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The importance of communication in concept design simulation

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The importance of communication in concept design simulation

Abstract

The European Union has taken a strong leadership role in promoting energy efficiency in buildings. This is among other things highlighted by the Directive on the Energy Performance of Buildings, which is designed to promote the improvement of energy performance of buildings in member states. One of the benefits of this directive is that it provides an integrated approach to different aspects of buildings energy use, which until now only a few member states were doing, and that all aspects are expressed in simple energy performance indicators.

In order to achieve such reductions of the energy use in new buildings it will require development of new construction solutions, new types of building envelopes, and development of new building materials. It will also require the development of more holistic building concepts, sustainable buildings where an integrated design approach is needed to ensure a system optimization and to enable the designer(s) to control the many design parameters that must be considered and integrated. It is therefore important to understand how this design process works and how the architect can be enabled to integrate sustainable design solutions.

Computer-based modeling and simulation is becoming more and more significant for the prediction of future energy and environmental performance of buildings and the systems that service them. Modeling and simulation can and should play a vital role in building and systems design, commissioning, management and operation. Although most practitioners will be aware of the emerging building simulation technologies, yet few are able to claim expertise in its application.

In the design of sustainable buildings it is therefore necessary to identify the most important design parameters in order to develop more efficiently alternative design proposals and/or reach optimized design solutions. This can be achieved by applying sensitivity analysis early in the design process.

Previously, environmental simulation of building performance was only done by engineers at the end of the design process. Any weak points in the performance of the design could then be 'fixed' by adding heating, cooling, shades, vents, fans, panels, etc …

However, at the end of the design process it is too late. The decisions made early on in the design process have the largest impact. In addition, environmental issues are becoming more important, the complexity of the building design is increasing, and simulation tools are becoming more architects friendly.

Therefore, in the design of sustainable buildings it will be very beneficial to be able identify the most important design parameters in order to develop more efficiently alternative design proposals and/or reach optimized design solutions. Communication between architects and engineers

will become more common but also more important. Digital architecture has to take these challenges into account and develop a common language for architects that enable integrated design in order to tackle the problems stated above.

Introduction

There is a world-wide need for sustainable development (Behling 1996). There are basic explanations of what sustainable development is and how it is reached therefore in order to develop appropriate strategies for sustainable development in the built environment it is useful to review the key reports on sustainability issues.

Brundtland Report

The concept of sustainability was developed in the late 1980s. The World Commission on Environment and Development (WCED) in the Brundtland Report in 1987 defined sustainable development as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The report highlighted three fundamental components to sustainable development:

- environmental protection,
- economic growth and
- social equity.

The environment should be conserved and our resource base enhanced, by gradually changing the ways in which we develop and use technologies (Brundtlandt 1987). This idea is illustrated in Figure 1.

Agenda21

In 1992 The Earth Summit conducted under the auspices of the UN took place in Rio de Janeiro. The objectives were "to extend the provision of more energy-efficient technology and alternative/renewable energy for human settlements and to reduce negative impacts of energy production and use on human health and on the environment".

In order to be able to react in a flexible way to the diverse issues originating in the participating countries it was proposed to apply new concepts tailored to the local situation. "Think globally – act locally" was the resulting slogan (UNCED 1992). This emphasises the need for an analysis of the local situation of the built environment followed by developing sustainable solutions for that specific location.

Kyoto protocol

In 1997, governments from 188 countries adopted the Kyoto Protocol, under which they agreed to reduce their greenhouse gas emissions by the period 2008 to 2012. A large part of these emissions – 85 percent across Annex I countries in 1995 – arises from the production and use of energy. As a result, the commitments made in Kyoto will require significant reductions in energy-sector emissions in many countries ((Philibert and Pershing 2002; UNCED 1997).

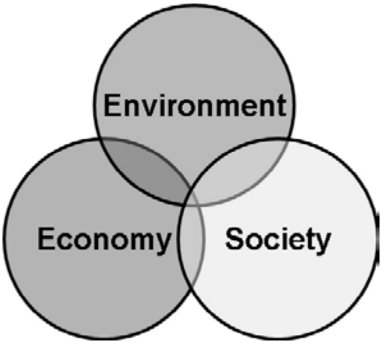

Figure 1
Sustainable development (Brundtland 1987)

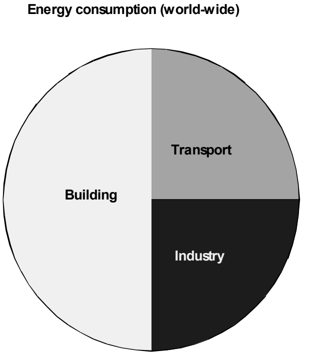

Figure 2
World-wide energy consumption distribution (Behling et al. 1996)

UN World Summit on Sustainable Development (WSSD) (2002)

The UN World Summit on Sustainable Development (WSSD) took place in Johannesburg, South Africa in 2002 and is also known as Rio +10 Summit because one of the two main goals was to review the progress on implementation of the 1992 Summit in Rio. The other goal was to develop a plan for the further implementation of sustainable development programs (UNEP 2002).

The primary Summit outcomes were

- the Johannesburg Declaration on Sustainable Development,
- the Plan of Implementation (The Plan of Implementation is designed as a framework for action to implement the commitments originally agreed at UNCED.),
- 283 Type II Initiatives (that are partnerships between government and different actors concerned with sustainable development).

Sustainable building design

Different countries have developed their specific vision of how to incorporate sustainable development in relation to the built environment.

The fundamental idea behind is that the built environment is responsible for 50% of energy consumed world-wide (Behling et al. 1996) as illustrated in Figure 2. Thus it is significant to reduce energy consumption of buildings.

The European Union has taken a strong leadership role in promoting energy efficiency in buildings. This is among other things highlighted by the Directive on the Energy Performance of Buildings, which is designed to promote the improvement of energy performance of buildings in member states. One of the benefits of this directive is that it provides an integrated approach to different aspects of buildings energy use, which until now only a few member states were doing, and that all aspects are expressed in simple energy performance indicators. The integrated approach allows flexibility regarding details, giving designers greater choice in meeting minimum standards. In order to achieve a certain degree of harmonisation of assessment of buildings for designers and users throughout the EU, a common methodology based on an integrated approach is established and includes the following aspects:

- thermal characteristics of the building;
- heating installations and hot water supply
- ventilation and air-conditioning installations;
- built-in lighting installations;
- position and orientation of buildings, including outdoor climate;
- passive solar systems, solar protection, natural ventilation and natural lighting;
- indoor climatic conditions, including the designed indoor climate;
- active solar systems and other heating and electricity systems based on renewable energy sources;
- district heating and cooling systems.

Design

In order to achieve such reductions of the energy use in new buildings it will require development of new construction solutions, new types of building envelopes, and development of new building materials. It will also require the development of more holistic building concepts, sustainable buildings where an integrated design approach is needed to ensure a system optimization and to enable the designer(s) to control the many design parameters that must be considered and integrated. It is therefore important to understand how this design process works and how the architect can be enabled to integrate sustainable design solutions.

Although many attempts to describe the design process have been made, there is no consensus or general theory about how design is handled. During the 80's design theory was developed, primarily through Schön's adaptation of Simon's ideas about modeling and simulation as the central activity in all design work (Simon 1969). Simon viewed design as the construction and use of models for developing a basis for the client's decision. He also argued that the designers first generate a set of alternatives and then test them against a set of criteria. In his renowned book: "Reflection in Action", Donald Schön presents design work as a dialectic between technical-rational thinking and intuition (Schön 1983). This theoretical argument has also been observed. "Essentially, design is a cumulative strategy of developing a solution and critically appraising it to see whether or not it meets the criteria of the client" Gray et al. presented observations (Gray et al. 1994). Bryan Lawson, in one of his books about design methodology, has made observations and descriptions of design processes. Among his main findings are that "There are no optimal solutions to design problems. Design almost invariably involves compromise." and "Design inevitably involves subjective value judgments" (Lawson 1997).

Papamichael and Prozen proposed a new design theory along Schön's lines, where they suggest that design involves "feeling and thinking while acting", supporting the position that design is only partially rational (Papamichael and Protzen 1993). They claim that design decisions are not entirely the product of reasoning, rather, they are based on judgments that require the notion of "good" and "bad", which is attributed to feelings, rather than thoughts. They further suggest that research and development efforts should concentrate on computer-based simulation of performance, factual databases and appropriate user interfaces (Papamichael et al. 1997). The new concept for computer-based design is based on the theory that building design is characterized by the following main stages:

- Generation of ideas and solutions (strategies and technologies)
- Performance prediction of potential solutions
- Evaluation of potential solutions

Within the work of the International Energy Agency, Task23 – Integrated Design Process, several design strategy methods and tools have been developed that try to optimize the building performance from the early design stage by including typical elements that are related to integration as

- Inter-disciplinary work between architects, engineers, costing specialists, operations people, and other relevant actors right from the beginning of the design process;
- Discussion of the relative importance of various performance issues and the establishment of a consensus on this matter between client and designers;
- Budget restrictions applied at the whole-building level, with no strict separation of budgets for individual building systems, such as HVAC or the building structure.
- The addition of a specialist in the field of energy, comfort, or sustainability;
- The testing of various design assumptions through the use of energy simulations throughout the process, to provide relatively objective information on this key aspect of performance;
- The addition of subject specialists (e.g. for daylighting, thermal storage etc.) for short consultations with the design team;
- A clear articulation of performance targets and strategies, to be updated throughout the process by the design team.
  (Larsson and Poel 2003)

An integrated design approach has impacts on the design team that differentiate it from a conventional design process in several respects. The client takes a more active role than usual; the architect becomes a team leader rather than the sole form-giver; and the structural, mechanical and electrical engineers take on active roles at early design stages. (Larsson and Poel 2003)
Within the framework of the IEA Annex 44 project examples of methods and tools that are used

in the design of integrated building have been described as shown in Table 1. Although the report did not aspire to give a complete overview of all possible design methods and tool it contains a description of 11 different methods and tools that are widely used in research and development work (Annex44 2006a).
Although the methods contain many similar aspects, they may be organised into 5 main categories:

- Design Process Methods/Tools
- Design Evaluation Methods/Tools
- Design Strategy Methods/Tools
- Design support Methods/Tools
- Simulation Tools

There are no sharp borders between the different types of tools. The design support tools may in some case also be used as design evaluation tools, and vice versa. The available computer simulation tools for predicting energy use and indoor climate are typically used as design evaluation tools, but may also be used as design support tools (Annex44 2006).

Architectural consequences

The building design is the first and most important step in developing an environment that fulfils the main key demands. The OECD project on sustainable buildings for the future identified five objectives for sustainable buildings (John 2005):

- Resource efficiency;
- Energy efficiency (including greenhouse gas emissions reduction);
- Pollution prevention (including indoor air quality and noise abatement);
- Harmonization with environment;
- Integrated and systemic approaches.

The background of these keywords range from ecological, environmental to technical, engineering topics. The role of the architect is to incorporate all these issues into the early design since this provides the largest benefits as illustrated in Figure 4.
The architect is not educated to deal with all of these issues. Resource and energy efficiency and pollution prevention are typical fields of engineering application. Harmonization with the environment is multidimensional and most architects deal with this task but is there an integrated and systematic approach to reach a sustainable building?

In this respect is important to educate architects and engineers on the:

- Energetic consequences of design
- Quantity of architectural concept
- Quantity of architectural quality
- Quality of energetic concept
- Architectural consequences of energetic concepts

Name	Origin	Year
The Integrated Design Process, Task 23	IEA SHCP Task 23 (International)	2003
The Integrated Design Process, Knudstrup	M-A.Knudstrup, Aalborg University, Denmark	2004
Integrated Building Design System, IBDS	K.Steemers, Cambridge University, UK	2005
The Eco-Factor Method	Erik Bjørn, Åsa Wahlström (Swedish National Testing and Research Institute, Henrik Brohus (Aalborg University)	2004
Trias Energetica	Ad van der Aa, Ir. Nick van der Valk, Cauberg-Huygen Consulting Engineers, The Netherlands	2005
Energy Triangle	Haase, M. and A. Amato, Hong Kong University	2005
The Kyoto Pyramid	T.H. Dokka, SINTEF, Norway	2004
E-Quartet	A. Satake, Maeda Corporation, Japan	
Eco-Facade	M. Kolokotroni (et al), Brunel University, UK	2004
LEHVE	T. Sawachi, NILIM, Japan	2005
VentSim	S. Nishizawa, Building Research Institute, Japan	

Table 1

Different methods and tools that are widely used in research and development work (Annex44 2006c)

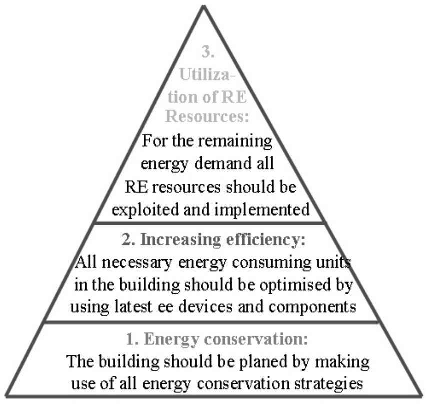

Figure 3

Energy triangle for sustainable building design (Amato and Haase 2005)

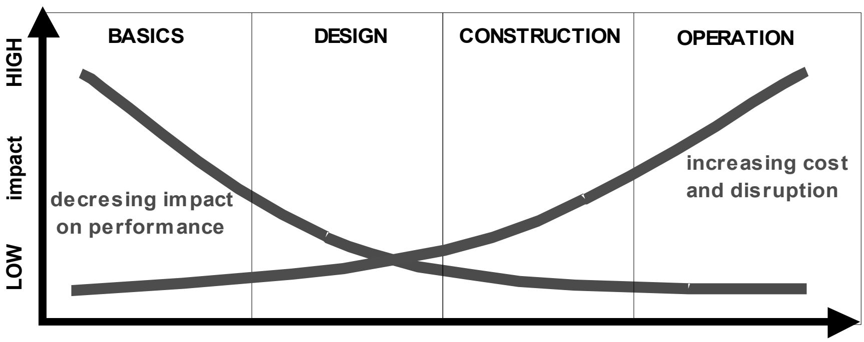

Figure 4

Benefits of early decisions

Here it becomes obvious that a main task of future architectural research should focus on quantifying architectural qualities and qualifying engineering quantities. This has to begin with the development of a common language for architects and engineers.

Simulation

For the purposes of discussion, the use of computers can be divided into the following categories:

- numerical analysis,
- symbolic manipulation,
- visualization,
- simulation, and the
- collection and analysis of data.

Numerical analysis refers to the result of well-defined mathematical problems to produce numerical (in contrast to symbolic) solutions.
Over the past two decades, the building sim
ulation discipline has matured into a field that offers unique expertise, methods and tools for building performance evaluation. It draws its underlying theories from diverse disciplines, mainly from

- physics,
- mathematics,
- material science,
- biophysics,
- human behavioral,
- environmental and
- computational sciences.

Computer-based modeling and simulation is becoming more and more significant for the prediction of future energy and environmental performance of buildings and the systems that service them. Modeling and simulation can and should play a vital role in building and systems design, commissioning, management and operation. Although most practitioners will be aware of the emerging building simulation technologies, yet few are able to claim expertise in its application. This situation will soon be improved due to developments and activities such as

- Introduction of performance-based (EU) standards – as opposed to prescriptive standards – in areas such as energy consumption, quality of the indoor environment, etc.
- Establishment of societies dedicated to promotion and the effective deployment of simulation such as the International Building Performance Simulation Association (IBPSA).
- Growth in small-to-medium-sized practices offering simulation-based services.
- Appropriate training, continuing education, and incorporation in the regular curricula of (higher) educational institutes.
  (Hensen et al. 2002b)

Theoretical challenges are plentiful when recognizing that the physical state of a building is the result of the complex interaction of a very large set of physical components. The integration of these interactions in one behavioral simulation poses major modeling and computational challenges. Its ability to deal with the resulting complexity of scale and diversity of component interactions has gained building simulation a uniquely recognized role in the prediction, assessment and verification of building performance. The building simulation discipline is continuously evolving and maturing and improvements are continuously taking place in model robustness and -fidelity. As a result, the discussion has shifted from the old agenda that focused on software features to a new agenda that focuses on the effectiveness of and team based control over simulation tools in building life cycle processes (Hensen and Nakahara 2001).

A lot of research is devoted to the better description, modeling and simulation of physical transport flows in buildings such as the flow of energy and matter as well as radiative transport phenomena such as light and sound. Applications of such studies deal with the simulation of energy conservation and storage systems, dynamic control systems for smart building technologies, optimal performance of heating and cooling devices, visual and acoustic comfort, smoke and fire safety, distribution of air borne contaminants, the growth of molds, and others. It is expected that new developments will radically influence the way that simulation is performed and its outputs used in design evolution and post occupancy decision making (Hensen et al. 2002a). Apart from this shift from simulation of phenomena to design decision making, there are a number of major trends, such as the shift from the need for "raw number crunching" to the need for support of the "process of simulation", and from "tool integration" to the "process of collaboration" (Augenbroe and Hensen 2004).

In this context, most traditional design tools are not particularly useful for analysis at concept stage, for a number of important reasons:

- There is no easy way of imbuing objects in the model with real architectural knowledge.
- CAD models have no concept of spaces and zones, they exist solely as a by-product of the layout of disassociated polygons and prisms.
- Whilst it is possible to assign tokens and indicators to individual objects, it is not possible to apply detailed thermal, lighting and acoustic material properties.
- Even if you could work out a way of embedding any of this data, most analysis engines will only read in a DXF file anyway, which will completely ignore this embedded data.

There are also a number of problems with using simulation software:

- It changes the way that the design must be modeled
- It is complex to learn; requires a lot of knowledge
- It favours conventional building types
- Is restricted in the types of geometries that can be modeled
- It can be inaccurate

Many different types of software system have been developed to evaluate buildings.
For example:

- Environmental impact analysis (e.g. embodied energy within materials)
- Cost analysis (e.g. fabric cost calculation)
- Structural analysis (e.g. structural stability)
- Environmental simulation (e,g, lighting, energy, acoustics)
- User behaviour simulation (e.g. people flow)

Linking the simulation process to the design process is a very important step. There has not been enough research on this aspect. A new framework of applying simulation tools into conceptual design stage was proposed (Xia et al. 2008). Several issues have been evaluated, including

- the subdivision of the conceptual design stage and their characteristics,
- the architects' requirements on the building simulation tools in each sub-stage,
- the available information for the building simulation in the different sub-stages, and
- the simulation procedure assisting the conceptual design.

What is missing in this programme is a further link to other aspects in conceptual design, e.g. programme (building use defined in design brief), environmental programme (incl. area and infrastructure, material use, etc.) (Støa et al. 2006) and architectural quality. Here, more architectural research is necessary in order to evaluate architectural consequences of low-energy measures that enable the designer to fully explore the possibilities (Kleiven 2004).

Robustness

In the design of sustainable buildings it is therefore necessary to identify the most important design parameters in order to develop more efficiently alternative design proposals and/or reach optimized design solutions (Heiselberg 2006). This can be achieved by applying sensitivity analysis early in the design process. A sensitivity analysis makes it possible to identify the most important design parameters in relation to building performance and to focus design and optimization of sustainable buildings on these fewer, but most important parameters (Lam and Hui 1996; Lomas and Eppel 1992; Saltelli et al. 2000). A sensitivity analysis will typically be performed at a reasonably early stage of the building design process, where it is still possible to influence the selection of important parameters.

Thus, sensitivity analysis and robustness studies make it possible to identify the most important design parameters for building performance and to focus the building design and optimization on these fewer parameters.
The main barrier for application of sensitivity analysis in building performance assessment is the increase in calculation time and complexity (Heiselberg 2006).

Table 2 shows the results of a recent study carried out at SINTEF. It illustrates the impact of different design parameter of a typical office building in Norway. A robustness factor has been

Design	Parameter	description	RI = (IP value that changes OP 10%)	
External				
	Climate	annual average temperature	1.62	[°C]
	Horizon	degree		
Building				
	Air tightness of envelope	air leakage	1.48	[ach at 50 Pa]
	Orientation	degrees		
	U-value	floor	42.3	[W/m^2/K]
		roof	0.28	[W/m^2/K]
		wall	0.33	[W/m^2/K]
	Windows/glazing type and size	U-value	0.89	[W/m^2/K]
		WFR	0.12	[-]
	Shading and daylighting systems	Fs	1.63	[-]
Technical				
	Efficiency of heat recovery system	μ	0.12	[-]
	heating capacity	Ch	212	[W/m^2]
	Occupancy	persons/m^2	0.27	[pers./m^2]
	cooling set point temperature	set point temperature	1.34	[°C]
	Heating set-back temperature	set-back temperature	4.31	[°C]
	lighting load	Inst. load	6.07	[W/m^2]
	Equipment load	Inst. load	5.91	[W/m^2]

Table 2

Results robustness study

calculated that identifies the robustness of various input parameter. It can be seen that e.g. the change of the U-value of the roof of 0.28 W/m^2/K results in a 10% change in annual energy consumption under south Norwegian climate conditions.

A robustness index has been proposed for each design parameter which can help to rank the importance in building design (Haase and Andresen 2008). For a typical office building design in Norway the robustness index gave more insight to which extend design parameter influence annual energy consumption (see Table 2).

Integration

AS mentioned before to achieve such reductions of the energy use in new buildings it will require development of new construction solutions, new types of building envelopes, and development of new building materials. It will also require the development of more holistic building concepts, sustainable buildings where an integrated design approach is needed to ensure a system optimization and to enable the designer(s) to control the many design parameters that must be considered and integrated.

In this context, Whole Building Concepts are defined as solutions where reactive building elements together with service functions are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. Reactive Building Elements are defined as building construction elements which are actively used for transfer of heat, light, water and air. This means

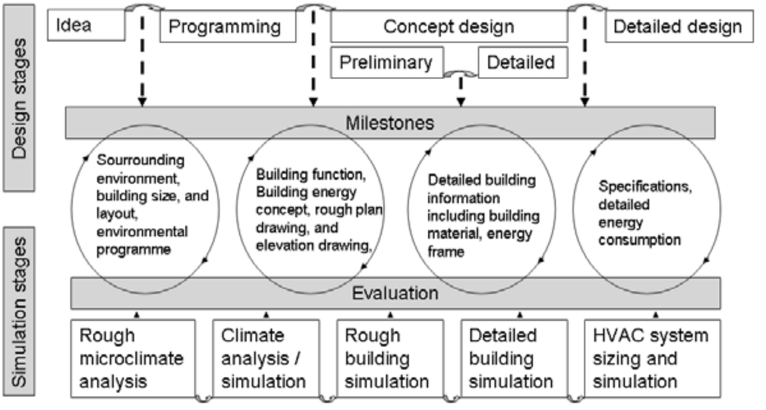

Figure 5

Linking design and simulation in the conceptual design stage (modified from Xia et al.)

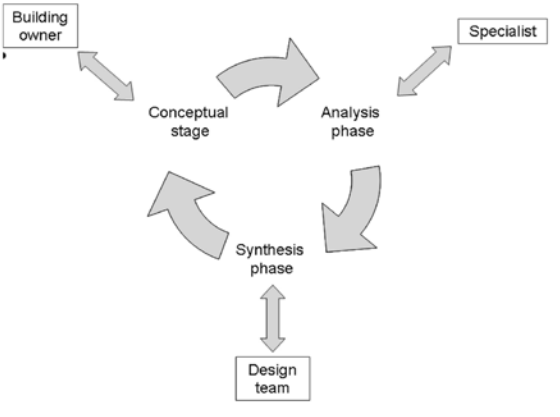

Figure 6

A different approach to concept design (modified from Knudstrup 2004)

that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and energy storage. The development, application and implementation of reactive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment (Annex44 2006b).

With the integration of reactive building elements and building services, building design completely changes from design of individual systems to integrated design of "whole building concepts, augmented by "intelligent" systems and equipment. Development of enabling technologies such as sensors, controls and information systems are needed to allow the integration. Design strategies should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices (Annex44 2006b).

The annex will, based on the knowledge gained in the work so far (particularly the results of IEA Annexes 32, 35 and 37, SHC Task 23), address the following objectives:

- Define state-of-the-art of reactive building elements
- Improve and optimize reactive building elements and technologies
- Develop and optimize new building concepts with integration of reactive building elements, building services as well as natural and renewable energy strategies
- Develop tools for the early assessment of the impact of reactive building elements on the environmental performance of buildings
- Develop guidelines for procedures and tools for detailed simulation of environmental performance of reactive building elements and integrated building concepts

Architects should have a basic understanding of the role of building elements in whole building concepts. They need to be able to communicate with specialized engineers on certain topics and to moderate the discussions between various engineering domains.

Conclusions

Previously, environmental simulation of building performance was only done by engineers at the end of the design process. Any weak points in the performance of the design could then be 'fixed' by adding heating, cooling, shades, vents, fans, panels, etc … However, at the end of the design process it is too late. The decisions made early on in the design process have the largest impact. In addition, environmental issues are becoming more important, the complexity of the building design is increasing, and simulation tools are becoming more architects friendly.

Fundamental to the development of concept design tools is the notion that environmental design principles are most effective when considered during the earliest most conceptual stages of the building design process. The conceptual stage of design occurs at the very beginning, when the brief is still being analyzed and decisions regarding

- geometry,
- materials and
- siting

are still to be made.

This is also the stage most ignored by traditional building analysis and simulation software, primarily because hard quantifiable data describing the building simply doesn't exist. The architects role in this implies also a fundamental understanding of the architectural consequences.

What is needed is calculation feedback and its support for very early stage conceptual design (ideally of visual nature) as well as final design validation. Designers must start generating vital performance-related design information before the building form has even been developed. It must be possible to start a detailed climatic analysis to calculate the potential effectiveness of various passive design techniques or to optimize the use of available solar, light and wind resources. It must further be possible to test these ideas on some simple sketch models before gradually developing up the final design. This would give the designer the possibility to evaluate his design and adjust it to the situation. Two methods can be used which are illustrated in Figure 7 and 8.

The architect should be able to:

- Energetic consequences of design
  - Perform daylight analysis
  - Understand energy concepts
- Quantify architectural concept
  - Perform heating and cooling load calculation
  - Calculate monthly heat loads and hourly temperature graphs
  - Generate full schedules of material costs and environmental impact
- Quantify architectural quality
  - Display and animate complex shadows and reflections
  - Generate interactive sun-path diagrams for instant overshadowing analysis
  - Calculate the incident solar radiation and its percentage shading
  - Work out daylight factors and artificial lighting levels spatially and at any point
  - Etc.

Therefore, in the design of sustainable buildings it will be very beneficial to be able identify the most important design parameters in order to develop more efficiently alternative design proposals and/or reach optimized design solutions. Communication between architects and engineers will become more common but also more important.
Digital architecture has to take these challenges into account and develop a common language for architects that enable integrated design in order to tackle the problems stated above.

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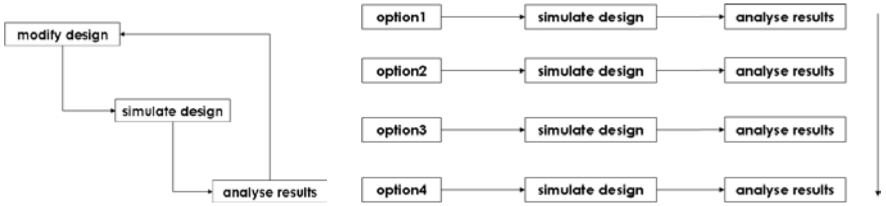

Figure 7

Two different design modification feedback methods

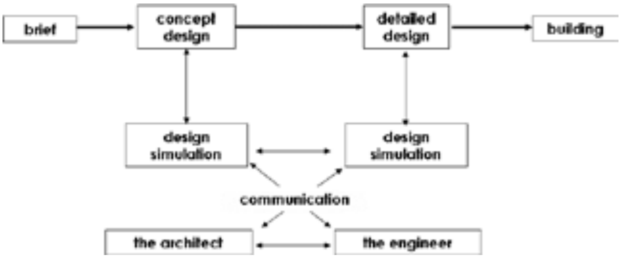

Figure 8

Communication between architect and engineer in design phases

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