Vision on ICT Developments for the Building Sector

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Abstract

The building sector is entering a new era. Developments in information and communication technology have an impact throughout the entire life cycle of a building, not only from a process and technical point of view but also from a creative design point of view. As a result of developments of advanced modeling software for architectural design, the gap between what the architect can envision and what the building technician or product architect can materialize is enlarging. Internet technology has already started to provide a closer link between the participants in the building process, their activities, knowledge, and information. Concurrent and collaborative engineering will be the future of building practice in respect to efficiency and quality improvement of this sector. The nature of the building process is complex, not only from a communication point of view, but also from the information of the number of participants, the spatial organization and the infrastructure etc. In the near future, soft computing techniques such as artificial neural networks, fuzzy logic, and genetic algorithms will make contributions to the problem solving aspects of the complex design process. This paper provides an overview of these and other future developments of information and communication technology (ICT) within the building sector.

1   Introduction

Looking back to historical developments in the building sector we conclude that the technological developments in general have always had an impact on how people designed, built, and lived in a built environment. If construction iron had not been found there would not have been an Eiffel tower, or if the car had not been invented we would still have the narrow streets of the middle ages. There are numerous examples that show the impact of the technological developments on the society itself, by changing habits and the way of living, hence the changes on the built environment.

As in any other science, ICT also has an influence on the building sector. We are entering a new era! This will bring innovations, improvements, and new challenges in this sector.

If we focus only on the design process as a part of the building process, we can generally say that there are four main domains of application of ICT in the design process.

1.   Creative design oriented ICT (applied in the conceptual design or inception phase)
2.   Materialization oriented ICT (building physics and building technology aspects such as calculating bearing structures and detailing)
3.   Realization oriented ICT
4.   Process and management oriented ICT (linking the first three categories or activities)

Within the ongoing developments of ICT, the role and the daily work of the people who are involved in the design process are changing. Until now this process was cut into few phases. When the architect has designed the concept, this then goes to the constructor who works out the step and, afterwards, to the contractor who builds it. There is also the supervisor, or manager, who leads this

process. We are now entering into a new stage where this process is no longer sequential, but more of a network type, which we call information, communication and collaboration networking in the design process.

2 ICT in the Building Design Process

When we look at the developments of ICT in the building sector, we see that computers were first put into practice as a tool, as an instrument for achieving a specific result, whether to produce a final drawing, an animation, a simulation, or an interactive visualization. Nowadays, computers have taken on a slightly different role as a new medium besides the existing media within the architectural design process. Especially the widespread use of Internet and the developments of the Web have pushed the computer into the role of a medium.

In the very near future, we can expect another shift in the role of computers in the design and building processes, namely, as a partner (Schmitt 1999; Sariyildiz et al. 1998; McCullough 1996). We are now at a stage that ICT allows us to develop new techniques and methodologies to use the computer as a partner by means of knowledge integration, decision support, and artificial intelligence. Decision support systems allow the computer to support the user through knowledge provided by experts or by the user herself. The computer can also be a partner when we teach it things it can reason with. It can even be a valuable and reliable friend when we let it solve problems that are not clearly defined, fuzzy, or uncertain. It can also assist us in generating forms by processing information that influences the shape, supported by self-learning techniques. Here, artificial intelligence techniques such as fuzzy logic, genetic algorithms, and neural networks play an important role.

ICT as a tool, medium, and partner provides the following support in the entire design process:

- *Tool*
  3D modeling
  CAD (Computer Aided Drafting)
  Presentation (Animation, Simulation, Composition, Rendering, etc.)
  Analysis
- *Medium*
  Interactive visualizations (VR-Virtual Reality, Cyber Space)
  Information processing
  Communication (Internet Technology)
  Collaborative and Concurrent engineering, CSCW
  CAD-CAM, CAE, EEM (Enterprise Engineering Management), etc.
- *Partner*
  Knowledge Integration (ANN-Artificial Neural Networks, Fuzzy Logic, Intelligent Agents, etc.)
  Decision Support Systems-DSS
  Advanced Modeling (Genetic Algorithms, Grammars, etc.)
  Intelligent Management

Finally, ICT is meant to support the designer in the design process in order to achieve the intended goal. This goal can be very different from user to user. The flexibility and the efficiency of these ICT means are important factors in the future.

3 Complexity in the Design Process

Buildings are becoming more and more complex nowadays, not only in their form and functions, but also in their infrastructure: their techniques and communications. Naturally, the design process is also becoming more complex. It is complex in the sense that many, often conflicting, interests and criteria are involved, and that many different types of expertise are required to find an optimal solution. Additionally, there is the uncertainty of the future use of the building, requiring the meeting of new criteria that are not defined explicitly at the moment of design. That means that a designer must have the ability to meet a certain range of criteria in a flexible way so that future demands are also met to a certain degree. The outcome of the design process has to fulfill different requirements of functional, formal, and technical nature. These requirements concern aspects like usability, economics, quality of form and space, social aspects of architectural design, technical norms or laws, and technical and mechanical aspects of the design.

Building design is a multi-actor, multi-discipline, and multi-interest process. Design is teamwork among architects, designers, and consultants for various fields, e.g., building physics, construction,

material science, electrical engineering, acoustics, geotechnics, building economy, and environmental engineering. The process of decision-making is often intuitive and based on experience. Tedious discussions may occur in committees where all or many of the criteria are presented. The resulting decision obviously is a compromise, but it is often unclear how the decision was reached and whether better solutions exist. In this respect, the ICT tools and their integration form an essential component in the *knowledge integration* process of the various disciplines. As such, they are increasingly becoming a valuable and, hopefully, reliable partner in the design process.

To reach better communication and information exchange during the building design, there have been some initiatives to try out concurrent engineering in Europe, but these were not successful for many reasons. In the first place because the building sector in Europe is very much fragmented and still a bit old-fashioned in thought concerning the innovations and technological developments. Concurrent engineering is now turning into collaborative engineering, especially through the influence of the Internet. There is no time and location dependence anymore. Work can be continued at any time and anywhere in the world. By means of Virtual Reality (VR), participants can communicate visually with each other. Therefore, it is worthwhile also in Europe to put an effort in the developments of broadband technology.

As it was mentioned earlier, in the building process we have to deal with complexity. There are many partners and knowledge disciplines involved in this process. This information must be ordered and the communication must be realized between various disciplines and people involved. Thus, the management of Information, Communication, and Collaboration between the partners in this process has to be done in a most efficient way. Therefore, the ICT means are inevitable tools in the future of the building sector. Collaborative engineering techniques can be a good start to reach this goal.

4   The Role of ICT in the Creative Design Process

When we look at the role of the designer in the building process, we see that as a professional she has to deal with three main categories of sciences, sometimes called alpha, beta, and gamma sciences. Alpha sciences deal with the subjective world of beauty and moral, as expressed by the artistic, intuitive soul. Beta sciences bring in the objective world of facts and logic, represented by the rational mind. Gamma sciences consider the interest of the society and culture. The integration of these sciences makes the task of the designer more complex, but also extraordinary and unique. This means that the designer must have the skills to integrate the various disciplines of knowledge, involving besides the artistic form expression of the building also the dimensioning of the structure, building physics, applied mechanics, the calculation of structures, building materials and techniques, etc. The most famous designers, such as Santiago Calatrava, are the ones who have the ability to combine these various disciplines in their designs as architect and building engineer at the same time.

It is known that when computers were first introduced in the building sector, the initial applications mainly concerned administrative tasks. Gradually their functionality has been extended to support repetitive tasks; nowadays, software applications are becoming essential tools for creative design, for materialization (building technical aspects), and also for the management of the entire building process. Already, for many architects, such as Peter Eisenman and Frank Gehry, the employment of computational programs is an instrumental, if indispensable, means, even if it holds no explanatory power over the results (Forster 1996).

With respect to creative design, we see that the spatial software developments for design during the last years have an influence on the form finding and the spatial design of the creative designer (figure 1). The designing architects are more and more using 3D modeling software such as Maya. During the International design workshop in the Dutch Architecture Institute (NAI), we experienced that the design tools that are offered to the designer have a considerable impact on how the designer is stimulated by the possibilities of the 3D modeling software. It is a fact that the designer dares to design more complex forms and has more flexibility to do so, than she needs. In order to see the influences of the new software in design, the NAI organized an experimental workshop last summer in Rotterdam. Dutch designing architect Lars Spuybroek guided the students within the design context in collaboration with the staff of the chair of Technical Design & Informatics. Our staff guided the students in the informatics aspects and, within a few days time, the students were able to learn to cope with various software, including Maya, in order to design a stadium. The design outcome was very extraordinary, even futuristic, concerning the form aspect (figure 2).

5 Advanced Modelling Software and its Impact on Practice

As a result of developments in advanced modelling software, and its use for architectural design, the gap between what the architect or designer can envision, on the one hand, and what the building technician or product architect can materialize, on the other hand, is enlarging. The Guggenheim Museum (figure 3) in Bilbao, Spain, designed by Frank Gehry, is a prime example. Designed using Catia, a modeling software first developed for the aerospace industry, it is a fact that the form of this design would be much more difficult to establish using traditional tools and methods for designing than using this or other advanced modelling software. With such tools, the architect is provided with a richer form vocabulary and more flexibility to realise her spatial ideas on the computer. Design software has reached a point where it can stimulate the designer's creativity rather than impede it as has been argued in opposition to the use of CAD software. Also in Europe, we can see many architects who have adopted advanced modeling software for their creative design, such as Dutch architects Kas Oosterhuis and Lars Spuybroek (Schwartz 1997).

The developments in the field of building technology and building materials have not followed these advances in modeling software, such that they can no longer answer all the requirements and demands of the new architectural forms. ICT may play an im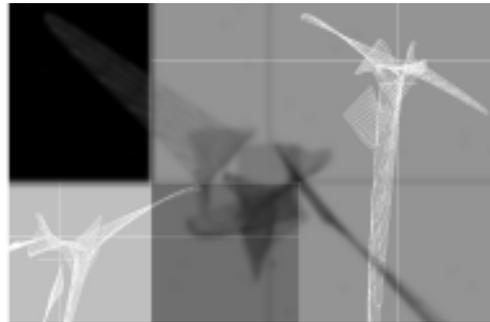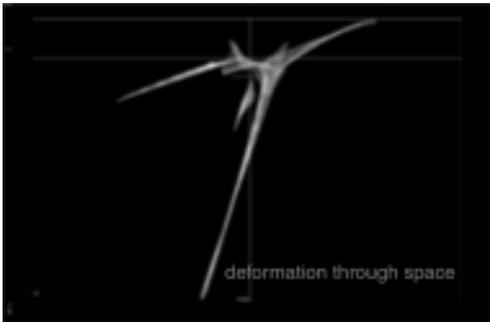portant role in narrowing this gap. CAD/CAM already counts heavily in the realization of such buildings as the Guggenheim Museum. Electronic form information is transferred directly from the design model to computer-controlled manufacturing machines, as in the case of stone cutting for a curved wall. Unlike straight or even cylindrical surfaces, free-formed surfaces cannot be composed simply of standardised components; potentially each element may be of a different size. This strongly complicates the manufacturing process and causes astronomical costs. Numerically or computer-controlled equipment enables custom components to be produced at a lower cost. Connecting such equipment to the Internet such that these can be controlled directly from the design model further cuts cost. As custom manufacturing increasingly replaces standardised production, these costs will further decrease. Furthermore, as electronic catalogues are extended to include information on custom manufacturing techniques, possibly allowing designers to check manufacturability and price in the design phase, custom production will become more accessible and common.

Figure 1. Student work using advanced modeling software.

Figure 2. Results from the NAI international design workshop.

6 Communication and Collaboration over the Internet

As the Web and Internet technologies are filtering into every aspect of society, so will they have an enormous impact on the building practice. Already, architectural offices are using the Internet in order to communicate with partners across the globe, discussing their designs using whiteboard software and teleconferencing. As distances become smaller, architects are empowered to take on a global role. Examples already abound, such as the world's highest skyscraper in Kuala Lumpur, Malaysia, designed by Cesar Pelli Associates in the US. The use of Islamic geometric patterns in the design nevertheless shows a strong influence from the local culture.

Such global access requires new ways of managing the design process. Building projects are increasingly becoming team-work, where no one person is solely responsible for a design. Well-defined control hierarchies and relationships are making place for more intricate collaborative processes that are not as easily planned and controlled. This requires an increasingly networked thinking that brings partners to closer interaction but, without appropriate computational support, impedes the ease of overview and understanding (Lottaz et al. 2000). Web-based document

Figure 3. The Guggenheim Museum, Bilbao, Spain.

management systems serve as media for the exchange of information between the collaborative partners and provide facilities for organizing, viewing, and redlining drawings and images (Roe 1999). These systems can also serve the development and dissemination of tools that support specific needs and processes (Lottaz et al. 2000), leading to integrated software environments as platforms for various applications to communicate with each other over the Internet (figure 4).

This evolution is founded on several universal Internet technologies, such as TCP/IP, HTML, Java, and XML. Using these technologies, it is pretty straightforward to create a Web application that runs on any platform. The role of XML is as a universal data interchange format among applications, freeing "Internet content from the browser in much the same way as Java frees program behavior from the platform" (Johnson 1999). XML also simplifies communication and improves agent technology (Tidwell 1999). When exchanging XML-structured data, the only thing the partners need to agree on is the XML tag set used to represent the data. No other information about each other's systems is required. This makes it simple for new organizations to join an existing structure of data exchange. Similarly, XML-structured data makes

Figure 4. Four types of functionalities to support information processing in an integrated environment. Image by David Kurmann.

it much easier for an agent to understand exactly what the data means and how it relates to other pieces of data it may already know, thereby easing one of the challenges when writing an agent, that is, to interpret the incoming information intelligently and respond to it accordingly. Another advantage to the use of XML for structuring data is that it can easily be applied to existing data and information, for the purpose of archiving or indexing such information. Unlike product model representations, XML structured data is easy for a human to read and understand, is flexible in its application, and can easily be applied for specific purposes (Tunçer and Stouffs 2000).
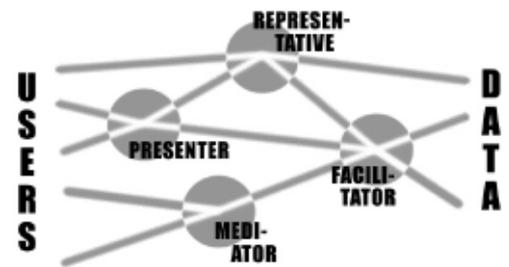
Many disciplines are in the process of developing a framework for using the XML standard for electronic communication and data interchange in their domain (Cover 2000), including the building industry (aecXML 1999). Considering the complexity of building projects and the unstructured and interrelated nature of the project data, it is sure that the building community can benefit from a unifying strategy for data interchange. This will not only make the current data exchange and reuse practices more efficient, but will also result in great savings by streamlining the worldwide transactions in the Architecture, Engineering, and Construction (AEC) community.

7 ICT in Architectural Education

In the near future, as a result of the ongoing developments of ICT, we, as designers and professionals who educate the future designers in the field of computing, need to think thoroughly and adapt ourselves to these rapid developments. Up to now, in most CAD curricula at faculties of architecture, more attention is paid to the computer as a tool and partially as a medium for communication and information processing. We are now at a stage that the technological developments allow us to look forward and go a step further than the present use of those tools in education.

It is now necessary to introduce the existing ICT means and techniques into the education and develop the above mentioned subjects of ICT. In the future, the architects must be able to extend the existing tools and integrate them for their specific needs. As such, the level of education must be pushed up to a higher level, to a level where the computer is used not only as a tool or medium but also as a partner with respect to knowledge integration and advanced modeling techniques, and as a

support environment during the design process.

If these developments will be left to others than architects, the architects will be faced with the danger that they will become the slave of the tools and not the boss. Partially, we face the same kind of problems at the moment with the commercial tools. None of the commercial CAD products support the designer, as it should be. Each program has its advantages and lesser advantages or disadvantages. The user must have to learn the basic principles in order to be able to use the software and to make use of the advantages of each in an efficient way. This basic knowledge should be given to the architecture students from the first year.

On the other hand, the student of the future will be a mobile student who will be able to work at any time and at any place. Therefore, distance-learning possibilities will gain an important role in the future for the academics that are involved in the education.

8 The Impact of Artificial Intelligence on ICT Enhanced Building Technology

Design requires more comprehensive attention than ever before. Building design involves multi-dimensional aspects, which need to be considered with respect to conflicting criteria, that themselves must be reconciled for optimal design solutions, and this in an industry where cost effectiveness and efficiency are becoming dominant requirements due to a hard competitive environment. In this respect, there is no doubt that the available building information must be used effectively, and ICT can play a role in eliciting this information in a timely and exhaustive manner. Several emerging technologies have important relevance to the use of ICT in the building process and, ensuing, important implications. Various implications of these advances in communication technology have already been pointed out in the preceding sections. In particular, due to these advances, design information is now communicated over the Internet and a start is being made of storing information and knowledge in databases and knowledge bases, respectively. At the same time, the volume of information to be processed is exponentially growing.

As information and knowledge are being stored at a continuously growing pace, buried in gigabytes of records, these are becoming far less comprehensible. Faced with difficulties of retrieving them and making them available in an easily comprehensible format at higher levels of summarization, this information becomes less and less useful. No human can use such data effectively and be able to understand the essential trends in order to make rational decisions. With reference to this phenomenon of overwhelming information, the emerging technologies of knowledge discovery and data mining offer a prospect of help. Knowledge discovery is inherently connected to databases: in an interaction with a database, a search for patterns or objects is performed, eliciting meaningful pieces of knowledge. Data mining provides the means or methods to attain this knowledge. Among the most promising methods for data mining are artificial neural networks, fuzzy logic, and heuristic search methods such as genetic algorithms. Collectively, these are referred to as soft computing methods; heuristic search methods are also referred to as evolutionary algorithms. Artificial neural networks are invoked toward processing numeric data and building non-linear relationships. Fuzzy sets concentrate on the representation of data at a nonnumeric level. The symbiotic cooperation of these two technologies results in an effect on the granularity of information.

These soft computing methods are receiving growing importance in almost every field, including building technology, though here at a relatively slower pace. Presumably, the basic reason for this is the difficulty of formulating building technological problems in a way that these become convenient for artificial neural treatment. However, these methods are especially important in the building sector, as they can handle information in various forms such as numerical specifications as well as linguistic qualifications, thus, information coming from all three alpha, beta, and gamma sciences. At present, a unified representation for artificial neural networks and fuzzy logic is already established (Jang et al. 1997). From this, it can be anticipated that the communication between building technology and soft computing technology will be much easier than before. This is due to the possibility of processing information at hand more human-like in the coming years than is achieved today. Currently, such information processing, in combination with knowledge based systems, is mostly introduced in the form of expert systems or decision support systems. So far, these are in most cases unsatisfactory. In the future, however, we can expect such computational intelligence systems to play an important role in decision making support.

Intelligent systems are increasingly replacing conventional systems, as exemplified by intelligent manufacturing and intelligent design technologies. Some basic Artificial Intelligence (AI) fields asso-

ciated with the emerging technologies connected to the development of ICT are indicated in figure 5. In order to cope with the demands of information acquisition and information handling of these intelligent technologies, new methodologies and techniques are being developed. Besides knowledge discovery and data mining technology, agent technology is another example of such emerging software technologies. An agent is a software program

Expert Systems (database systems, knowledge representation, machine learning)

Fuzzy logic

AI TECHNOLOGIES

Neural Networks

Evolutionary computation

Figure 5. Some basic AI fields of importance to ICT developments with impact on building technology.

designed for a specific purpose or functionality that acts autonomously to some extent, and may be intelligent too (Jennings and Wooldridge 1998). Agent technology is closely associated with ICT in the sense that agents are generally conceived for communication with other agents or software and for transmission to a distant computer if the task requires it. The Internet allows this distant computer to be any machine on the globe. Agents are especially promising for mining databases as they act autonomously. As an example, a fuzzy engineering agent can interact with a building design database in order to identify various trends of engineering or architectural nature. In connection with VR, agents can assist in design by providing sufficiently realistic feedback early in the design process. This should ease the early integration of design components, in particular, in collaborative design (Abarbanel et al. 1997). Especially for collaborative design, agents have an important role to play in order to assist participants in their task or communications, or to offer additional functionality in project-management applications (Stouffs et al. 1998).

9 Future ICT tools for the building sector?

We are still dealing with the material world for which ICT is highly appropriate. But what will happen to the immaterial world? Can we 'teach' computers immaterial values?

Early developments of information technology in the field of architecture involved two-dimensional applications; subsequently, the significance of the third dimension became manifest. Nowadays, people are already speaking of a fourth dimension, interpreting it as time or dynamics. And what, for instance, would a fifth, sixth or X-th dimension represent?

We are now able to communicate verbally and with sign language with computers. In the future we will perhaps speak of the fifth dimension as comprising the tangible qualities of the building materials around us. And one day a sixth dimension might be created, when it will be possible to establish direct communication with computers, because direct exchange between the computer and the human brain will have been realized. The ideas of designers can then be processed directly by the computer, and we will no longer be hampered by the physicality of screen and keyboard.

This is mere speculation, and seems to be far-fetched, but even 50 years ago nobody could even imagine that today everybody could be walking the streets with a wireless telephone.

10 Conclusions

The ongoing developments in the field of ICT have an important impact on the design and building processes. Designers can allow ideas and intuitions to take physical shape in ways that have not been possible before (Forster 1996). At the same time, building technical developments are lagging behind and alternative, innovative solutions have to be adopted. In Eisenman's Aronoff Center at the University of Cincinnati, "all of the building trades (plumbing, tiling, painting) were carried out through a three-dimensional coordinate numerical control system implemented by an electronic laser transit on the site" (Zaera-Polo 1996). Future ICT developments for architecture and the building sector will be in the field of knowledge integration and decision support environments, leading finally, to ICT support in the entire building process, from initiative until demolition. Collaborative engineering will pervade the building design process. By means of these technologies, the various branches of scientific disciplines will come closer than ever before into an integration of their disciplines. In the future, each participant in the design process will need to be able to make her own computer model in order to build up her specific knowledge within this computer model and to use it for her own support as a partner in the design. Developments in the software industry already show that if software firms provide the software core, architects and building engineers will be able to develop their own application tools according to their specific requirements and needs. Independent of the existing tools, they
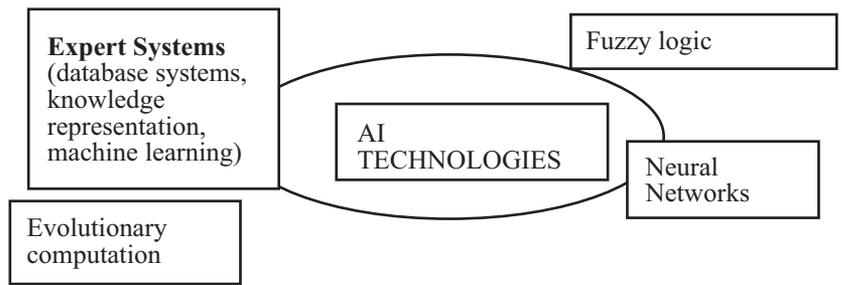
will even be free to create their own language of activities. Ongoing developments of Internet technology require other ways of design management and communication (data and partners communication) in the building process.

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