ICT and the architectural design process – introduction of an ICT impact matrix

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Abstract

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

Keywords: Architectural design process, ICT impact matrix, overview

1. Introduction

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

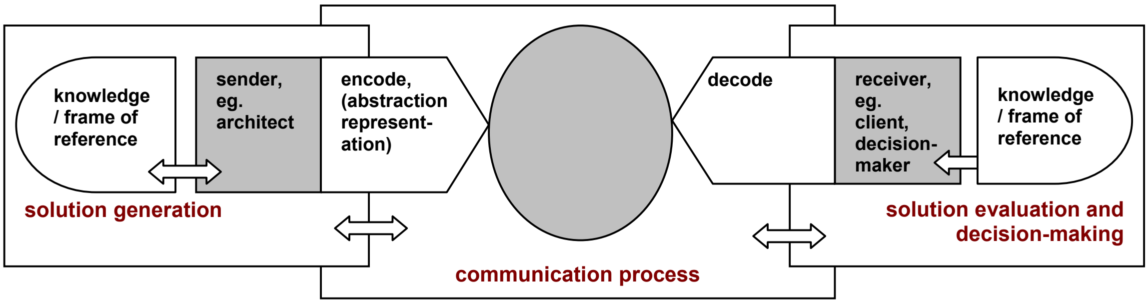

Figure 1: Illustration of the relations between the four selected architectural design aspects

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

2. The generation of design solutions

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

2.1 Computer Aided Design or Drafting

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

2.2 ICT as design partner

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

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

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

2.3 New design methods

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

3. Communication within the design process

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

3.1 The designer's conversation with the design situation

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

3.2 Network technologies and collaboration

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

Network technologies such as e-mail and the internet have contributed to the most radical changes within the average working day for the building process participants, for instance supporting processes independent of geographical and organizational borders. Collaborative design and communication within a virtual instead of collocated situation inherits many new properties, and this eventually leads to various challenges. The network technologies still offer neither the same social presence and information richness, nor the ability to transfer tacit knowledge that a face-to-face collaboration or conversation does [11]. Herein lies a challenge;

to develop network technologies offering the communication possibilities necessary for the achievement of a common understanding, to solve complex problems or to generate complex design solutions. Within the communication process between two or more individuals, ICT have had a dramatic impact on the medium of communication. This could possibly require another use of language and level of abstraction and challenge the skills of the message receiver, hence to another culture of communication.

3.3 Information access and distribution

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

3.4 Communication standards and 3D product models

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

3.5 Redefinition of planning stages, roles and responsibility

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

4. Evaluation of design solutions

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

4.1 “Almost real”

ICT offers a most powerful support of evaluation. Through simulation and highly realistic visualizations it is possible to get an impression of the real-world building project before it is finished. Unrecognized problems can be identified, uncertainty reduced and errors avoided already at an early stage of the building project. In the management area ICT support time-, cost- and resource planning, in the design process they simulate for example the financial and climatic effects of the ventilation-and heating system. Presentation tools supporting VR, 3D-modeling, animations etc. can support the evaluation of visual qualities [5]. However, a conceptual image communicated in a highly realistic manner can also give a false picture of the reality. There can be a conscious or unconscious mismatch between the intention of the sender and the interpretation of the receiver [1].

These tools usually require the presence of something to evaluate, and also that some level of precision has already been reached. And such a level is often not feasible in the early design stage. Lawson [1] characterizes the too early precision temptation as the design trap of over-precision, which can become a creative process impediment. Until now, the building of ICT models as foundation for simulations has been cumbersome and expensive. This often resulted in simulation of limited parts of the total design. But the design problem is multi-dimensional and interactive. Interconnectedness of different factors is an important issue. The focus only on parts can lead to a lack of integration, thereby reducing the quality of the project in total [1]. The possibility of importing 3D product models into simulation software reduces the model building effort and thus the building could be simulated and tested in total [7].

4.2 Information overload

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

5. Decision-making

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

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

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

6. Introduction of the ICT impact matrix

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

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

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

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

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

Table 1:Outline of the ICT impact matrix

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

7. Conclusion

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

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