A FRAMEWORK FOR EXPLORING THE ICT IMPACT ON THE ARCHITECTURAL DESIGN PROCESS

SUBMITTED: September 2005
REVISED: February 2006
PUBLISHED: May 2006 at http://itcon.org/2006/30/
EDITOR: R. Howard

Anita Moum, PhD-Candidate
Department of Architectural Design and Management, Norwegian University of Science and Technology
email: anita.moum@ntnu.no

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.*

KEYWORDS: *architectural design process, framework, ICT impact, benefits and challenges.*

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 (Computer 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.2). These three levels and the four design aspects are the main components in an ICT impact matrix (Fig.1), 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).

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.

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

FIG. 1: The ICT impact matrix

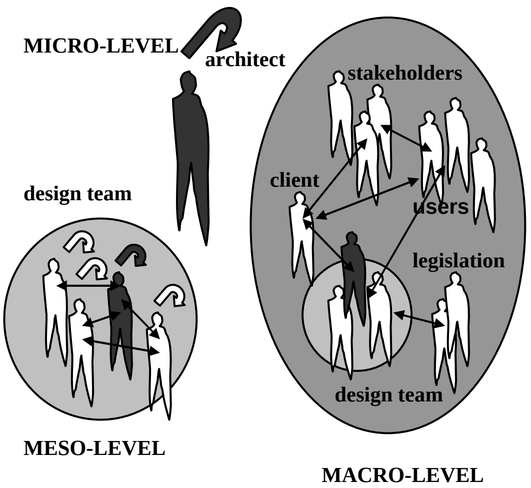

FIG. 2: The three hierarchical levels

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.

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. 2). The micro-level focuses on individual and cognitive processes, for instance the architect's individual development of design solutions. The designer's conversation 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, p.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, p.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. 1), 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.

3. PART 1: A LITERATURE BASED EXPLORATION OF THE ICT IMPACT ON FOUR ESSENTIAL ASPECTS OF THE ARCHITECTURAL DESIGN PROCESS

3.1 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.

3.1.1 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.

3.1.2 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.

3.1.3 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.

3.2 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). Fig. 3 attempts to illustrate the relations between interdependent and iterative processes.

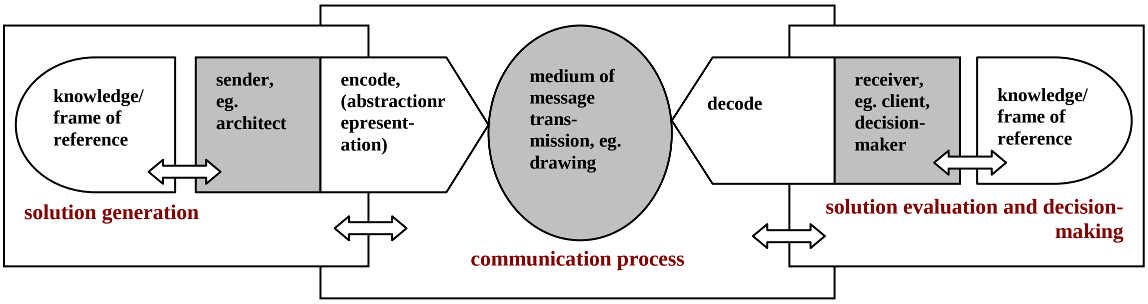

FIG. 3: Illustration of the relations between the four selected architectural design aspects

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).

3.2.1 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, p.140). The designer conversation with the design situation allows a fluid thinking process without constraints like disturbing accuracy. The sketching act can mediate creative processes. Can ICT replace the scribbling with a pen at a sketch paper as mediator of creativity, without disturbing the fluid thinking process? Is the computer able to interpret sketches, which often illustrate a variety of metaphors, and contain a high degree of uncertainty? Until now, the answer seems to be no.

3.2.2 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, pp 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.

3.2.3 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).

3.2.4 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 fundaments for a research field by many seen as one of the most promising within the construction sector: the development of the 3D product model or building information 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.

3.2.5 Redefinition of planning stages, roles and responsibility

Through the use of ICT, processes can be accelerated and traditional stages can overlap. Already at a very early stage of the design process, traditionally later participants can get access to e.g. the 3D product model. Contractors, specialists and manufacturer can contribute with knowledge that helps to reduce uncertainty early in the design process. The “wheel of dominance” (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” (Hannus 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 boarders 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?

3.3 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, Lundequist, 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, p.63). Lawson (2006) emphasizes further that a crucial skill of the designer is to balance qualitative and quantitative aspects.

3.3.1 “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).

3.3.2 Information overload

We do not now much about how the human being handles and edits information (Lundequist, 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?

3.4 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.

3.5 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 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.

TABLE 1: The ICT impact matrix summarizing the key points of the explorative literature review

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

4. PART 2: 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.

FIG. 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, QuickTime 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.

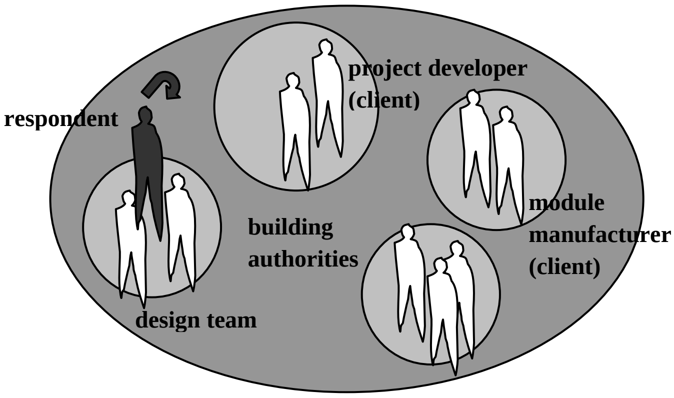

FIG. 5: Macro-level actors

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.

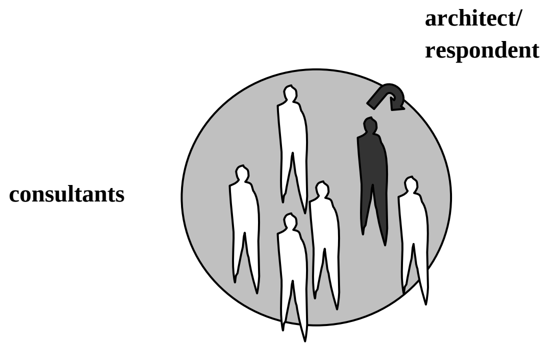

FIG. 6: Meso-level actors

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.

architect/
respondent

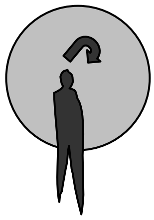

FIG. 7: Micro-level actor

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 2) attempts to summarize examples of ICT related benefits and challenges on all three hierarchical levels in this specific building project.

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.

TABLE 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	**Benefits:** • ICT supported modular system planning/design. **Challenges:** • 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?	**Benefits:** • ICT supported modular system planning/design. *little design solution generation activity – late involvement of consultants*	**Benefits:** • ICT supported modular system planning/design. **Challenges:** • early integration of production constraints – • short time available for free sketching
Communication within the design process	**Benefits:** • ICT supported early communication with manufacturer. • ICT supported the communication of esthetical aspects which would have been difficult to explain only with words. **Challenges:** • blurring border between planning and production, • unclear definition of responsibility resulted in misunderstandings, • misunderstandings could have been avoided with more face-to-face contact	**Challenges:** • 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? *little communication activity – late involvement of consultants*	**Challenges:** • ICT not used as an "interactive" design partner – ICT a drafting tool.
Evaluation of the design solution	**Benefits:** • realistic and real-world like 3D vizualisations and simulations supported the evaluation of e.g. day-light situations and esthetical aspects. • early evaluation and control regarding constructability of solutions possible.	*little evaluation activity – late involvement of consultants*	**Benefits:** • ICT supported the testing of the design solutions ability to fit into modular system . **Challenges:** • too early transforming of ideas into accurate and precise computer generated drawings for evaluation and testing?
Decision-making within the design process	**Benefits:** • 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). **Challenges:** • Forces too early decision not representative for the factual status of project?	**Benefits:** • Reuse of previous solutions/knowledge - reducing uncertainty. *little evaluation activity – late involvement of consultants*	**Benefits:** • 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. **Challenges:** • Too early decisions regarding which ideas to be further developed? Not allowing the "juggling" with several ideas and parallel lines of thought?

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.

5. 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 Modelling) 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.

6. 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.

7. REFERENCES

Barrow L.R. (2000). Cybernetic Architecture, Process and Form. The Impact of Information Technology, PhD-Thesis, Harvard University Cambridge, Massachusetts, USA.

Berg von Linde R. (2003). Kommunikation och nya arbetsformer, in Byggandets informationsteknologi - så används och utvecklas IT i byggandet (Wikforss Ö. ed), Svensk byggtjänst, Stockholm, 139-165.

Davenport T.H. and Beck J.C. (2002). The Attention Economy, Harvard Business School Press, Boston. Chapter 2: What Attention Is and Isn't, 17-33.

Duarte D.L. and Snyder N.T. (2001). Virtual Teams. Strategies, Tools, and Techniques that Succeed, Wiley, Chichester. Chapter 2: Crossing Technical Boundaries, 25-53.

Ekholm A. (2003). Teoretiska grunder för informationssystem vid byggande och förvaltning, in Byggandets informationsteknologi - så används och utvecklas IT i byggandet (Wikforss Ö. ed), Svensk byggtjänst, Stockholm, 203-250.

Emmitt S. and Gorse C. (2003). Construction Communication, Blackwell Publishing, Oxford.

Fekete R. (2003). Design Research and the Records of Architectural Design: Expanding the Foundations of Design Tool Development, in Construction Process Improvement (Atkin B., Borgbrant J. and Josephson P.-E. eds.), Blackwell Science Ltd, Oxford, 240-254.

Fritz O. (2002). Programmieren statt zeichnen? Vom Einfluss digitaler Technologie auf den architektonischen Entwurf, Arcitese, Vol. 32, No. 4, 14-19.

Gann D.M. (2000). Building innovation - complex constructs in a changing world, Thomas Telford, London.

Gray C. and Hughes W. (2001). Building Design Management, Butterworth Heinemann, Oxford.

Griffith T.L., Sawyer J. E. and Neale M.A. (2003). Virtualness and Knowledge in Teams: Managing the Love Triangle of Organizations, Individuals and Information Technology, MIS Quarterly, Vol. 27, No. 2, 265-287.

Hannus M., Penttilä H., Silèn P. (1987). Island of automation in construction, http://cic.vtt.fi/hannus/islands/index.html. October 2004.

Hinds P.J. and Weisband S.P. (2003). Knowledge Sharing and Shared Understanding in Virtual Teams, in Virtual Teams that Work, Creating the Conditions for Virtual Team Effectiveness (Cohen S.G. and Gibson C. B. eds.), Jossey-Bass, San Fransisco, 21-36.

Kalay Y.E. (2004). Architecture's new media principles, theories, and methods of computer-aided design, MIT Press, Cambridge.

Kiviniemi A. (2004). 3D Modeling in Architectural Design. CS 378 Phenomenological Foundations of Cognition, Language and Computation. Term Paper, 07.06.04, Stanford, USA. Unpublished Work.

Lawson B. (2006). How Designers Think - The Design Process Demystified, 4th edition, Architectural Press, Oxford.

Lawson B. (2005). Oracles, draughtsmen, and agents: the nature of knowledge and creativity in design and the role of IT, Automation in Construction, Vol. 14, 383-391.

Lundequist J. (2003). Yrkaskunnande och informationsteknologi, in Byggandets informationsteknologi - så används och utvecklas IT i byggandet (Wikforss Ö. ed), Svensk byggtjänst, Stockholm, 361-377.

Lundequist J. (1992a). Designteorins kunskapsteoretiska och estetiska utgångspunkter, KTH Reprocentral, Stockholm.

Lundequist J. (1992b). Projekteringsmetodikens teoretiska bakgrund, KTH Reprocentral, Stockholm.

Lundequist J. (1992c). Design av byggprojekt. Om design, kommunikation och kunskapsintegration i komplexa organisationer, specielt byggprojekt, MDA-rapport 8.

Moum A. (2005a). A Three Level Approach for Exploring the ICT Impact on the Building Design Process Applied to a Real-life Project, in CIB W78 22nd Conference on Information Technology in Construction (Scherer R. J. et al, editors), Institute for Construction Informatics, Technische Universität Dresden, Dresden, Germany, 669-676.

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

Public website, http://www.sketchup.com, February 2006.

Public website, http://www.tcw.utwente.nl/theorieenoverzicht/, February 2006.

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

Schwägerl K. (2004). CAD - eine Bestandsaufnahme. Teil 1: Konzeptionen und Zeitersparnis, Deutsche Bauzeitung, No. 8, 80-81.

Sundell G. (2003). Tillämpninger i praktiken. Handel och byggproduktion, in Byggandets informationsteknologi - så används och utvecklas IT i byggandet (Wikforss Ö. ed), Svensk byggtjänst, Stockholm, 21-49.

Tarandi V. (2003). Process- och byggproduktmodellering, in Byggandets informationsteknologi - så används och utvecklas IT i byggandet (Wikforss Ö. ed), Svensk byggtjänst, Stockholm, 253-299.

Wikforss Ö. (2003a). Datorernas intåg, in Byggandets informationsteknologi - så används och utvecklas IT i byggandet (Wikforss Ö. ed), Svensk byggtjänst, Stockholm, 21-49.

Wikforss Ö. (2003b). Tillämpninger i praktiken. Utformning och projektering, in Byggandets informationsteknologi - så används och utvecklas IT i byggandet (Wikforss Ö. ed), Svensk byggtjänst, Stockholm, 89-105.

Yin R.K. (2003). Case Study Research - Design and Methods, 3rd edition, SAGE Publications, USA.