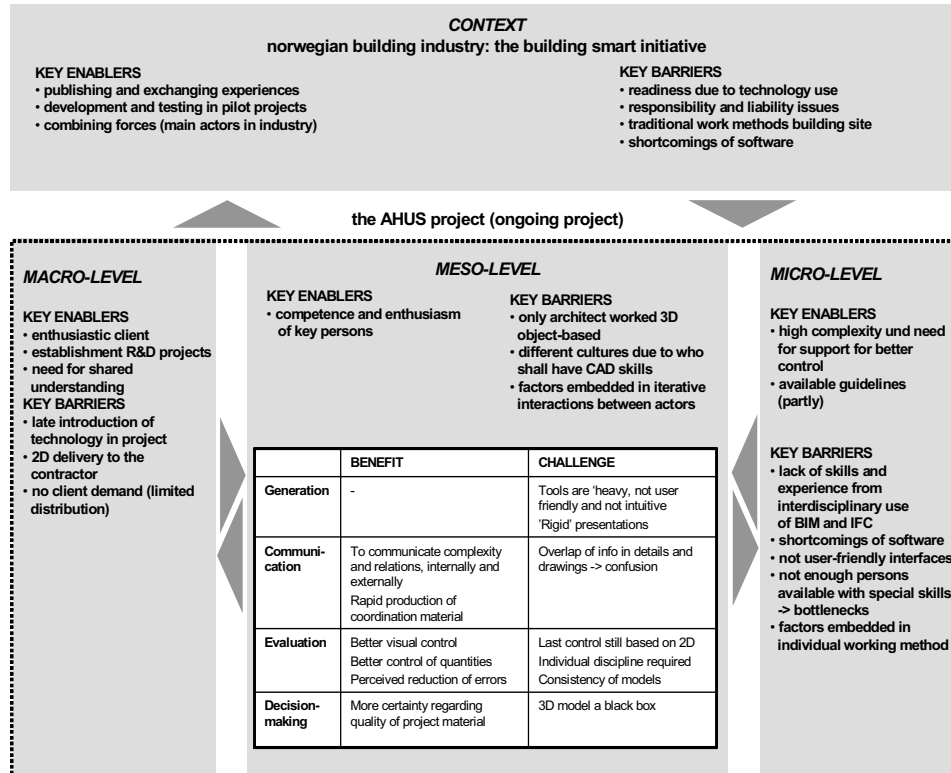


Figure 7-18. The multi-level factor model - overview of the identified enablers and barriers, and the experienced benefits and challenges within the design team.

reference case 3: AUDI

The production plant N42 was built in 2005 for the production of the new Audi TT. In 2006, N42 was extended with N24.

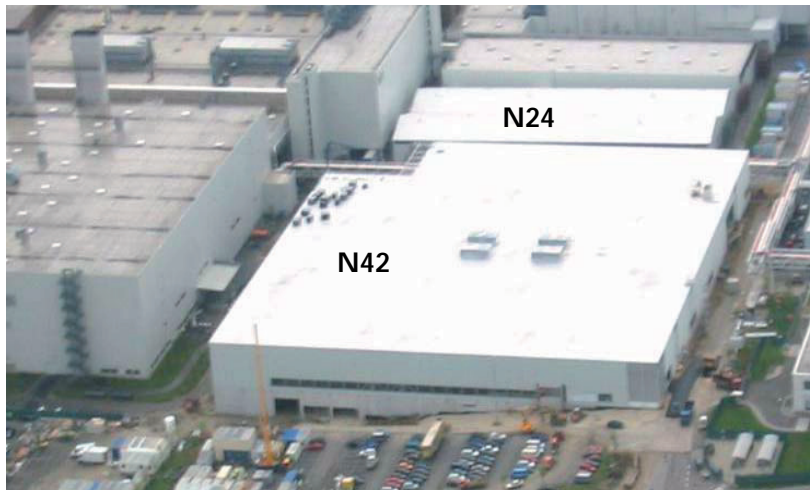


Figure 7-19. Air photo of the two production plants (Courtesy: Obermeyer Planen + Beraten).



Figure 7-20. Photo of production hall exterior (Courtesy: Obermeyer Planen + Beraten).

The AUDI project is the reference project which deviates at most from the main case due to scale and function. Still, it is an interesting reference project for several reasons;

the role of the client in using 3D models, the relation between the level of ambition and the perceived success, and the experiences from handling the interface between design and production. The German chapter of BuildingSMART has used the AUDI project as an example of implementation of IFC and 3D object models on several conferences and information seminars. At the time the case study was conducted (2006-07), the production phase of the buildings was completed.

7.1 the implementation of ICT in the AUDI project

the power of the 'implementer' and the distribution of technology

In contrast to the situation in Denmark and Norway, to bring the prime movers together and combine forces in the implementation of new technology in the German AEC industry, is understood as far more challenging by its German promoters. According to the leader of the German BuildingSMART chapter, reasons for this situation could be the complex and fragmented societal, political and business related structures of the country and the 'bad times' in the German AEC industry since the mid nineties. An essential target of the German BuildingSMART chapter's efforts is stakeholders in the AEC industry with the power and ability to implement the new standards and technologies. Audi represents an attractive client for German architects and engineers. To get commissioned for a building project might represent an opportunity for getting involved in further follow-up projects. Thus, the demands and requirements of this stakeholder are affecting the industry beyond the single project. The rapid development of car technologies and production scenarios, calls for a continuous extension and improvement of their large building stock. According to the respondent representing the client, the implementation and use of new technologies plays an important role in the company's strategies for controlling and managing the building processes and the interactions between the project actors.

Three technological cornerstones were implemented and used in this reference case. First, a 'virtual project room' (VOR: Virtueller Objekt Raum), second, 3D object models and third, IFC. The implementation of the 'virtual object room' was demanded by the client. All information relevant for the project (2D drawings, 3D model files, meeting minutes, hand sketches, details) should be stored and shared via this project web, which also included an e-mail function. The use of this 'virtual project room' required much discipline of the project actors. According to the respondent representing the client, "the actors must learn to communicate!" He emphasized the important role of the client and the managers in encouraging and follow-up the implementation of new technology and working methods over a longer time scale. The client furthermore demanded the designers to deliver 3D models to be imported into their 3D object models of the production infrastructure and logistics, so that the location of production robots and machines could be coordinated with the building. In order to address this requirement of the client, the

project actors had either to work with the same 3D modeling software, or with a software able to 'speak' with the 3D models of the client.

The company responsible for developing the HVAC and electrical systems (here called the engineering company), had been working together with the client in previous projects, and they used the same software. The company commissioned for the architectural and structural planning (here called the planning company), worked with other software systems. As a result, the planning company decided to build IFC-based 3D object models. This decision was furthermore triggered by the manager of the IT department in the company (here called the 'implementer'), who was (and still is) the leader of the German chapter of IAI/BuildingSMART.

guidelines for working and resources for learning

Both the architects and the engineers developing the HVAC and electrical systems had some previous experience with working with 3D object models (especially HVAC). However, to exchange these models by using IFC was new. There was no extra time or sufficient finance for the design team actors' training and learning. Thus, a negative impact of the technology implementation on the project schedules and deliveries would have to be carried by the companies themselves (and particularly the planning company). Nevertheless and according to the 'implementer', the client was highly interested in building up competence in using IFC, since this would enable them more freedom in selecting planners (independent of their software systems). The client supported among others the writing of a master diploma, where the analyzed the implementation of IFC to optimize processes (Dayal and Timmermans 2004). Additionally, the client brought in the support of an external expert on IFC-based data exchange. This expert 'task force' played an important role in solving the many upcoming technical problems and the limitations related to the IFC-based exchange of information, and they essentially contributed to the success of implementation. The architects provided the software vendors with their experiences from using their software, but according to the 'implementer', these experiences did not directly impact on the vendors' further development of the software.

A last point to be mentioned here, is based on an observation made by the 'implementer'. The HVAC and electrical engineers seemed to be more ready to adopt and learn 3D object-based working than the architects. From his point of view, a reason for this could be that the engineer is, due to his or her traditional way of working, more used to work with and 'pick' components and modules than the architect.

the level of ambition

The client's moderate level of ambition in regard to the 3D object models, was by the respondents mentioned as a factor enabling the design team actors' adoption of technology in the AUDI project. The client required the architectural model to address the scale

of 1:100, which they perceived as an adequate level of detail in order to coordinate the geometry of the different disciplines. They furthermore did not require the facades and the details to be included in the 3D models. The respondent representing the client, emphasized the importance of not to overload the models with information, which from his point of view would lead to more work in maintaining and updating the models. The further information and instructions needed by the contractors, was provided by traditional 2D details, hand sketches and textual descriptions.¹³

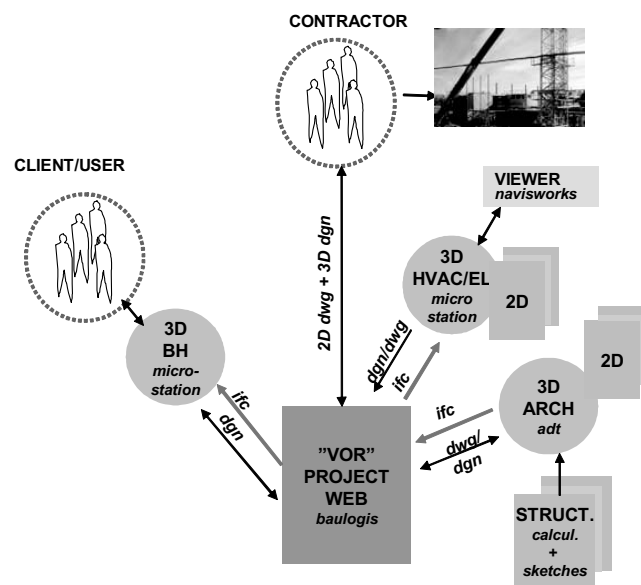


Figure 7-21. The 3D object model system, software and applications.

7.2 the role of ICT in the design team's work and interactions

individual and collective design development

In the past, the release of a new car model resulted in cost-intensive building of new plants or rebuilding of existing ones. Functionality, efficiency and flexibility were therefore important key-words in the design process of the AUDI project, and much effort was directed toward developing structures and systems both enabling the production of the Audi-TT and future car models. In addition, the design team actors' creativity was

13. The respondent representing the client emphasized furthermore that not the 3D model (which he explained to contain only 50% of the information relevant for the succeeding phases in the building life cycle), but the project web (in this case the 'virtual project room') is the appropriate arena for storing the broad range of project relevant information.

required when it came to the generation of design solutions for particularly two parts of the building; the building envelope and a small office area.

The architect responsible for developing the overall design explained that his main focus was on the overall systems and structures, and not so much on the generation of exiting architectural design solutions. From the start of the design phase he built a 3D object model, after some initial and brief sketching. Furthermore, he described that he regularly switched between the 2D and 3D view of the model. The 2D environment was for modeling and modifying and the 3D environment was for controlling and checking geometrical errors and conflicts. The architects who were developing the building envelope and the office areas were producing hand sketches and traditional 2D drawings, which were delivered as supplements to the 3D model files and the extracted documents. Thus, the digital 3D tools played a limited role in the creative part of the design development. In addition, the architect responsible for the design concept was pointing on an array of shortcomings of the tools when it came to the modeling of some specific parts of the building geometry (for instance the floors). In order to handle the lack of functionality, he had to spend time on finding 'roundabout' solutions.

The architects developed the overall architectural concept, before handing these to the engineering disciplines. The engineers started their design development with the establishment of what they called 2D structure plans, which illustrate the overall HVAC and electrical concepts. These 2D plans were then the basis for building the 3D object models, which again became the basis for the further coordination with the architects and the client. The main arena for collective design development and the 'ping-pong' interactions between the architects and engineers, was however the formal meetings.

the role of the technology in meeting situations

The issues to be discussed and decided upon in the meetings were introduced to the meeting participants in advance by making the relevant plans and models available in the 'virtual project room'. Additionally, the planners brought 2D drawings generated from the 3D models, as well as hand sketches and details (in particular of the building envelope and the office area). In some of the meetings the participants also brought lap tops, or they projected the models on the wall. However, they did not make real-time changes in the meeting situations.

Table 7-3. The meeting hierarchy in the AUDI-project (formal meetings),

	participants	purpose	frequency	media
PROJECT MEETINGS	Client and project-/ design managers from architects/engineers.	Problem identification, decision-making.	Every four weeks.	Paper prints, sketches, in some cases: projection of model views.
DESIGN MEETINGS	Architects and engineers involved in design and management from the planning and the engineering company.	Coordination, problem solving.	In the beginning weekly, then every second week.	Paper prints, sketches, in some cases: projection of model views.

achieving shared understanding and ensuring quality

In addition to being an arena for collective design generation and decision making, the meetings were also the forum for building up shared understanding of the design solutions among the project participants. The master student on the client's side made walk-throughs and animations of the office area based on the 3D object model, which supported the decision-making process in the overall client meetings (without participation of the planners). Both the architects and the engineers reported on benefits from using 3D visualizations and views in their evaluation of geometry within and between the disciplines. A key benefit from working with IFC-compliant 3D object models, was however the possibility to coordinate and control the overlap between the client's production systems and the main structures of the building.

IFC and the interactions between the project actors

The one-way flow of IFC-based information from the architect to the client and the engineering company (Fig. 7-21), resulted in additional workload for the architects in establishing the IFC files. Few benefits were reported on due to the fact that they did not get IFC-based files back. Thus, through the limited use of IFC in the exchange of information between the actors, the full potential of the IFC-based 3D object-based modeling could not be enhanced.

handling changes

There was a tight schedule for the design and production of the building. Based on strategic considerations of the client, several crucial decisions were made late in the design process. For instance, the steel structure of the roof was modified after the involvement of the contractor, and the office area was taken out of the construction process, which resulted in a 'missing corner' to be handled on the site (Fig. 7-19). According to the leader of the engineering team, the combined use of the 'virtual project room', the 3D

object models and IFC was helpful for them in order to handle the resulting amount of modifications. The design manager of the planning team emphasized that the experienced and stable team (same persons throughout the entire building process) was a key prerequisite for handling this challenging project situation.

from design to production

Before handing them over to the contractors, the extracted 2D drawings had to be supplemented with textual information and measurements. The screen dump of the architectural model below (Fig. 7-22) illustrates quite clearly the relation between 3D and 2D information. The additional instructions needed on the construction site were provided by a delivery of 2D details, hand sketches and building descriptions. The architects did not populate the models with object information and attributes for three reasons. First, this was not required by the client. Second, the delivery to the contractors was to be based on traditional 2D drawings and textual building descriptions. And third, the tight time schedule called for priorities about what to be done to comply with the requirements of the clients.

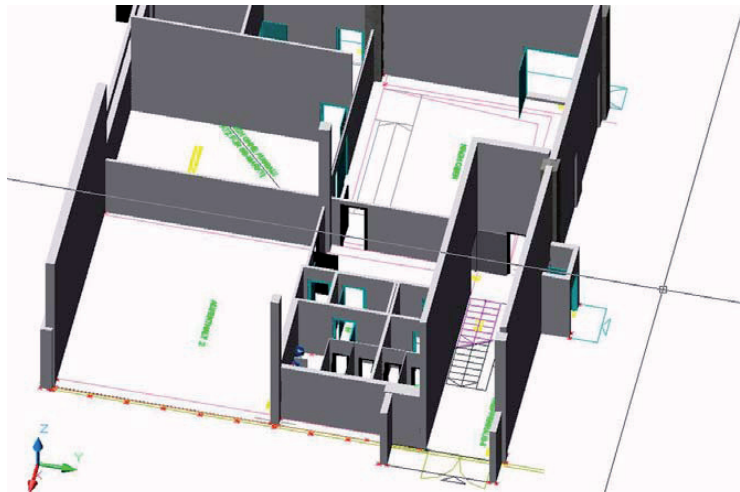


Figure 7-22. Screen dump of the architectural 3D object model (Courtesy: Obermeyer Planen + Beraten).

In contrast, because some of the contractors dealing with HVAC and electrical systems were able to handle 3D object models, the engineers' delivery to the contractor could partly be based on 3D object-model files. The leader of the engineering team explained furthermore the efforts of his company to develop a module/component based system which includes the descriptions and attributes needed by the contractor.

A final point to be mentioned here, was raised by the respondent representing the client. In German building projects, the design job and the building description job are typically conducted by different actors, who are representing various competence and working methods. Together with the incompatibility between the respective software systems, he regarded this as an additional factor which contributes to the gap between the design and production.

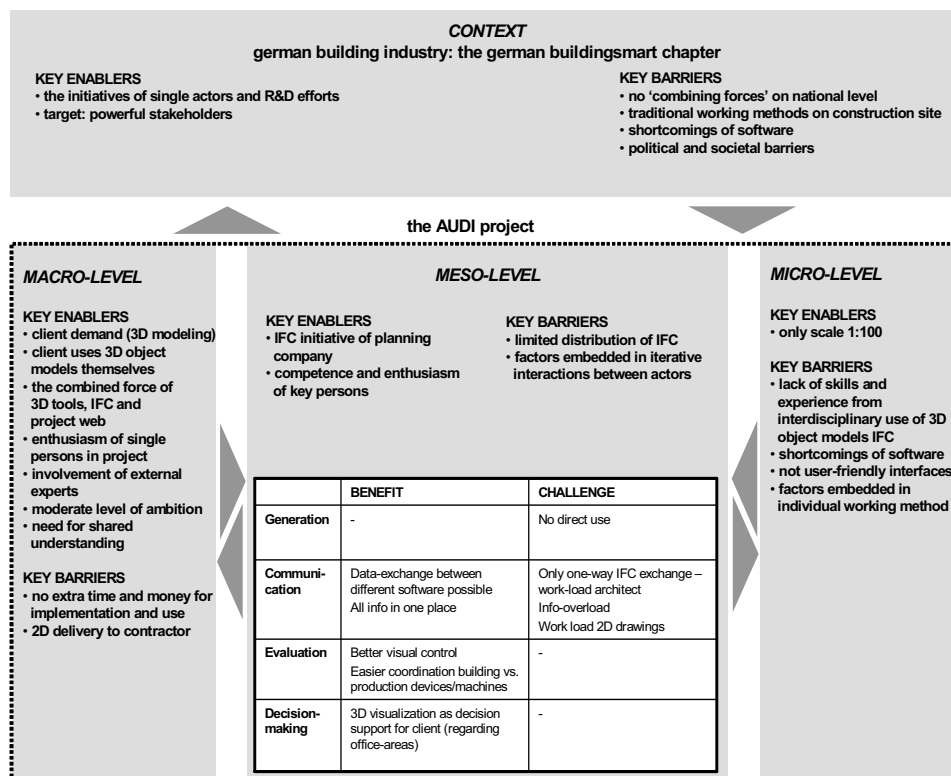


Figure 7-23. The multi-level factor model - overview of the identified enablers and barriers, and the experienced benefits and challenges within the design team.

Exploring relations between the architectural design process and ICT

8 case study findings: extracts

Throughout the last four chapters an array of findings from the four case studies has been explored and reported on. This chapter examines an extract of these findings from the main case study and the three reference studies.¹ First, the chapter reports on the key factors which affected the implementation and use of technologies supporting 3D object-based modeling or BIM in the projects. These factors are grouped into three areas. Second, the chapter presents the key benefits and challenges from adapting these technologies and related activities to the work and interactions of the practitioners involved in the architectural design process. Here the focus is on the four design process aspects defined by the framework; design generation, communication, design evaluation and decision making.

8.1 factors affecting the implementation and use of ICT

Several enablers and barriers facilitating or hindering the implementation and use of technologies, and crucial relationships between these, have been reported in each of the four case studies. These enablers and barriers can be grouped into three particular areas; factors related to user skills and behavior of actors, factors related to the affordance of the technologies supporting 3D object-based modeling or BIM, and factors related to architectural design process tasks and interactions. In the following, the key findings that are extracted relate to these three areas.²

user skills and behavior of actors

Before the benefits from implementing and using 3D object models or BIM can be harvested in the first place, the architect, the engineer or the draftsman needs skills in using these tools. In the CCC, AHUS and AUDI projects, with few exceptions, the actors involved in the architectural design process had no previous basic skills in using 3D technology. In the HITOS project some of the architects and engineers had previous experi-

1. As already pointed out in Chapter 3, the intention of conducting three case studies in addition to the main case is not to generalize findings, but to establish an empirical reference which is based on the findings of the main case study. See Chapter 3: The external validity of the research.

2. The findings presented from the AHUS project are extracted from observations of the ongoing project situation, not from the R&D project (the 'IFC-project').

ence of working with 3D object models, but not in exchanging these models or in populating them with IFC compliant design information. Here I will first provide an overview of some observed barriers which relate to the behavior and skills of the architects and engineers, as well as to their ability to adopt and utilize new technologies and related work methods.

- Limited power of the implementer to stimulate full implementation across all actors and project phases.

In the CCC and AHUS projects, the decision to implement the new technologies was made by the architectural or engineering company. It was not the result of a client demand. Together with concerns that the new tools would have a negative impact on the project outcomes, this led to a limited implementation of the technology, for instance in the main case, only the design-team actors used the new tools, and even here there were different ambitions as to the degree of implementation. The same situation was observed in the AHUS case, where only the architects (and later also the HVAC engineers) built and used IFC compliant 3D object models. Thus the full potential of the technologies in supporting interactions and flow of information across all actors and phases could not be utilized.

- Lack of resources for implementing and learning new technologies in the ongoing project situations.

In the CCC, AHUS and AUDI projects no or limited time and money were made available by the clients for implementing or testing the new tools. The architects and engineers had to learn how to use the new tools in an ongoing project environment where the main concern had to be the on-time delivery of the required project material to the client or the contractor - a situation several described as frustrating because they did not have enough time to learn to utilize the tools appropriately. The lack of experiences and overview of the consequences of using the new technology made the involved parties hesitant to commit to full implementation.

- The 'draftsman tradition', where the architects and engineers typically develop their ideas manually with pen and paper before they, after the ideas have reached a certain level of maturity or there is a need to test their quality, handed their sketches over to the draftsmen skilled in CAD to transform the ideas into 3D models.

This tradition dominated the engineering teams involved in the CCC and AHUS projects, and both the engineering and architectural teams involved in the HITOS project. The fact that the designers did not themselves master the tools diminished the role of the technologies, for example in the generation of design, and encouraged the late introduction of the tools (modeling start after the first ideas have settled down). The architects and engineers who relied on the skills of the draftsmen were typically actors with many years'

experience from practice and with decision-making and coordination responsibilities within the design team.

The four factors listed below enabled the implementation of the technologies among the project actors and motivated (or forced) learning and up-skilling.

- The client's involvement in demanding the implementation and use – as a part of the contract or according to legal stipulations.

In Paper II, the belief in the power of the client was described as one of the main features of the 'Digital Construction's strategies for stimulating ICT integration. Although the main case was not directly submitted to this program due to the project's location on Iceland and the Icelandic clients, the movement in the Danish AEC industry triggered by this program motivated the Danish engineers and architects to improve their competence in 3D object-based modeling. The HITOS project was the only one of the four projects where the client demanded all actors involved to test IFC compliant integrated BIM and related activities in the design process.

- The implementation of guidelines and manuals for how to use the new technologies.

Another observed factor influencing the implementation and use of the new technologies was the implementation of guidelines and manuals on how to use them, as for instance the '3D Working Method' manuals adapted by the design-team actors involved in the CCC project. These manuals enabled them to achieve a degree of shared understanding of how to work according to building and exchanging 3D object models. In the AHUS project manuals and guidelines developed internally in the project were made available to the project actors. However, according to one of the AHUS respondents, the continuous upgrading or extension of these manuals required the users of the technology to spend time on understanding and adapting new versions.

- A level of ambition addressing the skills of the users.

The implementers' ambitions regarding the use of the new technologies varied in the four projects. In the AUDI project the client demanded geometrical 3D object models to the 1:100 scale, which reduced the challenges the actors had to tackle, especially in the CCC and AHUS projects; namely to work with, modify and maintain models containing a large amount of information. In the CCC project the project managers emphasized from the beginning that the focus (due to the lack of skills and shortcomings of the technology) should be placed on building and exchanging 3D object-model geometry. In the HITOS project, the actors had to deal with a higher level of ambition through the demand from the client to feed the 3D model with IFC compliant object information, and to use a shared model server as a basis for the exchange of geometry and object infor-

mation. This higher level of ambition was compensated for by the client eliminating some of the barriers which affected the implementation and use in the other projects (e.g. no previous skills in 3D object-based modeling).

- The establishment of R&D arenas within the project enabling learning and testing.

Both within the HITOS and the AHUS projects, R&D projects were established as arenas for learning, testing and improving tools, and which were detached from the daily requirements of the ongoing project. Here extra time and resources were made available, and the 'noise' affecting the skills and behavior of the actors was reduced. The R&D projects were closely linked to the ongoing project situation (for instance by involving the same actors). This enabled a learning effect which came out of the possibility to test, learn and partly reconstruct and improve situations experienced in the ongoing project in an R&D environment.

affordance of the technology

- Shortcomings of the tools and the limited ability to address the complexity of the work and interactions of the actors involved.

In all the projects respondents reported that much time had to be invested in improving the functionality of the software, or in finding circuitous routes to outwit the lack in functionalities. In several situations the technology did not address the needs of the users in performing their work, for instance in making rapid changes, in generating complete 2D drawings, in being the 'mediator of the conversation with the design situation' or in supporting collective design development. In all projects, the users of the modeling tools commented that they are slow, not intuitive and 'heavy'. Although challenges relating to the shortcomings of the technology were expected in all the projects, solving the many technical problems and improving the affordance was more time-consuming than expected. In the HITOS project, one of the engineers pointed out that much time had to be invested in improving the IFC model. Thus, not as much time as planned could be spent on testing IFC-based information exchange or on merging the discipline models.

Nevertheless, most respondents were optimistic that technology-related problems are likely to be solved in the further course of the development of this technology. Especially five actions for handling the shortcomings and for 'rounding off the square peg' were observed in the case studies, and are described below.

- The introduction and development of several applications to increase the functionality of the modeling tools.

A central factor positively affecting the use of the tools in the CCC, HITOS and AHUS projects was the implementation of more user-friendly applications developed by the software vendors to enable for instance clash detections, 3D views and renderings.

- The establishment of a direct contact between the users of the technology and its developers.

In the CCC, HITOS and AHUS projects the design-team actors collaborated closely with the developers of the implemented technologies. Their experiences from using the tools were documented and reported to the developers, who then responded to this by working on and improving the tools. For example, the experiences made in the HITOS project were an important catalyst for a new version of the IFC standard. Several respondents perceived shortcomings in the technology to be a result of the lack in understanding of the program developers in the practice of architectural design and the work and interactions in the design team.

- The involvement of specialists in technologies supporting 3D object-based modeling or BIM in the project (for instance draftsmen and IT coordinators).

In all four projects specialists supported the implementation of the new technologies. These were in part employees of the architectural and/or engineering companies, as in the CCC and the AHUS projects, or they were external experts, as in the HITOS and AUDI projects.

- The combined use of digital and manual design media, especially by individual and collective design generation.

In all the projects the architects and engineers used traditional tools in addition to (or instead of) the 3D object models or BIM in the creative part of the design process. The comment of one of the architects in the CCC project pointed out an interesting issue; the importance of considering which tool is the best at a particular time/phase. The question might not be whether manual tools or 3D object models are best, but rather 'both please' and then how to best combine them for a win-win effect. He reported that in some situations, using such traditional tools as pen and paper, or physical models supported the actual task to be performed better than the digital tools, which provided more benefits in other situations.

- The involvement of influential AEC actors in lobbying the software vendors to improve the functionality and interoperability of their tools.

The last factor to be mentioned here is related to the context of the HITOS project. Through his influential position in the Norwegian AEC industry, the client is encouraging the ICT vendors to develop and improve IFC compliant tools and applications.

“The tools must be developed more before the participants can be operative in a digital world. And this world is not as easy as some of the software vendors would like to believe”.³

architectural design process tasks and interactions

Important but difficult-to-grasp factors impacting the implementation and use of the 3D object models or BIM are related to the nature of the architectural design process. In the design-team stories presented in Paper III, and in the reports from the reference case studies, several factors were pointed out. Here are five of them:

- The need to have an overview and to control complex geometrical and functional relationships within and between each discipline's contribution.

In all the projects the actors involved in the architectural design process were dealing with geometrical and functional relationships representing a high level of complexity. In the CCC project much focus was put on developing and mastering the Quasi-brick idea. In the AHUS and the HITOS projects the actors had to handle the ‘spaghetti’ of relationships between different technical systems, and in the AUDI project much focus was put on the coordinating the building structure with the location of the machines and robots in the automobile production.

- The need to achieve shared understanding among actors representing different interests, backgrounds and experiences.

The architects, engineers, clients and users of the four building projects represented, due to their various backgrounds, experiences and interests, different views on a design problem or solution. One issue here was the tacit knowledge embodied by the various actors related to the development of design solutions. For project managers less involved in the details and their interdependencies, it was challenging to rapidly grasp the full range of consequences of design modifications, whereas the experienced designer directly involved in developing design solutions needed little ‘external’ support to picture these for themselves (the CCC project). Other issues calling for support in achieving a shared understanding were that the actors in the CCC, AHUS and AUDI projects were working together for the first time and that they had no previous experiences from designing or producing buildings with the same functions. Finally, the architects and engineers had different approaches to the architectural design process and the related work methods.

- The need to improve and change design solutions in an asynchronous and two-step-forward-one-step-back process.

3. Said by one of the HITOS respondents. Author's free translation into English.

Particularly in the CCC, AHUS and AUDI projects, the designers modified and re-designed solutions until late in the process. Typical reasons for this were new decisions and requirements from the client that emerged throughout the process, in addition to the architects' continuous efforts to improve design solutions. In all projects the architect was responsible for imposing the design generation process on the other actors and for establishing the outline of the project material for further coordination, whereas the engineers responded with their expertise in calculating and evaluating such factors as the constructionability of the architects' design suggestions. In the CCC project, an additional factor was the asynchronous execution of the design phases; the engineers prepared detailed project materials for the building site (detailed design) at the time the architects still were developing design solutions.

- The need to switch between concretization and detail levels within a dynamic and unpredictable design environment.

The architects and engineers in the CCC project used such terms as 'loop', 'cycle' and 'ping-pong' to describe their interactions, which corresponds to the description of the architectural design process previously given in this work, where it was described as a highly complex and iterative process, not following a predictable and linear development or what Lawson (2006) calls a logical direction from the general to the particular. The architects particularly switched continuously between the overarching concept and details in their development of the design solutions. This was a factor that affected the applicability of the seven information levels defined in the '3D Working Method'.

- The need to handle the complex interfaces between the architectural design process and the other phases of the building project's life cycle.

Although the focus of this work is on the architectural design process, the findings from the case studies have drawn attention particularly to the interface between design and production. In all the projects studied, different actors and companies dominated these phases. Moreover, the design and production phases represent different processes and requirements, for example the level of detail and the representation of information. The needs inherited in the production process had impact back on the implementation and use of the new technology in all projects.

8.2 the impact of ICT on the work and interactions of practitioners involved in the architectural design process

*“The biggest challenge is the sum of all the small challenges”.*⁴

The key benefits and challenges, which have been explored in the four cases, provide an indication of the impact of the technologies supporting 3D object-based modeling or BIM on the work and interactions of the actors involved in the practice of architectural design. In the following, key benefits and barriers are extracted from the four design process focused on by the framework: the generation of design solution, communication, evaluation of design solutions and decision making.

benefits and challenges relating to generation of design solutions

Common to all four projects was that the technologies supporting 3D object-based modeling or BIM played a limited role in the architects' and engineers' efforts to generate design solutions. This was an observation which supports Lawson's point about the generation of design solutions being the area where ICT has gained less foothold (Lawson 2005). In none of the projects was the tool a design partner (Kalay 2004) or the 'media of the conversation' (Schön 1991). A typical situation observed in the CCC project, as well as in the HITOS project, was that the designer, and here particularly the engineers, developed their concepts by using traditional tools (hand sketching, physical models). When their brainstorming was over, a draftsman took over and 'transformed' the hand sketches into a digital model. In the AUDI project, the architects involved in developing the facades and the office areas produced the drawings independently as the client did not require the integration of this information into the 3D model. In the AHUS case, one of the architects used 2D CAD in addition to hand sketching to 'test' her ideas with a tool she felt provided more accuracy. Other architects in the CCC and AHUS projects based their generation of design solutions on a rapid interplay between traditional hand sketching (generation) and 3D CAD modeling (evaluation). The respondents who directly or indirectly dealt with the tools for the generation of design solutions reported the following challenges:

- The tools are 'heavy', not intuitive and not user-friendly – with limited ability to serve as the medium of 'design conversation' (reported by the architects in the CCC and AHUS projects).
- The need to feed the models with object information in the early design phase (which was perceived as a new task in the design phase) and to deal with this task in the creative processes.

4. Said by one of the respondents from the HITOS project about the main lesson learnt from the implementation and use of IFC-based BIM. Author's free translation into English.

- The need to avoid having too much focus on detail and too little focus on the overarching level too early in the process (the trap of over-precision and the seductive accuracy of the tools). This was mentioned as an issue in the CCC project.
- The need to handle an elaborate level of detail and a large amount of information where solutions still might not have been settled, when there is also a need for continuous change and improvement, and a need for 'parallel lines of thought'.
- The amount of information and the higher level of precision in the project material early in the process, which also resulted in an 'inner resistance' among some respondents in the CCC and HITOS projects to improving or re-designing something which they felt was finished and well thought through.
- Ambiguities as to who is responsible for objects with shared ownership in the early phases of design. A typical example observed in all projects was the architects' and engineers' shared ownership of, for instance, columns and load-bearing walls.

benefits and challenges relating to communication of design solutions

When exploring communication of design solutions in the case studies, the focus was on communication taking place face-to-face in formal or informal meetings where the technologies supporting 3D object-based modeling or BIM played an indirect role, and on virtual communication via the computer medium.

With respect to communication in the meetings, the role of the technologies depended on the type of meeting and the participating actors. In a work-meeting setting (between architects and engineers attempting to solve problems or to generate solutions), a typical situation observed in all projects was that the designers brought with them printed project material (2D CAD drawings, pdf excerpts from 3D models and so on). This material was used as the basis for explaining and convincing by pointing or sketching. In meetings with the clients and the users, the media of communication were, in addition to the traditional paper plots, wall projected views of the 3D model (not possible to edit or change in real time, but possible to maneuver and turn-around) or walk-through animations. In the AHUS project, the participants in the meeting also brought their laptops with them to the overarching project or user meetings. In the same project 3D visualizations of the 'spaghetti network' of ducts and pipes in the cellar were used on the construction site.

The communication of design information via the computer medium in all four projects (in the ongoing project situations) was restricted to the efforts of the actors to exchange geometrical information. The most obvious reason for this was the limitation of the implemented technologies in processing object information and attributes from one discipline model to another. However, the first experiences made in the HITOS and AUDI projects indicated the potential of IFC in supporting the flow of information between the design actors. Interesting here, are the comments of the architects and engineers in the

CCC and AUDI projects on not needing access to the discipline-specific information linked to objects in other discipline models.

Two key points can be extracted from the benefits perceived in the four projects:

- Improved communication of intentions, requirements and consequences of change to other disciplines, to the clients and building users and to actors involved on the construction site.
- Better understanding of other actors' intentions and needs, particularly through the visualizations and views of the 3D models.

A number of the perceived challenges from using the tools for communication were related to:

- The data exchange between the architects and engineers. First, because not all the disciplines were using digital tools for design development (e.g. in the CCC and AHUS projects). Second, as the various discipline models were not synchronous when it came to the level of information and detail.
- The still important role of 2D drawings in the information exchange between the architects and engineers. In the HITOS project some of the engineers pointed out the difficulties of getting access to information on measurements and materiality in the 2D drawings generated from the architectural IFC-compliant 3D model.
- The overlap between information in the model and in the hand-made details. In the AHUS project this was a source of confusion in the communication with the contractors since the models and the details could not be synchronously updated.
- The time-consuming generation of 2D drawings. These were the main media of formal communication of design information to the contractors and the clients. In addition, 2D drawings were needed in several meetings. In the CCC project the architects described that such meetings could not be arranged spontaneously since time was needed to extract the necessary drawings.

It must be added to the last bullet point that the experiences made in the AHUS project demonstrate that automatically generating all 2D drawings (plans, sections and facades) from one model also has a powerful benefit – particularly in this large-scale project where a large number of drawings were needed to communicate the design solutions to the users or to the construction site.

benefits and challenges relating to evaluation of design solutions

Whereas the technologies supporting 3D object-based modeling or BIM played a limited role in the generation of design solutions, they substantially supported the evaluation of design solutions in all four projects. Key benefits pointed out by the respondents were:

- Improved control and overview of consequences of changes and re-design through parametric modeling and 'virtually real' visualizations (observed in the architectural team developing the Quasi-brick facades in the CCC project).
- Easier and earlier recognition of geometrical conflicts and errors within and between the disciplines (observed in all four projects) through visualizations and clash detections. This resulted in a perceived reduction of geometrical errors (based on the respondents' experiences from other projects). In the CCC project, the draftsmen projected the model on the wall to jointly check the interfaces between the various disciplines.
- Improved control of whether the actual design solutions address the client's requirements, through the use of model checkers, and the generation of lists with equipment, quantities, gross area and so on (observed in the AHUS and HITOS projects).

However, the respondents also reported several challenges:

- The new tools enabled simulations and calculations of, for instance, load-bearing or energy-related features of the building. To utilize these functions and especially to evaluate their outcome engineering skills were required of the user beyond the traditional 'drafting'.
- Can the outcome of automated calculations and simulations be trusted? The lack of insight into the 'blackbox' between input and output resulted partly in not using these functionalities in the first place and partly in time-consuming manual controlling.
- Discipline and the need to 'follow the rules' to avoid having inconsistencies in the models which would result in errors and flaws in the extracted material and information. This was a challenge reported on in both the CCC and AHUS projects.
- The need for more synchronous modeling and concretization of details between the various disciplines to enhance the benefits of interdisciplinary activities related to 3D object-based modeling or BIM (e.g. interdisciplinary clash detections) at an early stage in the design process.
- 2D documents were the statutory documents in all projects, which meant that these were the main objects of evaluation and quality assurance among the project managers.

benefits and challenges relating to decision making

In the CCC and AHUS projects the respondents explained that the technologies supporting 3D object-based modeling or BIM played a more important role in decision making on the operative level (among the actors directly involved in design tasks) than in decision making on the overall project level. Benefits perceived by the actors:

Exploring relations between the architectural design process and ICT

- More certainty that the decisions are based on more coordinated, well considered and consistent project material.
- More certainty that the decisions made are based on a shared understanding of the design solutions and of their consequences related to clients' and users' requirements (observed in the CCC, HITOS and AHUS projects).

Key challenges pointed out were:

- The level of detail in the decision-making material. The client of the HITOS project emphasized the importance of not losing focus on what is necessary to decide at which time in the process.
- To achieve the richness of information and the level of detail required for carrying out the 3D object model/BIM related activities, the respondents, especially in the CCC and HITOS projects reported the need to make decisions related to later phases in the process.
- Some respondents in the main case perceived the need to decide upon detailed object attributes before the overarching ideas and concepts were clear to be a disturbing factor in the creative process.

It is necessary to add to the last two bullet points that the need for making earlier decisions was not generally perceived as negative. One of the architects in the HITOS project explained that actors involved in design often tend to defer decisions until (too) late in the process, and that the need to make these decisions earlier is rather a positive side effect of the technologies.

9 synthesis and conclusions

This chapter concludes with the research findings for the research questions. Furthermore, the chapter offers a reflection on the research activities, particularly the development and application of the descriptive and holistic framework. Moreover, the threefold contribution of the research in relation to the overall aim is described and the chapter rounds off the thesis by looking at the implications of the findings for practice and providing recommendations for further research.

9.1 synthesis

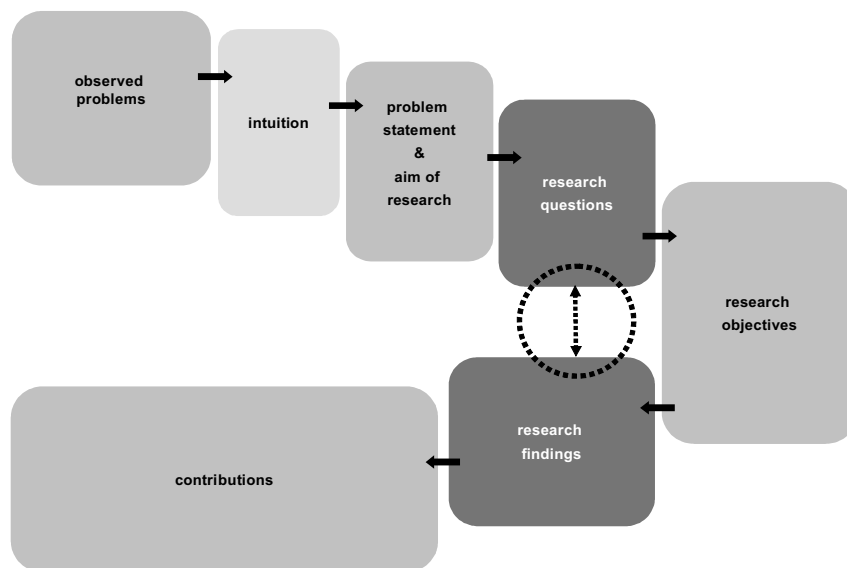


Figure 9-1. The relation between the research questions and the research findings.

Based on the observed need for more knowledge on what happens when new technologies are implemented and used in the practice of architectural design, two research questions were defined in the introduction, repeated here:

RQ 1: What are the factors affecting the implementation and use of ICT in the practice of architectural design?

RQ 2: How does the implementation and use of ICT impact the work and interactions of practitioners involved in the architectural design process?

A number of enablers and barriers which either facilitate or hinder the implementation and use of technologies supporting 3D object-based modeling or BIM in the case studies have been identified and explored to address the first research question. The second research question is addressed through elaborative studies on the role of these technologies in the design team actors' work and interactions, paying particular attention to the perceived benefits and challenges from implementation and use. The focus was on four aspects of the architectural design process (design generation, communication, design evaluation and decision making) and related tasks linked to the technologies (for instance: drawing production, exchange, visualization, consistency control, automated take-offs, simulations). The case-study findings have been explored and reported on in detail in the previous chapters of this thesis. This section presents the synthesis of these findings and the lessons learned from real-life practice.

First, the factors affecting the implementation and use of ICT are linked both to implementation efforts and the strategies formulated within national R&D programs or by the project stakeholders and managers and to the experiences gained from using them in real-life building projects (Fig. 9-2).

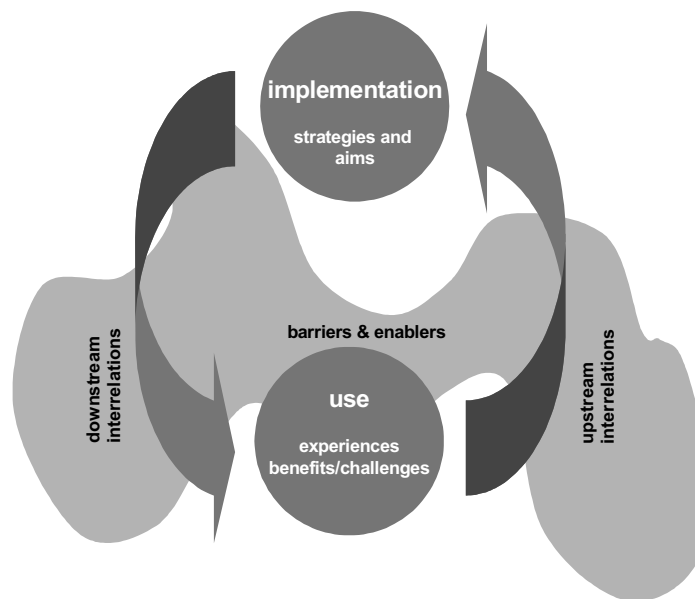


Figure 9-2. Exploring the relation between strategies for implementation and the experiences gained from using them.

Understanding and balancing upstream and downstream interrelations between these factors is recognized as a crucial step towards the successful implementation and use of the new technologies. Important relations and balancing acts recognized in the case studies are for instance:

- The power of the implementer versus the expected benefits and challenges.
- The strategies and guidelines versus the resources available for learning and the traditions for technology use.
- The level of ambition versus the skills of the users and the affordance of the technologies supporting 3D object-based modeling and BIM.

Second, the many enablers and barriers observed in the cases can be particularly related to three main areas:

- The skills and behavior of the project participants when it comes to adapting to new tools and related work methods.
- The affordance of the tools with respect to the complexity of the work and the interactions of its users.
- The tasks and interactions embedded in the practice of architectural design.

Third, a large number of the explored benefits and challenges arise out of the encounter between these three main areas. The 'wheel of tasks, tools and skills' below illustrates the relation between the efforts for implementation, the three main fields of enablers and barriers, and the benefits and challenges from use in the real-life projects (Fig. 9-3).

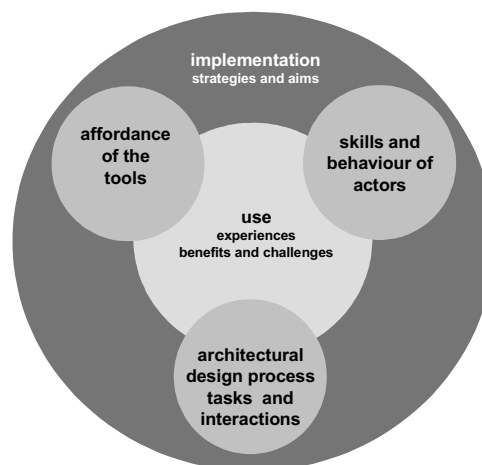


Figure 9-3. The wheel of tasks, tools and skills.

Several interrelationships related to the wheel impacted the role of the technologies supporting 3D object-based modeling or BIM in the work and interactions of the practitioners involved in the architectural design process.¹ Examples:

- The importance of having an overview and controlling a large amount of information and a large number of geometrical and functional relationships versus the ability of the technologies to address these needs (for instance through visualizations, consistency controls and automated take-offs). This was a 'round-peg-and-round-hole' relation which in all four building projects resulted in several benefits and which secured the tools an important role in evaluation and quality assurance of design solutions (from the macro down to the micro level), and in decision making among the actors directly involved in design tasks (the micro and the meso level).²
- The many interests, backgrounds and experiences represented by the actors involved in the architectural design process versus the potential of the technologies to enhance shared understanding (for instance through visualizations, views on the discipline models or the merged models, animations, and so on). This was a second 'round-peg-and-round-hole' relation which in all four projects resulted in further benefits and gave an important role to the technologies in communicating between actors on all levels, as well as in individual and collective decision making within the design team (the micro and the meso level).
- The 'two-steps-forward-one-step-back' process and the need for continuously improving and modifying design solutions versus the ability of the implemented technologies in enabling these interactions. This was a 'square-peg-and-round-hole' relation which particularly in the CCC and HITOS projects resulted in several challenges with respect to collective design generation and to the exchange and communication of data and information between the design team actors (the meso level).
- The 'loop', 'cycle' and 'ping-pong' nature of the architectural design process and the 'up-and-down-from-the-overall-to-the-detail' versus the potential of the technology to formalize and control processes. This was another interrelationship which was hard to grasp and which, particularly in the CCC project, affected the role of the technologies in the communication and exchange of information between the disciplines, and in individual and collective design generation (the meso and the micro level).
- The interface between design and production versus the potential of the technologies to enable consistent information flow between project phases versus the readiness and skills of the actors involved in the construction phase to utilize these tools. The design and construction phase comprise different tasks, needs and actors, and the handling of this interface was a source of many challenges in the daily work of the design team actors (the meso and the micro level).

1. The lack of skills among the project actors played a role in all of these.

2. The 'square-peg-and-round-hole' metaphor is referred to in the introductory chapter and borrowed from Chastain et al. (2002:239).

It can be concluded that the identified and explored factors and relations have influenced both the efforts for implementing technologies supporting 3D object-based modeling and BIM in the examined projects, and the role of these technologies in the work and interactions of the design team actors. The findings indicate that understanding and handling the interdependencies between these factors is crucial for the implementation and use of ICT in the architectural design process. Particularly with respect to the balancing acts between:

- The strategies and aims for ICT implementation versus the experiences from adaptation and use in the practice of architectural design.³
- The digital tools versus the skills and behavior of the project actors versus the tasks and interactions related to the architectural design process.

9.2 the descriptive and holistic framework: reflection-on-action and conclusions about development and use

“The two greatest tyrants on the earth: coincidence and time.” Johann Gottfried von Herder.⁴

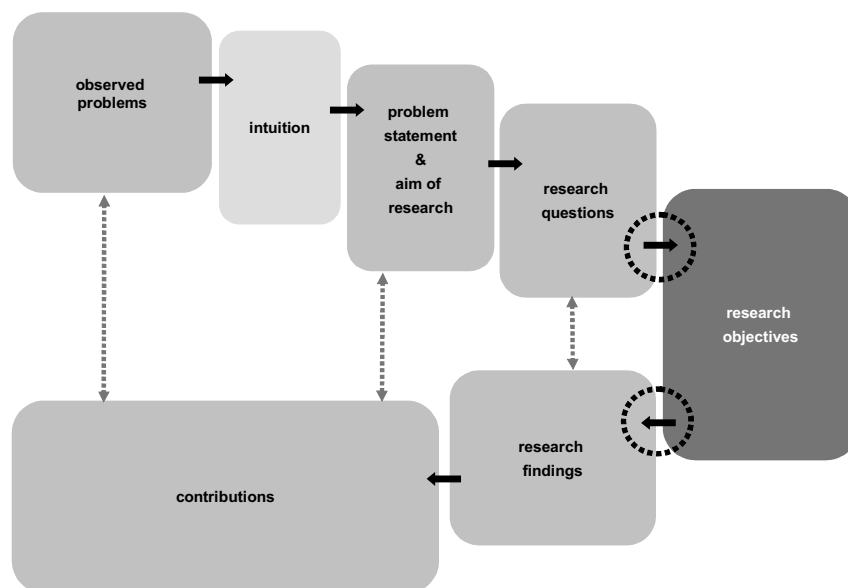


Figure 9-4. The relation between the objectives, the research questions and the findings.

3. Which relates to the importance of regarding both a problem and its context (described in Chapter 3: The case study as a research strategy).

4. Author's translation. Johann Gottfried von Herder. "Die zwei grössten Tyrannen der Erde: der Zufall und die Zeit".

The above-mentioned tyrants are two of many that have influenced the research process and the actions undertaken. The limited timeframe has triggered the need to set priorities and make difficult decisions. The second tyrant, coincidence, has been less obvious but probably the most powerful in terms of undermining the foundation and rigor of scientific research. The third part of Chapter 3 described the actions and strategies undertaken to ensure the validity and reliability of the research. In this section I reflect on the research actions with particular focus on the development and application of the descriptive and holistic framework.

The six objectives described in the introductory chapter have guided and supported the research process and the efforts to address the two research questions. The three first of these were related to the development of the framework and the tools for exploring the implementation and use of ICT in the practice of architectural design, which then were applied to the last three objectives. This framework was developed and improved throughout the entire research process, and it has played different roles in the two main phases of the research; from 'digging broadly' on the overarching level down to 'digging deep' and its detailed elaboration. The three papers included in the thesis demonstrate different stages of the framework development and provide examples of its application. Below I provide a brief summary.

Paper I presents the outline and foundations of the framework, as well as a demonstration of the application of the ICT-impact matrix in a pilot project.⁵ In Paper II, the framework and the multi-level factor model are used to explore and organize the derived findings by using various research strategies and data-collection instruments (a qualitative case study and process evaluation strategy based on different sources of evidence). Paper III, reports the findings, analyzed and organized according to the framework, in five design-team stories by means of a narrative technique.

The framework was useful in defining focus and scope, in establishing the research and case-study design, in selecting the respondents and in guiding the interview situations. It has particularly supported the analyzing and organizing of the collected data. The framework tools provided helpful overviews of the research findings and their relationships. Generally it can be concluded that the framework, based on the idea of 'merging' two central dimensions of architectural design practice (the process dimension and the level dimension), has played a crucial role in the efforts to address the overall aim and the research questions. In addition, combining the application of the framework with a number of research strategies and instruments for data collection, and with various techniques for reporting the findings, turned out to be powerful for acknowledging some of the complexity of the studied real-life situations.

5. The two appended conference papers and the working paper provide further insight into this stage of the framework development.

Finally, the framework has helped to operationalize the exploration of relations between the architectural design process and ICT. Identifying enablers and barriers, as well as benefits and challenges, has been helpful for gaining insight into the studied projects with respect to factors affecting the implementation and use of the technologies, and to how ICT impacts the work and interactions of the practitioners involved.

The holistic and multilayered nature of the framework also resulted in several challenges. One of these, particularly in the first phase of the research, was to approach the interconnectedness between the different levels and process aspects. This challenge was foreseen and already in the introduction of the framework it was pointed out that its purpose was not to force findings into rigid boxes or categories. Such efforts would have underestimated the complexity of the field and contradicted the focus of this work on investigating relations. This issue notwithstanding, the structure of the framework, and in particular the ICT impact matrix, required effort and care in allocating the collected data to the different levels and tasks. Although challenging, these efforts were also useful as they increased sensibility when it came to the complexity of the observed situations. In the second phase of the research, the relations between the tasks and levels increasingly became the main object of investigation and exploration.

A further challenge was related to the broad and holistic nature of the framework; which findings should be focused on and highlighted? To control and report on all levels and relations revealed by its application, from the overarching level down to each single detail, would require a substantial effort and resources and widely extend the intentions and scope of this work. The last section of Chapter 3 describes the role of the researcher's previous knowledge in approaching the research problems. Together with the regular checking of the relevance of the findings for an external audience (practitioners and experts from research and academia), this knowledge was valuable for selecting the 'snapshots' from current practice which are reported on in this thesis. These 'snapshots' provided a good insight into the studied projects and a sufficient basis for addressing the research questions.

limitations of the framework

The 'merging' of the multi-level dimension with process dimensions limits the applicability of the framework to explorations of the practice of architectural design. The exploration of related issues which fall outside the scope of this thesis, as for instance the ICT impact on organizations and company structures, or on other phases of the buildings' life-cycle, would require a re-consideration of the framework outline. Furthermore, the framework has been developed to investigate the current situation in the AEC industry and established practice. The investigated design teams represent the traditional constellation of architects and engineers. However, as indicated by the technology-related visions and trends described in Chapter 2, the borders between actors and

design phases might blur and change, which would require a reconsideration of the level definitions. Moreover, the application of the framework is limited to studies of middle- to large-scale projects. The adoption of the framework to small-scale projects (e.g. housing projects), is likely to be challenging, as the activities in such projects cannot be easily allocated to different levels.

"I have yet to see any problem, however complicated, which, when looked at in the right way did not become still more complicated." Poul Anderson⁶

9.3 research contributions

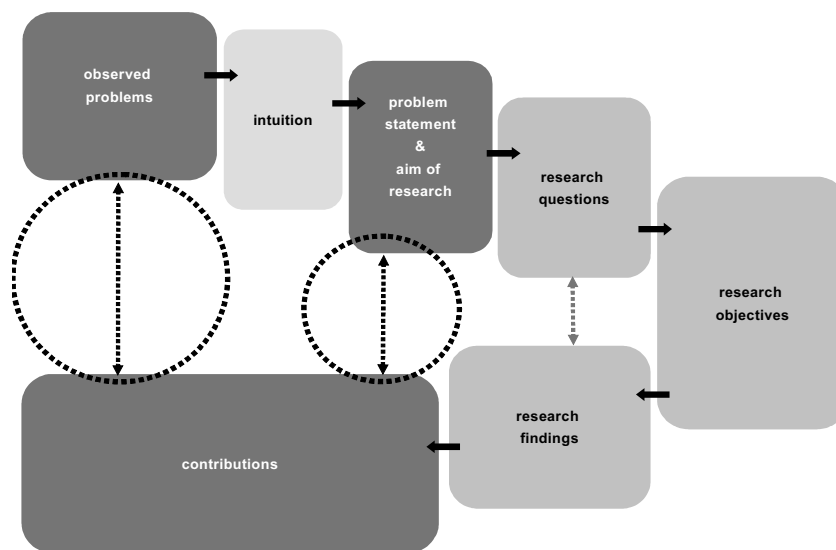


Figure 9-5. The relation between the contributions, the observed problems, and the aim of the research.

The overall aim of this research is, here repeated: to gain more knowledge on the current situation in practice by investigating relations between the architectural design process and ICT. The contribution of the research is threefold, providing:

- A holistic framework for explorations and descriptions of real-life practice - and the framework tools for analyzing and organizing complex and qualitative findings.
- A comprehensive and multilayered overview of factors and relations affecting the implementation and use of ICT in the practice of architectural design.

6. Poul William Anderson (1926-2001) was an American science fiction author. Quotation from: http://www.saidwhat.co.uk/quotes/favourite/poul_anderson (retrieved February 2008).

- Case-study narratives and design-team stories as 'stand-alone' examples from current practice.

The research contributions are significant for the research field in several ways. In the widest context, the framework and the findings generated by its application, contribute to a flow of knowledge from practice to research. The descriptive and holistic framework and 'digging-broadly and digging-deep' strategy could also be an approach researchers and academia could use to gain knowledge on real-life practice. The findings generated by its application could be useful in establishing future strategies and guidelines for ICT integration, and in improving the further implementation and use of new technologies in the practice of architectural design.

Altogether, this thesis represents a detailed and reflective documentation of current practice and a basis for future research and learning from real-life situations.

"It seemed that the next minute they would discover a solution. Yet it was clear to both of them that the end was still, far off, and that the hardest and most complicated part was only just beginning." Anton Chekhov, *The Lady with the Dog*.⁷

9.4 implications of the findings for practice

*"It is an evolution, not a revolution!"*⁸

The practitioners involved in the current AEC industry face a shift from 2D and document-based design tools to technologies supporting 3D object-based modeling and BIM. However, a paradigm shift as suggested at the international information seminar on IFC and IAI in Oslo 2004, has not yet found its place in the case studies reported on in this thesis.⁹ The respondents generally agreed that the fulfillment of the R&D visions formulated by, for instance, the IAI and BuildingSMART, is some years in the future.¹⁰ Although several benefits could be harvested from implementing and using the technologies supporting 3D object-based modeling and BIM, the practitioners were still struggling with an array of challenges of the 'square- pegs-in-round-holes' and 'horseless-carriage' types. The implications for practice suggested below indicate fields for further focus, effort and discussion.

7. Quoted by Lawson (1997:51).

8. Said by one of the clients of the HITOS project, whom I interviewed in November 2006, about the strategies for implementing IFC compliant BIM.

9. For more about the information seminar, see Chapter 1: The practice of architectural design meets the digital world.

10. The respondents represented, however, different views on how far into the future.

- It is likely that skills and tools will be substantially upgraded in the next few years. Even in the case studies, much of the focus of both the R&D efforts and the project actors was on up-skilling and technological improvement. The respondents could report on steep learning curves and a continuous (although slower than expected) improvement of the tools. Nevertheless, a large number of the explored factors were linked to the nature of the architectural design process. The research findings show that it is important for industry actors involved in implementing ICT in the practice of architectural design to consider factors related to tasks of architectural design, in addition to factors linked to the skills and the tools.
- The findings also indicate the importance of understanding and handling downstream and upstream interdependencies between strategies and guidelines for implementation, and the needs and experiences of actors involved in real-life projects.
- “The processes represent more challenges than the technology. The technology is only a tool. What is important is HOW we use it. To enhance the benefits of the technology, a very good overview is needed of all relations and interactions in the building project, throughout the whole lifecycle and across all actors.” This recognition of the implementers involved in the AHUS project points out the need for a shift from single-discipline ‘over-the-fence’ thinking, to an interdisciplinary approach among the implementers and decision-makers with respect to both the project processes and the implementation and use of technology.¹¹
- Two trends were observed which relate to the interfaces between the different project phases, and which imply both challenges and benefits for future practice; first, the ‘cut’ between the 3D object model/BIM related and digital activities in the design process, and the traditional and analogue processes on the building site. Second, the increasing focus on pre-fabrication and module-based building and planning. The last trend is likely to be further triggered by current research efforts for pre-defining and standardizing building objects, components and processes.¹²
- Moreover, the findings indicate a reallocation of tasks and efforts between the traditional phases, in particular a front-loading of design solution specifications and decisions on earlier phases in the process (the observations do not, however, indicate a clear trend toward a reallocation of efforts between the different design-team disciplines, which might be a consequence of the single-discipline modeling system).
- The disciplines started in all four projects to develop their design solutions successively (for instance; at first the architect, then the structural engineer, followed by HVAC and the electrical systems). The findings indicate, however, a need for simultaneous development and specification of geometry and design information across the design disciplines to enhance the potential of the technology to support interdisciplinary work.

11. Where each discipline focuses on their parts of the performance only before handing their contribution “over-the-fence” to the next actor in the chain of actions.

12. For instance the IFD project (Information Framework for Dictionaries) and the IDM project (Information Delivery Manuals).

- The findings indicate the emergence of new tasks in the early design process. For instance to feed the 3D object models with design information and object attributes. Moreover, the findings imply that skills are required beyond pure drafting or modeling.
- One of the implementers in the AHUS project commented; the designer should not only learn to model, but also to think, in an object-oriented way. In all four real-life building projects, 3D object-based modeling or BIM was adapted to traditional processes and established practice of architectural design.¹³ The implemented technologies have not fundamentally changed the practitioners' work and interactions. The findings imply that up-skilling is not only a matter of mastering and operating software, but also of learning and adapting new work methods.

9.5 recommendations for future research

"It has often been suggested that design is as much a matter of finding problems as it is of solving them." Lawson (1997:118)

The research findings and implications, as well as the increasing efforts in the AEC industry to integrate new technologies in the practice of architectural design underpin the motivation for further investigations of practice and for learning beyond the time scale of single projects and R&D efforts. The descriptive and holistic framework developed in this work represents one possible step in the development of approaches which aim to embrace the complexity of real-life problems and to contribute to a more comprehensive understanding of what is going on in practice. The following actions are recommended for its further development and improvement, one should:

- Apply the framework to more real-life projects to substantiate and improve the definition of its main elements, and to evaluate the potential of the framework for cross-case analysis and analytical generalization based on multiple case studies.
- Discuss the framework and its holistic approach to studies of, for instance, complexity theories, organizational multi-level theories, communication theories and philosophies of science.
- Try out the usefulness of the framework in supporting the explorations by other researchers and academics. An important point here is that the user of the framework should have a basic understanding of real-life practice and the work and interactions of project actors.

Moreover, the research findings should be compared with the findings of related studies of real-life projects and the implementation and use of ICT.

13. This relates to the ongoing project situations. In the R&D projects of the HITOS and AHUS project, one of the aims was also to test out new ways of interaction between the project actors.

Each element of the framework and each single enabler, barrier, benefit and challenge explored by its application merits further examination. The three focus fields for future research recommended below relate to the three areas illustrated in 'the wheel of tasks, tools and skills'. As they represent groups of factors affecting the implementation and use of ICT, these three areas also represent fields which can be influenced by further actions within research and academia.

- The first field thus relates to the impact of ICT on the practitioners involved in the architectural design process; their roles, responsibilities and skills. Issues for further investigation could be contracting systems and the interfaces between the actors' roles and responsibilities.¹⁴ Or in a narrower context, the future role of the architects and engineers in using and mastering new technologies. What competence will the operator of the tools need to have, and which role does this operator play in architectural design and management?
- The second field is linked to the affordance of the tools and related activities with respect to the complexity of the tasks and interactions taking place in real-life projects. In the cases presented here, there was a limited utilization of the technologies supporting 3D object-based modeling and BIM beyond geometry-related activities. Furthermore, the tools were used only by single groups of actors (typically the architects and the engineers) or phases (typically the design phases). Issues for further investigation could be the affordance of the integrated BIM concept across project actors and phases in real life and ongoing building projects, as well as the applicability of guidelines and manuals developed for supporting BIM-related work in real-life projects.
- The third field which can be influenced by future research relates to the tasks and interactions embedded in the practice of architectural design. An issue for further investigation could be the transition from established practice to new practice with respect to definition and handling of project phases and their interfaces, collaborative scenarios across actors and phases and work methods of each architect and engineer.

More knowledge *about* current practice, together with appropriate approaches and methods for 'unlocking' knowledge *in* practice, will establish an important foundation from which to tackle and have impact on the changes to come. This work represents one of many bricks in this foundation, where the connecting and stabilizing mortar should be the practitioners', researchers' and academics' shared responsibility for ensuring good architecture and physical environments.

14. An interesting reference here is the Norwegian R&D project 'Samspillet i byggeprosessen' (1996-2000). It could be interesting to discuss the thoughts on partnering models and contracts made in this program in light of the emerging 3D object modeling/BIM technologies and their related activities.

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Exploring relations between the architectural design process and ICT

glossary of technical terms

The purpose is here to provide a brief introduction to some of the technical terms used in this thesis. The quotations of experts' descriptions and explanations, the references to encyclopedia as well as the comments of the thesis author, are intended to contribute to a basic understanding of the terms and how they are used in this work. Detailed technical specifications falls outside the scope of this thesis.

building information model/-ing (BIM)

BIM is a 'hot topic' and frequently used abbreviation in the current AEC industry. Below some experts' and expert groups' descriptions or comments are quoted:

"BIM (Building Information Model) is an object-oriented, AEC-specific model - a digital representation of a building to facilitate exchange and interoperability of information in digital format. The model can be without geometry or with 2D or 3D representations." Kiviniemi et al. (2007:9).

Bazjanac (2004) explains BIM to be: "(...) an instance of a populated data model of buildings that contains multidisciplinary data specific to particular building which they describe unambiguously (...) a BIM includes all relationships and inheritances for each of the building components it describes unambiguously. (...) A three-dimensional 'surface' model of geometry alone that is used only in visualization is usually not a BIM."

"A key concept in attaining direct data exchange and/or sharing is BIM as the authoritative repository of project information. BIM in this context is a data model of buildings instantiated with data that uniquely define a specific building; it serves as a repository for all project information that is subject to exchange and/or sharing. Populating such a data repository requires the use of software applications that are capable of populating the repository with data or retrieving data from it." Bazjanac and Kiviniemi (2007:164).

"An essential capability of the BIM (Building Information Model) design tools is their support in parametric modeling; Revit®, ArchiCad®, Bentley Architecture, Digital Project®, and VectorWorks® are all parametric modelers. Parametric modeling matured in the 1980s and the '90s through intense industrial development and university research. The basic idea is that 2D or 3D solid object shapes can be defined according to parameters, some of which are user-defined values and others relative to other shapes." Eastman (2006).

“Building Information Modelling, also known as BIM, is a method that is based on a building model containing any information about the construction. In addition to the contents of the 3D object-based models, this is information such as specifications, economy and programmes. (...) Building Information Modelling (BIM) is a modelling concept in which all parties create and use consistent digital information throughout the life of a construction project. (...) The software suppliers have begun to label their 3D CAD systems ‘BIM’, but at the best they are only approaching the fully integrated building model status.” bips (2006:12).

3D object models or 3D product models or BIM?

Today, the terms **3D object models**, **3D product models** and **Building Information Models (BIM)** are used rather ‘helter-skelter’ within the field. According to some key persons involved in the development of these technologies, 3D object models and 3D product models might be regarded as more or less the same.¹ The STEP group used the term ‘product model’, whereas the information and computer scientist probably would use the term ‘object model’. However, 3D object or product models are not the same as Building Information Models. A BIM does not have to be connected to a geometrical model, and a 3D object model is not necessarily a BIM. In several of the quotations above, the experts point out that the use of these terms are mixed up in the current AEC industry. On the CIB W78 conference ‘Bringing ITC knowledge to work’ in Maribor 2007, some of the key persons behind the development of this technology agreed to use BIM as a ‘collective term’ for both 3D product models and the ‘true’ BIMs. Thus, due to this use of the ‘brand’ Building Information Modeling (BIM) within different research and development communities today, the term BIM could also be used to describe the technology implemented and used in the four investigated building projects.

However, in the CCC, AHUS and AUDI projects (the ongoing projects) the efforts are focused on geometry-related 3D model activities. Although the single discipline models to some extent are populated with object information and object attributes, the actors are not exchanging or sharing this information. Thus, 3D object model or 3D object-based modeling are the terms used in the descriptions of these three projects. This relates additionally to the terminology used by the project actors themselves at the time the case studies were carried out. In the HITOS project (and the R&D part of the AHUS project) the actors have attempted to implement **integrated BIM**. In the Erabuild report on the implementation of IFC compatible BIM (Kiviniemi et al. 2007:10) integrated BIM is described to be:

“A Building Information Model whose information needs to be shared and thus warrants open international standards for information sharing.”

1. Interview with Professor Richard Junge March 2007, and with Dr. Thomas Liebich December 2006.

The frequently used 'umbrella term' **technologies supporting 3D object-based modeling or BIM**, comprises not only the 3D modeling tools themselves, but also technologies supporting the use of the models, such as software **applications** (viewers, clash detectors) and **IFC**. The applications are enabling a number of activities related to 3D modeling, such as visualization, consistency control and simulation. According to Wikipedia, an application is:

"... a subclass of computer software that employs the capabilities of a computer directly and thoroughly to a task that the user wishes to perform. This should be contrasted with system software which is involved in integrating a computer's various capabilities, but typically does not directly apply them in the performance of tasks that benefit the user." Wikipedia (www.wikipedia.com, retrieved November 2007).

As a wrap-up, here Wikipedias description of BIM:

"BIM stands for both Building Information Model and Building Information Modeling. The Building Information Model (BIM) is a set of information generated and maintained throughout the lifecycle of a building. Building Information Modeling (BIM) is the process of generating and managing a building information model. There are two theories on the origin of the term. The first one is that the term was coined by Autodesk to describe '3D, object-oriented, AEC-specific CAD'. The second theory claims that Professor Charles M. Eastman at Georgia Institute of Technology coined the term. This theory is based on a view that the term Building Information Model is basically the same as Building Product Model, which Professor Eastman has used extensively in his book and papers since the late 1970s. ('Product model' means 'data model' or 'information model' in engineering). Nevertheless, it is agreed upon that the term was popularized by Jerry Laiserin as a common name for a digital representation of the building process to facilitate exchange and interoperability of information in digital format. This capability is offered by several technology providers such as Autodesk, Bentley Systems, Graphisoft, CADdetails and others (...) The American Institute of Architects has further defined BIM as 'a model-based technology linked with a database of project information'." Wikipedia (www.wikipedia.com, retrieved November 2007).

buildingSMART

"The use of BIM is gaining significant momentum. BuildingSMART is integrated project working and value-based life cycle management using Building Information Modelling and IFCs. In the last two years IAI has turned its attention to the broader issues of achieving beneficial change in industry, using Building Information Models (BIMs) and IFCs as the trigger to smarter ways of working. This is the origin of the branding of IAI as BuildingSMART. Smarter ways of working will directly affect the processes and skill sets used in industry and indirectly other issues such as contracts, payment systems, insurance, education and training.

Under the BuildingSMART banner, IAI is seeking alliances with other similarly motivated organisations to support processes which deliver faster, better, less expensive and more predictable results than can be achieved with traditional methods. BuildingSMART = BIM + IFC". An introduction to buildingSMART, from the public web site of buildingSMART, Australasia Chapter, International Alliance for Interoperability - Australasia Chapter of IAI (<http://buildingsmart.org.au/>, retrieved June 2008).

IAI

"IAI is an alliance of organizations within the construction and facilities management industries dedicated to improving processes within the industry through defining the use and sharing of information. Organizations within the alliance include architects, engineers, contractors, building owners, facility managers, manufacturers, software vendors, information providers, government agencies, research laboratories, universities and more (...) The International Alliance for Interoperability (IAI) was started by twelve companies that wanted to be able to work with each other's information without being concerned about the software that they or anyone else was using. They created a set of prototype software applications that were demonstrated at the A/E/C Systems '95 show in Atlanta, Georgia. These prototypes proved that interoperability was not just a dream; it could be made into reality. In September 1995, they opened up participation to AEC/FM companies worldwide and formed the IAI. (...). The IAI specifies how the 'things' that could occur in a constructed facility (including real things such as doors, walls, fans, etc. and abstract concepts such as space, organization, process etc.) should be represented electronically. These specifications represent a data structure that can be shared between software applications (...) The classes defined by the IAI are termed 'Industry Foundation Classes' or IFCs. The reasons for this are: They are defined by the AEC/FM industry, They provide a foundation for shared information, They specify the classes of things in an agreed manner that enables the development of a common language for construction." From the public IAI web site of the UK chapter (http://cig.bre.co.uk/iai_uk/new/index.jsp, retrieved December 2005).

industry foundation classes (IFC)

Kiviniemi et al. (2007:4) describes IFC as "an exchange format, defining HOW to share information". Here some further quotations about IFC:

"An international specification for product data exchange and sharing for AEC/FM. IFC enables interoperability between computer applications for AEC/FM. A subset of IFC is approved as ISO/PAS 16739." SINTEF Building and Infrastructure (2007:9).

Eastman (2006) describes IFC as follows: *"The Industry Foundation Classes (IFC) is an international, public-domain standard managed by the International Alliance for Interoperability (IAI), made up of a consortium of industry firms*

worldwide. The IFC uses the technology of ISO-STEP 10303, the international product modeling standard used in manufacturing and defense industries. The STEP technology uses a product modeling schema defined in EXPRESS, and a set of standard libraries, called Integrated Resources. The IFC is an object-based extensible data schema defined in EXPRESS for the definition of buildings and their components. It provides both a set of data models with which to exchange data, and a set of abstract constructs to extend the current capabilities.”

“The Industry Foundation Classes (IFC) data model is a neutral and open specification that is not controlled by a singular vendor or group of vendors. It is an object oriented file format with a data model developed by the International Alliance for Interoperability (IAI) to facilitate interoperability in the building industry, and is a commonly used format for Building Information Modeling (BIM). The IFC model specification is open and available.” Wikipedia (www.wikipedia.com, retrieved November 2007).

information and communication technologies (ICT)

In this thesis, the term ICT is limited to computer-based tools and devices which are applicable to the practice of architectural design. Below Wikipedia’s description:

“Information technology (IT), as defined by the Information Technology Association of America (ITAA), is ‘the study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware.’ IT deals with the use of electronic computers and computer software to convert, store, protect, process, transmit and retrieve information, securely. Recently it has become popular to broaden the term to explicitly include the field of electronic communication so that people tend to use the abbreviation ICT (Information and Communications Technology), it is common for this to be referred to as IT & T in the Australasia region, standing for Information Technology and Telecommunications. Today, the term information technology has ballooned to encompass many aspects of computing and technology, and the term is more recognizable than ever before. The information technology umbrella can be quite large, covering many fields.” Wikipedia (www.wikipedia.com, retrieved November 2007).

information delivery manual (IDM)

Kiviniemi et al. (2007:4) describes IDM to be “information requirements, defining WHICH information to share, WHEN”. Furthermore:

“Collectively, the set of process maps, exchange requirements, functional parts, business rules and BIM guidance that enables close control of the information exchange process within a project.” Kiviniemi et al. (2007:9).

international framework of dictionaries (IFD)

Kiviniemi et al. (2007:4) describes IFD as “a reference library, to define WHAT information we are sharing”. Furthermore:

“An international development of an object library for the AEC/FM industry that is compatible with IFC and can be used to get more detailed information in and out of a construction design. An alternative identity for the conceptual model within ISO 12006 Part 3.” Kiviniemi et al. (2007:10).

appendix a

list of interview respondents

project	respondent	place and date	company/ institution	role/position/ title
Context	Rasso Steinmann	Munich, 06.02.06	FH München	Professor
Context	Rudolf Juli	Munich, 17.02.06	IAI Germany	Leader German Chapter
Context	Christian Koch	Copenhagen, 20.09.06	DTU	Professor
Context	Lee Anderson	Trondheim, 25.10.06	University of Minnesota	Professor
Context	Illka Romo	Helsinki, 31.10.06	ProIT/Skanska	Project manager
Context	Thomas Liebich	Munich, 20.12.06	aec3	Dr. IT consultant in AUDI project
Context	Ludger Hovestadt	Zürich, 15.01.07	ETHZ	Professor
Context (short chat)	Gerhard Schmidt	Zürich, 16.01.07	ETHZ	Professor
Context (short chat)	Jeffrey Huang	Lausanne, 17.01.07	LPFL	Professor
Context	Vladimir Bazjanac	Berkeley, 21.03.07	Lawrence Berkeley Lab/IAI	Dr.
Context	Yehuda Kalay	Berkeley, 22.03.07	UC Berkeley	Professor
Context	John F. Marx	San Fransisco, 23.03.07	Form4 Architects	Principal and archi- tect
Context	Lachmi Khemlani	San Fransisco, 23.03.07	AECBytes	Editor
Context	Armando Trento	Berkeley, 26.03.07	UC Berkeley	Guest PhD-student
Context	Patrick MacLeamy	San Fransisco, 27.03.07	HOK/ IAI International	CEO
Context	Mario Guttman	San Fransisco, 27.03.07	HOK	Vice President

Exploring relations between the architectural design process and ICT

project	respondent	place and date	company/ institution	role/position/ title
Context	John Haymaker	Palo Alto, 29.03.07	CIFE, Stanford	Assistant Professor
Context	Renate Fruchter	Palo Alto, 29.03.07	CIFE, Stanford	Director
Context	Martin Fischer	Palo Alto, 30.03.07	CIFE, Stanford	Director
Context	Carrie E. Byles	San Fransisco, 04.04.07	Skidmore, Owings & Merrill	Partner
Context	Markus Peter	Karlsruhe, 19.04.07	ifib, TU Karlsruhe	PhD, researcher
Context	Niklaus Kohler	Karlsruhe, 19.04.07	ifib, TU Karlsruhe	Professor
Context	Richard Junge	Munich, 25.04.07	TU München	Professor
Context	Mike Martin	Copenhagen, 05.06.07	DTU/UC Berkeley	Professor
CCC	Berit Bankel	Copenhagen, 18.09.06	Ramboll Denmark	Leader piping team
CCC	Birgit Thomsen	Copenhagen, 20.09.06 (incl. "guided tour") 04.06.07	Ramboll Denmark	IT coordinator
CCC	Birte Bæk	Copenhagen, 19.09.06 (incl. "guided tour") 04.06.07	Henning Larsen Architects	IT coordinator in architectural team
CCC	Geert Stryg	Copenhagen, 16.06.06, 18.09.06, 04.06.07	Ramboll Denmark	Project manager of engineering team
CCC	Henrik K. Hansen	Copenhagen, 18.09.06, 04.06.07	Ramboll Denmark	Leader steel structure team
CCC	Jørgen Olesen	Copenhagen, 21.09.06	Henning Larsen Architects	Architect
CCC/bips	Kim Jacobsen	Copenhagen, 18.09.06, 22.10.07	Ramboll Denmark	IT Manager
CCC	Kim S. Pedersen	Copenhagen, 18.09.06, 04.06.07	Ramboll Denmark	Draftsman HVAC
CCC	Klaus H. Madsen	Copenhagen, 16.06.06, 21.09.06, 04.06.07	Henning Larsen Architects	Project manager of architectural team
CCC	Niels C. Weigelt	Copenhagen, 16.06.06	Ramboll Denmark	Engineer/draftsman ventilation
CCC	Osbjørn Jacobsen	Copenhagen, 21.09.06	Henning Larsen Architects	Design manager of architectural team

project	respondent	place and date	company/ institution	role/position/ title
HITOS	Diderik Haug	Oslo, 15.11.06	Statsbygg	Client, project manager R&D
HITOS	Ernst Eberg	Bodø, 09.11.06 Phone, 22.06.07	Norconsult	Project manager design team
HITOS	Jan Olsen	Bodø, 08.11.06	Norconsult	Leader Structural systems
HITOS	Ole M. Hartløfsen	Bodø, 08.11.06	Arkitektstudio	Design manager architectural team
HITOS	Sigmund Eriksen	Bodø, 09.11.06	Norconsult	Leader electrical systems
HITOS	Svein Eidissen	Bodø, 08.11.06	Sweco Grøner	Leader HVAC
HITOS	Tor Tunvang	Oslo, 15.11.06	Statsbygg	Project manager
HITOS	Turi Heieraas	Bodø, 08.11.06 09.11.06 ("guided tour")	Arkitektstudio	IT coordinator and architect
AHUS	Astrid Seeberg	Lørenskog, 19.05.05 16.11.06 (incl. "guided tour")	C.F. Møller Architects	Architect, front building team
AHUS	Bjørn Sund	Lørenskog, 17.11.06	Helse Øst	Client, project director
AHUS	Bård Rane	Lørenskog, 20.05.05, 17.11.06	Helse Øst	Client, project manager
AHUS	John E. Johnsen	Lørenskog, 16.11.06 (incl. "guided tour")	Sweco Grøner	Engineer HVAC
AHUS	Kjell I. Bakkmoen	Lørenskog, 20.05.05, 17.11.05	C.F. Møller Architects	Project manager of architectural team (whole project)
AHUS	Steen Suneses	Lørenskog, 19.05.05, 17.11.05	C.F. Møller Architects	Design manager of front building architectural team
AUDI	Bernhard Schirmer	Munich, 24.11.06, 10.12.06	Obermeyer P+B	Project manager architectural team
AUDI	Robert Gruschke	Munich, 24.11.06 10.12.06 (incl. "guided tour")	Obermeyer P+B	Architect
AUDI	Rolf Kwanka	Munich, 10.12.06	Obermeyer P+B	Engineer structural systems

project	respondent	place and date	company/ institution	role/position/ title
AUDI	Rudolf Juli	Munich, 24.11.06	Obermeyer P+B	IT manager
AUDI	Sebastian Gohl	Telephone, 26.02.07	FACT	Project manager engineering team , N24
AUDI	Wolfram Wiesböck	Ingolstadt, 19.02.07 (with R. Juli)	Audi	Client, project man- ager

workshop

Arranged by thesis' author December 12th 2005 (10:00-12:00 am) at the Norwegian University of Science and Technology, Trondheim. Topic: presentation and discussion of the descriptive framework and its application on the AHUS project.

Participants (included their positions December 2005):

- Birgit Sudbø, Ass. Professor, Department of Architectural Design and Management, NTNU
- Bjørn O. Braaten, Ass. Professor, Department of Architectural Design and Management, NTNU
- Geir K. Hansen, Ass. Professor, Department of Architectural Design and Management, NTNU
- Gunnar Næss, Architect, Principal Gunnar Næss Architects, Leader 'Arkitektbedriftene i Norge'
- Håkon K. Gissinger, Coordinator of Centre of Real Estate and Facilities Management, Department of Architectural Design and Management, NTNU
- Kai R. Bakke, Architect
- Ole J. Klakegg, Research Director of the Concept Research Program, Department of Civil and Transport Engineering, NTNU
- Tore I. Haugen, Professor, Department of Architectural Design and Management, NTNU
- Tor G. Syversen, Professor, NTNU/Studio Apertura

conferences and seminars

2007

- CIBW78 24th Conference 'Bringing ITC knowledge to work'. June 26-29 2007, Maribor, Slovenia. Presentation paper.
- CAADfutures 2007, July 11-13, 2007. Sydney, Australia. Paper submitted and published in proceedings. Participation on conference not possible due to illness.

2006

- BIM-gathering. October 24th, 2006. NTNU, Trondheim.
- Seminar 'Nordic IT' part 2, November 2006, Helsinki, Finland. Presentation PhD project.
- Workshop 'Bygg ned Barrierene' (Building down Barriers), Byggekostmadsprogrammet, June 7th, 2006. Oslo. Participation in discussions.
- IAI/BuildingSMART International Conference, April 5th, 2006. Munich, Germany.
- IAI Gathering German Universities, status research about BIM and IFC, April 4th, 2006. Munich, Germany.
- Seminar 'Nordic IT' part 1, March 29-30, 2006, Helsinki, Finland. Presentation PhD project.
- Workshop 'Bygg ned Barrierene' (Building down Barriers), Byggekostmadsprogrammet, February 14th, 2006. Trondheim. Presentation PhD project and participation in discussions.

2005

- CIBW96 international conference on Architectural Management 'Designing Value', November 2-4, 2005. Lyngby, Denmark. Presentation paper.
- CIBW78 22nd Conference on 'Information Technology in Construction', July 19-21, 2005. Dresden, Germany. Presentation paper.
- CIB 2005, 11th CIB Joint Symposium 'Combining Forces', June 11-16, 2005. Helsinki, Finland. Presentation paper. Price for 'Best Paper'.
- IAI/BuildingSMART international conference, May 31 - June 1, 2005. Oslo, Norway.

2004

- Research methodology. Seminar part 2 at KTH, Stockholm, Sweden, October 20-21, 2004. Organized by Competitive Building/NOCS. Course leader: Professor Brian Atkin, program director of Competitive Building.
- Ensuring success in projects. PhD workshop at NTNU, Trondheim, Norway, October 4-6, 2004. Organized jointly by the Concept Research Program, three departments at the NTNU and CII/University of Texas.
- Research methodology. Seminar part 1 at Lund University, Sweden, September 1-2, 2004. Organized by Competitive Building/NOCS. Course leader: Professor Brian Atkin, program director of Competitive Building.
- Information seminar on IAI and IFC ('IFC - en revolusjon for byggenæringen'), Oslo, June 15th 2004. Organized by IAI Forum Norway in co-operation with Foreningen Næringseiendom (FNE) and Norwegian Society for Facilities Management (NBEF).

visits and residences at other universities

2005-2007

- TU München, br+i (Lehrstuhl für Baurealisierung und Bauinformatik). Guest PhD student/residential in periods 2005-2007. Professor T. Bock.

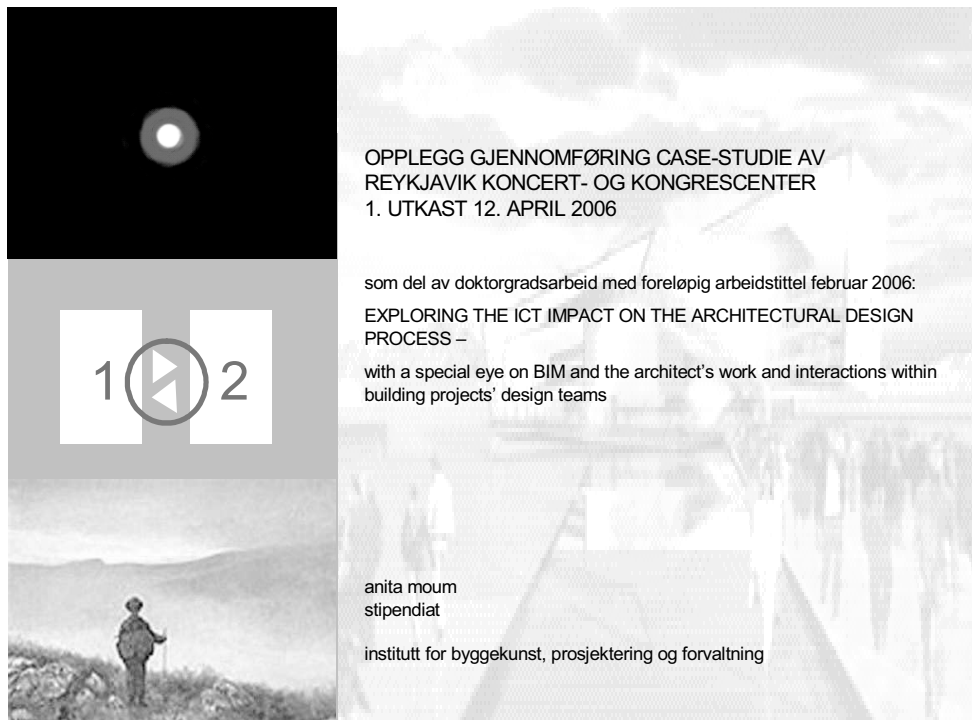
2007

- TU Karlsruhe, ifib (Institut für Industrielle Bauproduktion), April 18-19, 2007. Professor N. Kohler/Professor H. Penttilä.
- University of Stanford, CIFE (Center for Integrated Facilities Engineering), March 28-April 1, 2007. Professor M. Fischer.
- UC Berkeley. Center of New Media, March 22 and 26, 2007. Professor Y. Kalay.
- EPBL Lausanne, Media and Design Laboratory, January 16, 2007, Professor J. Huang.
- ETH Zürich, Chair of CAAD, January 15, 2007. Professor L. Hovestadt.
- ETH Zürich, Chair of Information Architecture, January 16, 2007. Professor G. Schmitt.

appendix b

case study protocol from main case

norwegian language



OPPLEGG GJENNOMFØRING CASE-STUDIE AV
REYKJAVIK KONCERT- OG KONGRESSENTER
1. UTKAST 12. APRIL 2006

som del av doktorgradsarbeid med foreløpig arbeidstittel februar 2006:
EXPLORING THE ICT IMPACT ON THE ARCHITECTURAL DESIGN
PROCESS –
with a special eye on BIM and the architect's work and interactions within
building projects' design teams

anita moum
stipendiat
institutt for byggekunst, prosjektering og forvaltning



*So little done, so much to do.
Cecil Rhodes, last words*

*Die zwei grössten Tyrannen der
Erde – der Zufall und die Zeit.
Johann Gottfried Herder*

INNHold

noen punkter til avklaring før kick-off
formål, fokus og oversikt case-studie
skisse tidsplan gjennomføring
gjennomføring og struktur intervjuer
hva skjer med informasjonen fra case studiet?
generelt om bakgrunn og motivasjon
til oversikt: avhandlingens to hoveddeler
kontakt

se ellers også kort presentasjon doktorgradsarbeid fra februar 2006

NOEN PUNKTER TIL AVKLARING FØR KICK-OFF (1. opphold København)



FASTLEGGING KONTAKTPERSON(ER)

- for generelle spørsmål angående gjennomføring
- for hjelp med tilgang til prosjektmateriale og -info
- for koordinasjon avtaler angående tidspunkter intervjuer etc.

hos Rambøll Geert Stryg?

hos HLT Klavs Holm Madsen eller Birte Bæk?

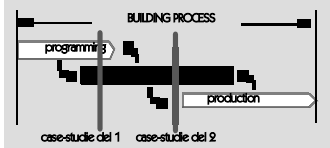
AVKLARING TIDSPUNKT 1. OPPHOLD KØBENHAVN:

- for gjennomføring 1. del intervjuer (både hos HLT og Rambøll)
- samling av dokumenter
- evt. besøk hos HLT og Rambøll (arbeidssted)
- evt. deltakelse i 1 designteammøte mellom arkitekt og konsulenter

forslag: uke 25, 2-3 dager i perioden 19.-23.06.06

alternativ: uke 22, i perioden 29.05.-02.06 eller uke 23 i perioden 06.-09.06.

(om mulig fra min side blir avklart slutt april/start mai)



DEFINISJON AV INTERVJU-OBJEKTER

trenger oversikt over prosjektdeltakere og/eller forslag fra HLT og Rambøll

TILSENDING INFO SOM FORBEREDELSE FØR 1.OPPHOLD KØBENHAVN

enhver informasjon på forhånd er til hjelp for å kunne få mest mulig ut av dette oppholdet – nesten ingen info tilgjengelig på internet

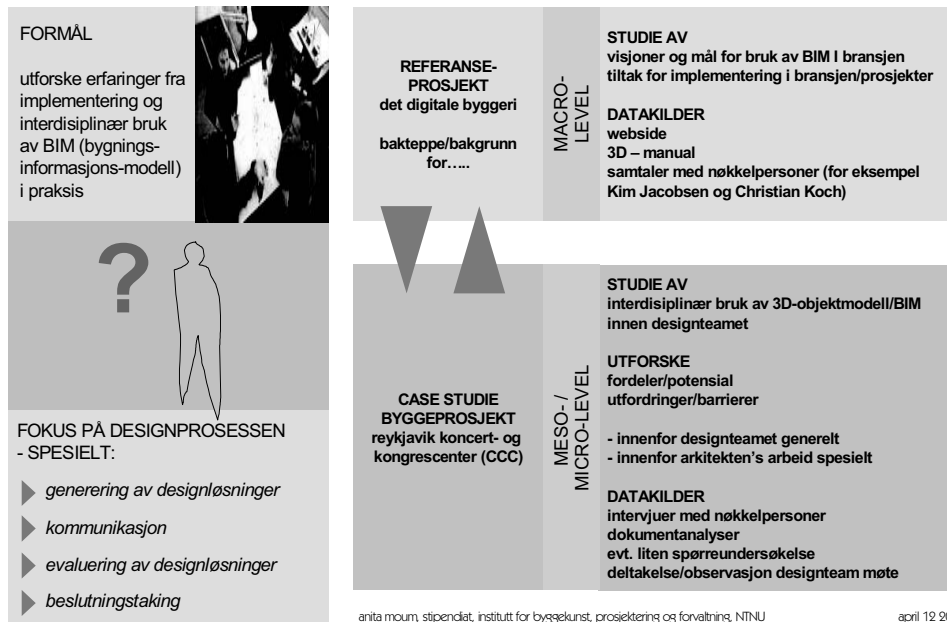


anita moum, stipendiat, institutt for byggekunst, prosjektering og forvaltning, NTNU

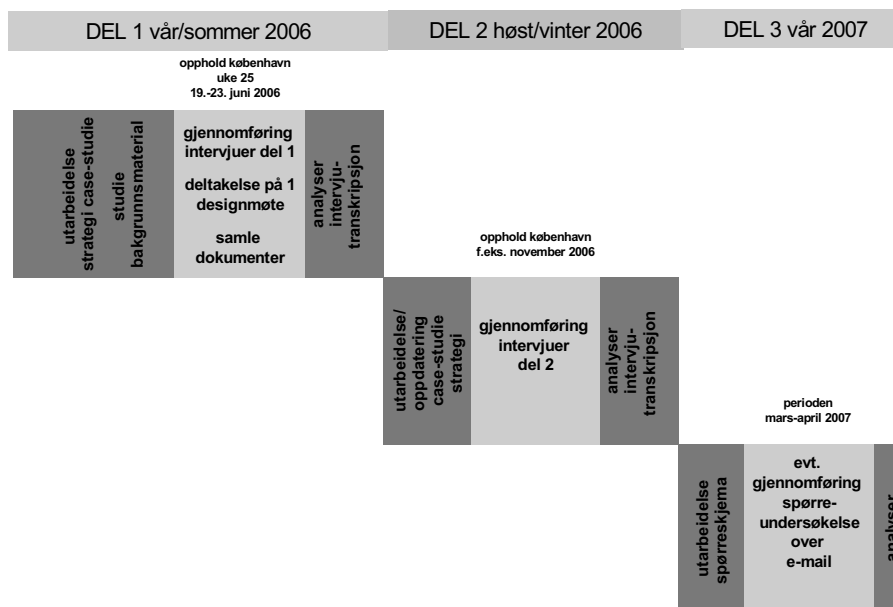
april 12 2006

Exploring relations between the architectural design process and ICT

FORMÅL, FOKUS, OVERSIKT CASE-STUDIE



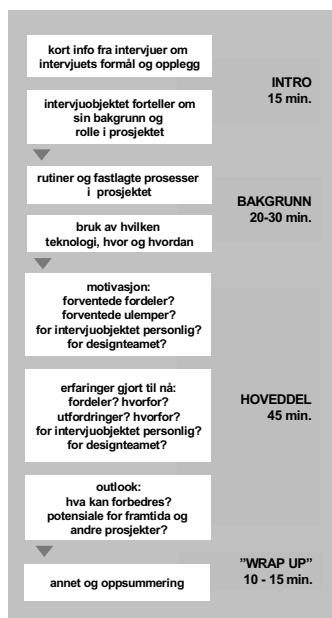
SKISSE TIDSPLAN



anita moum, stipendiat, institutt for byggekunst, prosjektering og forvaltning, NTNU

april 12 2006

SKISSE GJENNOMFØRING OG STRUKTUR INTERVJUER



FOKUS INTERVJUER

erfaringer og forventninger ved implementering og bruk av BIM knyttet til generering design ideer
 kommunikasjon
 evaluering av design ideer
 beslutningstaking
 angående designteamet generelt og den enkelte spesielt

HVA SLAGS INTERVJUER

åpne intervjuer – intervju-objektet bes fortelle om sine erfaringer og holdninger
 utgangspunkt er en liste med noen nøkkelpunkter

MED HVEM?

2-3 aktører på arkitektsida (HLT):

prosjekteringsleder (oversikt over prosesser, mål, visjoner)
 bruker av teknologi (som er involvert både i designaktiviteter og samarbeid/koordinasjon med konsulenter, og som deltar i designmøter)
 – evt. oppsplitting på to personer

2-3 aktører på konsulentsida (Rambøll):

prosjekteringsleder (oversikt over prosesser, mål, visjoner)
 bruker av teknologi (som er involvert både i designaktiviteter og samarbeid/koordinasjon med arkitekter, og som deltar i designmøter)
 – evt. oppsplitting på to personer

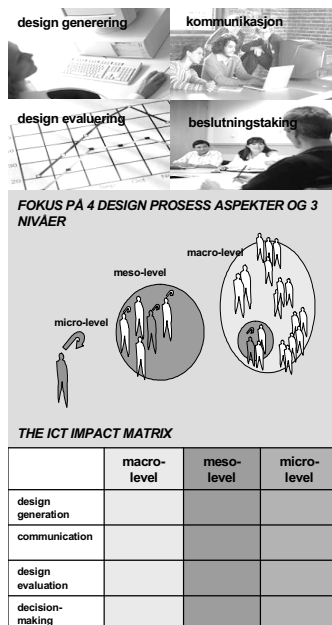
TIDSRAMME ETT INTERVJU

komplett ca. 1 time og 45 minutter. bakgrunnsdelen kan tas vekk etter de første intervjuene og/eller med god briefing før intervjuer – tidsramme intervju kan med det reduseres med en halv time.

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april 12 2006

HVA SKJER MED INFORMASJONEN FRA CASE-STUDIET?



intervjuene blir tatt opp på bånd, og transkribert (ordrett eller kun meningsgjengivelse) – intervjuobjekt får tilsendt en versjon av opptaket – dette er såkalt "rådata" – evt. må enkelte sekvenser avklares med intervjuobjektet i ettertid hvis usikkerhet om mening (per telefon eller e-mail)

data samlet fra intervjuer, dokumenter og evt. spørreundersøkelse blir analysert/tolket og oppsummert gjennom bruk av rammeverk. spissing av spørsmål og fokus skjer etter hvert som case-studiet gjennomføres.

data fra flere case-studier (flere byggeprosjekter) blir sammenlignet gjennom bruk av rammeverk

funn og data fra case-studiene blir brukt for å utforske og diskutere temaene definert i doktorgradsarbeidet – publisering planlagt i artikler – som til slutt blir samlet til en avhandling –

tema grad av anonymisering ved gjengivelse av funn må avklares før gjennomføring case-studie og senest før publisering.

kontaktpersonene i case-studiene blir holdt orientert om publiseringer og får et eksemplar av avhandlingen når den er ferdigstilt (digital eller hard-copy)

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april 12 2006

GENERELT OM BAKGRUNN OG MOTIVASJON FOR CASE-STUDIET



i andre bransjer som bil- og off-shore industrien har man lenge brukt 3D objektmodeller innenfor design og planlegging, - med suksess...

i flere land står man også innenfor byggebransjen på terskelen til det enkelte kaller et paradigmeskifte – gjennom implementering og bruk av 3D objektmodeller eller BIM (byggningsinformasjonsmodeller) i reelle byggeprosjekter forventes blant annet raskere gjennomføring, mer effektiv kommunikasjon og bedre beslutninger–

men det forventes også konsekvenser for tradisjonelle rolle- og prosessdefinisjoner.....

er implementering og interdisiplinær bruk av denne teknologien også i byggebransjen et skritt i riktig retning for å sikre utvikling og realisering av god arkitektur og gode byggeprosjekter?

hvor ligger barrierene for god bruk av BIM i praksis – innenfor prosessene? innenfor rolledefinisjonene? innenfor selve teknologien? hvordan kan disse barrierene oppheves? kan disse oppheves uten tap av kvalitet?

må de tradisjonelle prosessene innenfor designteamet og innefor samarbeidet mellom arkitekt og konsulent redefineres? må arkitekten tenke nytt angående sine arbeidsmetoder og sin rolle?

doktoravhandlingen og funn fra case-studiet kan ikke gi svar på disse spørsmålene – men arbeidet kan kanskje bidra til diskusjoner og videre forskning rundt disse og lignende spørsmål

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april 12 2006

PÅMINNELSE: OVERSIKT OVER AVHANDLINGENS TO HOVEDDELER

DEL 1: 02/2004 – 03/2008

TILNÆRMING
overordnet og bred

MÅL

bidra til bedre oversikt og forståelse for hvordan IKT påvirker/forandrer komplekse prosesser og relasjoner på alle nivåer i designprosessen

GJENNOM et vekselspill mellom

- 1) teori/litteraturstudier
 - designteori
 - management/prosesser
 - samarbeidsteknologi
- 2) utvikling rammeverk
- 3) overordnede studier av byggeprosjekter
 - pilot/test ilsvikaprosjektet trondheim
 - 1.del case-studie nye AHUS
- 4) referanseprosjekter (se del 2)

rammeverk er publisert og presentert på tre internasjonale konferanser

DEL 2: 06/2006 – 03/2008 (skisse)

TILNÆRMING
avgrenset "dykk"

MÅL

bidra til dypere forståelse for hvordan bruk av BIM påvirker valgte prosesser og arkitektens arbeid og samarbeid (fx med rådgivende ingeniører) innen designteamet

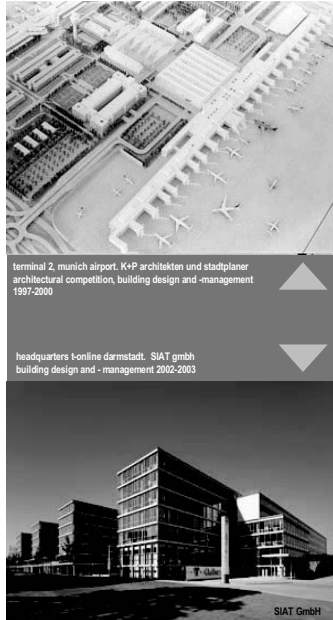
GJENNOM

- 1) bruk/videreutvikling rammeverk
- 2) studier referanseprosjekter
 - det digitale byggeri, danmark
 - byggekostnadsprogrammet, norge
 - proIT, finland
 - building smart
- 3) mulige case-studier av byggeprosjekter
 - nye AHUS, norge
 - høyskolen i Tromsø, norge (HITOS)?
 - concert- og kongrescenter reykjavik
 - berlin brandenburg international airport?

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BACKGROUND - CONTACT



graduated as a master of architecture in 1995 on the norwegian university of science and tehnology (NTNU)

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april 12 2006

Exploring relations between the architectural design process and ICT

conference paper a

Title: A three level approach for exploring ICT impact on architectural design and management applied to a hospital development project

Moum A (2005). Published in: Proceedings of the CIB W096 Architectural Management, Designing value: new directions within architectural management, DTU Lyngby, Denmark, November 2-4, 2005 (Emmitt S and Prins M, eds). pp. 83-92.

A THREE LEVEL APPROACH FOR EXPLORING ICT IMPACT ON ARCHITECTURAL DESIGN AND MANAGEMENT APPLIED TO A HOSPITAL DEVELOPMENT PROJECT

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ABSTRACT

An understanding of how ICT impacts the building design process and the architect's role and contribution within it can be crucial for ensuring good architectural design and management of building projects. This paper is based on a possible approach of organizing and structuring design process actions and roles, and how ICT impact on them. The approach is founded on the recognition of three levels within the building design process and focuses especially on four essential, interdependent and iterative aspects: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. This approach aims to contribute to a better overview of how ICT impact the building design process in general, and the architect's role and contribution in special. The purpose of this paper is to illustrate how this approach can be used to explore several architects' experiences due to use and implementation of ICT in a large hospital development project in Norway. The main experiences regarding the ICT implementation and use are summarized within an ICT impact matrix.

Keywords: ICT impact, architectural design and management, three level approach

INTRODUCTION

A fundamental pillar of a successful building project is a good design process. The future and development of a good architectural design solution depends on complex and iterative processes on several levels and with different actors (Lawson 1997). Over the years, the ICT (information and communication technologies) impact has led to dramatic changes within the construction sector average working day, affecting both processes and roles (Wikforss 2003). The participants within the building design process face ICT related benefits and challenges at several levels. On the international IAI (International Alliance of Interoperability) conference "BuildingSMART" in Oslo June 2005, one of the key-themes was the ICT related paradigm shift within the AEC sector and which threats and opportunities this shift inherits for the architect. The architect has traditionally a distinct and important role within the building design process (Gray & Hughes 2001). His skills makes him adaptable for several roles, from being a design specialist, translating the many project constraints into physical form, to being involved with management tasks; leading, coordinating and administrating the design process as the building design- or even the project manager. Although the traditional leadership role of the architect within these management tasks partly has passed to other management oriented professions (Emmitt 1999). An understanding of how ICT impact the building design process and the architect's role and contribution within it can be crucial for ensuring good architectural design and management of building projects.

This paper is based on a possible approach of organizing and structuring design process actions and roles, and how ICT impact them (Moum 2005a; Moum 2005b). The approach is founded on the suggestion of three levels within the building design process and focuses especially on four essential, interdependent and iterative aspects: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. This approach aims to contribute to a better overview of how ICT impact the building design

process in general, and the architect's role and contribution in special. The purpose of this paper is to illustrate how this approach can be used to explore several architects' experiences due to use and implementation of ICT (especially an IFC-based 3D object model) in a large hospital development project in Norway. This is one of the first attempts of applying the approach to a real-life building project. The resulting first and tentative impressions of the approach's adaptability on practice are intended to establish a basis for further development of the approach.

After a short description of the project, the three-level-approach will be explained and the four interview respondents introduced. All respondents are architects involved in management tasks on different levels in the project. The main points from the interviews regarding the implementation and use of ICT will be explored and described. The interview respondents' perception of the project processes, participants, and the use and impact of ICT, can deviate from how something really happened. Also, the intention of this paper is not to cover all aspects which came up during the interviews, rather some of the key points will be described to illustrate and discuss the adaptability of the approach on practice. At the end of the paper, an ICT impact matrix summarizes these key points (Table 1). This paper and the three-level approach contribute to a framework for further inquiry about the relation between ICT and the architect's role and contribution within design and management of building projects.

INTRODUCING THE REAL-LIFE PROJECT: AHUS

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 (Figure 1). 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 (www.nyeahus.no). The architect suggested early to implement a 3D object model (building information model or BIM) based on IFC (Industry Foundation Classes) and intelligent objects. The client's "go" for this suggestion, made the AHUS project to what Khemlani (2005) 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 the main entrance, an auditorium and a cantina (Figure 2). 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. Summer 2005 the front building project is going to be handed over to the contractor and the production of the building starts. All key participants of the total building project work collocated directly beside the building site.

The four ICT cornerstones of the project and some of the visions behind them

There are four ICT cornerstones in the front building project. Firstly, the 3D object model (AutoCad ADT 2004) which: *Given the huge size and complexity of the project (...), the main focus of the use of BIM 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* (Khemlani 2005). This paper focuses mainly on the implementation and use of this 3D object model. According to the contract, the 3D object model is the property of the client. Secondly, in a document database (ProArc) all drawings and documents are archived and distributed, no parallel document archiving is allowed. Up-to-date project material is accessible to every project participant, independent of time and place and without the danger of working with or discussing obsolete material. Thirdly, a room database containing room

lists, equipment lists etc. represents the users programme and requirements (dRofus). And finally, e-mail is an important tool in the everyday project communication. IFC-based BIM could eventually become a standard building process tool in some years, and an essential aim for using this tool within AHUS, is to collect experiences and build up competence around the implementation and use of this still quite new and untested technology within the AEC sector. Against the original intention comprising both architects and consultants, only the architect work directly with the 3D object model. Three IFC R&D projects are going to be and partly are implemented and tested within the planning of the front building. 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. The last project is to transfer object information to Facilities Management (FM) systems (Bakkmoen, BuildingSMART conference in Oslo, 31.05.-01.06.2005). An open question in the project today, is to which extent the contractor will implement and use the 3D object model in the further realization of the project.

THE THREE LEVEL APPROACH AND THE INTERVIEW RESPONDENTS

Three levels of operations and actions within the building design process are suggested. The micro-level comprises individual and cognitive processes, as the creative processes in the head of the individual architect. 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 organizational or project level (Figure 3), as e.g. architectural- or project management (Moum 2005a).

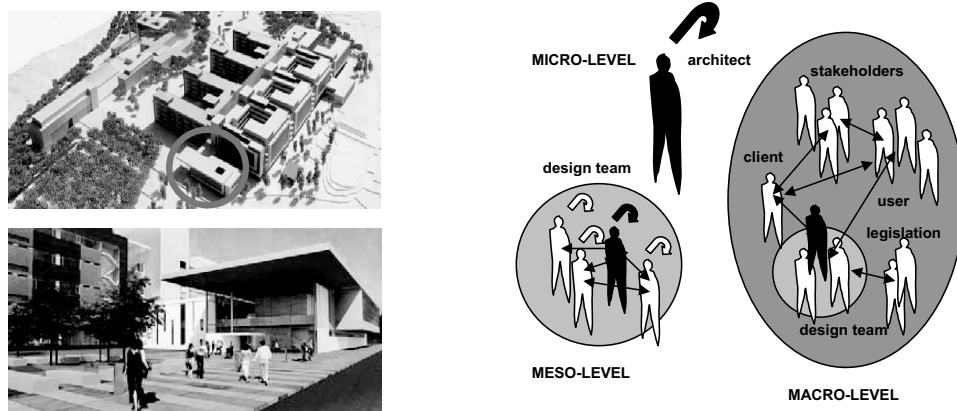


Figure 1 (left top): The new Akershus University Hospital (from: www.nyeahus.no)

Figure 2 (left bottom): The front building (from: www.nyeahus.no)

Figure 3 (right): The three hierarchical levels

All four persons interviewed are architects, involved with management tasks on different levels and within different contexts.

Respondent A: female architect, employee of the architectural company, 20 years practical experience. Her main tasks are the individual generation of design solutions regarding the front building interior (micro-level) and the development and coordination of these design solutions within the design team (meso-level). Since she is the vice manager of the

architectural team, she also to some extent takes part in the discussions with users and clients (macro-level).

Respondent B: male architect, employee of the architectural company, 9 years practical experience. He has the formal responsibility of managing and representing the architectural front building team (meso- and macro-level), in addition (since the team only comprises three persons) he designs and develops the front building envelope (micro-level).

Respondent C: male architect, employee of the architectural company, 27 years practical experience. He is the vice building design manager for the total project from the architect group, responsible for the administration of the work processes and the production of planning material (macro-level). He is also the key-person behind the overall project systematization and the implementation and development of the 3D object model and the R&D programme.

Respondent D: male architect, employee of the client organization, 24 years practical experience. He is one of five project managers, with responsibility for the planning part of the overall building project and the management of the contracts with the architect and the other consultants (macro-level).

The presented data from the interviews are intended to give a rough picture of how ICT impact on all levels and all four design aspects, thus demonstrating and illustrating how the approach can be applied to a real-life project. Therefore interview respondents were selected representing experiences perceived from different levels, views and positions within the front building project. Respondent A is a frequent user of the 3D object model, without a direct influence on the implementation and development of the model. This is the responsibility of respondent B and C, who both administrate and facilitate the implementation of the model in the front building team and on project level. Respondent D has 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.

AHUS: USE AND IMPLEMENTATION OF ICT ON MACRO-LEVEL

On macro-level there are 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. Every decision regarding the design and development of the front building is made here. The participants in these meetings are, in addition to a person representing the user and the client (project part manager), the responsible persons from the different building planning disciplines. Thus, both respondent A and B participate in these meetings. Another meeting forum is the total project meeting, which focuses on strategic and administrative aspects due to the total project. Meeting leader is the respondent D. Respondent C participates in some of these meetings as a vice leader of the architectural discipline. Finally, the future users of the new hospital have a central position in the definition of requirements. The extensive degree of user participation required regular meetings between the users, clients and the planners autumn 2004.

Macro-level experiences from implementation and use of ICT- some examples

The 3D object model is not used directly in the formal meetings. Evaluation of the project development and decision-making are based on views or cut-off drawings (2D) generated from the model, partly projected on a screen using a beamer. In the total project meetings, every participant brings their own laptop. Once a week a cut-off of the 3D object model is laid

out into the document database, thus every relevant and up to date drawing or document is easy and fast accessible, which respondent D regards as a huge advantage of ICT. In comparison, within the front building planners meetings the pen, sketch paper and physical models are still central tools supporting ad hoc solution generation and decision-making. Regarding the user meetings, the 3D object 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.

An interesting aspect, which came up in the interview with respondent D, was the rigidity of the ICT tools regarding presentations. He perceived that perfect, static and almost finished looking drawings and illustrations presented in the meetings did not lead to dynamic, open and flexible discussions. Rather the presentations paralyzed the meeting participants and made it difficult for them to suggest changes.

The implemented IFC based 3D object model version does not support rendering of the objects. Thus, it is not possible to generate realistic visualizations and walk-throughs directly in the 3D model environment, which could be used for more dynamic and interactive presentations of design solutions in e.g. the users meetings. However, the 3D object model of the front building has now reached a stage where calculations and simulations regarding indoor climate, energy consumption etc. are possible. But the model is "heavy" to use and change in this late stage of design. Therefore, to work directly in the 3D environment in meeting situations demonstrating e.g. "live" simulations seems to remain being difficult since more rapid simulations or visualizations of results are required.

From the client's view (respondent D) ICT offer good possibilities for better could follow, control and evaluate the development of the planning. Cut-offs and the viewer technology make the access to the 3D object model easier. However, respondent D perceives the model being a black box to which the client has no directly access, unless he has special ICT competence. In this project, this drawback of ICT is compensated by the collocated situation, since the client can easily get information from informal face-to-face meetings with the architect.

An unexpected limitation of the implementation was the need for more powerful computer processors. The object model files are heavier than the traditional line-based 3D models. With this experience, another and improved file structures could be adapted to future projects. The emerging viewer technologies could support a better overview and help preventing information overload. In this project physical views make the 3D object model easier accessible.

AHUS: USE AND IMPLEMENTATION OF ICT ON MESO-LEVEL

Although every communication between the architects and the other consultants theoretically should include the client, informal communication within the design team is 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. Because of the collocated situation, there is only a limited use of ICT and the 3D object model within the meso-level design process.

Meso-level experiences from implementation and use of ICT- some examples

As only the architects work directly with the 3D object model, the other consultants use the once a week 2D cut-offs and dwg-files as their base of planning. The cut-offs and the dwg-files are accessible in the document database. The elements received from the consultants, for instance columns and slabs from the structural engineers, the architects partly must “transform” to fit into the model. Since the architects themselves generate model objects from other consultants’ elements, they have according to respondent B, better control of the consistency between e.g. architectural and structural elements. As described, the everyday communication within the design team comprising architects and other consultants are mostly face-to-face, but also telephone and e-mail are important communication tools. Tentative and informal drawings are often exchanged using e-mail.

AHUS: USE AND IMPLEMENTATION OF ICT ON MICRO-LEVEL

Every architect working with the AHUS project shall be able to operate the ICT tools implemented in the different project parts. There are offered courses and manuals for learning and updating knowledge about continuously and rapidly developing software.

Micro-level experiences from implementation and use of ICT- some examples

The individual architect works within a 2D user environment, dragging and dropping 3D objects. According to respondent C, this way to “draw” should be easier as the traditional drawing with lines, and normally no special competence of the every day operator is necessary as long as pre-defined objects are accessible. However, till now, there are no pre-defined library of objects and building elements available. Every intelligent and IFC exportable object must be defined “from scratch”. Both defining and changing these objects means time consuming processes within narrow time limits. There are not many architects within the project having the required competence for such tasks. This leads to bottlenecks in the planning and loss of valuable time. Respondent A indicates the danger that planners could be tempted to avoid improving changes in stressed project periods. Furthermore, she points out that the lacking time and recourses to learn and be up-to-date partly lead to an inefficient use of the rapidly developing ICT tools. The implementation of the model requires that the architects working with it continuously have to extend their competence concerning the use of the software, which till now is difficult to operate, not intuitive and parametric. The narrow time limits do not allow much time for absorbing information offered through courses and user-manuals.

Respondent B emphasizes the importance of knowing the limitations and problems due to the technology used, in order to realistically understand and manage the manpower and time needed to build up the front building 3D object model. More time than expected had to be invested in programming and modelling. In the front building team, one person is full time involved with programming and building the 3D model. Also the maintenance of the room database requires extra effort, since every change must be made in both the 3D object model and this database. However, the R&D project regarding the linking of the room database with the 3D object model is partly implemented. In close future every participant in the architectural team should be able to enjoy the benefits of this combined technologies. Generally, the working with the ICT tools implemented in this project requires much discipline, effort and resources.

Both respondent A and B only to a limited degree use the 3D object model in the individual generation and visualization of design solutions. According to respondent A, she first makes some rough sketches with pen and paper, before she transforms the idea into computer

generated drawings, which with its accuracy offer an early “test” of the design idea’s feasibility. However, her concern is that the middle stage between rough sketch and detailed precise drawing has disappeared, eventually leading to loss of creative freedom and overview of the totality. She tests her design ideas traditionally in 2D computer environment, using lines, not objects. Transforming the 2D lines into 3D objects is made later, which partly results in a 3D model not completely based on objects. In addition, both respondents see 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. However, respondent A emphasized the possibilities of reusing details and solutions as a benefit of ICT and a support of generating design solutions.

SUMMARY

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. The focus of the 3D object model in this project lies more on the implementation of an object-oriented way to work than the possibilities due to 3D visualization (Bakkmoen, BuildingSMART conference in Oslo, 31.05.-01.06.2005). According to the interview respondents, the key advantages and possibilities of the ICT are better project material quality and consistency, and a more uncomplicated project transition from planning to construction. 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, are aware of what they perceive as the overall 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 of the building, the key persons behind the ICT implementation hopes to “reap the fruits” of the many participants’ effort and commitment.

CONCLUSIONS

This paper has illustrated how the introduced three-level-approach can be used to explore the ICT impact on a hospital development project in Norway. The tentative impressions of the approach’ 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. The intention behind this approach is not to force aspects of the complex architectural design process into rigid categories, rather it aims to contribute to a better overview of how ICT impact on the building design process in general, and on the architect’s role and contribution within architectural design and management in special. This paper only presents the first impressions of the approach’s adaptability on practice. For extending the empirical basis, further case studies and interviews should be carried out. Also more participants of the AHUS project could be interviewed, not only architects. The applying of the approach to more real-life projects could on the one hand contribute to further improvement and development of the approach, and on the other hand contribute to a better understanding of how ICT impact on the design process and the architect’s role and work.

Table 1: the ICT impact matrix, outline summary of experiences from implementation and use of the 3D object model

	Micro-level	Meso-level	Macro-level
Generation of the design solution	<p>Use and experiences:</p> <ul style="list-style-type: none"> • 3D object model not used directly for design generation, rough hand sketches and 2D line-based drawings the facilitators of design generation – after finding an appropriate solution, it is “transformed” into object-based modelling. • 3D object model heavy to operate and change – it is not intuitive and parametric. • Individual architect is working within a 2D environment, dragging and dropping 3D objects. • No pre-defined objects available, every object and element must be defined from scratch – time consuming. • Few people have competence to change objects – bottlenecks and delays by changing - danger of avoiding improving changes. • Possibility of reusing solutions and details benefit. 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • Ad hoc solutions mostly developed using traditional tools as pen and paper, physical models etc. in a face-to-face environment. 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • Rigidity of ICT generated finished looking drawings and illustrations presented in the meetings paralyzed the participants and made it difficult for them to suggest changes. In this case, the ICT tools did not support dynamic, open and flexible discussions.
Communication within the design process	<p>Use and experiences:</p> <ul style="list-style-type: none"> • 3D object model not used directly for design generation, rough hand sketches and 2D line-based drawings are the basis for the “designers conversation with the design situation” (Schön 1991) 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • On this level there is mostly informal face-2-face communication. • Only architect work with 3D object model. • Once a week cut-offs from model (dwg) is made accessible on document data base. • Exchange of tentative data by using e-mail. 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • All participants have access to document and room database – always up to date material. • Use of beamer makes the project material easy accessible to all participants in meeting situations. • 3D model itself a “black-box” for client, unless special competence. A limitation of directly following the design development. In this project collocated situation compensate the limitation.
Evaluation of the design solution	<p>Use and experiences:</p> <ul style="list-style-type: none"> • Much information to be overviewed and maintained in the model, development of viewer technologies could help focusing attention for evaluation. • Use of hand-drawn perspectives, sketches and 2D computer line-based drawings rather than directly using 3D model for evaluation– which is to “heavy”, unless special competence. 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • Today, the 3D object model is only to a limited or no degree used in design idea evaluation. • However, the model shall in close future support simulations of e.g. indoor climate etc. • The architect partly “transforms” slabs and columns from structural engineer to 3D model objects – gives opportunity to directly control consistency between architecture and structure. 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • 2D views and cut-offs of the 3D object model regularly accessible to the client and the other participants. • The 3D object model not directly used for “live” simulations and visualisations in meeting situations – model to “heavy” and the IFC version implemented does not support rendering of the objects.
Decision-making within the design process	<p>Use and experiences:</p> <ul style="list-style-type: none"> • Use of hand-drawn perspectives, sketches and 2D computer line-based drawings rather than directly using 3D model for decision-making. • The model-checker enables clash-and doubles detection of 3D object model –higher quality and consistency of drawings before passing drawing to next level. 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • On this level there is mostly informal, ad-hoc and face-2-face decision-making. Formal decisions on macro-level. • Ad hoc decisions based on f2f discussions and the use of pen, sketch paper and physical drawings. 	<p>Use and experiences:</p> <ul style="list-style-type: none"> • Decisions made only in formal meetings. • In the project meetings participants have own laptops – always directly access to data base and up to date material. • High quality and consistency of project material. • Generation of drawings from 3D object model benefit when decision material regarding 1000 unique room must be made.

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), who suggested the AHUS as case, and associate professor Birgit Sudbø. A thank goes also to Kjell Ivar Bakkmoen, Bård Rane, Astrid Seeberg and Steen Sunesen for their willingness to sacrifice time and effort, giving interesting answers on many questions.

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conference paper b

Title: 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.

Moum A and Bock T (2006). Published in: Proceedings of 23rd International Symposium on Automation and Robotics in Construction (ISARC), Tokyo, Japan, October 3-5, 2006. pp. 107-112.

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 a 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 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 (Fig.1).

An ICT impact matrix (Table 1), 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 aim 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 and to achieve a well structured and consistent

information environment as a prerequisite for construction and service robot applications.

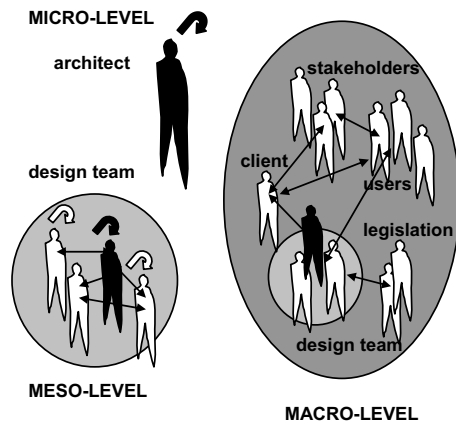


Figure 1. The three hierarchical levels

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 product 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 product 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 product 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 (Illustration: C.F. Møller Architects).

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 were 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 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 NORWEGIAN 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) 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 feasibility and investment analysis to briefing and maintenance of building. Intelligence acquisition from investment decision, to rentability and serviceability, buildability and reusability 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 is to define which information is necessary for making the best decisions on every stage in the project.

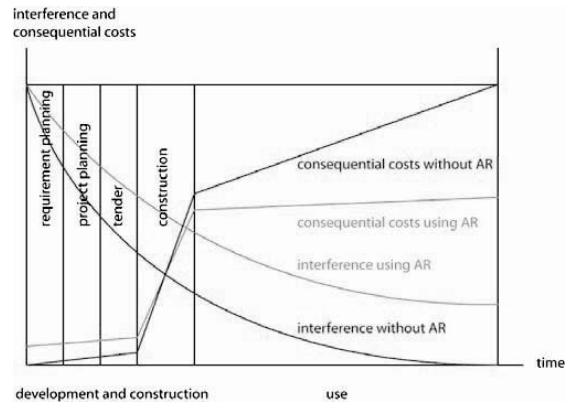


Figure 3. Interference of building investments

The use of a 3D product model supports 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 the capturing of 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 Cincinnati 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 direct 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 INDIVIDUAL 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 led 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 used 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.

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.

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	<p>benefits:</p> <ul style="list-style-type: none"> - design generation based on life cycle knowledge <p>challenges:</p> <ul style="list-style-type: none"> - understanding the creative processes - technical competence required 	<p>challenges:</p> <ul style="list-style-type: none"> - model not intuitive and parametric, heavy 	<p>benefits:</p> <ul style="list-style-type: none"> - reuse of solutions - pre-defined objects <p>challenges:</p> <ul style="list-style-type: none"> - model not intuitive and parametric - much competence required - time-consuming - implementing object-oriented working method - predefinition of products
Communication	<p>benefits:</p> <ul style="list-style-type: none"> - interoperability - less communication friction - merging of borders between planning, production and maintenance <p>challenges:</p> <ul style="list-style-type: none"> - contractual issues/definition responsibilities - cultural issues/different working cultures 	<p>benefits:</p> <ul style="list-style-type: none"> - better access to consistent and updated information <p>challenges:</p> <ul style="list-style-type: none"> - different working cultures - lack of trust regarding quality of documents received from other disciplines - redefinition of working methods 	<p>benefits:</p> <ul style="list-style-type: none"> - better access to consistent and updated information - potential of generating ideas in virtual reality - rapid production of consistent project material <p>challenges:</p> <ul style="list-style-type: none"> - not intuitive and parametric - rough hand-sketches the basis for the ideation
Evaluation of design solutions	<p>benefits:</p> <ul style="list-style-type: none"> - testing virtual building before physical building <p>challenges:</p> <ul style="list-style-type: none"> - degree of detail - info overload 	<p>benefits:</p> <ul style="list-style-type: none"> - potential of real-time simulations - potential better coordination (e.g. clash-control) <p>challenges:</p> <ul style="list-style-type: none"> - time-consuming - not intuitive 	<p>benefits:</p> <ul style="list-style-type: none"> - precision - “visual” control of complex esthetical issues <p>challenges:</p> <ul style="list-style-type: none"> - time-consuming
Decision-making	<p>benefits:</p> <ul style="list-style-type: none"> - decision-making based on consistent information - reduction of uncertainty <p>challenges:</p> <ul style="list-style-type: none"> - definition of which info is necessary - info overload 	<p>benefits:</p> <ul style="list-style-type: none"> - consistency and precision of decision material - reduction of uncertainty <p>challenges:</p> <ul style="list-style-type: none"> - bias relation technical and esthetical aspects 	<p>benefits:</p> <ul style="list-style-type: none"> - consistency and precision of decision material - reduction of uncertainty <p>challenges:</p> <ul style="list-style-type: none"> - presentation taking focus from content of design

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 of 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.

9. ACKNOWLEDGEMENTS

This paper is based on collaboration between a PhD study and doctoral scholarship financed by the Norwegian University of Science and Technology (NTNU) and research carried out on the Technical University in Munich, Department of Building Construction and Informatics. The authors would like to thank Kjell Ivar Bakkmoen, Bård Rane, Astrid Seeberg and Steen Sunesen for their willingness to sacrifice time and effort, giving interesting answers on many questions.

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working paper

Title: ICT and the architect's work and contribution in the design process. An exploration of the implementation and use of IFC-based BIM in the AHUS project.

Working paper written as a part of the course: 'Architectural design theory and practice' (DIXIL-01) in the autumn of 2005. NTNU. Not published!



ICT AND THE ARCHITECT'S WORK AND CONTRIBUTION
IN THE DESIGN PROCESS
an exploration of use and implementation of IFC-based
BIM in the AHUS project

project report "architectural design: theory and practice"
autumn 2005, DIXIL-01

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FOREWORD

Design in general can be seen to pass through phases of relative certainty and doubt.” (Lamson, 1997, p. 163)

This report is part of a subject called “Architectural design: theory and practice”. The purpose of this subject is to gain knowledge about theory and practice within architectural design. How does the architect think and work in practice, and how does the architect interact with the other participants in the architectural design process? How does the use and implementation of ICT impact on these issues?

The subject is part of a PhD-study and doctoral scholarship financed by the Norwegian University of Science and Technology (NTNU). The main topic of the PhD-study is to explore the relation between ICT and the complex and iterative processes embedded in the development of architectural design, with special focus on the architect’s work and interaction with other design process actors.

The main purpose of the report is to explore benefits and challenges regarding the implementation and use of an IFC-based 3D object model (BIM) in practice. The exploration is based on a case-study of a hospital development project in Norway and a review of key elements in recent literature. A theoretical framework for exploring and analysing empirical and theoretical data is applied.

I would like to thank Tore Haugen, the main supervisor of the PhD-project, for his helpful comments and advice, and especially for his advice to explore this particular project. In addition, my sincere thank to Kjell Ivar Bakmoen, Bård Rane, Astrid Seeberg and Steen Sunesen for their willingness to sacrifice time and effort for answering my many questions. C.F.Møller Architects is credited here for making their images available for this report.

Anita Moum, 5 December 2005



Figure 1. *The work of the architect (www.viat.de)*

Figure front page: *Based on Theodor Kittelsen’s “Soria Moria slott” (from: www.bergen.folkebibl.no)*

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1 INTRODUCTION

1.1 Overview

A fundamental pillar of a successful building project is a good design process. The field of architectural 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 ICT has led to several changes in the AEC industry. The network technologies, advanced visualization tools and CAD are some examples of ICT, which represent powerful potential of facilitating change and improvement. Much research of today focuses on the development of new and improved ICT (Information and Communication Technologies). However, the participants within the building design process face ICT related benefits and challenges on several levels. Both working processes and role definitions (Wikfors 2003) are affected. An understanding of how ICT impact the complex building design process (and the architect's work and contribution within it) can be crucial for ensuring good architectural design and management of building projects.

The new Akershus University Hospital (AHUS) is a major hospital development project in the suburbs of Oslo, Norway. The front building (one of five building parts) team uses an IFC-based 3D object model (BIM) to (almost) its full extent. Until now, there have not been collected much experiences regarding BIM-use in Norway, and an exploration of the AHUS project, for the moment regarded as a "front runner in Norway in the use of IFC-based BIM" (Khemlani, 2005), could give valuable insight in how such technology impacts the architectural design process and the architect's work and interaction with other participants.

1.2 Purpose and scope

The main purpose of the report is to explore the experiences made in the AHUS project regarding the implementation and use of an IFC-based 3D object model (BIM) in the architectural design process. Special attention is paid to the architect's work and interaction with other design process participants. Based on interviews with four architects involved in the front building project, the exploration attempts to give an insight in the motivations and aims behind the implementation, the experiences made from the use of the technology and the key respondents attitudes regarding future potential and challenges. For exploring and analysing the AHUS project and the interviews, a theoretical framework is applied. A brief explanation of the framework is given in the method section of the report, and the adaptability of the



FOCUS OF REPORT AND CASE-STUDY

WHAT: benefits and challenges regarding the use of IFC-based BIM in the AHUS project.

WHEN: architectural design process

WHO: the architect involved in management and design tasks



framework is discussed in the conclusion part. The key BIM related benefits and challenges are summarized at the end of the report and some lessons learnt from the AHUS project are suggested. Finally, possible next steps and areas of further investigation are discussed.

1.3 Some central terms and how they are used in this report

The following section explains how central terms are used in this report.

The architect's work and contribution

The architect has traditionally a distinct and important role within the building design process (Gray & Hughes 2001). His skills makes him suitable for several tasks and roles, from being in design specialist, translating the many project constraints into physical form, to being involved with management tasks; leading, coordinating and administrating the design process as the building design- or even the project manager. This report focuses on architects involved in management as well as in design development.

The architectural design process

As a simplified explanation, one could say that the design process are situated between the statement of the brief and the start of the building site. One could perhaps also say, that the design process aims to translate the requirements and constraints defined in the brief into an architectural design idea, which through drawings/models/words again can be translated into physical form. The architectural design process can be sub-divided into different phases; for instance the outline design phase, the scheme design phase and the consultants' detailed design phase (Gray & Hughes, 2001). Different countries can have different definitions of the required performances of each of these phases. These definitions are often formal embedded in rules or guidances (Norway: AY, Germany: HOAI). However, in practice, a pure sequential process, where one phase follows the other, is a seldom phenomena. Because of several reasons, as for instance limited time recourses and poorly defined briefs, and the increased use of ICT, phases often overlap (Fig. 2). Therefor, it seems difficult to focus on the design process as an isolated phenomena, although the focus of the work is clearly placed in a project phase with a high density of design actions. The connections and joints to briefing and constructions will remain an issue, at least on an overall level. In the case-study introduced in this report, a "cut" through a late phase of the architectural design process is analysed and presented.

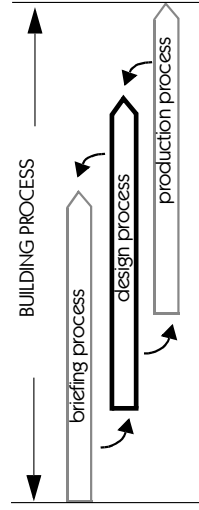


Figure 2. The building process and its main three phases (based on illustration in "Samspillet i Byggeprosessen" Haugen & Hansen 2000, p. 10).

FOUR STRATEGIC CATEGORIES OF TECHNOLOGY

Wikfors (2003) describes four strategic categories of technology: database technology (server- or web-based database offering a pool of information as documents, drawings etc.), the network technologies (e-mail, Internet, World Wide Web), development of understandable user surfaces and the technology of computer graphic and new media (Virtual Reality, 3D object models/BIM, cyberspace etc.).

Architect. A master-builder. spec. A skilled professor of the art of building, whose business it is to prepare the plans of edifices, and exercise a general superintendence over the course of their erection. Oxford English Dictionary Online.

Benefit. Advantage, profit, good. (The ordinary sense.) For the benefit of; for the advantage of, on behalf of. To take benefit of (a thing): to take advantage of, avail oneself of. (Latin: benefactum good deed, kind action, lit. (a thing) well done, from bene (avere to do well), Oxford English Dictionary Online.

Challenge. A calling into question or disputing; the state of being called in question. An invitation or summons to a trial or contest of any kind; a defiance. In weakened use: a difficult or demanding task, esp. one seen as a test of one's abilities or character (Latin: calumnia, trickery, artifice, misinterpretation, false accusation, malicious action at law; probably from calvi, calvere to devise tricks). Oxford English Dictionary Online.

ICT and BIM

The term Information and Communication Technologies comprises a broad range of devices and tools. This report and the PhD research generally focuses on computer supported technologies developed for the AEC industry. Communication technologies as e.g. cell phones are outside the scope. This report focuses especially on IFC based 3D object models, also called BIM (building information models). A more detailed explanation of IFC-based BIM will follow later in this report.

ICT related benefits and challenges

As an attempt to operationalize the very broad and diffuse word “impact”, the terms benefit and challenge are used. Generally, the intention of this report is not to classify any of the explored ICT impacts on the architectural design process and the architect's work, as purely bad or good. Which seems to be a disadvantage in one situation or according to one person, could be perceived as an advantage in another situation, perhaps because the computer program is not used efficiently or the user is not skilled enough. To use the word challenge instead of weakness or disadvantage is a conscious choice. Challenge implies that something is questioned, without necessarily giving a judgement in the terms of good or bad.

2 METHOD AND FRAMEWORK

2.1 Methodological strategy

The underlying aim of this report is to gain understanding of how ICT impact the architectural design process, with special focus on the architect's work and interaction with other key participants. A case-study strategy is chosen as main method for collecting data about the phenomena. A "learning from practice" can give valuable insight about processes and actors. An exploratory approach underpins the conducting of the case study. According to Robson (2002) an explorative strategy is appropriate when trying to find out what is happening in little understood situations, seeking new insight, asking questions, and generate ideas and questions for future research. The AHUS project was selected as the case study object, since this project is in a front position in Norway regarding the implementation and use of IFC-based BIM. The main part of the case study (the interviews) was carried out in May 2005.

A literature review of the field and the development of a theoretical framework establishes a "back drop" for conducting and analysing this explorative case study of the AHUS project.

As described in the introduction, the main objective of the case-study is to collect data about the key actors' (architects') experiences and attitudes regarding the use and implementation of IFC-based BIM in their daily work. Since a theoretical framework is used as a help to conduct the case study, another issue is to reflect on the ability of the developed framework to support the exploration of this real-life project. The scope of the case-study is consciously relatively open, since the aim of the exploration is to contribute with an overview of the complex relationships between processes and actors. However, in a next step, the exploration could become the fundament for narrowing the scope of further investigation in order to gain deeper insight within some of the problem areas.

2.2 The theoretical framework

To explore the ICT impact on the architectural design process is a huge undertaking. The need for an approach for organizing and analysing the multiple and complex amount of information collected from theory and practice, led to the development of a theoretical framework. The intention of the framework is to support the exploration of the topic, in order to help keeping overview and to contribute to a better understanding of relationships and events. This framework has already been introduced in papers presented on three international conferences (Moum a-c, 2005).

The case study method allows investigators to retain the holistic and meaningful characteristics of real-life events (Yin, 2003, p. 2).

WORKING WITH LEVELS

Yin (2003) describes four different groups of theory: individual theories (e.g. cognitive behaviour, individual perception), group theories (e.g. work teams, interpersonal networks), organizational theories (e.g. interorganizational partnerships) and societal theories (e.g. marketplace functions, international behaviour). (Yin, 2003, p. 31).

Emmitt and Gorse (2003) refers to Kreps (1989), who divides human communication into four levels: 1) intrapersonal communication (thought process of one person), 2) interpersonal communication (communication between two), 3) small-group communication and 4) multi-group communication (enables different groups to coordinate efforts). (Emmitt & Gorse, 2003, p. 44)

The terms micro-, meso- and macro are used in different settings, among others within economics and communications.

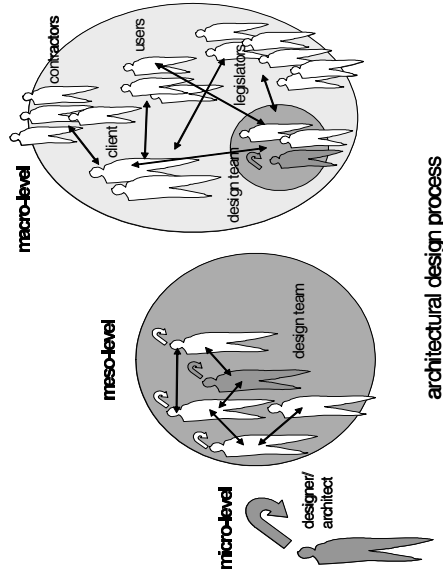


Figure 3: The three hierarchical levels

The framework is based on the suggestion of three levels of operations and actions within the architectural design process; called the micro-, meso- and macro-level (fig. 3). The micro-level comprises individual and cognitive processes, as the creative processes in the head of the individual architect. 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 organizational or project level, as e.g. architectural- or project management (Moum, 2005a-c).

The framework focuses furthermore on four central aspects of the architectural design process; the generation of design solutions, communication, the evaluation of design solutions and decision-making. 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" into something that can become the conceptual fundament of the building project (Lawson 1997). Making good decisions regarding which design solutions are worth being put to the paper or which proposed architectural design concept should become the foundation of further development, relies heavily on the designer's individual ability to generate, but also to communicate good design solutions. Communication is in much literature emphasized as a key to success and good decision-making on several levels in the architectural design process (Emmitt and Gorse 2003, Kalay 2004, Lawson 1997, Lundquist 1992c, Schön 1991). The communication and interaction between the building process actors, each representing different interests and experiences as basis for evaluation and interpretation of the proposed design solution, can essentially impact the decisions made and the further development of the architectural design solution.

As a part of the framework, an ICT impact matrix is suggested (fig. 4) as a tool for summarizing and giving overview of the key points of an exploration (Moum, 2005a). The lines between the different levels and design aspects in the illustration, should rather be understood as a "translucent" screen between interdependent elements than fixed borders between rigid categories. A puzzle could probably be an appropriate metaphor to describe the complexity embedded in the matrix (fig. 5).

Figure 4: The ICT Impact Matrix

	micro-level	meso-level	macro-level
design generation			
communication			
design evaluation			
decision-making			
	Summarizing key points from ICT impact exploration		

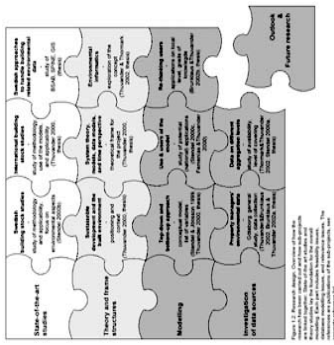


Figure 5. Puzzle (from: thesis Liane Thumader 2002, p. 7)

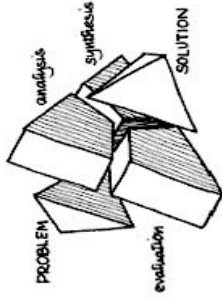
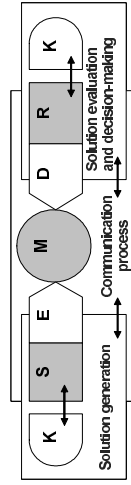


Figure 6: What is going on in the head of the designer? (from "How designers think - the design process demystified" Lawson, 1997, p.47)



K=knowledge, S=sender, E=encode, M=message, D=decode, R=receiver

Figure 7: Illustration of communication process.

THE FOUR DESIGN ASPECTS

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 (Lundquist 1992b). The first generation design methodologists focus on the design process as something sequential and linear, was to be challenged. Lawson (1997) critically emphasizes that there is no clear distinction between problem and solution, analysis, syntheses or evaluation in the design process (Fig. 4). 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 (Lawson 1997). The generation of design solutions is not reserved the individual. The importance of collaboration is growing. The focus changes from the individual to the collaborative design process, and this introduces a challenging dimension in the idea finding process: the interaction between the individual and the group (Lawson 1997).

Communication. Schön's (1991) description of the design practice (e.g. sketching) as a conversation or reflective dialogue between the designer and the design situation or design issue, or what Kalay (2004) calls 'iteration or an intra-process role of communication represents one level. The dialogue between two individuals, the extra-process role of communication represents another. As illustrated in figure 7, 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. The architect must encode the design solution in the form of some symbolic language, which is then transmitted, through a suitable medium (e.g. paper drawing scale 1:100), to the client, which must decode the design solution to understand it. Both the client and the architect decode and encode information based on their knowledge, or frame of reference (Kalay 2004). 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 (Griffith et al 2003). Wittgenstein's language game theory is one illustration of this problem area (Lundquist 1992a). 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. A central part of the architect's competence is to understand the language games and to use terms in a meaningful way (Lundquist 1992a).

Evaluation of design solutions. The architectural design process is in addition to the measurable, quantitative and conscious based on the qualitative, intuitive and tacit (Kivimäki 2004, Lawson 1997, Wikfors 2003). 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?" (Lawson 1997, p.62). Lawson (1997) emphasizes that a crucial skill of the designer is to balance qualitative and quantitative aspects. Lawson (1997) relates the use of computer within the design process to several roles. The computer in a solution generation role actually designs for us. The computer in the solution evaluation role however, only responds to the design ideas of the designer, giving feedback on e.g. how it will work.

Decision-making. The generation and evaluation of design solutions, and the issue of communication, can be seen to establish the foundation of decision-making. The moments of decision-making on different levels are crucial for the development of design solutions and building projects, as they distinct impact on both process and product. A German PR slogan claims that "success is the sum of good decisions".

The application of the framework on the case-study, have similarity with the use of what Yin (2003) calls table shells (see quotation). The framework should support the defining of focus

METHOD AND FRAMEWORK

Table shells: These are the outlines of a table, defining precisely the rows and columns of a data array - but in the absence of having the actual data. In this sense, the table shell indicates the data to be collected, and your job is to collect the data called forth by the table. Such table shells help in several ways. First, the table shells force you to identify exactly what data are being sought. Second, they ensure that parallel information will be collected at different sites where a multiple-case design is being used. Finally, the table shells aid in understanding what will be done with the data once they have been collected. (Yin, 2003, p. 75)

and the decision which persons to be interviewed, what questions to be asked, how to analyse and finally present the findings.

It could be tempting to order these four design process aspects sequential or chronological. At first the architect generates his idea, before he communicates it to e.g. a client, who after an evaluation of the design idea, makes his decision about further development of the design idea. However, such an approach would be a misleading simplification of the very complex field of design. The four aspects are highly interdependent and interconnected, and do in a dynamic and iterative interplay between all three levels, together form the process of design

2.3 Conducting the case-study

Yin (2003) recommends to use appropriate time on the preparation of a case study. For instance, a case study protocol should be established. Such a case study protocol as a guide for collecting the data has been made also for this case-study (appendix 2). Key elements of the protocol are for instance an overview of the project, field procedures and the case-study questions (both the research questions and the questions to be asked in the interviews).

To get an overview of the project and its context, information from different sources was studied. There is a huge amount of information about the AHUS project, since it is a public and one of the biggest projects built in Norway for the time being (2005). The main source for collecting "hard facts" about the project (size, time plans, strategies etc.) was the public website (www.nyeahus.no). In addition, records of different project presentations has been reviewed. Since the main focus of the case-study is to gain knowledge about the project processes, not about the product, other sources in addition to documents and records had to be consulted.

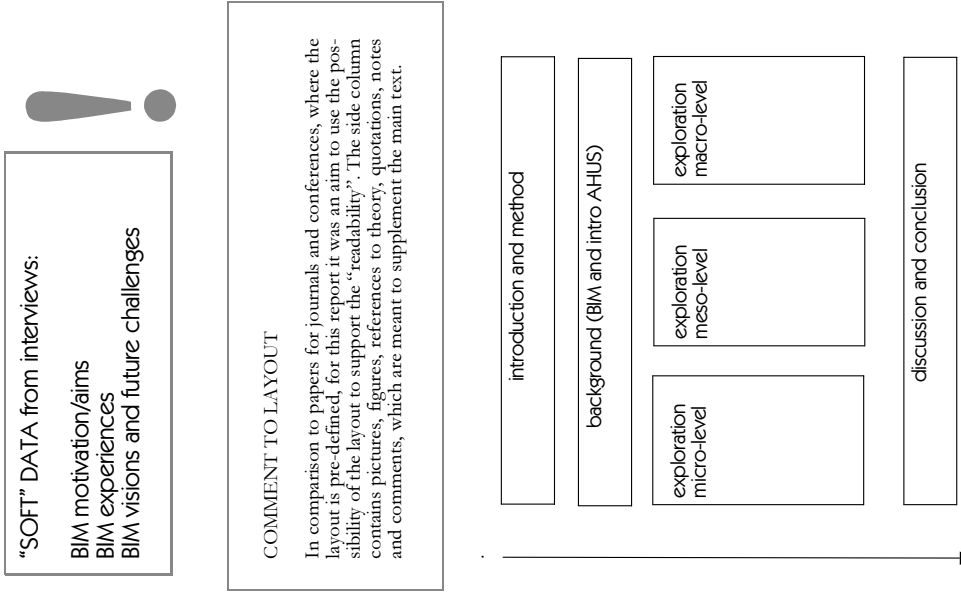
To collect information about some more "soft facts" (attitudes, experiences) about the project and especially regarding the impact of ICT, four key persons were interviewed. These persons are all architects, involved on different levels and with different tasks (presentation of respondents on page 15-16). Since the intention of this report is to give a rough and broad picture of how the use and implementation of IFC-based BIM impact on all levels of the architectural design process, rather than achieving converging lines of evidence, interview respondents were selected representing experiences perceived from different levels, views and positions within the front building project. The interview respondents' perception of an event or situation can deviate from how something really happened. However, interviews could contribute with insight into not very visible and explicit processes and events.

INTERVIEW TRANSCRIPTION AND EXPLORATION

Four interviews are carried out with architects involved in the hospital project. Originally, the intention was to transcribe all four interviews. This was not possible within the time limits, thus the key points of two of the interviews can be found in handwritten notes. However, since the exploration focuses on the meaning and not on the use of words, these handwritten notes have been a sufficient basis for analysis, at least for the purpose of this report.

This report among others explores and presents the interview respondents "speculations" about the future. Such "speculations" can give an impression of the benefits and challenges users eventually can expect. At least, this reflecting regarding implications for the future, can be a good starting point for further discussions, although they probably cannot be counted as "scientific data".

The interview respondents are made anonymous in this report.



The case-study represents a “cut” of the running project (spring 2005). The respondents experiences, attitudes and expectations regarding what have been (past), what is (present) and what is going to be (future) are viewed from this “cut”. Thus, the respondents were questioned about three issues regarding BIM use and implementation; motivation/aims, experiences and visions/future challenges. The framework was used as a guideline throughout the interview situations, which were open and not structured. Only some main points for defining questions were pre-defined. In a test-interview carried out before the case-study, it was made an attempt to use the ICT impact matrix as an interview guide. This did not work out well, since it was difficult to separate between the four design process aspects, especially regarding the partly unconscious cognitive processes on the micro-level. Therefore, in this case the framework was used to generate “orientation points” in a freer interview form.

2.4 Structure of report

The next section of this report will give an overview of recent research regarding 3D object models or BIM. What are the intentions and the challenges within resent research? Furthermore, the AHUS (the front building project) and the interview respondents will be briefly presented.

The main part of this report, the analysing and presenting of the case-study data, is divided into three parts, since the use and implementation of BIM in the AHUS project are explored due to each of the three hierarchical levels. As a “back drop” of the exploration of the empirical data within each level, some references to theory are included in the discussion. In the last part of the report (discussion and conclusions), an ICT impact matrix will summarize the key points of the exploration, and the adaptability of the framework on this case study will be discussed. Furthermore, some lessons learnt from the AHUS project, and the next steps and possible areas of further investigation regarding the relation between IFC-based BIM and the architect’s work, and interaction with other participants in the architectural design process, will be discussed and suggested (Fig. 8).

Figure 8. Structure of report



Figure 9. The "IAI-Logo" (from www.IAI-international.org).

LAI is an alliance of organizations within the construction and facilities management industries dedicated to improving processes within the industry through defining the use and sharing of information. Organizations within the alliance include architects, engineers, contractors, building owners, facility managers, manufacturers, software vendors, information providers, government agencies, research laboratories, universities and more (...). The International Alliance for Interoperability (LAI) was started by twelve companies that wanted to be able to work with each other's information without being concerned about the software that they or anyone else was using. They created a set of prototype software applications that were demonstrated at the A/E/C Systems '95 show in Atlanta, Georgia. These prototypes proved that interoperability was not just a dream; it could be made into reality. In September 1995, they opened up participation to AEC/FM companies worldwide and formed the LAI. (http://vig.brw.co.uk/iai_uk/new/index.jsp).

Improving communication, productivity, delivery time, cost, and quality throughout the whole building life cycle (...). Providing a universal basis for process improvement and information sharing in the construction and facilities management industries. (...) Building on the collective knowledge of the global construction and facilities management industries to define Industry Foundation Classes (www.iai-international.org).

The LAI specifies how the 'things' that could occur in a constructed facility (including real things such as doors, walls, fans, etc. and abstract concepts such as space, organization, process etc.) should be represented electronically. These specifications represent a data structure that can be shared between software applications (...). The classes defined by the LAI are termed 'Industry Foundation Classes' or IFCs. The reasons for this are: They are defined by the AEC/FM industry, They provide a foundation for shared information, They specify the classes of things in an agreed manner that enables the development of a common language for construction. (http://vig.brw.co.uk/iai_uk/new/index.jsp)

3 BUILDING SMART WITH BIM?

3.1 IAI and the development of IFC

Parallel with the growth of several ICT vendors developing different software systems, interoperability and system "lock ins" have become an increasing problem. There has not been possible to sufficient exchange files and information between different systems. Double work and the risk of losing information during the exchange of data are some of the unpleasant consequences. With the aim to ensure interoperability and efficient information exchange between different ICT systems, IAI (International Alliance of Interoperability) was founded in 1995. IAI is the key actor behind the development of IFC (Industry Foundation Classes), which shall ensure an "system-independent" exchange of information between all actors in the whole life cycle of the building (from briefing to maintenance of building).

3.2 3D object models /BIM

With the development of IFC it will be possible for all building process actors to work with the same 3D object model. Today (end of 2005), the abbreviation BIM is more commonly used for this type of models. But what is BIM or 3D object models?

The following explanation attempts to give a general understanding and overview of the technologies. A specific technical description falls outside the scope of this report.

BIM is the abbreviation for Building Information Model, a computer model based on three-dimensional objects containing intelligent information about e.g. materials, qualities, prices etc. All building project information is 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. A change must be made only once; in the model. This can reduce one of the main sources of building site failures: inconsistency within the fragmented drawing and document material (Kiviniemi 2004, Wikforss 2003). When the defined BIM objects are based on IFC, this opens for powerful possibilities of interoperability. BIM data can be exchanged between all different systems, building process phases, actors and organisations. In a guest lecture on the Norwegian University of Science and Technology on the 28. October 2005, Bakkmoen (the chairman of the Norwegian IAI Chapter and involved in the development of the AHUS project) referred to several investigations of efficiency in the AEC industry, stating that between 15 - 30% of the total building costs can be related to failures, misunderstandings and bottlenecks in the build-

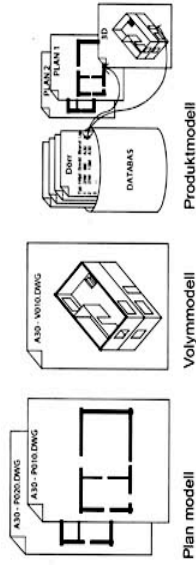


Figure 10. From 2D drawing to 3D object oriented modelling (from Wikifons, 2003, p.352)

ing process. Same information must be drawn or described up to seven times, which makes it seven times more probably to make a failure. According to him, the use of IFC-based BIM could reduce the costs related to communication friction in a building project. The potential of BIM is illustrated in “Islands of Automatisation in Construction” (fig.11). A “landrissing” can be achieved, where the fragmented situation (many small islands) develops, with the help of for instance BIM, to one big island.

Throughout the whole life-cycle of the building, and through the many actors contributing, with the time the BIM will contain a huge amount of information. Both the limited capacity of human ability to absorb information and the capacity of the computers, triggers some recent research.

For instance the development of different viewer technologies. A view shows a selected amount of information. Within the AHUS project, a view represents a physical limitation of the model, shown as a drawing (of e.g. one building floor). Another approach is to limit the information through a thematic focus (the architect’s view, the contractor’s view etc.). And a third approach and possibility is to use the viewer technology to make more efficient walkthroughs. The computer does in such a case know what it have to build up when the person “looks around the corner” (respondent C).

Finally, here another glance into some of the research going on in the moment (summer 2005) regarding BIM. On the CIB W78 conference on “Information Technology in Construction” (Dresden, Germany, July 2005), one of the workshops discusses the development of multiple product models (Kiviniemi & Haymaker, 2005, p.35). “Although the IFC model specification covers a substantial part of the required information, AEC projects still have encountered many problems putting this model into practice. AEC professionals still find it difficult to have dynamic, lossless, truly effective data flow amongst the different participants and applications. It is obvious that file based data exchange alone is not a feasible solution; some other solution for integrating project information is necessary.” (Kiviniemi & Haymaker, 2005, p.35). Kiviniemi suggests to break the one big building information model into 4 main types of models (requirements models, design models, construction models, maintenance models) is suggested. This requires a standard way to link the objects in different models to each other, which could become one of the challenges in further research (of VVT/Finland and CIFE/Stanford).

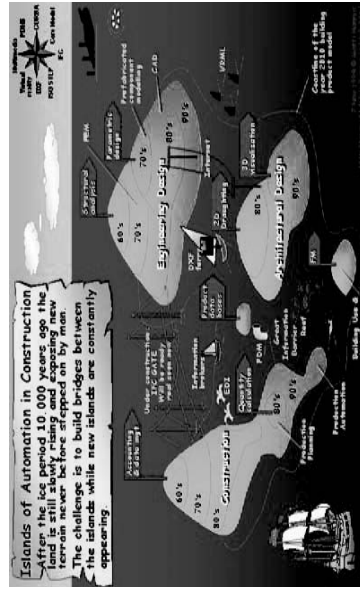


Figure 11. Islands of Automation in Construction (from <http://cit.vvt.fi/bannus>)



Figure 12: “Nye AHUS” (Courtesy: C.F. Møller Architects).

AHUS KEY DATES:

- Total floor space whole project 116.000 m² (new buildings)
- Total floor space front building 2.500 m²
- Architectural competition 2000
- Final project outline completed 2003
- Full operation autumn 2008

4 The AHUS project and R&D

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. 12). 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 (www.nyeahus.no). The architect suggested early to implement a 3D object model (BIM) based on IFC (Industry Foundation Classes) and intelligent objects. The client’s “go” for this suggestion, made the AHUS project to what Khemlani (2005) 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. The case-study and this report focuses on this front building part (2.500m²), which contains the main entrance, an auditorium and a canteen (fig. 13). 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. The case-study represents a “cut” of the running project, made at the end of the design process, shortly before the front building project is going to be handed over to the contractors and the production of the building starts (fig. 14). The front building has its own building contractor. However, the technical contractors are the same for the whole AHUS complex.

Figure 13: The front building (Courtesy: C.F. Møller Architects)



Some “specialities” of this project should be mentioned for better understanding the processes and strategies. At first, all key participants of the total building project work collocated directly beside the building site. Secondly, this is a huge project, demanding years of planning and production. The size of the project and the time issue make it possible to establish long term strategies, for instance strategies regarding BIM. Thirdly, the future users play a very central and influential role in the design process. Fourth, the need for saving cost and space resulted in an extensive “re-design” of the whole project in 2003 within very limited time frames (1/2 year). And finally, in this project the client organization carries the juridical responsibility for the planning, also including the responsibility for project management.

4.1 The four ICT cornerstones and the R&D project

There are four ICT cornerstones in the front building project. Firstly, the 3D object model (AutoCad ADT 2004). This report focuses mainly on the implementation and use of this 3D

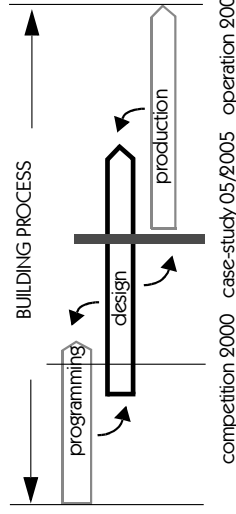


Figure 14. Case study "cut"

Given the huge size and complexity of the project (see Figure 6), the main focus of the use of BIM 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. To date, over 3000 drawings have been derived from the model created in A/D/T. IFC was again a critical component of this project, enabling the model to be used for consistency checks, quantity takeoffs, clash detection, energy analysis, fire egress and environmental hazard studies, 4D visualization, and checking the design for the satisfaction of programming requirements. Needless to say, the Akerhus University Hospital project is regarded as a front runner in Norway in the use of IFC-based BIM. (www.aecbytes.com/feature/norway_prefab.htm, 28.02.2005).



Figure 15. All the key participants in the AHUS project work collocated directly beside the building site (author's photo).

object model. According to the contract, the 3D object model is the property of the client. Secondly, in a document database (ProArc) all drawings and documents are archived and distributed, no parallel document archiving is allowed. Thirdly, a room database containing room lists, equipment lists etc. represents the users programme and requirements (dRkofus). And finally, e-mail is an important tool in the everyday project communication.

Three IFC R&D projects are going to be and partly are implemented and tested within the planning of the front building (fig. 16). 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. At the time of the case study, this project has partly been implemented. The last project is to transfer object information to Facilities Management (FM) systems (Bakkmoen, BuildingSMARTI conference in Oslo, 31.05.-01.06.2005). Against the original intention comprising both architects and consultants, only the architect work directly with the 3D object model (at the time the interviews were carried out). In close future every participant in the architectural team should be able to enjoy the benefits of this "merging" of different technologies. As a part of the R&D project, the next step is to test the potential of interoperability; all central actors in the building process (consultants and building contractors) shall start implementing and using the front building BIM during autumn 2005.

4.2 Introducing the interview respondents

All four persons interviewed are architects, involved with different tasks on different levels and within different contexts.

Respondent A: female architect, employee of the architectural company, 20 years practical experience. Her main tasks are the individual generation of design solutions regarding the front building interior (micro-level) and the development and coordination of these design solutions within the design team (meso-level). Since she is the vice manager of the architectural team, she also to some extent takes part in the discussions with users and clients (macro-level).

Respondent B: male architect, employee of the architectural company, 9 years practical experience. He has the formal responsibility of managing and representing the architectural front

building team (meso- and macro-level), in addition (since the team only comprises three persons) he designs and develops the front building envelope (micro-level).

Respondent C: male architect, employee of the architectural company, 27 years practical experience. He is the vice building design manager for the total project from the architect group, responsible for the administration of the work processes and the production of planning material (macro-level). He is also the key-person behind the overall project systematization and the implementation and development of the 3D object model and the R&D programme.

Respondent D: male architect, employee of the client organization, 24 years practical experience. He is one of five project managers, with responsibility for the planning part of the overall building project and the management of the contracts with the architect and the other consultants (macro-level).

Respondent A is a frequent user of the 3D object model, without a direct influence on the implementation and development of the model. This is the responsibility of respondent B and C, who both administrate and facilitate the implementation of the model in the front building team and on project level. Respondent D has 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.

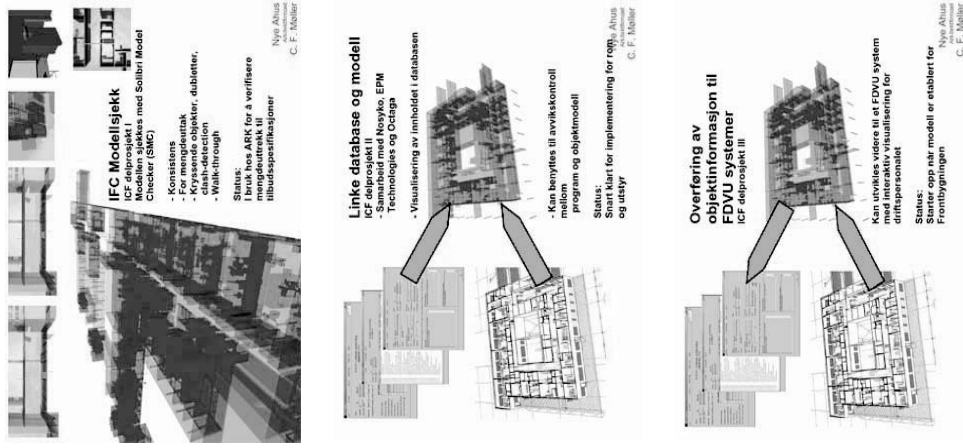


Figure 16. Three R&D projects (Courtesy: C.F. Møller-Architects).

5 AHUS: USE AND IMPLEMENTATION OF BIM ON MACRO-LEVEL

The macro-level comprises processes and actors on overall project level. At the time of the case-study, the client organization, the users and the design team are playing the main roles in the interview respondents' descriptions.

5.1 Processes and routines

On the macro-level in this project, most processes are formalized and shall involve the client organization. There are established three main fora for communication, evaluation and decision-making regarding design and development; the building part meetings, the user meetings and the total project meetings. These meetings find place regularly every 1-2 weeks (fig. 18).

The **building part meeting** is the operational instrument of each of the five main AHUS building parts. Every presentation, evaluation and decision regarding the design and development of the front building is made here. The participants in these meetings are, in addition to a person representing the user and the client (project part manager), the responsible persons from the different building planning disciplines. Thus, both respondent A and B participate in these meetings. The **total project meetings** focus on strategic and administrative aspects due to the total project. Meeting leader is the respondent D. Respondent C participates in some of these meetings as a vice leader of the architectural discipline. Finally, the future users of the new hospital have a central position in the definition of requirements. The extensive degree of user participation required regular meetings between the users, clients and the planners during autumn 2004 (**user meetings**).

5.2 Strategies and motivations behind the BIM implementation and use

On overall level there are three main motivations behind the implementation of IFC-based BIM.

At first, the overall motivation is the learning 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. Such knowledge could give the companies involved a front position on the AEC market. Both the client organization and the architectural company are convinced that IFC-based BIM within few years will become the major planning tool in building projects.

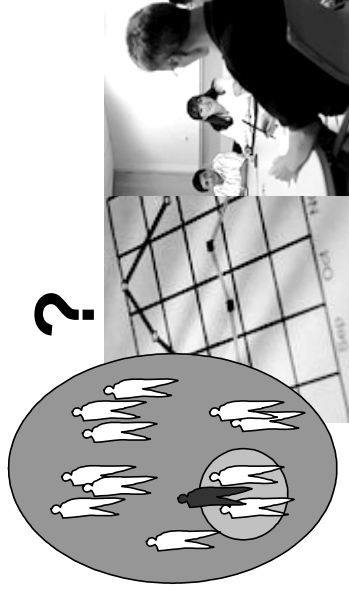


Figure 17. How do ICT impact the macro-level?

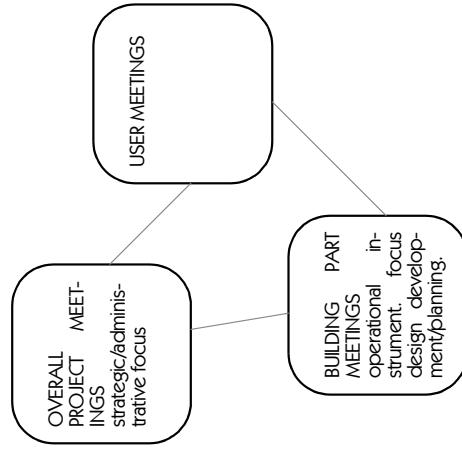


Figure 18. The three main fora for communication, evaluation and decision-making

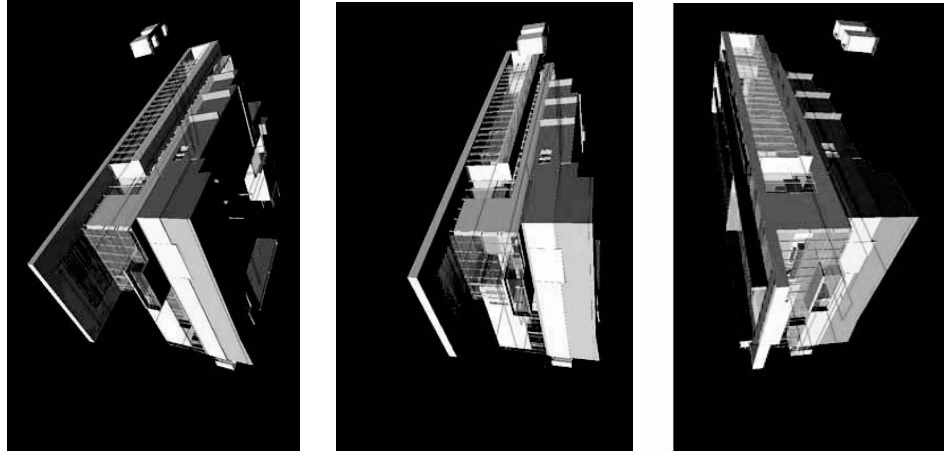


Figure 19. Three views of the front building (Courtesy: C.F. Møller Architects).

Secondly, the possibility of IFC-based BIM to support interoperability; an uncomplicated, transparent and efficient exchange of information between the different actors and systems involved in the AHUS project, is another essential motivation behind the implementation.

And thirdly, as Baksmoen emphasized in a guest lecture at NTNU (28 of October 2005), the potential of BIM to control and ensure consistency and quality of project material, is viewed as a crucial benefit. All information shall be found on only one place (in the model), everybody shall have access to this information, and know that it is updated and correct. In this project, the development and testing of the quality assurance abilities of BIM, is more important than exploring and developing the possibilities of visualization.

Both the aspects of interoperability and quality assurance could reduce failures and misunderstandings in the whole building process, thus decreasing building time and costs.

5.3 Experiences from implementation and use of BIM - some examples

Generally, the 3D object model is to a limited degree used directly in the formal meetings. And to directly use BIM for real-time simulations, have until now not been an issue. The implemented IFC version does not support rendering of the objects. Thus, it is not possible to generate realistic visualization and walk-throughs directly in the 3D model environment, which could be used for more dynamic and interactive presentations of design solutions in e.g. the users meetings. However, the 3D object model of the front building has now reached a stage where calculations and simulations regarding indoor climate, energy consumption etc. are possible. Regarding this potential of easy simulation of technical aspects, respondent B warns against a biased focus in the decision-making process, and eventually a misbalance in the relationship between quantitative and qualitative aspects.

Since the model is heavy to use and change in this late stage of design, to work directly in the 3D environment in meeting situations demonstrating e.g. "live" simulations seems to remain being difficult. For being an effective support for real-time evaluation of alternatives and solutions, more rapid simulations or visualization of results are required (respondent B).

The size of the BIM files is huge, and computer capacity was an underestimated issue in the moment the decisions were made regarding file structures. It is partly very time-consuming for the computer to build up the model. With this experience, another and improved file structure could be adapted to future projects. Still, within this project the use of physical views or cut-offs make the 3D object model easier accessible. The BIM files are for the mo-



Figure 20. The physical model is still supporting the design process (author's photo).

ment maintained by the architect, and are part of the architects' own server. However, a common and shared future model should only be available from a common and "independent" server.

In the **overall project meetings**, every participant brings his own laptop, which can be connected to the whole project database. In addition, cut-offs from the model can be projected on the wall with a beamer.

Once a week cut-offs (2D drawings and views generated from the BIM) are made available through the document database (ProArc). Thus every relevant and up to date drawing or document is easy and fast accessible. Every participant in the project have access to updated project material, any time. As long as e.g. the client or the consultants regularly use this database to get the updated material, there is no risk to use obsolete project material as background for planning or decisions. This requires a certain discipline, since this means a change from the traditional "push" (passive receiving) to "pull" (active collecting) of information.

From the client's view (respondent D) ICT and BIM offer good possibilities for better to could follow, control and evaluate the development of the planning. Cut-offs and the viewer technology make the access to the 3D object model easy. Still, respondent D perceives the model being a black box to which the client has no directly access, unless he has special ICT competence. In this project, this drawback of ICT is compensated by the collocated situation, since the client can easily get information from informal face-to-face meetings with the architects or consultants.

An interesting aspect, which came up in the interview with respondent D, was the rigidity of the ICT tools regarding presentations. He perceived that perfect, static and almost finished looking drawings and illustrations presented in the meetings, did not lead to dynamic, open and flexible discussions. Rather the presentations paralysed the meeting participants and made it difficult for them to suggest changes.

A huge benefit of BIM the AHUS team experienced in the negotiations with the users. The 3D object 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 **user meetings**. All these drawings (sections, plans and elevations) were generated directly from the 3D model, thus saving lots of time. In the user meetings, the architects sometimes, on a laptop, made changes in the model simultaneously with the decisions made.

“WORKING” VS. “PRESETTING” MEETING FOCUS

Based on my own experience, in the formal meetings with the clients and the users, the architect often focuses on the issues of “selling” his design idea. The design idea must be visualized and presented in a convincing way, in order to impact on the client’s decision. Much effort is therefore put in the production of perfect presentations in advance. The meetings with the consultants mostly have another setting. Here the focus are on coordination, and on the common effort to generate and develop design solutions. The setting is rather of a “working” than “presenting” character, perhaps encouraging more lively and freer discussions and dialogues.

In the **building part meetings**, the evaluation and decision-making material are 2D paper drawings (scale 1:200), normally printed out in advance. Pen, sketch paper and a physical 3D model are the main tools applied to mediate discussions and generate solutions in the meeting situation.

5.4 Potential and challenges for the future

What are the interview respondents attitudes about future BIM implications and potential on the macro-level, based on their experiences from the AHUS-project?

Re-thinking processes: interoperability, shared responsibility and transparency

A vision behind the development of BIM is to achieve a “land-raising” in the AEC industry and to reduce the borders between planning phases and roles which lead to communication friction, delays and misunderstandings. IFC-based BIM supports interoperability; all participants can work with the same model throughout the whole life cycle of the project. Such a blurring of the traditional borders and definitions, inherits several benefits, but also challenges.

In discussions about the implementation of IFC-based BIM, the emerging challenges linked to the issues of responsibility and contracts are “hot” topics. However, these challenges can, according to some of the respondents also be turned into benefits.

When all actors in the building process contributes to the same 3D object model, it could become easier to formulate and work toward common goals. A shared feeling of ownership can be built up, since all participants would carry their part of the responsibility for a well-working 3D object model. It can become easier for participants to share information. More efficient information delivery, transparency and less mistrust could be positive side effects. To integrate contractors early in the design process increases the contact area between the planners and the producers (between the design team and the contractors and craftsmen on the building site). This issue can lead to a better understanding of each others problems and intentions, thus some of the misunderstandings and conflicts often seen in the transition between design and production can be reduced (in the information meeting regarding BIM and tendering in the AHUS project, 30 contractors participated, which indicates a distinct interest in the contractor community).

Today, the negotiation of contracts and fees are experience based, and the contracts are not always optimal suited to the actual needs in a specific project. The blurring of borders be-

BLURRING OF BORDERS BETWEEN DESIGN PHASES AND ROLES

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” (Gray and Hughes 2001), 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 Construction” (<http://cic.vvt.fi/hannus>) 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 borders between roles or planning stages blur and change. The separate bits of the planning process are melting and compressed to a conglomerate. 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?



Figure 21. Live demonstration of interoperability on the international Building Smart Conference in Oslo June 2005 (from www.I-A.I.no).

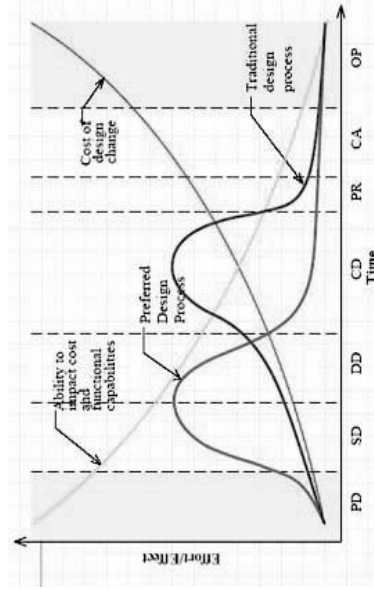


Figure 22. Preferred design process or “front-loaded” process. Presented on the international Building Smart Conference in Oslo June 2005, of Norbert Young, F.A.I.A.

tween actors and project phases requires eventually a better understanding of the processes and the relationships between the actors. And an increasing consciousness could make it easier to deviate from classical contract making and lead to contracts and project organizations better suited to meet the special needs of a building project. Generally, as a consequence and potential of IFC-based BIM implementation, new types of contracts and partnerships can emerge (respondent C).

Professional clients, who develop and produce buildings for rent or sale, would probably appreciate a “merged” design process, eventually even a “merged” building process (parallel phases). However, a strong user participation makes it difficult to reduce the planning time and to eliminate borders between traditional design phases. The user participation can eventually be seen as a major reason for keeping, maintaining and documenting the traditional phases (respondent C).

Respondent C emphasizes the potential of the object based planning seen from a life-cycle point of view. According to him, generic objects from pre-defined object libraries could be the “building stones” of the design in the architectural design process. In the moment the project gets handed over to the contractor, he would replace the generic objects with his specific objects. In course of the building process also FM oriented information could be embedded in the intelligent objects. The use of genius pre-defined objects could reduce the planning time normally needed for detailing, and support the idea of a front-loaded building process (fig. 22). The pre-defined objects can support the capturing of (explicit) knowledge, since they inherit “reusable” information collected through the whole life-cycle of one or more buildings. However, libraries of pre-defined objects still do not exist, but the transaction of object information between the actors shall be tested out in the front building project.

To use IFC makes it possible to easy connect several programmes for achieving efficient functions of different technologies. The four R&D projects are based on this thought (e.g. the connecting the a room database with the BIM). Since IFC allows a communication between systems independent of provider and vendor, the growth of more “specialized” systems better suited to the many needs in the building process can be encouraged. Also the previous investment risk for a company regarding product lock-ins and incompatibility between different systems and versions can be limited (respondent C).

The power of simulation and visualization

The potential of visualization Bakkmoen in his lecture on NTNU 28.10.2005 described as a “nice side-effect” of the tool. Although the visualization of design ideas was no important

THE CHALLENGE OF MAKING DECISIONS

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. Lundquist (Wikforss 2003) 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 mismatch 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 (2003) ICT supports the declarative nature of explicit knowledge. Possibly the analytical, 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.

issue of the BIM implementation and use in the AHUS project, BIM still represents a huge potential also on this field (respondent B). A very immature version of the 3D model was in some cases used to visualize a problem not easy to understand for the client or user by only looking at the plan or the section. The visualization of the problem helped verifying the advice of the architect, and could thus perhaps help building up trust. For the case the IFC-based BIM applied to this project had been more complete, intuitive, parametric and easier to handle, the model could have supported the architect in the “selling” and verifying of his ideas better than the traditional drawings did. The visualization potential of BIM can help making the aesthetic and qualitative issues more visible, thus increasing the understanding of the more subjective and less measurable intentions of the architect. The intentions and aims of the architect are often not easy to measure and quantify. The fact that a building can fall down or that the ventilation does not sufficiently supply fresh air, are very cogent arguments compared to the fact that a building could get “ugly”. Respondent B regards this issue as very problematic in decision-making processes regarding e.g. cost saving matters.

According to respondent C, in the AHUS project, they are only a very small step from utilizing the power of visualization and simulation. The next IFC version will be able to support rendering, and when the objects get surface information as a part of their definition, complete 3D visualization can easily be generated from the 3D object model. and “we can walk with the users into the (virtual) rooms”. With pre-defined objects offered from suppliers containing correct information about properties and surfaces, the e.g. mechanical consultant could have made his quantity take-off directly based on the 3D model. Simulation of fire and escape scenarios, daylight simulations etc. could easily have been carried out. Today for instance materials are tested in a physical “sample room”. In the case complete objects are available and applied, a virtual sample room could be established, for evaluating ceiling types, flooring materials etc. Some of these visions shall be tested out in the further planning of the front building. Dependent on the further development of the model server technology, the visions could become reality within 2006 (respondent C). Today, other programmes are used to generate walk-throughs etc. (e.g. Solibri, fig. 23).

It would be nice to put the virtual glove and glasses on, take the client by the hand and walk together with him through the building and decide which chairs shall be chosen for the virtual canteen, and how the acoustic should be handled in a specific room (...) they hear an echo, and through changing the material in real-time, they together can evaluate the acoustic effect in the virtual room. That would be ok. Then we get a more experience-based understanding of the factors of success and the fundament of decision-making (respondent B, authors's free translation to english).

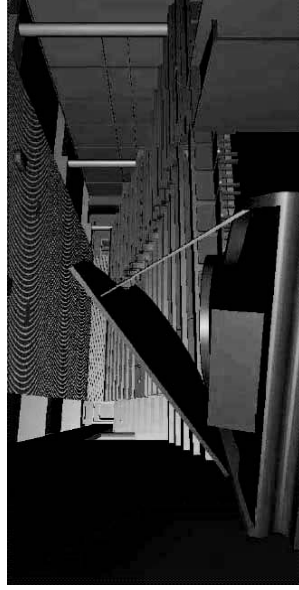


Figure 23. Rough visualization of auditorium directly from walk-through in IFC file by using Solibri (Courtesy: C.F. Møller Architect)

BIM and the future contribution of the architect

A frequent attitude and opinion among architects, and an issue also described in some literature (Gray & Hughes 2001, Emmitt 1999), is the diminishing standing and influence of the architect in the AEC industry. According to Emmitt (1999), the traditional leadership role of the architect within management partly has passed to other management oriented professions. An interesting question is to which extent ICT and IFC-based BIM can support the “strengthening” of the architects position in building projects.

Respondent B and C both emphasizes the importance for the architect to be a in a front position in the development of IFC and BIM. Architects could be suitable for taking the powerful position of the “information distributor” in a BIM-based building project and the architect should be the one claiming his ownership to the model. In the AHUS project it seems that the architects have a central and influential position. Some reasons for this can be the architects’ key role in the testing and development of IFC-based BIM, and the client organization’s interest and enthusiasm regarding the R&D project.

Especially the architectural companies can play an important part in this development, as they can offer services based on a broad range of expertise, object libraries etc. In the AHUS project, the quantity-surveyor played a crucial part in the development of the hospital plans (even more crucial role as the architect). This competence, however, was a part of the service of the architectural team (respondent C).

A last issue to be mentioned here, is the architects challenge to utilize the potential of ICT without generating too big expectations of the other actors. A negative spin-off effect of more powerful tools could be the client’s increasing expectations and requirements to the design services, regarding the time needed, the level of precision and certainty etc. (respondent B).

THREATS AND OPPORTUNITIES

Gray and Hughes (2001) describes in their book “Building Design Management” (p. 2) the development from the yesterdays “Architects hold the dominant position of authority in the design processes” to the today’s “Architects are losing position and authority within the design team to managers, specialist designers, services and other engineers”.

On the international IAI (International Alliance of Interoperability) conference “BuildingSMART” in Oslo June 2005, one of the key-themes was the ICT (especially IFC-based BIM) related paradigm shift within the AEC industry and which threats and opportunities this shift could inherit for the architect.

EXAMPLES POSSIBLE AREAS OF FURTHER INVESTIGATION:

- contract and responsibilities
- do the use of BIM lead to more efficiency (drawing production)?
- do the use of BIM lead to a more conscious attitude to roles and processes - hence to indirectly improve processes?
- BIM potential for the architect regarding work and/or position in project
- re-use of knowledge vs. innovation
- front-loaded (“merged”) design process vs. the need for time for “maturation” and the challenge of info overload

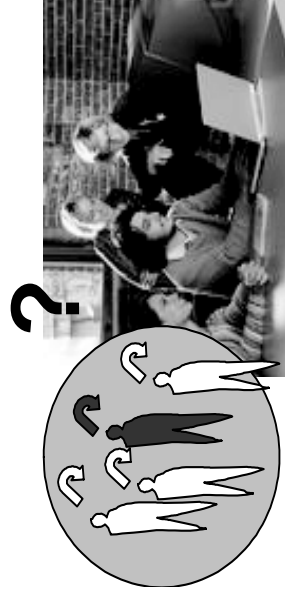


Figure 24. How do ICT impact the meso-level?

THE CHALLENGE OF COLLABORATION

The importance of collaboration is growing, as globalisation 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 (Lawson 1997). Participants with different backgrounds, preferences and experiences try to achieve a common goal. Barrow (2000) 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 speciality skills found in many individuals" (Barrow 2000, pp 272-273). Successful teamwork is among others based on shared understanding. If the group participants have similar background and a common base of experiences, with the opportunity to learn about each other over time, to communicate, share information, and to develop a team spirit, this will be ideal conditions to ensure a shared understanding of goals and tasks (Hinds and Weisband 2003). Within the design team, this is mostly not the case. Failed communication can cause conflicts and misunderstandings, negatively influencing the building project if not recognized and solved at an early stage. The issue of communication is a challenging aspect in the design process, since the building process actors come from different companies and organizations, have different experiences and frames of reference, they have often never worked together before and will perhaps never work together again.

6 AHUS: USE AND IMPLEMENTATION OF BIM ON MESO-LEVEL

On the meso-level, the case study focuses on the interaction between the architects and the other consultants in the architectural design process.

6.1 Processes and routines on meso-level

Although every communication between the architects and the other consultants in the AHUS project formally must include the client, informal communication within the design team is 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 a direct, uncomplicated and rapid way. If important issues and problems are recognized, the decisions regarding further development have to be made on a formal (macro-)level including the client and the users (respondent B).

6.2 Strategies and motivations behind the BIM implementation and use

One of the LAI-aims behind the development of IFC is to frontier interoperability. The front building architectural team have built up a BIM based on IFC, enabling interoperability. As a next step (part of the R&D program), all actors of the design team are supposed to work with this one model (during autumn/winter 2005).

6.3 Experiences from implementation and use of BIM - some examples

However, at the time this case-study was carried out, only the architects worked directly with the 3D object model. The other consultants used the 2D cut-offs and dwg-files as their base of planning. The architects formally made these cut-offs and the dwg-files accessible once a week in the document database (ProArc). Informally, as a short-cut to this procedure, participants exchanged project material, for instance tentative and informal drawings, by using e-mail (respondent A). Because of the collocated situation and the fact that only the architects worked directly with the IFC-based BIM, this model only to a very limited degree was used on the meso-level.

The building elements received from the consultants, for instance columns and slabs from the structural engineers, the architect at this time "transformed" to fit into the 3D object

“The designer has a prescriptive rather than descriptive job. Unlike scientists who describe how the world is, designers suggest how it might be (...) This is obviously a rather hazardous business, and carries with it at least two ways of being unpopular. First, the new often seems strange and therefore to some people at least unsettling and threatening. Second, of course, the designer can turn out to be wrong about the future. It is very easy with that wonderful benefit of hindsight to see building failures” (Lawson, 1997, p. 113).

model. Since the architects themselves generate the model objects from other consultants' elements, they have, according to respondent B, better control of the consistency between e.g. architectural and structural elements.

The everyday informal communication within the design team is mostly based on a face-to-face situation. In the informal meetings between the architect and the consultants, they use the “traditional” tools of design, as pen and sketch paper, and physical models, to generate and evaluate design solutions. According to respondent A, she sees no immediate need for using computer generated 3D visualization in such meetings, since all participants involved in the front building design team are well experienced and used to “think in 3D”. Although, for the case the discussion partner does not have this experience and understanding, or alternative solutions should be tested directly in the meeting situation, a more intuitive and “easy-to-handle” version of BIM could become a valuable support (respondent A)

6.4 Potential and challenges for the future

Challenge of different “working cultures”

The vision of interoperability inherit several challenges regarding the “merging” of architects' and consultants' efforts and contributions to one shared 3D object model. How to define the borderlines between responsibilities and services in contracts and in the daily work is an often discussed and questioned issue also on this level. To decide how to handle and divide the model requires coordination and an agreement about processes and systems (respondent B).

Respondent C points on another, more indefinable, challenge behind the vision of interoperability; the issue of different working cultures. The consultants' way to develop and produce project material seems to be based on other traditions and working methods than the architect's way to develop design solutions. The architect produce drawings/models very early in the process. The architect's models and drawings change frequently throughout the design process, as the design solution develops and step-by-step gets more precise. The consultants seem to work toward the attitude that drawings etc. (ideally) should be produced only once. For them, to change project material frequently, leads to seemingly unacceptable cost- and time consuming processes.

The architect as the only master of design?

Respondent B describes following scenario which could be enabled by the development of advanced simulation systems within BIM. Computer programmes which simulate for instance structural loads or ventilation issues, could eventually make the traditional services of

DIFFERENT WORKING CULTURES?

Regarding the different traditions of design development, I would like to give an example from another project (own experience). In this project, architects and consultants were employees in the same company, and worked in a collocated situation based on frequent face to face contact. A challenge in the collaboration between the architect and the consultants was the exchange of mutual necessary informations. Following situation can illustrate this difficulty. The client requires a conceptual solution of climate, energy, aspects of the building. The architect, which is the responsible design manager in the project, asks one of his consultants whether the capacity of the floor heating maintains the requirements to room temperatures in a huge meeting hall. The consultant must then estimate the capacity of this system, and he involves a supplier of a specific floor heating system. This supplier needs detailed information to make his estimate, a time consuming service based on his goodwill to deliver this information for free (thus, the consultant attempts to avoid a situation, where he must ask the supplier to carry out this estimate more than once). The consultant contacts the architect, and requires more detailed and final defined information about e.g. the placing of floor joints and the properties of the flooring material. The architect have obvious problems of giving the consultant this information. The client still has not given green light for the architect's suggestion of applying natural stone flooring material. To decide the sizes and format of the stones as basis for deciding the positions of floor joints, would be the next step. The architect does not understand why there is not possible to make a rapid and rough estimate based on sketches, the consultant does not understand why the architect cannot give information, which will not change again within short time. This situation develops to become a bottleneck in the design development and decision-making process.

THE ONLY MASTER OF DESIGN

However, such a scenario implies and requires an architect role based on a very broad base of knowledge base. Although the technical consultants could face such a situation in the future, a critical question would be whether the client automatically and necessarily sees the architect as the right person for the described key position. Thus, the future of the architect position in a building project will further depend on the profession's and the architectural firm's ability to convince the client about the importance of the architect's contribution in a building process. ICT could play an essential role in the "battle fight" about leading positions in the AEC industry

EXAMPLES POSSIBLE AREAS OF FURTHER INVESTIGATION:

- different working cultures
- responsibilities and contract
- do the use of BIM lead to more efficiency on the meso-level?
- BIM potential for the architect regarding work and/or position in project?

the consultants redundant (also an issue in the lecture of Bakkmoen, NTNU 28.10.2005). Respondent B portrays a situation where the architect, supported by powerful simulation tools, can be able to take over all building design services, included the services of the consultants. The role of e.g. a structural engineer could in such a scenario change from being a consultant to become a "verifier", employed by the architect.

7 AHUS: USE AND IMPLEMENTATION OF BIM ON MICRO-LEVEL



The micro-level comprises cognitive and individual processes, and is here illustrated by the architect's experiences and attitudes from the BIM user's point of view, regarding both design development and production of project material (drawings, models, descriptions etc.).

7.1 Processes and routines on micro-level

As the interviews were carried out, the design of the main concept behind the front building was completed and all major decisions about the design were made. Thus, the main design task at the time of the case study was to "translate" the overall design concept into buildable and specific solutions and details, considering several requirements regarding legislation, environment etc. As a consequence, the collaboration with consultants, users and client, and the coordination of efforts, were crucial tasks of the architects. Before taking part in formal or informal meetings, the architects had to use time and effort to develop and prepare solutions as basis for evaluation and decision-making. In addition, the production of the building project material was crucial at the time of the interviews, since the "handing over" deadline regarding contracting and the involvement of the building contractors was close (summer 2005).

Figure 25. How do ICT impact on micro-level?



Figure 26. The work space environment of the AHUS architect (author's photo)

7.2 Visions and motivations behind the BIM implementation and use

The potential of BIM regarding the (visual) control and assurance of consistency and quality of project material, was described as a major motivation behind the implementation on macro-level. This is of course also an important issue for the individual user of the tools, as the other macro-level visions are. Both respondent B and C emphasized the importance of communicating the overall benefits of using BIM to the everyday users, since the use of BIM in several cases leads to more work for the individual. The visions and expected benefits defined on the macro-level, are not necessarily perceived as such for the every day user of BIM.

Every architect working with the AHUS project shall be able to operate the ICT tools implemented in the different project parts, a division between architectural- and "technical drawer" tasks is not wanted. There are offered courses and manuals for learning and updating knowledge about continuously and rapidly developing software.

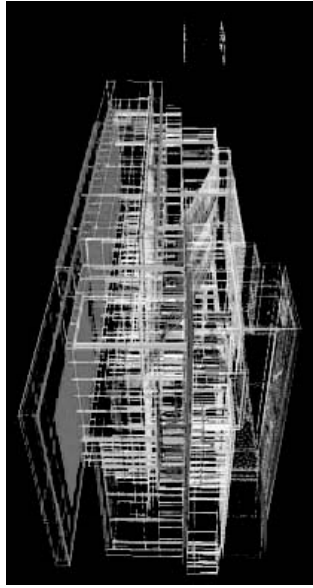


Figure 27. The aim is to build up a well-working and IFC based BIM of the front building (Courtesy: C.F. Møller Architects).

The front building team aims to establish a 3D object model that can become a sufficient and well-working basis for achieving the aims on macro-level. According to respondent C, another vision on this level, is not only to implement a new tool, but to implement a new way of working and thinking. The architect shall not only model, but also think, object-oriented.

7.3 Experiences from implementation and use of BIM- some examples

BIM and design generation

The “traditional” design tools as pen, paper and physical models are still of major importance for the individual architect in the front building team. According to respondent A, she first makes some rough sketches with pen and paper, before she transforms the idea into computer generated line-based 2D drawings. The computer offers, with its accuracy, an early “test” of the design idea’s feasibility, which she perceives as a distinct benefit of the tool. The transformation of the 2D lines into 3D objects is made later, which partly results in a 3D model not completely based on objects.

Respondent A expresses the concern that the middle stage between rough sketch and detailed precise drawing has disappeared, eventually leading to loss of creative freedom and overview of the totality. In the traditional “2D process”, the designer generates several sets of drawings with increasing precision and scale. She further questions whether this traditional step-by-step process is an important element for the “maturation” of design ideas.

Also respondent B only to a limited degree uses the 3D object model when he generates and visualizes design solutions. However, as a support to achieve a visual control of very complex situations, he in some cases models directly in the BIM (e.g. visualization of glass roof construction of main traffic area). But this is rather an exception, since such requires too much effort and time resources to be used frequently. Both respondent A and B see the lack of time resources and the “heavy” operating of the 3D object model as the main barrier of using the model directly for visualization in this specific project.

Object-oriented working

The individual architect works within a 2D user environment, dragging and dropping 3D objects. According to respondent C, this way to “draw” should be easier than the traditional drawing with lines, and normally no special competence of the every day operator is necessary as long as pre-defined objects are accessible. However, since AHUS is the first major project where the architectural company has implemented an IFC-based BIM, and BIM generally is a new CAD technology in the norwegian AEC industry, there are no pre-defined li-

CAD = COMPUTER AIDED DRAFTING?

The generation of design solutions is still perhaps the area, in which the ICT has gained less foothold (Lawson, 2005, Lawson 1997). The CAD (Computer Aided Design) systems used within the design process, supports drafting and modelling rather than special design attributes and analytical capabilities and have not changed the task of drafting or modelling (Kalay, 2004). 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.

JUGGLING WITH SEVERAL BALLS

An important skill of the designer is to juggle with several ideas at the same time, without forcing a premature precision or decision (Lawson 1997). 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 (2003) 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.

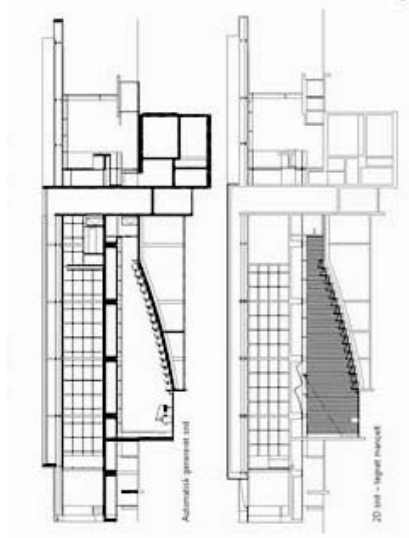


Figure 28. 2D sections generated from the IFC-based BIM.

brary of objects and building elements available. Every intelligent and IFC exportable object in the project must be defined “from scratch”. Both defining and changing these objects means time consuming processes within narrow time limits. The persons responsible for maintenance of the object library and the structures, must have much expertise. There are not many architects within the AHUS project having the required competence for such tasks. This leads to bottlenecks in the planning and loss of valuable time. Respondent A indicates the danger that planners could be tempted to avoid improving changes in stressed project periods.

Required user effort

It has been more time consuming than expected to build up and work with BIM, especially to define and change the objects. When a wall must be changed, the user cannot only move two lines as in a traditional 2D line-based drawing. In the 3D object model, such changes have to be made on a completely another level, ensuring that the intelligent objects contains the right information which again shall be exportable to IFC. In the front building project, one person is more than full time involved with building up the BIM. There is still very much to do and improve on the programming and system development side of implementing and using BIM (respondent B).

The implementation of the model requires that the architects working with it continuously have to extend their competence concerning the use of the software, which till now is difficult to operate, not intuitive nor parametric. There are handbooks and updated information about the programme available. However, according to respondent A, the narrow time limits do not allow much time for absorbing information offered through courses and user-manuals. Which again could lead to an inefficient use of the rapidly developing ICT tools.

Thus, the implementation and use of BIM requires much effort of the everyday user, but also of the person managing the team. Respondent B emphasizes the importance of knowing the benefits and challenges due to the technology used, in order to realistically understand and manage the manpower and time needed to build up the front building 3D object model.

Rapid production of consistent project material

BIM is perceived as a crucial support for the drawing production since 2D drawings from interior situations (plan, section) can be automatically generated from the model (fig. 28). Changes thus have to be made only once, in the model, which help to ensure the production of consistent and correct drawings.

THE DANGER OF INFORMATION OVERLOAD

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 Schwagerl (Schwagerl 2004), contributed more to accelerate the design processes than the CAD tools. The use of data bases, 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. We do not know much about how the human being handles and edits information (Wikfors 2003). 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. The attention of the receiver is becoming an important resource (Davenport and Beck 2002).

Wall.0.1.9		Wall.0.1.9		Wall.0.1.9		Wall.0.1.9	
Identification	Quantity	Identification	Quantity	Identification	Quantity	Identification	Quantity
Name	Wall.0.1.9	Code	W_200 * H_210	Material		Thickness	200 mm
GLID	Building Storey	Material	Concrete	Quantity	1.00	Volume	28.75 m ³
Layer	0.1	Pre Rating	0.1	Height	4.30 m	Length	15.18 m

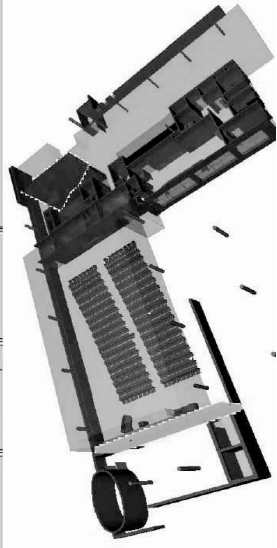


Figure 29. A glance into the front building IFC file with Solibri Model Checker (Courtesy: C.F. Møller Architects).

In addition, respondent A emphasizes the benefit of reusing details and solutions as support of generating design solutions and producing project material.

These benefits made several users (originally not only positive to the BIM implementation) realize that the everyday effort and struggle actually can bring some benefits. However, respondent B still emphasizes that it is not easy to fulfil all the aims and visions behind the implementation. A very high degree of discipline and effort of each of the involved is required.

7.4 Potential and challenges for the future

The object-oriented way of thinking: re-enforcing the standing of the architect?

The future architect shall have access to libraries of pre-defined objects. This is one of respondent C's visions. Independent research institutions such as e.g. "Byggforsk" could be responsible for pre-defining the objects, based on many years research and experiences. It can be questioned whether the use of pre-defined objects can obstruct innovation in the architectural design process. Respondent C does not regard this issue as a problem. He emphasizes that the architect can change or re-define the pre-defined objects. However, this requires a knowledge about the program and about the objects itself. If the user wants to use a wall type not available in the pre-defined wall-library, he must define a new type, which requires knowledge about how this particular wall should be built up. To build up knowledge required for developing a new wall type, respondent C regards as a more difficult task than to handle a computer programme. Furthermore, the implementation of IFC-based BIM can force the designer to become more conscious about the elements of his design earlier in the process (respondent C). To define a wall type, is normally made much later in the design process (building description).

One could say that the architect "thinks" both in terms of space and objects. But, according to respondent C, many architects of today are not skilled in the object-oriented way of thinking. He perceives this as a huge problem and one of the reasons for the architect's loss of position in the building process. The architect must build up his competence about how actually a building works. Not only draw lines without knowing what these lines implies. The use of IFC-based BIM can make the architect (again) expand his competence beyond the borders of "only doing design".

On the question whether the use of pre-defined objects rather could lead to a loss of competence about how to build and detail, than the other way round, respondent C gives following answer. Compared to the situation of unskilled detailing, he would from his point of view

EXAMPLES POSSIBLE AREAS OF FURTHER INVESTIGATION:

- use of pre-defined objects: standardization vs. innovation
- do the use of BIM encourage competence building?
- do the use of BIM lead to more efficiency on the micro-level?
- BIM potential for the architect regarding work and/or position in project

prefer to know that the objects chosen actually do work and respond to legislation etc. The use of pre-defined objects could thus itself ensure quality. And furthermore lead to a reduction of the time traditionally needed for production of details, which again could release more time for other central aspects in the design process.

ICT can support the capturing of (explicit) knowledge, for instance can the information embedded in the intelligent 3D model objects be seen as capturing of knowledge, which thus can be reused in other projects. An evaluation of the experiences made in the AHUS project could also help capturing the knowledge and the competence built up. By interviewing key participants also individual knowledge can be made available for the company. The findings of such an evaluation could be a sufficient starting point for new projects (vision of respondent B).

Challenges for the users

A frequent motivation regarding ICT use, is the expectation of increased efficiency through faster project material production. According to respondent A, there are several “spin-off” effects from ICT implementation and use that counteracts efficiency (in terms of drawing production). She questions whether the possibilities of faster production leads to increasing client requirements and expectations regarding work speed and the possibility to reduce planning and building time. According to her experience, with the implementation of ICT systems, the users of the technology face an increasing and time-consuming bureaucracy, built on the need for pre-defined procedures and systems.

For utilizing the benefits and potential of ICT, it is crucial that the architect knows how to use the tools (at least until the moment where the computer develops from being stupid” tool to becoming an intelligent partner. Respondent B).

The development of more advanced computer programmes requires more hardware capacity. However, according to respondent B, the challenge is not to develop computers able to handle larger amounts of information. The challenge lies rather in the human ability to absorb and overview information. The development of viewers and multiple models are attempts to solve this problem.

Table 1. The ICT impact matrix and key points of exploration

	micro-level	meso-level	macro-level
design generation	<p>benefits:</p> <ul style="list-style-type: none"> - reuse of solutions - pre-defined objects <p>challenges:</p> <ul style="list-style-type: none"> - not intuitive and parametric - much competence required - time-consuming - object-oriented working method and pre-definition of objects 	<p>challenges:</p> <ul style="list-style-type: none"> - not intuitive and parametric, heavy - BIM not used directly for design generation 	<p>challenges:</p> <ul style="list-style-type: none"> - not intuitive and parametric - rigid presentation not allowing dynamic design generation with e.g. clients
communication	<p>benefits:</p> <ul style="list-style-type: none"> - better access to consistent and updated information - potential of generating ideas in virtual reality - rapid production of consistent project material <p>challenges:</p> <ul style="list-style-type: none"> - not intuitive and parametric - rough hierarchies: the basis for the ideation 	<p>benefits:</p> <ul style="list-style-type: none"> - better access to consistent and updated information - potential of increased shared understanding <p>challenges:</p> <ul style="list-style-type: none"> - different working cultures - responsibility - from push to pull communication processes and culture 	<p>benefits:</p> <ul style="list-style-type: none"> - better access to consistent and updated information - visualisation support communication of esthetic issues <p>challenges:</p> <ul style="list-style-type: none"> - BIM a black-box if not special competence - redefinition of communication processes and culture
design evaluation	<p>benefits:</p> <ul style="list-style-type: none"> - precision - "visual" control of complex esthetic issues <p>challenges:</p> <ul style="list-style-type: none"> - too time-consuming 	<p>benefits:</p> <ul style="list-style-type: none"> - potential of real-time simulations - potential better control of interfaces between participants <p>challenges:</p> <ul style="list-style-type: none"> - too time-consuming 	<p>benefits:</p> <ul style="list-style-type: none"> - BIM a testable prototype of real building - visualisation of difficult understandable issues <p>challenges:</p> <ul style="list-style-type: none"> - increased expectation to precision - time-consuming
decision-making	<p>benefits:</p> <ul style="list-style-type: none"> - consistency and precision of decision material - reduction of uncertainty <p>challenges:</p> <ul style="list-style-type: none"> - presentation taking focus from content of design 	<p>benefits:</p> <ul style="list-style-type: none"> - consistency and precision of decision material - reduction of uncertainty <p>challenges:</p> <ul style="list-style-type: none"> - bias in relation qualitative and quantitative aspects 	<p>benefits:</p> <ul style="list-style-type: none"> - consistency and precision of decision material - reduction of uncertainty <p>challenges:</p> <ul style="list-style-type: none"> - bias in relation qualitative and quantitative aspects - presentation taking focus from content of design

8 DISCUSSION AND CONCLUSION

This report has explored the use and implementation of IFC-based BIM in the AHUS project. The exploration was limited to the architect's work and interaction with other participants in the architectural design process. A theoretical framework and references to theory have been used to discuss and summarize the key points in the interview material. The motivation behind the implementation, the experiences from use and the implications and visions for the future was explored on three hierarchical levels in the design process.

8.1 Summary of the explored key points

The ICT impact matrix (table 1) summarizes some of the explored BIM related benefits and challenges in the AHUS project.

The focus of the 3D object model in this project lies rather on the implementation of an object-oriented way to work than the possibilities due to 3D visualization (Bakmoen, BuildingsSMART conference in Oslo, 31.05.-01.06.2005). According to the interview respondents, the key advantages and possibilities of IFC-based BIM are better project material quality and consistency, and a more uncomplicated project transition from planning to construction. Regarding the generation of design ideas, the 3D object model was not used directly either by the design generation nor by real-time evaluation or decision-making. Instead, the traditional tools as pen, paper and physical models "mediated" the creative processes and e.g. the direct testing of alternative solutions in an meeting situation. BIM partly supported evaluation of design solutions and decision-making through the possibility to (before a meeting situation) visualize complex, not understandable and recognizable issues in 2D. 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.

However, all respondents, also the every-day users of the 3D object model, seems to be aware of what they perceive as the overall 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 of the building, the key persons behind the ICT implementation hopes to reap the fruits of the many participants effort and commitment.

6 LESSONS LEARNT

1. visions and motivation should be visible on all levels
2. not underestimate time and personnel resources required for learning new technology
3. competence and expertise required both from BIM user and manager of the design development
4. still much work to do regarding further development of technology
5. discipline required by modelling
6. establish strategies for implementation and use

8.2 Lessons learnt from the AHUS-project

What can we learn from the experiences made in this project regarding use and implementation of IFC-based BIM? Derived from the exploration of the project, at least six key “lessons” can be suggested. These six key points do of course not cover all the interesting aspects in the exploration. The intention is to supplement the ICT impact matrix (summarizing benefits and challenges) and the suggestion of future interesting fields of research, with some practice oriented “findings”. The suggested lessons could be interesting for the participants in leading positions on both meso- and macro-level.

Firstly an important issue in the AHUS project was to make the visions made on macro-level visible for actors also on the meso- and micro-level. Especially since the implementation of this quite untested technology led to much extra work and effort for the every day users of the technology. This was essential in respect of motivating the users to use the technology in an efficient way.

Secondly, implementation seems to require much time resources for training and updating. At least as long as the technology is new for the project participants. Although the key persons behind the implementation seem to invest much effort in arranging courses, making user manual available etc., the general time pressure in the project made it difficult for the user (according to respondent A) to actually update themselves as often as they should, in order to optimal enjoy the benefits of the tools. This could indicate that the time plans for building projects should allow enough “free” time for learning and practising.

Thirdly, as a continuation of “lesson” two, the use of IFC-based BIM requires special competence of the user, and also of the persons managing the planning (for estimating the real needs for time- and personnel in the AHUS project resources). In the AHUS-project, not every user had the expertise to define objects from the basic, which, according to user A, sometimes led to bottlenecks in the planning and production, especially in cases with many changes. A more optimal situation would perhaps be if every user had such expertise. However, at least in such a big project, it would be a huge undertaking to bring everybody up to this level of special competence. This problem will probably be reduced in the case all objects are pre-defined and available from libraries. Thus, theoretically, it will be no need to change objects.

Fourth, since to use IFC-based BIM is a quite untested and new situation (at least in Norway), there is still much work to do with improving the software and with building up and defining the objects. In the AHUS project, this was part of the R&D project, however, as indicated in

lesson two, this requires time and effort which must be considered in addition to the resources needed in for purely carrying out the planning of the project.

Fifth, although IFC-based BIM reduce the need for drawing same information in e.g. plan, sections and descriptions, to use the system still requires much discipline and precision of the users. They must strictly follow the definitions and guidelines set for the modelling. For instance, in the case the user draw an object with lines instead of using or defining an intelligent 3D object, programmes made for quantity take-offs, clash controls etc. will not recognize these, and the informations generated of such systems will not be correct.

An finally, sixth and based on the first five points, to have a clear strategy and vision before the implementation would be of advantage. For instance, questions could be asked in which phases of design the model should be implemented, what are the expected benefits, which resources are required etc. For instance, in the AHUS project, it was from the beginning clear that BIM in this project should primarily support control and assurance of project material quality and consistency, rather than supporting the architect in his creative tasks.

At the time the case-study was carried out, only the architect was using the model directly in their planning day. The next step in the project is to include the other consultants and the contractors (autumn 2005), and thus also experiences regarding the potential of interoperability can be collected. What are the benefits and challenges for the architect in his work and in his interaction with the other participants on mese- and macro-level. Which lessons can further be learnt?

8.3 Adaptability of the framework

The tentative impressions of the frameworks adaptability on practice, is the potential for supporting and guiding the collecting, analysing and presenting of the empirical data. Regarding the project presented in this report, the framework helped keeping overview of actors and processes, and their experiences due to use and implementation of BIM. 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. The organizing of actions and actors due to the three hierarchical levels functioned well. More challenging it was to “place” the benefits and challenges in the right design aspect “box” in the matrix. In the further development of the framework it could be considered whether there are other ways to “draw the lines” between the four design aspects. Should it

A BROAD APPROACH

It could be questioned whether the framework is based on a too broad and ambitious approach. Each of the “boxes” in the matrix themselves represent complex fields of research. This report does not give deeper insight into each of the many aspects. However, this is also not the intention in this phase of the investigation. To understand the mechanisms in the architectural design process and the architect’s work and interaction with other participants seems to require a process-oriented thinking and the “aspiration” for an overview. At least in the first steps of the exploration. Next steps could be to, based on this broad exploration, to chose one or more of the suggested possible areas for further investigation.



Figure 30. Theodor Kittelsen's "Soria Moria slott" (from: www.bergen.folkemuseum.no)

be made differences in the matrix between expected benefits and challenges and the experienced ones?

8.4 Next steps

As basis for further exploration of the topic, and further improvement of the framework applied, the empirical basis should be extended by carrying out more case-studies of relevant projects (multiple case-studies). The framework could have potential for supporting a comparison of empirical data from multiple case-studies (pattern matching). The focus of this report has been on the architect and the architect's interaction to other key-participants in the architectural design process. It could be discussed whether the focus should be extended to e.g. all actors in the design team.

The intention of this report and the case-study of the AHUS project, was to be as open as possible within the chosen scope. The exploration aims to give a insight in many facets and levels of the project, and to contribute with an overview of a complex area. Thus, eventually and hopefully this report can contribute to a better understanding of the use and implementation of IFC-based BIM in the AHUS (front building) project. To gain deeper insight in some of the many interesting themes explored in this report, another next step would be to narrow the scope of further investigation. This report and the exploration of the AHUS project could become a good fundament for doing so.

"So little done, so much to do." Cecil Rhodes, last words

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