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EXPLORATION OF THE USE OF BUILDING PERFORMANCE SIMULATION FOR CONCEPTUAL DESIGN

Christina J. Hopfe[1], Christian Struck[1], Gülsu Ulukavak Harputlugil[2],
Jan Hensen[1], Pieter De Wilde[3]
[1]Eindhoven University of Technology, Eindhoven, Netherlands
[2]Gazi University Engineering and Architecture, Ankara, Turkey
[3] University of Plymouth, School of Engineering, Plymouth, United Kingdom (*)

ABSTRACT

This paper reports on an exploration of the use of building performance simulation tools in current building design practice.

Firstly the paper identifies the features and capabilities of six software tools (Orca, MIT Design Advisor, h.e.n.k., Energy-10, BDA and e-QUEST) obtained from a software review. Secondly, the current use of simulation tools is illustrated by reporting findings of interviews with building and system designers focusing on limits and opportunities for using building simulation tools for conceptual building design now and in the future.

INTRODUCTION

During the design process a great number of decisions need to be taken. Typical design assessment criteria are costs, flexibility, energy efficiency, environmental impact as well as comfort, productivity and creativity of occupants. It is self-evident, that decisions at earlier phases of the design have a bigger impact on the building performance than measures taken at later design stages or during building operation (Hensen, 2004). It is hypothesized that more efficient use of Building Performance Simulation during the early design stage would be very beneficial for the end result.

In order to indicate the benefits of building performance simulation for the design process, this paper addresses two aspects:

1. What makes building performance simulation tools state-of-the-art for the use during the early phases of the building design process?
2. How do designers feel about computational support, what is the current state and what future developments are needed?

METHODS

The research has been carried out in two parts. The first part consisted of a critical software review, necessary to understand the tools usefulness in daily design practice. The second part comprised a number of interviews with building design practitioners in order to identify the opportunities and limits for using building performance simulation tools in daily practice. Each part was started with a literature review on the specific subject.

Part 1: Critical review of building performance simulation tools

The focus of the critical review lays on finding answers to the following key questions:

- How is the software currently used?
- Who is the intended user group?
- Is the software validated and tested on usefulness and accuracy?

Six tools, Orca (A), MIT Design Advisor (B), h.e.n.k. (C), Energy-10 (D), Building Design Advisor (E) and e-QUEST (F) were considered (Table 1).

These tools were selected more or less randomly on the basis that they claim to be of use during the conceptual design stage. The selected tools give a representative overview of state of the art building performance software for professional use (Crawley et. al., 2005).

The assessment criteria were categorised using headers such as – technique, general requirements and test (Appendix-Table 2).

In addition, two case studies were conducted; on one hand to evaluate the tools from a specific research perspective, on the other hand to obtain an undisturbed view at the usability of the tools. Two buildings located in Amsterdam, the Netherlands were chosen for the hands on case study – one single family house and one office building.

The buildings are characterised by a number of special features. The office building is defined by a double skin façade, atrium and full air conditioning system. The residential building comprises special features such as a pitched roof and a double height living room.

* previously with TNO Built Environment and Geosciences, Delft, the Netherlands

The modelling process was initiated and analysed based on the defined assessment criteria. Important assessment criteria were geometric modelling, input defaulting, calculation process, output variables, optimisation and limitations (Appendix-Table.3-4).

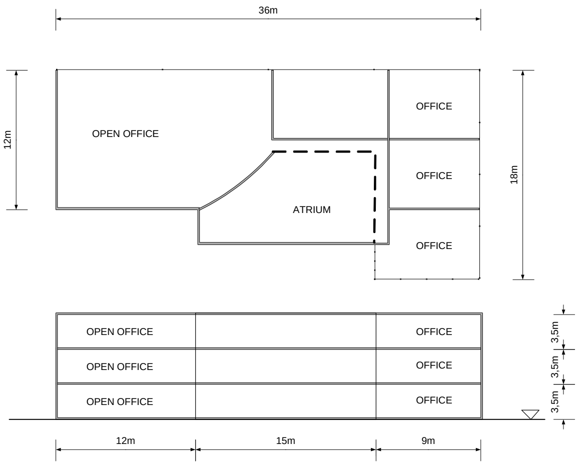

Figure 1a. The case study: office building.

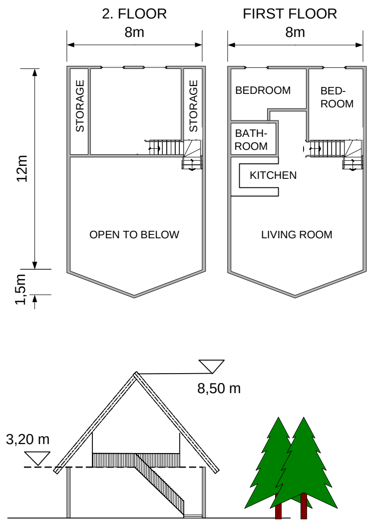

Figure 1b.The case study: single family house.

Part 2: Interviews with Building and System Designers

In order to provide an introduction to the context in which simulation tools are being used in practice, a number of interviews with design professionals were carried out. These interviews were accomplished to improve the researchers understanding of the design process and the use of building performance simulation software.

The first part of the interview was to classify the interviewees as either "conservatives", "early adopters" or "innovators"; academics or professionals; and based on their process involvement (final or the early phase of design). In the second part, it was evaluated how they understand the different stages of the design process. Based on the information provided, the third step looked at their role in each phase. The fourth and last step was to find out which computational support is being used and how, what the main shortcomings are of current computational support and what they would like to see in the future.

CRITICAL SOFTWARE REVIEW

The result and discussion section of the critical software review is divided in five categories: geometric building representation, defaulting, calculation engine, design optimisation and applicability.

Limitations

Some tools are limited in the representation of building types i.e. offices. However, other tools are more widely applicable (Appendix- Table 3).

Geometric building representation

The resolution level of tool A and B is one representative room. Two of the tools (E, F) allow the definition of zones according to room layout. In one tool (D) a box model is built and tool C represents the building as one thermal zone.

As geometrical limitation, there are the double skin façade, the atrium, the building type and the possibility of another roof definition than flat to be modelled. B and D have the option to work with a double skin façade. In tool C, there exists the possibility to have another kind of roof. A building type can be chosen in two of the tools (E, D). The tools A and C only provide for modelling of an office building.

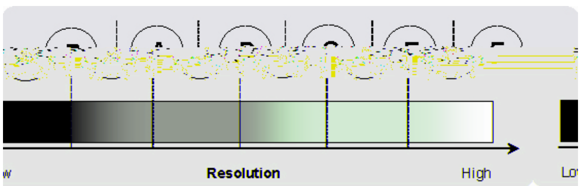

Figure 2. Geometric building representation

Tool F meets all design alternatives checked in the case study.

Defaulting

The conceptual design stage is characterized by the limited availability of design data, that's why it is important to fill in blanks with assumptions – default values. As to energy calculations defaulting is required for the definition of the glazing, building fabric, internal loads and HVAC components.

It was found that three of the tested tools have an extensive database of default values for the given input requirements. One tool (A) has no defaulting feature for the HVAC components present. However, due to its limited capabilities representing HVAC systems, defaulting is not required. Another tool (B) requires the user to manually input the required parameter. It is possible to refer to example models for verification.

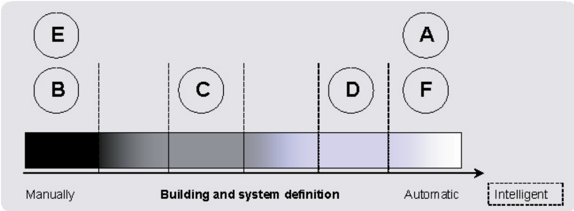

Figure 3. Defaulting

The tool E is lacking a defaulting feature for defining internal loads and HVAC systems. Nevertheless the material database contains predefined transparent and opaque building components which can be used for the model set up.

Building and system defaulting capabilities of the tools do form clusters between manually and automatic. Whilst some of the tools require the user to input the design parameter manually, for some tools the definition process is semi automated. Tool C is different because of the greater number of predefined system definitions to choose from. However, the defaulting features of all tools are far from intelligent as they do not suggest settings or setting combinations.

Calculation engine

Some tools use unique application based calculation engines and some act as an interface to high resolution engines.

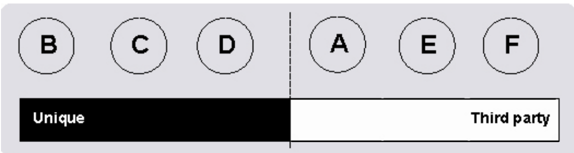

Figure 4. Calculation engine

A potential advantage would be the simplified model exchange between tools using the same engine as process variables are identical. By using tested and validated 3rd party engines the user could gain confidence in the calculations.

Design optimisation

Once the most appropriate building concept has been chosen an optimisation process could be initiated to identify optimum values for selected design parameter. Considering the six tools only three of them (B, C, D) are offering optimisation features.

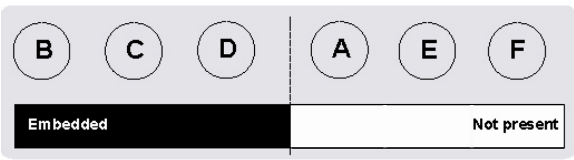

Figure 5. Design optimisation

Applicability

The case studies gave some insight into the applicability of the tools.
Four of the six tools were found appropriate for the conceptual design stage. The capabilities of tool A were perceived to be too limited. Tool F required a too detailed building and system representation to be used for the conceptual design.

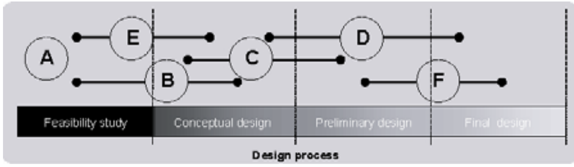

Figure 6. Applicability

Others

All six tested tools offer graphical output, text files and comparable solutions.

INTERVIEWS

To date eleven professionals were interviewed. Six mechanical engineers, two building physicists, one civil engineer and two architects; three of them were academic, the other eight were professionals.

Type of interviewees

It was attempted to categorise the interviewees as innovators, early adopters or conservatives. It was found that different aspects such as computational tools, design team integration and communication have to be considered.

I (Innovators)	Software developers
EA (Early Adopters)	Users of wide range of tools
C (Conservative)	Users of standard Building Performance Simulation tools
/	Don't use simulation tools at all

Figure 7. Computational tools

It appears that in terms of attitude towards computational tools, there are developers, people who are interested in every variety of simulation tools and those, who are only users of some building simulation tools.

I (Innovators)	Proposes new concepts/ way of working for design process
EA (Early Adopters)	People, who see usefulness of the team integration in every project
C (Conservative)	People, who don't try to get to the bottom of team integration; state of the art process

Figure 8 Design Team Integration

Design team integration indicates people with new concepts in the design process from those, who do not mention the importance of an integrated way of working. As early adopters people were called, who see a great usefulness of working in integrated teams but do not find new concepts to implement this.

I (Innovators)	People, who convinced with a new technique
EA (Early Adopters)	Interviewees, who found communication very important
C (Conservative)	People, who accepted the current standard in communication

Figure 9. Communication

In the field of communication the team only contemplates the communication taking place in the integrated design teams. Some interviewees (Innovators) convinced the researchers for example with a new communication technique that the interviewers did not come across talking to other industrial professionals.

Inter-viewee	Computa-tional tools	Design team integration	Commun-ication
1	I	EA	EA
2	C	EA	C
3	/	C	C
4	C	EA	EA
5	/	I	C
6	/	C	C
7	EA	EA	I
8	C	EA	I
9	C	EA	EA
10	EA	C	C
11	I	EA	EA

Figure 10. Classification of interviewees

Early adopters were people, who found the communication with other engineers, architects etc. very important and are willing to adapt to more efficient concept of communication. Interviewees were called conservatives, if they only see a miner importance in the field of communication (see Figure 9).

Outcomes of these subdivisions are that interviewees can be conservatives as well as innovators at the same time. The classification does not depend on their profession. (see Figure 9).

People combining professional and academic duties offer a great potential to propose innovative solutions to problems experienced in practice. The position in the company is relevant, too. For instance, if involved in engineering design solutions, then the person is most likely an early adopter or a conservative. If more involved in managing the institution, then the person is rather an innovator than a conservative.

Perspective of the design process

The understanding of the design process is the starting point to obtain a first impression of the attitude of the interviewees to the design stages in general. Many interviewees understood the design process to consist of different stages. However, some interviewees saw the design process as one phase, whilst other parties were confident that there exist no design phases as the process was perceived as highly unstructured and iterative. If the interviewees identified more than one design stage, they agreed upon the fact that the most important phase is the early conceptual design stage, because of the impact of decisions made on the project.

It was found that there exist value drivers relevant for each interviewee but differing depending on their engineering discipline. A value driver can be understood as a responsive variable, which when changed, has a significant impact on the design process. Value drivers mentioned by the interviewees include costs, spatial flexibility, thermal and acoustic comfort, energy consumption, indoor environmental quality, sustainability, productivity etc..

The program of requirement prescribes the building performance in terms of value drivers. It dictates details on user requirements, user conditions (like moisture production, heat release etc.), limit and target values (consumption of energy, water, comfort) and the geometric boundary conditions (floor area, ceiling height, etc.). The program of requirements is very important to the building design as it expresses the clients “wish list”. But above all the program of requirements can also prove to be a hindrance during the design process if it prescribes engineering solutions.

Practice

The interviewees understanding of an integrated design team was queried. Focus was given to the existence of a design team, synchronization and hierarchy. Another aspect discussed was the number and the complexity of the design alternatives (concepts) produced by the interviewees. During this part of the interview design process difficulties as well as suggestions for the future improvement were requested.

For most of the interviewees an integrated design team is the most suitable forum to produce integrated buildings. It was perceived as important to integrate all team members from the very beginning of the design process. One proposal made for initiating a building design was instigating a workshop/ brainstorming session with design team members such as architects, engineers, building physicists together with the client and the user.

It was found that one of the biggest problems is the synchronization of the design stages for the multitude of participating engineering disciplines. Most interviewees agreed to the fact of that the starting point should be the same for all parties. The interviewees drew attention to the fact, that consultants were often not invited early enough, resulting in less integrated and insufficient design solutions. It was also stressed that small and/ or not synchronized design teams run the risk of limiting themselves too early to an insufficient number of design alternatives resulting in the decision for a sub-optimal design. The number of concepts developed, often depends on the complexity of the design problem. Mostly more than one concept is being developed and discussed during design team meetings. In order to assess concepts, value drivers are being used. Value drivers can be characterized as either being discipline and/or project specific. The interviewees agreed that economic value drivers such as costs, planning issues (time schedules) etc. are of greatest important for scaling up the success of any building project. However a condensed collection of disciplinary value drivers such as flexibility, logistics and sustainability are identified in the program of requirements accommodating the client's expectation on the building performance.

The coverage of design concepts was perceived differently by the interviewees. Whilst some interviewees stated that one drawing could indicate a concept, some refereed to whole building representations, whilst other interviewees indicated the need for multiple concepts for the consideration of difficult building sections. However, to produce concepts some of them use simulation tools, whilst other parties rely on their past experience. They all agreed to the fact that the concepts are only useful when comparable. Lack of communication was, by nearly all of the interviewees, perceived as a major problem for integrating the team members of the design process. For example, communication problems could result from having more than one client present, from making different statements about design problems, or from team members misunderstanding the ranking of value drivers.

Computational support

Asked if the use of computational support was common practice during the design process all interviewees responded positively. However, it depends on how the conceptual support is defined. Subsequently the interviewees were asked whether they use computational simulation support in general and if, in which phase of the design. The tools themselves were discussed, and the way of using (visualization/ simulation/ results presentation) them, ascertained. The interviewees were asked where they locate a lack in using computational support and how they expect the computational support to develop in the future.

While some people trust in preparing simple sketches, other people use simulation tools during the conceptual design stage. Whatever technique is being used, the outcome should inform the design team about matters related to the building performance and initiate a discussion to pinpoint the most favorable concept. Because of the lack of information in the conceptual design stage, almost all interviewees prefer common, global tools in the beginning. One problem of tools dedicated to the conceptual design stage is that most of them request extensive input data, or address only one value driver. All interviewees agreed that experience is essential for developing design concepts. It was stated that the use of simulation tools enables an impact assessment of different parameters. However the use of simulation tools without having an idea of building performance simulation does not bring the necessary benefit.

It was found that the interviewees have a different understanding when it comes to simulation. Whilst they agreed, that simulation is the representation of physical processes, the techniques used to simulate differs significantly. And this was reflected while conducting the interviews. For some interviewees, simulation is drawing/ sketching concepts. For instance, one interviewee told the interviewers about simulating room conditions with actors in real world. Whilst for others, a simulation is conducted by using a computational tool.

The comments made on future expectations of computational support were contradictory. It was stated by the interviewees that tools should address a multitude of value drivers, should be easy to use, be able to represent complex scientific phenomena, and that they should be tested and validated. A computer program for the conceptual design stage should be an intuitive tool, offering 3D modeling capabilities, with an easy interface and a copy and paste opportunity - to facilitate the possibility to reuse parts of projects in compiling new projects. Such a tool should be able to produce initial results from a rough building representation and then allow for detailing parts of the building.

CONCLUSIONS AND FUTURE WORK

In this paper a critical software review and a number of interviews were contemplated to have a close look at the current use of building performance simulation tools in the conceptual design.

As the paper is a part of an ongoing work, the preliminary conclusions based on critical software review and up to date interviews are assessed.

Building performance simulation tools in the conceptual design stage are used in some cases instead of hand drawings, for basic visual simulations, less for start-up simulations, calculating, or ranking the value drivers bearing the program of requirements, showing a tendency on the future behavior of the building.

Typically, architects, civil engineers and mechanical engineers are allocated specific but different design responsibilities on building projects. Those design responsibilities are fulfilled successfully, when in accordance with the program of requirements, appropriate discipline specific value drivers were placed at the right level in the selection of project specific value drivers. However, value drivers of different disciplines overlap and connect, why it was thought to be important to consider the subject of the intended user group from different professional perspectives.

By conducting a survey of software related literature and two case studies the project team was able to consider the tools from the developer's perspective as well as gaining a subjective impression of the tool functionality. As a subjective impression does not make a scientific conclusion, it was planned to conduct interviews with a number of industrial professionals. Thereby the authors gained a better insight in the relevance and the significance of the program of requirements and its relation to value drivers. These parameters manifested to have a enormous impact at different value frameworks.

In the future Building Performance Simulation tools should be used to show the impact of the value drivers and enabling simulation results to influence the decisions taken in this early design stage.

The authors will continue with working on the use of simulation tools for the conceptual design. The process will involve conducting more interviews, reviewing literature and observing design team meetings.

As a result of the current work process the authors have dissimilar ideas to improve the conceptual design in three different areas: optimization, quality assurance and concept development.

In the way of optimization the concept development/ generation could be improved. One aspect for instance is the reuse and the meliorating of old concepts.

Quality assurance would be important to guarantee the development of more sustainable buildings while improving the role of performance simulation tools within the design process.

A third challenge is the capturing of professional design experience for a better concept development and evaluation.

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Appendix

Table 1
Tools Overview

	Name	**Developer**	**Website**
A	Orca	Vabi	http://www.vabi.nl
B	MIT design advisor	Massachusetts Institute of technology	http://designadvisor.mit.edu/design/
C	H.e.n.k.	DEERNS	http://www.deerns.nl/
D	Energy-10	Sustainable Buildings Industries Council	http://www.nrel.gov/buildings/ energy10/
E	BDA	Lawrence Berkeley National Laboratory	http://gaia.lbl.gov/bda/
F	eQUEST	James J. Hirsch Associates Energy Design Resources	http://doe2.com/equest/index.html

Table 2
Software Assessment Criteria

Pos.	**Technique**	**General requirements**	**Test**
1	Input/ Output details	Manuals	Ease to access information on user group
2	Output representation	Accessibility	Tested on user group
3	Calculation time	Cost	Tested on accuracy (BESTEST)
4	Calculation methodology	Intended user	Tested on real building (case studies)
5	/	Level of user interface	Development/maintenance
6	/	Specific design areas	User meeting/ exchange information
7	/	Optimisation and or comparison	/

Table 3
Tools Classification

<table>
<tr><th>Classification</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td colspan="4">Capability</td></tr>
<tr><td>Energy calculation</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Comfort assessment</td><td>Yes</td><td>No</td><td>Yes</td></tr>
<tr><td>Day lighting analysis</td><td>No</td><td>Yes</td><td>No</td></tr>
<tr><td>Artificial lighting analysis</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td>Code compliance</td><td>No</td><td>US and UK</td><td>No</td></tr>
<tr><td>Life cycle costing</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td colspan="4">Geometric building representation</td></tr>
<tr><td>Level of resolution</td><td>One representative room</td><td>One representative room, entire building extrapolation possible</td><td>Building as one thermal zone</td></tr>
<tr><td>Interoperability</td><td>3rd Party</td><td>No</td><td>Excel, Matlab</td></tr>
<tr><td colspan="4">Defaulting</td></tr>
<tr><td>Building fabric</td><td rowspan="3">Yes</td><td rowspan="4">No – Example model can be referred too</td><td rowspan="4">Yes</td></tr>
<tr><td>Glazing</td></tr>
<tr><td>Internal loads</td></tr>
<tr><td>HVAC</td><td>No</td></tr>
<tr><td colspan="4">Calculation process</td></tr>
<tr><td>Unique calculation engine (CE)</td><td>No</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Third party CE</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td colspan="4">Limitation</td></tr>
<tr><td>Building type</td><td>Only office</td><td>By occupancy load</td><td>Only office</td></tr>
<tr><td>Units</td><td>SI</td><td>SI</td><td>SI</td></tr>
<tr><td colspan="4">Optimization</td></tr>
<tr><td>Design optimization</td><td>No</td><td>No</td><td>Yes</td></tr>
</table>

Table 4
Tools Classification (continue)

Classification	D	E	F
Capability			
Energy calculation	Yes	Yes	Yes
Comfort assessment	No	Yes	No
Day lighting analysis	No	Yes	Yes
Artificial lighting analysis	No	Yes	No
Code compliance	No	No	US
Life cycle costing	No	No	Yes
Geometric building representation			
Level of resolution	Box model	Definition of zones according to room layout	Definition of zones according to room layout
Interoperability	No	3rd Party	3rd Party
Defaulting			
Building fabric	Yes	No – predefinition available	Yes
Glazing		No – predefinition available	
Internal loads		No	
HVAC		No	
Calculation process			
Unique calculation engine (CE)	Yes	No	No
Third party CE	No	Yes	Yes
Limitations			
Building type	Public, commercial, residential	Office, Lodging, Restaurant	Public, commercial, residential
Units	IP	SI/IP	IP
Optimization			
Design optimization	Yes	No	No