MSc Program "Building Science and Technology"

Exploring The Availability and Usability of Web-based Building Performance Simulation Tools

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"Master of Science"

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ABSTRACT

During the last decade, web-supported tools for knowledge inquiry and problem solving have been increasingly become popular (Augenbroe 2003). The growing availability of web-based sources of advisory information and decision-making support tools "anywhere and anytime" holds a promising future for professionals and stakeholders in many different domains. The ease of use and instantly distributed updates to the applications are amongst the features that enhance the pervasive use of such resources and tools (Byrne et al. 2009). Particularly in engineering fields, the expenses associated with acquiring and maintaining conventional software applications represents often a detriment and an obstacle to users with limited resources (for example potential users in the developing countries). Thus, also in the area of building design and construction, free (or low-cost), low-maintenance, and easy to use web-based tools could provide a highly effective alternative to users (students, architects, engineers, etc.).

The present contribution focuses on an assessment of web-based computational applications in the field of building (thermal) performance analysis. Thereby, a number of questions are posed and pursued: how do such web-based tools perform in comparison with "classical" building performance simulation applications? What is the state of usability of such tools in the context of conceptual design stage? The contribution briefly enumerates, classifies, and compares twenty-two available web-based tools. A subset of these tools is subsequently presented to a small group of potential users within the framework of a usability assessment session (Nielsen 1995).

The contribution thus outlines the state of the art and provides suggestions toward improving and subsequent development of such tools.

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0. EXTENDED SUMMARY

The following extended summary of the present work is based on a conference paper published in BauSIM 2010 proceedings.

EXPLORING THE AVAILABILTY AND USABILITY OF WEB-BASED BUILDING PERFORMANCE SIMULATION TOOLS

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ABSTRACT

In the last two decades web-based simulation (WBS) has become increasingly available. In the process, it has also become relevant for building performance simulation (BPS). After discussing the present state of web-based BPS tools, a framework is offered to categorize the currently available tools. In order to address usability issues, selected tools (in thermal and energy domain) are considered in more detail. A sub-set of these tools are subsequently tested by a small user group.

INTRODUCTION

During the last decade, web-supported tools for knowledge inquiry and problem solving have been increasingly become popular. The growing availability of web-based sources of advisory information and decision-making support tools "anywhere and anytime" holds a promising future for professionals and stakeholders in many different domains. The ease of use and instantly distributed updates to the applications are amongst the features that enhance the pervasive use of such resources and tools (Byrne et al. 2009).

Particularly in engineering fields, expenses associated with acquiring and maintaining conventional software applications often represents a detriment and an obstacle to users with limited resources (for example potential users in the developing countries). Thus, in the area of building design and construction too, free (or low-cost), low-maintenance, and easy to use web-based tools could provide an effective alternative to users (students, architects, engineers, etc). The present contribution focuses on an assessment of web-based computational applications in the field of building (thermal) performance analysis. An overview is provided, and priliminary usability tests are undertaken. Specifically, the usability of web-based tools in the context of conceptual design stage (Zhu et al. 2007) is explored.

The contribution briefly enumerates, classifies, and compares some 24 available web-based simulation (WBS) tools. A small subset of these tools is subsequently presented to a small group of potential users within the framework of a usability assessment session (Nielsen 1995). Moreover, suggestions are made toward further development and subsequent improvement of such tools.

Augenbroe (2003) has assessed the role of "e-simulation" in the future context and its potential benefits over the traditional BPS applications. There are several prior studies about WBS on Building Science field. Mills 2002 discussed (for USA and Canada) the current state of residential energy analysis for both web-based and conventional tools. The review consisted of 50 web-based tools, which was narrowed down to 21 tools and compared with 6 conventional tools. A large number of WBS tools were found to lack updates or inaccessible altogether.

SURVEY

We selected a number of tools from (Crawley 1998). The rest was identified based on internet and literature search. The tools were classified in two dimensions: 1) the simulation domain, 2) the tool type (see Table 1). Six simulation domains were distinguished: i) thermal/energy performance, ii) code compliance, iii) cost analysis, iv) active energy systems, v) lightning, and vi) others. The type dimension involves 3 categories: a) remote simulation and visualization (RSV), indicating tools that are entirely internet driven; b) hybrid simulation and visualization (HSV), in which the simulation runs remotely on a simulation server and visualization engine is downloaded to the client side via a web-browser; c) local Simulation and visualization (LSV), where both the simulation engine and visualization components are downloaded to the client server (Byrne et al. 2009). We included LSVs, since they can be employed without a charge. A total of 136 tools were mapped onto the framework, namely 51 RSVs, 6 HSVs, and 79 LSVs.

PRELIMINARY EVALUATION

We conducted a preliminary assessment of selected WBS tools in the thermal and energy domain. Thereby, usability problems were the starting point for the development of a questionnaire (see Figure 1) including of 11 items. We evaluated 24 tools (see Table 2) in view of the issues addressed in this questionnaire.

Table 1 Categorization of the 136 surveyed WBS tools (note that certain tool are categorized in more than one category)

Domain	**RSV**	**HSV**	**LSV**
THERMAL/ENERGY	19	5	18
COST ANALYSIS	5	-	4
CODE COMPLIANCE	9	1	14
LIGHTING	3	-	19
ACTIVE SYSTEMS	10	1	13
OTHERS	13	-	25

Table 2 List of tools for preliminarily evaluation

CODE	TOOL NAME	SIMULATION DOMAIN
A	Acuity Energy Platform	Energy management tool
B	Appliance Calculator	Appliances' cost/energy estimation
C	Home Energy Saver	Cost/energy and saving estimation
D	Home/ Commercial Energy Suite	Cost/energy estimation
E	ArchiPHYSIKweb pro	Energy estimation and code compliance
F	Building/ Green Energy Performance Compass	Energy use and savings, CO2 emissions
G	Cal- Arch	Energy use
H	Clariti	Energy management
I	MIT Design Advisor	Energy use, daylight
J	EnergyCAP Energy Benchmark	Energy use
K	Energy Profile Tool	Energy use, cost estimation, CO2 emissions
L	foAudits	Energy use (PDA or Palms)
M	My e-Home	Energy use
N	Rehab Advisor	Energy saving
O	Smeasure	Energy use and green house gas emissions
P	Building Advice	Energy use and savings, code compliance
Q	Building Green House Rating	Energy use and savings, code compliance
R	Energy Work Site	Energy use, cost estimation, code compliance
S	Green Quest	Energy use, cost estimation, CO2 emissions, code compliance
T	H1 Compliance Calculator	Energy use, code compliance
U	COM Check Web	Code compliance
V	Energy Star Home Advisor	Energy saving
W	IC3	Code compliance
X	RES Check Web	Code compliance

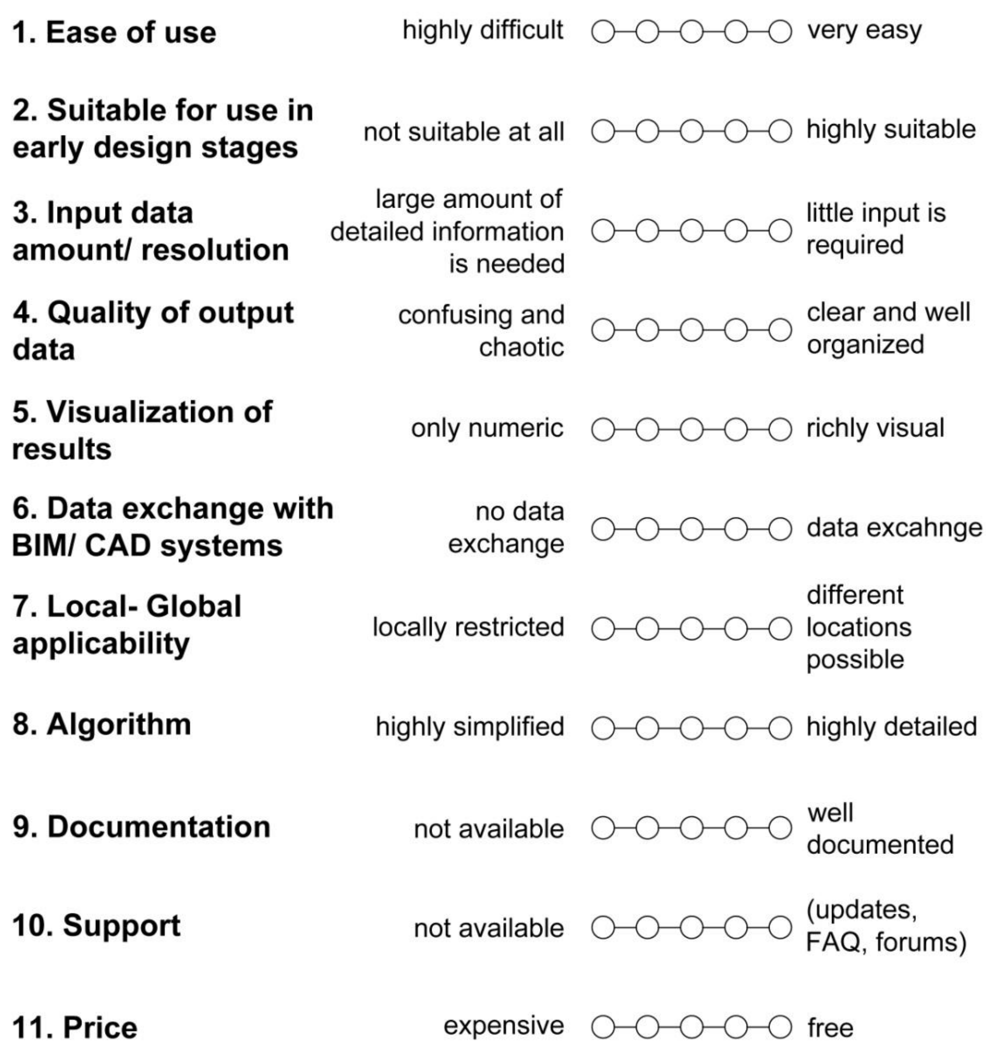

Figure 1 Questionnaire for tool assessment

To aggregate the 11 items of the questionnaire into a simple single-number indicator, a weighting scheme would be necessary. For the purpose of the present study, the weighting scheme of Table 3 was applied. In this scheme, weights associated to each question are expressed in percentage adding up to 100%.

Authors' preliminary evaluation of the 24 tools mentioned in Table 2 resulted in the total scores depicted in Figure 2. From this set, 3 tools were selected (***I***, ***M***, and ***T***) for further evaluation by a small group of users. ***I*** had the highest value

(Figure 2) in the authors' evaluation. ***M*** supports the construction of 2D and 3D geometric building models. Lastly, ***T*** possesses data exchange capability.

Table 3 Evaluation of the Questionnaire

	QUESTIONNAIRE ITEM	WEIGHT (%)
1	Ease of use	10
2	Suitable for use in early design stages	12.5
3	Input data amount/ resolution	7.5
4	Quality of output data	10
5	Visualization of the results	7.5
6	Data exchange with BIM/ CAD systems	7.5
7	Local- Global applicability	12.5
8	Algorithm	12.5
9	Documentation	7.5
10	Support	5
11	Price	7.5
	TOTAL	**100**

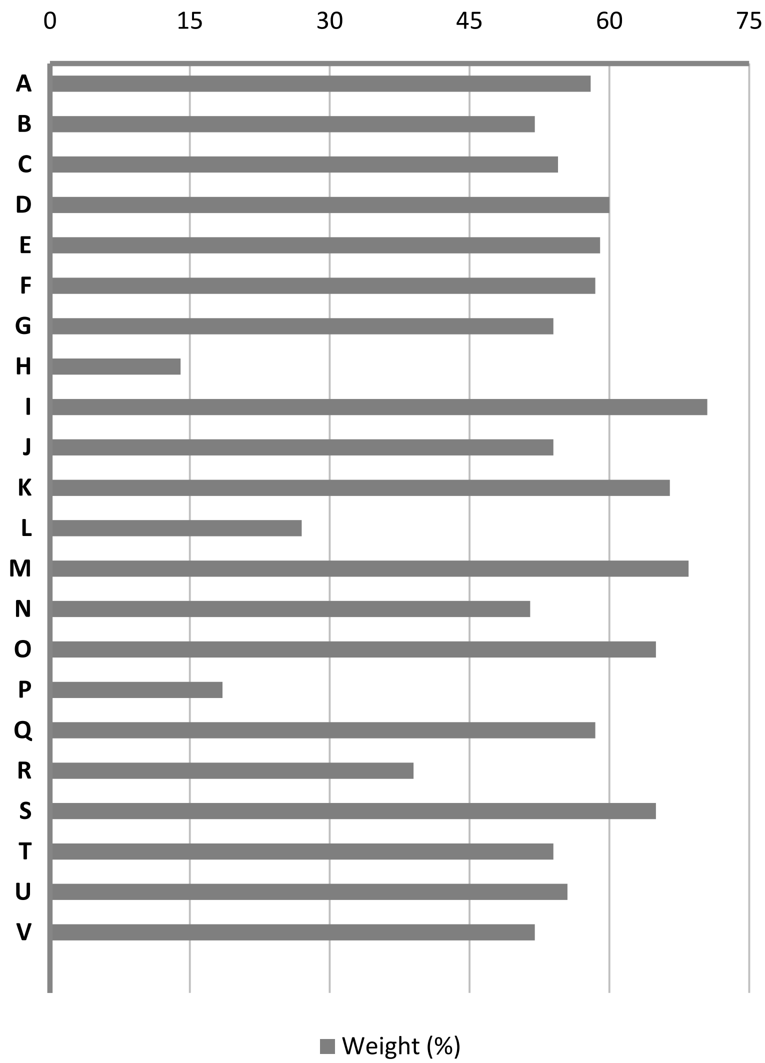

Figure 2 Preliminary Evaluation for Thermal-Energy Calculators

TEST WITH A SMALL GROUP

The test was conducted with a small group of potential users (16 architecture and engineering students). A specific task (evaluation of the energy performance of a small building) was given to the participants, for which the 3 above mentioned tools were to be used. Before conducting the test with the participants, we formulated our expectations (conjectures as to how the participants would evaluated the tools) based on our own evaluation. These formulations are summarized in Table 4 in terms of 12 hypotheses.

The participants' evaluations of the 3 tools are summarized in Figure 3 in terms of mean values. The general trend in the evaluations of the authors and the participants are similar (see Figure 4). ***I*** ranks, in both cases, ahead of ***M***, followed by ***T***.

A more detailed analysis of the results is provided in Table 4, which includes remarks concerning the authors' conjectures (see Table 5) and the participants' views (see Figure 3) on a question by question basis.

Table 4 A summary of the authors' conjectures regarding tools T, I, and M, as formulated prior to the test with a small group of users

QUESTION	HYPOTHESIS
1. Ease of Use	Selected tools are generally easy to use. ***T***'s GUI is deficient, making navigation difficult.
2. Early design stage suitability	***T*** and ***I*** do not support schematic design stage effectively.
3. Input data amount/ resolution	***T*** requires large amount of input data. ***I*** requires the least amount of input data.
4. Quality of output data	***M*** and ***I*** provide clear and well-organized output. ***T*** appears rather confusing.
5. Visualization of results	Except ***T***, tools provide effective visualization.
6. Data exchange with BIM or CAD	***I*** does not support data exchange. ***M*** exports and imports only *.meh extensions. Tool ***T*** imports *.gbxml and *.xml extensions.
7. Local – Global applicability	***M*** and ***T*** are locally restricted. ***I*** offers multiple locations.
8. Algorithm	***T*** is most detailed, followed by ***M.***
9. Documentation	All tools are well documented.
10. Support	***M*** offers only an email contact. ***I*** provides FAQ and email support. ***T*** provides these features plus a forum.
11. Price	All tools are free, but ***T***'s report must be purchased.
12. Satisfaction	***I*** is easier to use and requires less input data. ***M*** provides better visualization, and does not require deep technical background, but is limited concerning building types. ***T***'s GUI is deficient, but appears to be more detailed and reliable.

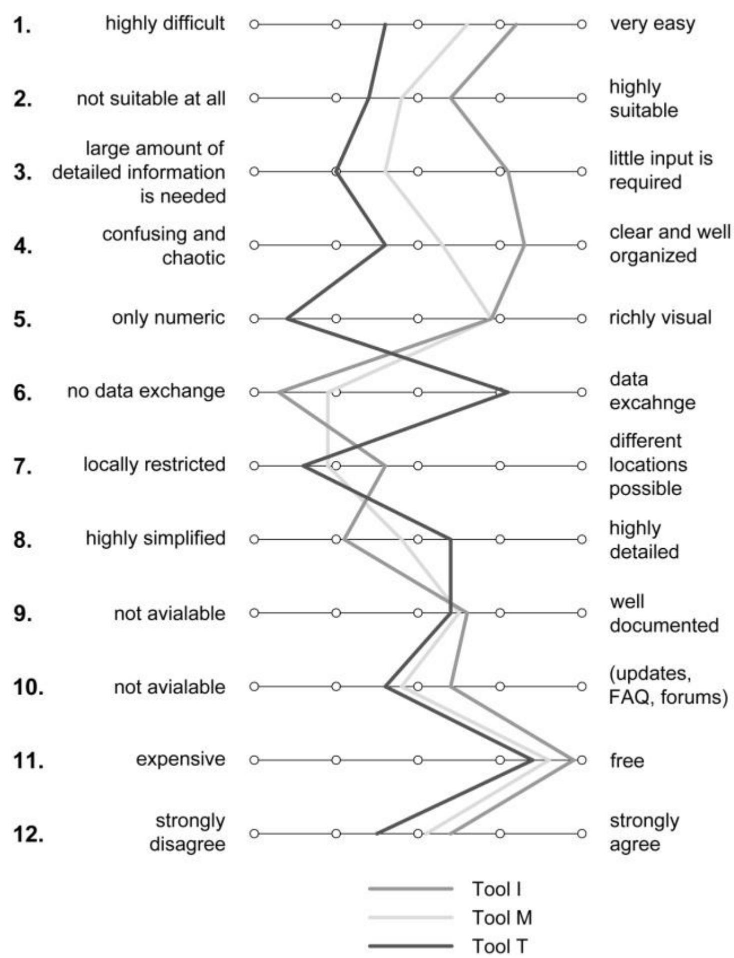

Figure 3 Mean values of the user group evaluation

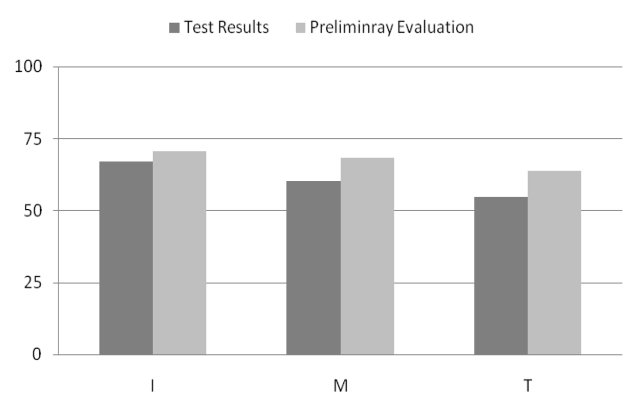

Figure 4 Comparison between the participants' test results and the authors' preliminary evaluation

Table 5 Analysis of the test results

QUESTION	ANALYSIS
1. Ease of Use	***I*** requires less input data and provides default settings, hence it was found easy to use. ***M*** has a friendlier user interface as compared to ***T***.
2. Early design stage suitability	Contrary to the authors' conjectures, they found ***I*** more suitable then the other two. The reason seems to be that users focused on the fact that ***I*** requires less information, not that this information is not necessary available at the early stages of design.
3. Input data amount/ resolution	Similar to authors' conjecture, ***I*** was seen as requiring the least amount of data input and ***T*** has the highest.
4. Quality of output data	***I*** offers users a combined view of the results of different design alternatives, explaining users' preference. Users agreed with the preliminary evaluation in finding ***T***'s output confusing.
5. Visualization of the results	Since ***T*** does not provide charts or graphs for results, it received the lowest evaluation.
6. Data exchange with BIM or CAD	***T*** was the only tool that enables the users to import files with BIM extensions.
7. Local – Global applicability	Even though ***I*** offers a variety of locations, it received a lesser evaluation than expected: users implied that the locations were not distributed well enough. ***M*** is available only in Denmark and ***T*** in New Zealand.
8. Algorithms	Users' views confirm the preliminary evaluation.
9. Documentation	Users' views confirm the preliminary evaluation.
10. Support	As opposed to our conjecture, ***T***'s support function was not considered high, as the users could not access forum, due to the tool's GUI.
11. Price	All tools are free in principle. But the registration requirement of ***M*** and the report cost for ***T*** appear to have affected participants' judgment.
12. Satisfaction	All tools were found modestly satisfactory.

CONCLUSION

Web-based BPS tools have the potential to reach a large and diverse range of users from architects to facility owners. As participants in our small experiment suggest, the ease of use, instant accessibility, effective visualization, and low cost of the tools represent the main advantages of such tools. However, participants in our test commented that they expected more efficient data management and exchange capabilities so that building models (including geometry and material information) may be reused, thus saving time. Moreover, most tools are applicable only for limited locations, mostly due to the lack of pertinent weather information and local building materials and systems data.

Generally speaking, most WBS tools do not offer the possibility of collective developments and enhancements. If an open-source mentality would prevail in the BPS community, such tools could be developed by larger groups of collaborators, leading to richer and more widely applicable tools. Likewise, supporting functionalities such as data bases for weather information as well as materials and systems information could be more efficiently developed.

To maintain the advantages of WBS tools in terms of instant accessibility, simple user interaction features, low costs but provide, at the same time, sufficiently detailed and reliable results, tools with a hybrid structure may offer the best opportunity: they combine the best features of local and remote simulation (Byrne et al. 2009). The workload on the server is reduced (as compared to conventional WBS approaches) by exporting the animation/visualization functionality to the client side (Myers 2004). Thus, BPS tools with hybrid approach could offer the same features as the conventional tools in terms of data interoperability and provision of a database.

In conclusion, it must be stated, that while the increased application of web-based BPS tools is highly desirable, it may also contain a risk: the authors as well as the users with some technical background question the reliability of the underlying abstractions, data bases, and computational algorithms of currently available simplistic tools. Users lacking a sufficient technical background in building physics and technology may use tools in an inappropriate manner, arrive at mistaken results, or interpret results wrongly. It would be thus important (as one of the many possible and necessary measures); to augment WBS tools availability with effective online courses and curricula in the relevant areas of building physics.

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1. INTRODUCTION

1.1. Overview

Since the early 1990s acquiring and disseminating knowledge were encouraged by the development of the world-wide-web and become increasingly popular (Paxson and Floyd 1997). Subsequently the use of internet pervaded into various disciplines. The tool developers employed researchers to engage their current tools with the web or to create a new one. Web-based simulation (WBS) is one of these integrated applications that allow the classical simulation to combine with internet (Soliman and Alfantookh 1999). The growing availability of web-based sources of advisory information and decision-making support tools "anywhere and anytime" holds a promising future for professionals and stakeholders in many different domains (Augenbroe 2003).

The ease of use and instantly distributed updates to the applications are amongst the features that enhance the pervasive use of such resources and tools (Byrne et al. 2009). Utilization of these tools is limited. Traditional simulation (1) is not portable; (2) requires long term learning to use and (3) involves high expenses. Despite above mentioned features traditional simulations contain detailed algorithms which enable users to perform complex simulations. WBS has the capability to combine the positive features of classical tools with instant accessibility via web (Veith et al. 1998). Besides the advantages of WBS over traditional simulation it is still ambiguous whether it will fulfill its enormous potential.

Ultimately this new breed of simulation evolved in building performance simulation (BPS). The expenses associated with acquiring and maintaining BPS software often represents a detriment and an obstacle to users with limited resources (i.e. potential users in the developing countries). Thus, in the area of building design and construction, free, low-maintenance and easy to use web-based tools could provide an effective alternative. They are mainly employed by small firms, students, architects, and engineers who are greater in numbers than the current users of conventional tools.

Traditional BPSs require detailed information of building geometry, properties of construction materials, heating and cooling system information, building location, orientation and etc. In order to perform a reliable simulation: weather data's of numerous locations and material libraries have to necessarily be provided.

Several studies on web-based BPS tools are provided; the current state of them is still indefinite. The usability problems noted, contributed in recommendations for further future tool developments. Questions noted: "To which extent they can perform the capabilities of mature tools? Is it possible to exchange data to integrate the design process with the BPS tool from the early stages till the final?"

Suggestions toward improving and subsequent development of web-based building simulation tools, the features of the current web-based BPS were explored in different scales.

1.2. Motivation

One fifth of world's total delivered energy consumption is caused by the building sector (both residential and commercial) (EIA 2010), improving the energy efficiency in buildings has become one of the world's major concerns (Hong et al 2000). In architecture, BPS has indispensable role in integrated design process. It is uncertain whether the ramification and frequency of usage of these tools are in the desired places. An empirical study was conducted in Austria with 198 architects in exploring the level utilization of BPS (Mahdavi et al. 2003). The results of the study showed only 16.7% of architects used BPS tools in their projects. The reason behind this result is argued by low costs and easy use of these tools.

The classical tools are accessible mainly by large companies due to the expenses. In quantity number of projects realized from large firms is smaller than the projects from smaller firms, although there is difference in the complexity of projects. Costs of projects from small firms cannot afford these tools.

Most of these tools require high amount of input data and a significant level of expertise. Simulation tools are developed by researchers who are technically oriented while designers focus on practical solutions.

The major features of web-based BPS tools are user friendly environment and low maintenance which provide an alternative to traditional tools. The instant accessibility via a simple web-browser improves the availability and these aspects enhance the increased use of such tools. WBS has the potential to overcome the difficulties of traditional simulation technologies.

Although it is a rapidly growing area, can web-based BPS replace traditional simulation or to which extent an efficient simulation can be performed? Therefore numerous applications offered by classical tools were examined such as the data exchange capability and applying BPS in conceptual design stage.

The ultimate goal of this work is to explore the state of the art web-based BPS tools. First of all the current web-based tools were categorized. The study was restricted to thermal-energy performance analysis. There is a diverse range of domains and most of the available tools perform thermal-energy simulations. Subsequently, a subset of the classification was evaluated in detail. The functionality and usability problems are addressed. A questionnaire is developed depending on previous step and also for a comprehensive understanding three tools were tested by a small user group.

1.3. Background

In this chapter web-based simulation environment, building performance simulation (BPS), web-based BPS and usability analysis are discussed.

1.3.1. Web-based simulation (WBS)

Numerous publications express the impact on computer simulation formed by web called “Web-based Simulation” (WBS). The new breed of simulation experienced a tremendous growth in the last two decades (Luo et al. 2000, Page et al. 1999; 2000). Besides the benefits of this simulation, it has several features that remain obstacles to the employment of such tools. For a better understanding of web-based BPS environment it is beneficial to explore the WBS context by examining the advantages and disadvantages of such applications.

1.3.1.1. Advantages of WBS

WBS tools have many advantages compared to the classical simulation technologies. Beginning with “wide availability”, WBS applications provide the users an instant access through a simple web browser anywhere and at anytime. Thus transportation and installation of software is not required. With the platform independent nature, the users are not obligated to employ specific systems. Therefore platform, hardware and system independency provides a considerable number of users with such applications (Veith et al. 1998). Since these tools are driven via internet, they offer a familiar interface to the users: ease of navigation and ease of use is one of the strengths of WBS. Instantly distributed updates provide the user always with the latest version of the tool. These modifications interact with the current projects well and eliminate the errors. WBS enables the users a better environment for project management. Communication and interaction with the design team members is immediately possible and controlled access can be provided via password application. (Byrne et al. 2009).

1.3.1.2. Disadvantages of WBS

WBS has to be enhanced also in several features. The use of WBS can be time-consuming due to the network traffic. The simultaneous access of a large number of users may affect the workload of the server negatively. The site simulation process may not be executed sufficiently; it can be interrupted or stopped. Their graphical user interface (GUI) is limited and data security is more vulnerable compared to the traditional desktop applications (Wiedemann 2001). Because of the dynamic environment of web the disappearance of any site is probable (Kuljis et al. 2001).

In table 1 the comparison between web-based and conventional tools is shown. The general features are compared in terms of advantages and disadvantages.

Table 6 *Comparison between WBS and classical simulation tools*

	WEB BASED SIMULATION TOOLS	**CLASSICAL SIMULATION TOOLS (DESKTOP APPLICATIONS)**
ADVANTAGES	• Wide availability • Ease of use/ navigation • Better environment for project management • Platform, hardware and system independency • Instantly distributed updates • Reasonable charges	• Detailed algorithm • Efficient GUI • Advanced software security
DISADVANTAGES	• Network traffic • GUI limited • Instable web environment • Vulnerable security	• Hard to use/ navigate • Platform, hardware and system dependent

Even though the disadvantages of web-based such simulation tools remain an obstacle to their deployment, BPS can benefit from the distributed nature of simulation by improving WBS tools and combining them with the positive features of classical tools.

1.3.2. Building performance simulation (BPS)

Because of the considerable range of choices, question: “How to choose a simulation program?” remains a problem for potential users of BPS. This situation leads to another question: “what are the features of a mature BPS tool?” For a comprehensive understanding of BPS it is fundamental to discuss its current level of development.

Employment of World Wide Web enhanced the collaborative team work, involving specialists constitutes no longer a problem.

1.3.3. Web-based BPS tools

1.3.3.1. Past research

There are several prior studies about WBS on Building Science field. In Westerman’s study (2001) “Home Energy Analysis Software Study: Final Report”, 8 home energy audits were evaluated. Although the samples were small still the collected information was more comprehensive. Three guidelines were proposed for tool developers: (1) no-cost options, such as behavioral changes, (2) envelope measures applicable during remodeling, and (3) equipment retrofits. The evaluation is consisted of comparisons between multiple design scenarios, re-editable results and the capability of providing single measurements.

Mills’s study (2002) “Review and Comparison of Web- and Disk-based Tools for Residential Energy Analysis” is one of the most comprehensive researches. It has discussed (in USA and Canada) the current state of residential energy analysis for both web-based and conventional tools. They provide recommendations for the tool developers under four topics:

I. Targeting and usability: identifying carefully the diverse audience and the provision of qualitative decision support services

II. Technical feature and rigor: maximizing the geographical availability and ensuring the technical rigor

III. Platform: platform independency provides low-cost of distribution, instant updates and interoperability

IV. Strategic considerations: to unify existing disparate developments and in the meantime to enhance them in quality and reliability

The review consisted of 50 web-based tools. It was narrowed down to a "whole-house" tools consisting of 21 tools and compared with 6 conventional tools with the same domain. The selected web integrated BPS tools were quantified and compared on the ground of accuracy among all output results that were offered. The experiment revealed the fact that the tested tools employ a wide array of approaches and levels of detail. The problems of inaccuracy have been found and classified as following:

- Incompleteness of algorithm,
- Accuracy of savings calculations,
- Errors in programming,
- Completeness of user specified options,
- User misunderstandings,
- Weather normalization and inter-tool references.

To further summarize the findings:

A) Existing tools exhibit considerable range. Not the quantity the value of the detailed inputs is significant.

B) Specialized tools can augment whole-house tools in useful way.

C) Users face bewildering choices and often-confusing questions: the wide array of choices, similar tool names.

D) Web- and disk-based tools differ considerably. Because of the instability of web environment, a large number of WBS tools were found to lack updates or inaccessible altogether.

CEEEP study (2004) "Evaluation of Home Energy Audit Tools" reviewed 4 residential energy audit tools. They performed an evaluation in the light of the previously stated two researches (Westerman 2001 and Mills 2002). They incorporate the “best practices” (an evaluation method for web-based BPS tools provided by Mills (2002)) in order to compare the selected tools. Subsequently recommendations for residential energy audits were composed.

The ultimate goal of the present study is to provide a categorization of the current web-simulation tools in order to eliminate the confusion generated by the wide array of alternatives. It is not only embracing the residential building audits but also commercial ones and additionally 6 different domains. The second difference to previous study is our target our target audience who are users with technical backgrounds. Afterwards usability problems of the current tools were identified and consequently a subset was tested by a small user group.

1.3.3.2. Tool development

A recent project “S2” serves as a good precedent for a web-based simulation tool. S2 is the modified prototype a web integrated version of the initial application “SEMPER”. It is a multi-domain simulation tool, engages performance and design processes in a bi-directional mechanism. The researches started with stating the current problems of the classical simulation programs (i.e. poor integration between the design and engineering tools). In the light of those subsequent evaluations they stated the requirements of a multi-domain design support tool. They try to overcome the difficulties of the data exchange process by developing a new system that concurrently integrates every design changes coming from all design parties during whole process. Furthermore a seamless and active communication between the simulation model and building general representation is generated by mapping these two representations into each other without geometry interpretation and user intervention. The consequences of numerous design decisions are optimized based on the performance attributes. Moreover SEMPER’s multi-domain simulation environment can support energy, air flow, HVAC, thermal comfort, lighting, acoustics and life-cycle analysis (Mahdavi 1999).

The second step of the SEMPER project was to develop a modified prototype executes remotely via web. The SEMPER 2 (S2) project combined the features of the previous prototype with a platform independent version provided by the integration of internet (Lam et al. 2003). Most of the CAD systems do not generate models that match with the building representation needed to run a simulation. Therefore shared object model (SOM) is used. SOM eliminates the redundant information of the CAD model and captures the essential elements for the S2 environment. In order to employ SOM for a simulation a certain domain, a domain object model (DOM) is required. The acquired information must be filtrated and modified for the use of a sufficient simulation. They reduce data input redundancy by developing a “homology-based” SOM to DOM mapping technology. After the provision of bi-directional mapping (design-to-performance and performance-to-design), building representation and domain representation into each other; the S2 environment was integrated with another tool “Thermal Suite” which includes building energy modeling, simple HVAC and multi-zone air flow analysis (Lam et al. 2004).

COBRA was used as the communication framework between components, Graphical User Interface (GUI) was implemented in Java, database for building model and libraries was provided and afterwards simulation modules are developed to execute the simulations for the related domains (Mahdavi et al. 1999). S2-Kernel use different databases and run on either server or client side. To reduce the work load of GUI when simulations are to be run, the applications communicate with S2-Kernel. They enhanced the capability of S2 hub to handle the network traffic. Then weather and material databases are provided to analyze the prototype in case studies. Eventually the prototype was tested in the web environment involved 3 different locations (the 3 institutions of the research participants) (Lam et al 2001).

The S2 project provided detailed and comprehensive information of an ideal distributed BPS environment. It guided us in this study especially by defining the usability problems and evaluating the tools.

1.3.4. Usability testing

Information technology is one of the fastest growing industries (Colecchia et al. 2001), but only recently human-computer-interaction has developing attention (Buxton 2007).

In the development of qualitative software systems besides the functional attributes and the non-functional characters (i.e. usability, flexibility, performance and interoperability) must be taken into consideration too (Chung and Sampaio do Prado Leite 2009).

According to ISO 9241 (1998) the literal meaning of usability is “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.” On the other hand Nielson (1993) expands it by stating requirements of system usability and composed this task in five dimensions:

I. Learnabilty: the system should enable the users to accomplish easily basic tasks the first time they encounter the design.

II. Efficiency: once the users learned the design, the system should be used efficiently.

III. Memorabilty: after a period of time when the users return to the application, the system should be easily remembered in order to reestablish proficiency.

IV. Errors: the system should cause low error rates and should recover them quickly.

V. Satisfaction: the design should be pleasant to use.

The main reason of employing usability testing in software development process is due to enhancement of system acceptability by increasing the level of satisfaction, user efficiency and productivity (Ferre et al. 2001).

One of the obstacles on deployment of BPS tools is non-user friendly simulation environment (Mahdavi et al. 2003). After defining usability problems of web-based BPS tools, we conducted the preliminary evaluation and tested tools with a user group.

The other topic discussed was the ease of use versus functionality of WBS tools. Despite the impact of ease of use on accelerating and accepting simulation technologies, a question was raised on “how does it affect the level of satisfaction of the small user group who are particularly technically oriented?”

2. METHODOLOGY

This chapter describes the approach of exploring the availability of web-based BPS tools. It consists of three main topics: i) identifying the current tools, ii) evaluating the tools in the thermal- energy domain and iii) conducting a test on three preselected tools.

2.1. Survey

In this section, it was aimed to compose a framework of the current BPS tools which are available in internet. We selected a number of tools from the on-line version of DOE's Building Energy Software Tool Directory (Crawley 1998). The rest was identified based on internet and literature search.

To classify the list, we employed two main aspects: i) simulation domain and ii) simulation type. In the light of these two dimensions the list formed a framework.

2.1.1. Classification by Simulation Domain

Web-based BPSs have the same simulation domains with the “classical” BPSs. After an overview on the listed softwares, six domains were distinguished: i) thermal/energy performance, ii) code compliance, iii) cost analysis, iv) active energy systems, v) lighting and vi) others. No acoustical performance has been identified after the exploration. Thus this domain doesn’t exist in the framework.

2.1.2. Classification by Simulation Type

The WBS applications can be developed architecturally in three different approaches. They are categorized depending on the location of simulation and visualization engines.

i) **Remote simulation and visualization (RSV):** both the simulation and visualization engines are located on the server side and are executed remotely. Briefly, in RSV indicating tools are entirely internet driven. To use the software only a web browser is required.

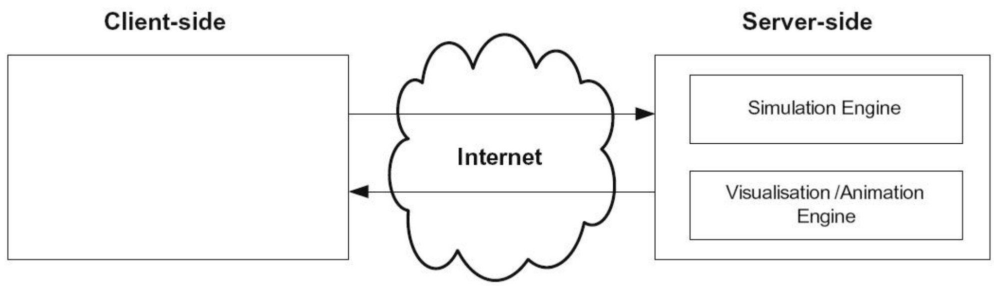

Figure 5 *The working scheme of remote simulation and visualization (Byrne et al. 2009)*

ii) **Hybrid simulation and visualization (HSV):** while the simulation engine is running remotely, in this case the visualization engine exists on the client side. Therefore, it reduces the workload on server and performs more efficiently.

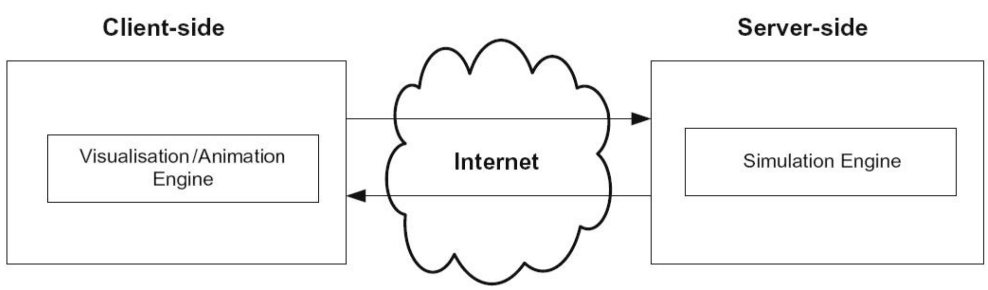

Figure 6 *The working scheme of hybrid simulation and visualization (Byrne et al. 2009*

iii) **Local simulation and visualization (LSV):** the simulation and visualization components are downloaded to the clients' local computer. Except distributing the software, server has no other function (Byrne et al. 2009). We included the LSVs that can be employed without a charge.

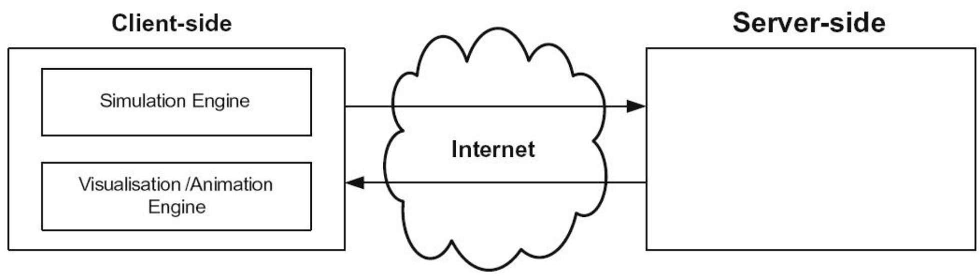

Figure 7 *The working scheme of local simulation and visualization (Byrne et al. 2009)*

2.2. Preliminary Evaluation

The purpose of this chapter is to examine the web-based BPS tools in detail. We restricted our study with RSV in thermal-energy domain.

2.2.1. Observing the features of the tool set

In order to reach a comprehensive understanding of such tools, we listed the features of the subset. The list was organized under a number of topics such as the type, amount and quality of data input/ output, data exchange capability, ease of use, algorithms and availability.

2.2.2. Developing the questionnaire

To address the usability problems and to evaluate the tools more effectively a questionnaire is developed regarding the previous section (figure 4 and table 2). We have developed two types of questions those are functional attributes (feature set, capabilities, security) and non-functional attributes (usability, flexibility, performance) (Chung and Sampaio do Prado Leite 2009). The functional attributes are fewer in numbers. These include items: suitability for use in early design stages, data exchange capability and algorithms. The rest represent non-functional features.

Apart from the overview we added: documentation, visualization of the results and support items to the questionnaire. Each item consists of 5 multiple-choices and from left to right the answers maintain a greater value. The tools are reevaluated depending on this questionnaire.

1. Ease of use	highly difficult	○–○–○–○–○	very easy
2. Suitable for use in early design stages	not suitable at all	○–○–○–○–○	highly suitable
3. Input data amount/ resolution	large amount of detailed information is needed	○–○–○–○–○	little input is required
4. Quality of output data	confusing and chaotic	○–○–○–○–○	clear and well organized
5. Visualization of results	only numeric	○–○–○–○–○	richly visual
6. Data exchange with BIM/ CAD systems	no data exchange	○–○–○–○–○	data excahnge
7. Local- Global applicability	locally restricted	○–○–○–○–○	different locations possible
8. Algorithm	highly simplified	○–○–○–○–○	highly detailed
9. Documentation	not available	○–○–○–○–○	well documented
10. Support	not available	○–○–○–○–○	(updates, FAQ, forums)
11. Price	expensive	○–○–○–○–○	free

Figure 8 *Questionnaire for tool assessment*

Table 7 *Explanations for each item*

ITEM	COMMENTARY
1. Ease of Use	In conventional BPS simulation the user profile usually consists of specialists who developed a comprehensive understanding of the subject and can overcome the difficulties/ complexity of the software by a long term learning cycle. Generally speaking, the term ease of use addresses the issues of easy to learn, easy to navigate and easy to build the simulation.
2. Early design stage suitability	Great amount of the advanced tools requires always detailed information about the building geometry and materials. The significant impact on decision making in the conceptual design stage is being simply ignored. For more energy efficient buildings the integration of the BIM tools and BPS tools should perform simultaneously starting with the schematic design (Zhu et al. 2007).
3. Input data amount/ resolution	Compared to the classical simulation applications web-based BPS tools require considerably less amount of inputs (Mills 2002). The input data amount reflects also the complexity and ease of use of the tools.
4. Quality of output data	To benefit from the results more efficiently a well organized and clear output data is necessary.
5. Visualization of results	Similarly to previous item visualization of the results has an important role on interacting with the users.
6. Data exchange with BIM or CAD	The integration of the design and BPS tools is an iterative process that requires data exchange in almost every single stage. Furthermore it reduces the life cycle of building the simulation.
7. Local - Global applicability	The definition of the location is needed to perform a simulation regarding with the historical weather data of the certain area. The local global applicability defines the range of these location settings.
8. Algorithm	Algorithm is a method to solve a problem (in our case building performance simulation) that expressed as a finite series of

	instructions. It reflects the complexity of the software and a well defined detailed algorithm generates more reliable simulation.
9. Documentation	Documentation is a description that explains how software operates and how to use it. A well prepared documentation provides the information that guides the user well and reduces the learning life cycle.
10. Support	The support feature enables the user to access remotely for the need of instant problem solving. It varies from a direct e-mail contact to the tool developers, to forums.
11. Price	The purchasing options have a significant impact on deployment of tools.

2.2.3. Evaluation of the questionnaire

Each question contributes to the study in a different level. For instance the level of integration in conceptual design stage is one of the constraints of this study. Similarly the local- global applicability is to define the effective area of the tool which is also an attribute of the availability domain and algorithms play a key role as well as in any software. Therefore these three items have a greater impact on the evaluation than others. To aggregate the 11 items of the questionnaire into a simple single-number indicator, a weighting scheme was composed. In this scheme, weights associated to each question are expressed in percentage adding up to 100%.

Seven of the users who associated to the further step by conducting the usability test were also asked to compose their own weighting schemes. Regarding the mean values of this evaluation, we compared these two schemes. As a result of this evaluation the original weighting scheme was slightly changed in the light of user's evaluation. For the purpose of the present study, the weighting scheme of table 6 was applied. Therefore the total scores indicated the total assessment of these tools and associated to the selection of the subset.

2.3. Test with a small user group

The preliminary evaluation provided us a general understanding of the web-based BPSs tools, as well as the strengths or weaknesses of these tools. However there is still a need for a detailed approach to address the user needs, limitations and preferences. Therefore we conducted a usability test on a small user group. A specific task (evaluation of the performance of a small building) is given to the participants for the selected tools. The same questionnaire is implemented on the usability test. We add another item to let the participant's state their level of satisfaction (for the sample questionnaire see Appendix C). The users are asked to evaluate the items regarding with several questions listed in table 3.

Table 8 *Guidelines for questionnaire items*

ITEM	QUESTIONS
1. Ease of Use	Is it easy to navigate and use? Are building, performing and analyzing the simulation time consuming? Did you receive any errors?
2. Early design stage suitability	In what degree is it possible to integrate a schematic design into the tool?
3. Input data amount/ resolution	To build the simulation what is the amount of required information?
4. Quality of output data	What is the quality of the results? Is the generated data clear and well organized? Does it lead you for a comprehensive understanding of the related task's performance or is it a source of confusion?
5. Visualization of results	Is the generated report richly visual? Does it consist of only numeric and verbal output data?
6. Data exchange with BIM or CAD	To what extent is it possible to import and export the files with BIM and CAD extensions (*.dwg, *.3ds, *.ifc, *.xml, *gbxml … etc.)?
7. Local – Global applicability	What is the range of locations options that the tools offer? Is it restricted locally (with a region/ state/ country) or is the selection of different locations possible? If the software can be used only in a specific regions or it is available world-wide?
8. Algorithm	What is the state of algorithm of this tool? Is it well-defined and highly detailed or simplified? (note that if you cannot reach to an evidence of algorithm, it is possible to left this item blank)
9. Documentation	Is it communicating well with the users how the software operates? Is there any text along with it to describe various aspects of its intended operation?
10. Support	To what extend the support function is provided by the tool developers? Does it offer an e-mail contact, FAQ, updates or forums?
11. Price	Is the software too expensive? Has it reasonable charges or is it free?
12. Satisfaction	After the completion of the task what is your level of satisfaction overall the tool features?

2.3.1. Selection of the tools

Even though there are numerous tools in the same category most of them have diverse audiences and approaches. Since one of the strengths of this study is to provide recommendations for future tools, instead of making comparisons with similar tools, we decided to choose them depending on their different features. Regarding with the previous section we selected three tools.

2.3.2. Test Plan

We originated a test plan in order to get more efficient test results. After retailing the purpose of performing the test, we stated the problems that have been discovered from the author's preliminary evaluation. We formulated our expectations (conjectures as to how the participants would evaluated the tools) based on our own evaluation in order to compare the author's conjecture with the test results.

2.3.3. User group

We conducted the test on a small group of potential users (20 architecture and engineering students) (table 4). All of the participants used at least one "classical" BPS tool in thermal domain. Not all of the users are specialized on a BPS tool but they are all familiar with the content of thermal-energy analysis.

The test is conducted with 20 participants. First group of users (10 participants) have taken the test simultaneously, they started to evaluate in a sequence of ***I, M*** and ***T***. The sequence altered to ***M, T*** and ***I*** in the second group evaluation, in order to avoid the perception that could be created by the sequence and to reach a more accurate results. We performed the test one-to-one with the second group.

Table 9 *List of the small user group*

	USER CODE	GENDER	PROFICIENCY	GROUP
1	user 05	Male	Architecture	1
2	user 07	Female	Architecture	2
3	user 09	Male	Architecture	1
4	user 18	Female	Architecture	2
5	user 18M	Male	Architecture	2
6	user 22	Male	Architecture	1
7	user 24	Female	Architecture	1
8	user 28	Female	Architecture	2
9	user 40	Male	Architecture	1
10	user 41	Female	Architecture	1
11	user 42	Female	Architecture	2
12	user 68	Female	Architecture	2
13	user 73	Male	Architecture	1
14	user 80	Female	Architecture	2
15	user 81	Male	Architecture	1
16	user 85	Female	Building science	2
17	user 86	Male	Architecture	1
18	user 90	Male	Architecture	2
19	user 94	Female	Civil engineering	1
20	user 97	Male	Architecture	2

3. RESULTS

3.1. Survey

A total of 141 tools were mapped on to this framework, namely 56 RSVs, 6 HSVs and 79 LSVs (table 5). The complete list provided in Appendix A. The majority of the RSVs calculate thermal- energy performance. We included cost analysis and code compliance domains. They are listed also under the thermal- energy domain, because to run the simulation these kinds of tools calculate formerly the thermal- energy use. Active systems domain consists of diverse tools that estimate the efficiency of photovoltaic's (PVs), solar collectors and air conditioning systems. Under the topic of others we listed a number of tools that calculates R/ U- Values, thermal bridges, degree days and the energy use of appliances etc.

Compared to the remotely controlled tools, HSVs are well developed and are more detailed in algorithms. However the available tools are fewer in numbers.

In this framework LSVs are mainly the classical tools which are available via internet. We included those that can be employed without any charge. Similarly with the RSVs most of the tools calculate thermal performance. However in this case we found many tools that provide lighting calculations too. Comparing with the RSVs, these classical tools offer large number of inputs and control over the building performance in diverse aspects.

Table 10 *Categorization of the 141 surveyed WBS tools (note that certain tool are categorized in more than one category)*

DOMAIN	RSV	HSV	LSV
Thermal/energy	22	5	18
Cost analysis	4	-	4
Code Compliance	9	1	14
Lighting	3	-	19
Active systems	10	1	13
Others	19	-	24

3.2. Preliminary evaluation

3.2.1. Overview of the preliminarily evaluated tools

The tools of RSV with thermal-energy domain are in total 22 (table 6) that are evaluated. We provided an overview of the tools with listing the features that they offer Appendix B. Afterwards they were reviewed with the questionnaire.

Table 11 *List of tools for preliminary evaluation*

CODE	TOOL NAME	SIMULATION DOMAIN
A	Acuity Energy Platform	Energy management tool
B	IC3	Code compliance
C	Home Energy Saver	Cost/energy and saving estimation
D	Home/ Commercial Energy Suite	Cost/energy estimation
E	ArchiPHYSIKweb pro	Energy estimation and code compliance
F	Building/ Green Energy Performance Compass	Energy use and savings, CO_2 emissions
G	Cal- Arch	Energy use
H	Clariti	Energy management
I	MIT Design Advisor	Energy use, daylight
J	EnergyCAP Energy Benchmark	Energy use
K	Energy Profile Tool	Energy use, cost estimation, CO_2 emissions
L	foAudits	Energy use (PDA or Palms)
M	My e-Home	Energy use
N	Rehab Advisor	Energy saving
O	Smeasure	Energy use and green house gas emissions
P	Building Advice	Energy use and savings, code compliance
Q	Building Green House Rating	Energy use and savings, code compliance
R	Energy Work Site	Energy use, cost estimation, code compliance
S	Green Quest	Energy use, cost estimation, CO_2 emissions, code compliance
T	H1 Compliance Calculator	Energy use, code compliance
U	COM Check Web	Code compliance
V	RES Check Web	Code compliance

The author's evaluation is given in figure 5 in terms of mean values. According to these results most of the tools are easy to use, the documentation is adequate and it can be employed with low amount of charges. The input data amount, the quality of output data, visualization of the results, support and algorithm items were found in an intermediate level. The majority of the tools were considered as not suitable for use in conceptual design stages. Similarly they don't support the data exchange function and they are available only in certain locations.

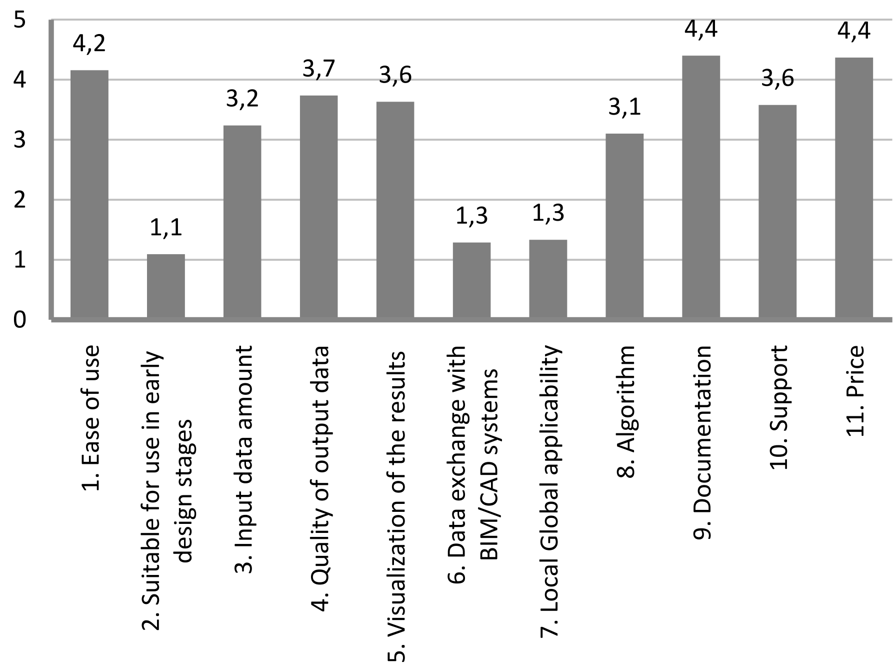

Figure 9 *Mean values of preliminarily evaluated tools*

3.2.2. Weighting scheme

To visualize these 22 tools in terms of their total assessment by giving single number indicators to these 11 items, a weighting scheme has been developed. The comparison with the authors' weighting scheme and mean values of the users' evaluation is stated in figure 6. As a result of this, four of the items are adjusted and a new scheme was developed table 7. While second and forth item was being reduced by the order of 15% and 12.5%, the values of sixth and ninth was being increased to 7.5%.

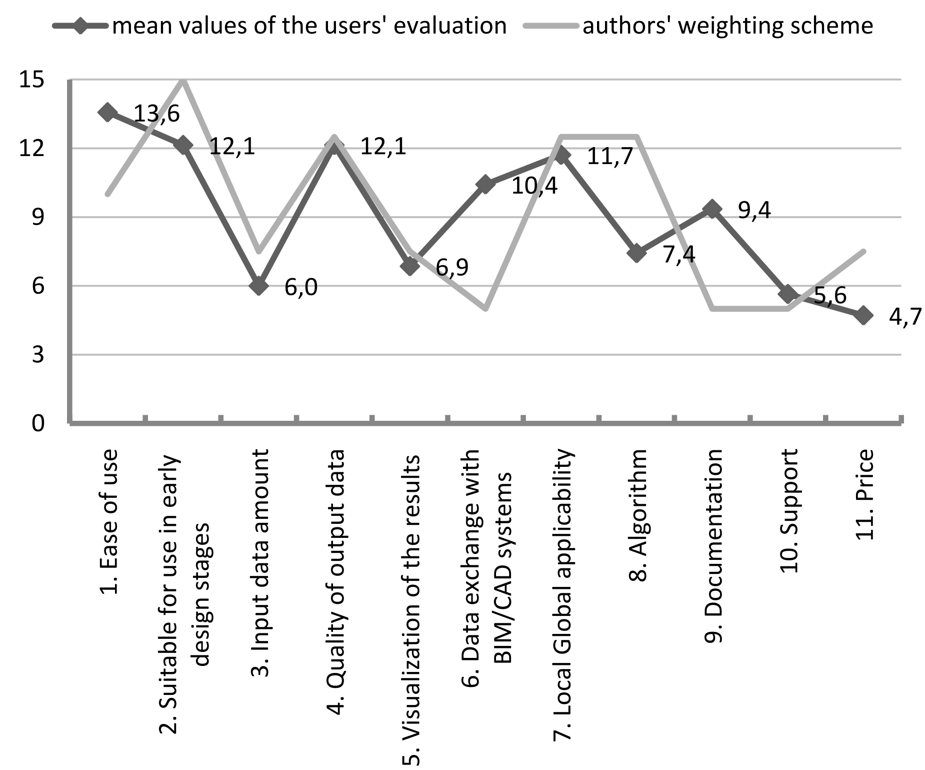

Figure 10 *The comparison between the authors' weighting scheme and users' evaluation*

Table 12 *Evaluation of the questionnaire*

	QUESTIONNAIRE ITEM	WEIGHT (%)
1	Ease of use	10
2	Suitable for use in early design stages	12.5
3	Input data amount/ resolution	7.5
4	Quality of output data	10
5	Visualization of the results	7.5
6	Data exchange with BIM/ CAD systems	7.5
7	Local- Global applicability	12.5
8	Algorithm	12.5
9	Documentation	7.5
10	Support	5
11	Price	7.5
	TOTAL	100

The weighting scheme of table 7 was applied to the questionnaire results. The total scores of authors' preliminary evaluation are visualized in figure 7.

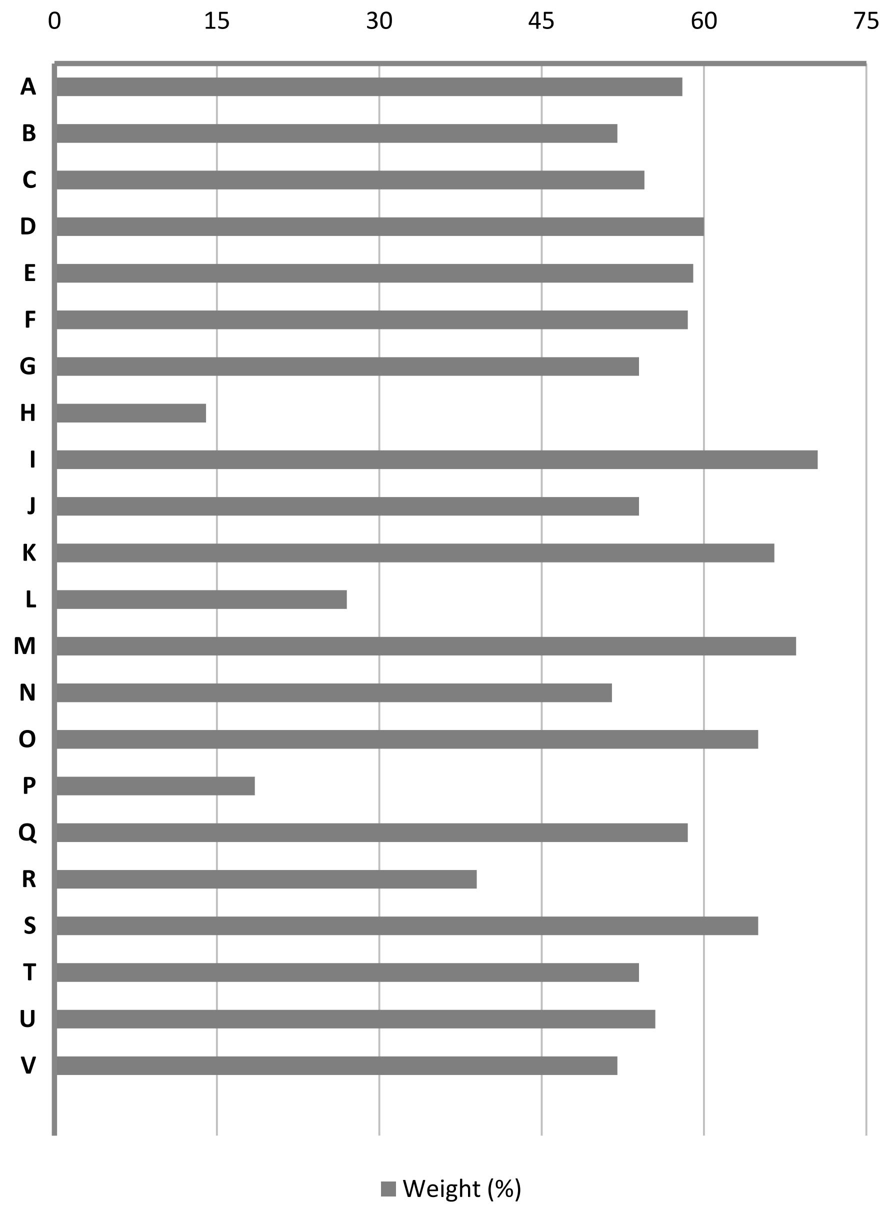

Figure 11 *Preliminary Evaluation for Thermal- Energy Calculators*

According to the results ***I*** had the highest value (note that due to the lack of information, some of the tools weren't evaluated in several questions). The majority of the tools are in between 55-65% which has not much difference with ***I***.

For the further step, to explore the WBS tools more effectively, we selected the tools depending on their different capabilities: ***I*** can be executed in various locations and the audience consists of users with technical backgrounds, ***M*** supports the construction of 2D, 3D geometric building models and ***T*** possesses data exchange capability.

3.3. Test with a small group

Before reviewing the test results of these three tools, it is significant to mention the previous statements of the author's preliminary evaluation.

3.3.1. Overview of the tested tools

It is beneficial to provide general information about the three tested tools. They were selected since they possess different features which are considered to be indispensable for an ideal tool. Tool ***I*** provides numerous options for locations settings: it is widely available than the others. In addition to that ***I*** is more suitable for architectural purposes. In tool ***M*** 2D and 3D design is supported. Tool ***T*** offers data import of building information modeling (BIM) extensions.

While the target audience in ***I*** is mostly users with technical backgrounds like architects and engineers, in ***M*** they are home owners. Even though ***T*** provides code compliance calculations for facility owners, it requires technical information of the materials that have been used in the building construction.

I can be completed in 9 steps that consist of building and typical room properties. It is possible to use this application in 4 continents consisting of 67 different locations. The amount of required input is less than the other two. The default settings are provided but they cannot be changed in terms of different selections. In several occasions (4 of the 20) the simulation has crashed. On the other hand the results of four design alternatives can be compared simultaneously. It provides visualizations of energy consumption, level of thermal comfort, indoor temperature, daylighting and energy cost analysis.

M have a more complex structure compared to ***I***. Apart from that ***M*** is available only in Denmark. It requires the information of building model, heating-cooling system and the appliances which are being used. Similarly the simulation has crashed in several occasions (3 of the 20). The results consists of energy use and CO_2 emissions. It exports files with *.gbxml extension, but it does not work practically good.

T is available in New Zealand and is developed to provide code compliance for existing buildings. It requires detailed information of the building model and it provides material libraries of a several companies. Three different code compliance methods can be followed. The results consist of compliance report which is only verbal and numerical. Importing the 3d model of a design is supported.

3.3.2. Author's Conjecture

In order to perform an efficient test before all else we stated our expectations of the test results. Afterwards a comparison was provided between the conjectures and results. The formulations of the author's conjecture are summarized in the table 8 in terms of 12 hypotheses.

Table 13 *A summary of the authors' conjectures regarding tools T, I, and M, as formulated prior to the test with a small group of users*

QUESTION	HYPOTHESIS
1. Ease of Use	Selected tools are generally easy to use. ***T***'s GUI is deficient, making navigation difficult.
2. Early design stage suitability	***T*** does not support schematic design stage effectively.
3. Input data amount/ resolution	***T*** requires large amount of input data. ***I*** requires the least amount of input data.
4. Quality of output data	***M*** and ***I*** provide clear and well-organized output. ***T*** appears rather confusing.
5. Visualization of results	Except ***T***, tools provide effective visualization.
6. Data exchange with BIM or CAD	***I*** does not support data exchange. ***M*** imports *.meh extensions. Tool ***T*** imports *.gbxml and *.xml extensions.
7. Local – Global applicability	***M*** and ***T*** are locally restricted. ***I*** offers multiple locations.
8. Algorithm	***T*** is most detailed, followed by ***M.***
9. Documentation	All tools are well documented.
10. Support	***M*** offers only an email contact. ***I*** provides FAQ and email support. ***T*** provides these features plus a forum.
11. Price	All tools are free, but ***T***'s report must be purchased.
12. Satisfaction	***I*** is easier to use and requires less input data. ***M*** provides better visualization, and does not require deep technical background, but is limited concerning building types. ***T***'s GUI is deficient, but appears to be more detailed and reliable.

3.3.3. Test results

The mean value of the test duration was approximately 90min. The participants' evaluations of the 3 tools are summarized in Figure 5 in terms of mean values.

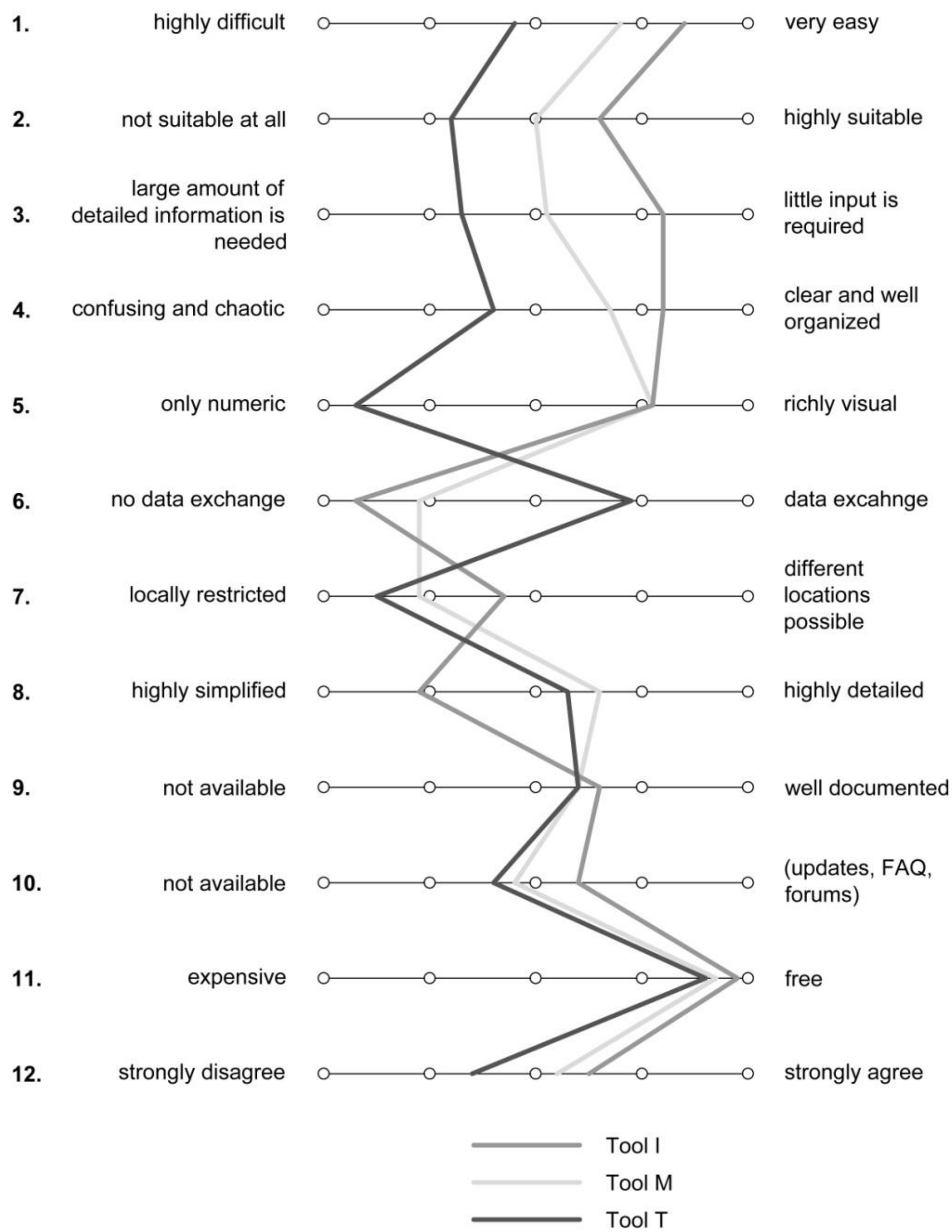

Figure 12 *Mean values of the user group evaluation*

The general trend in the evaluations of the authors and the participants are similar (Figure 9). ***I*** ranks, in both cases, ahead of ***M***, followed by ***T***.

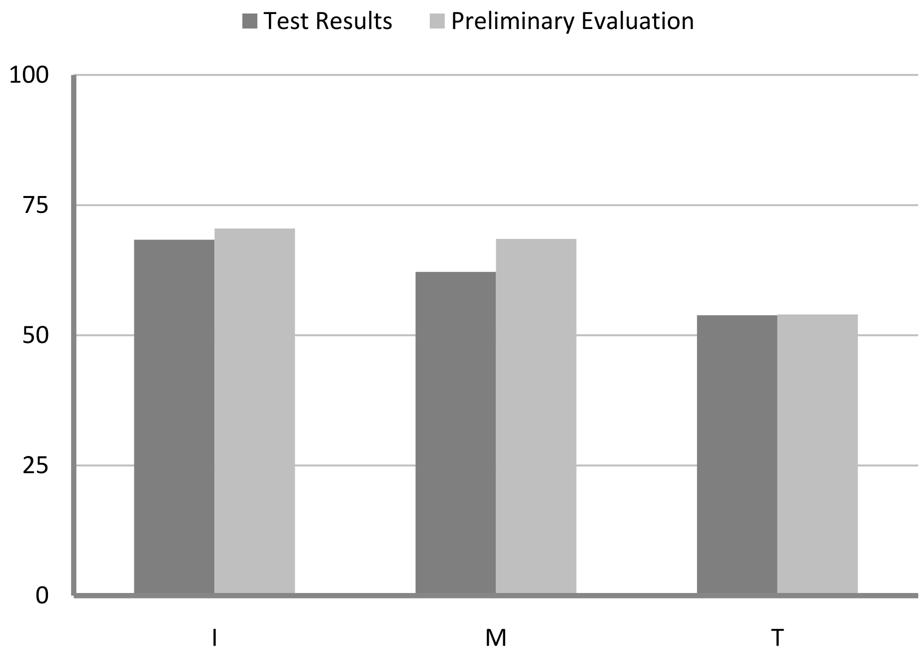

Figure 13 *Comparison between the participants' test results and the authors' preliminary evaluation*

A more detailed analysis of the results is provided in **Table 9**, which includes remarks concerning the authors' conjectures (**Table 10**) and the participants' views (**Figure 10, 11, 12**) on a question by question basis.

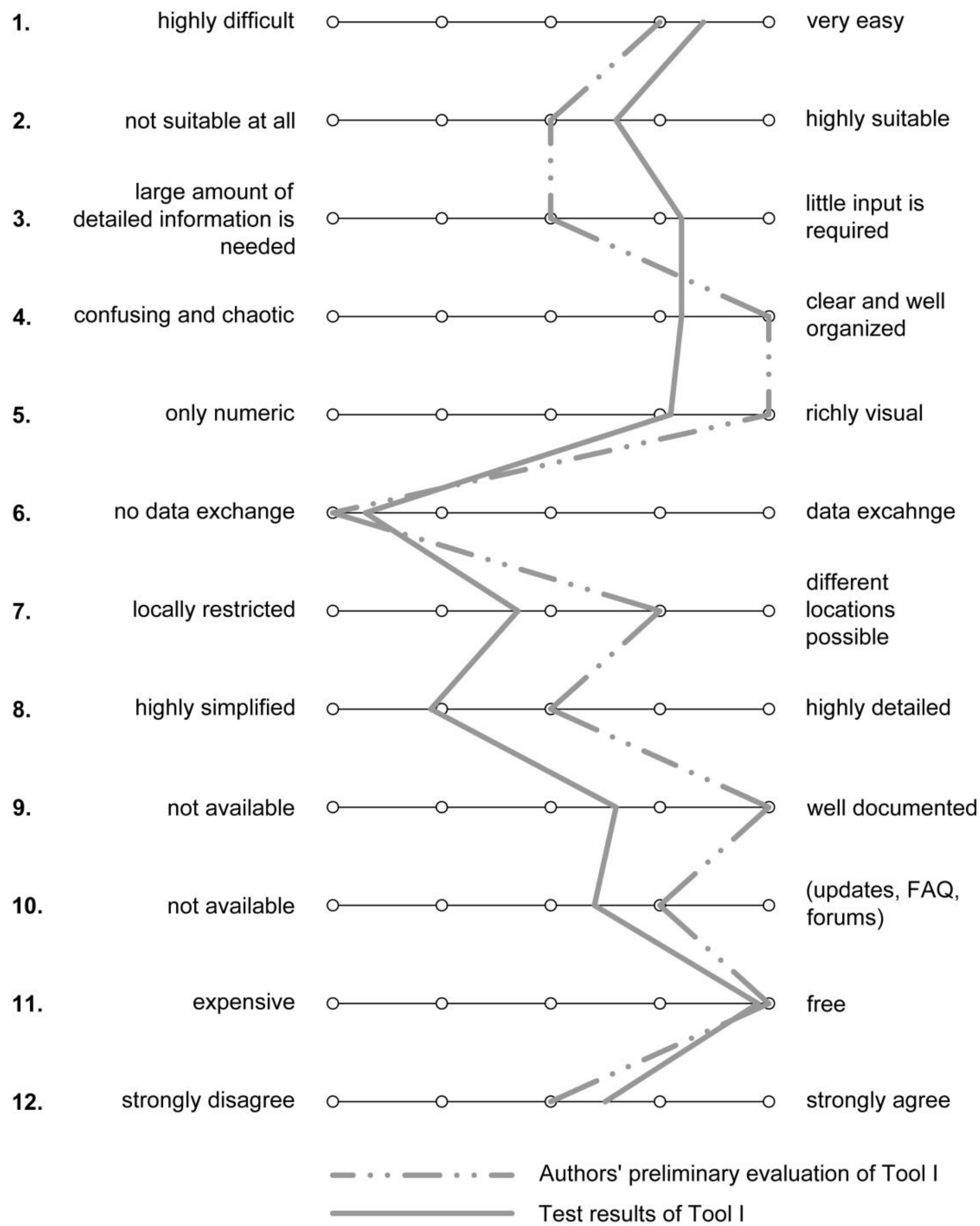

Figure 14 *Comparison between authors' preliminary evaluation and test results of Tool I*

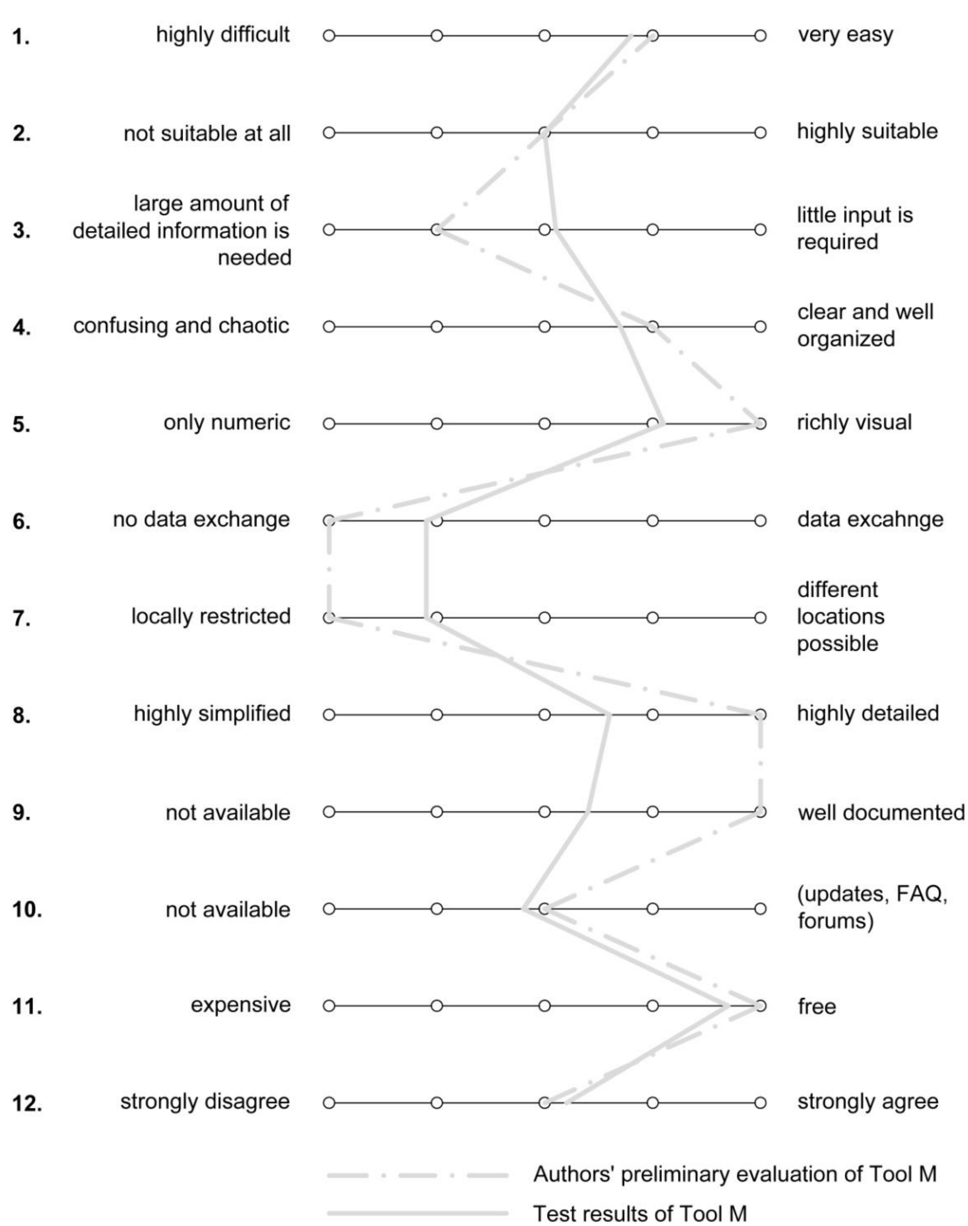

Figure 15 *Comparison between authors' preliminary evaluation and test results of Tool M*

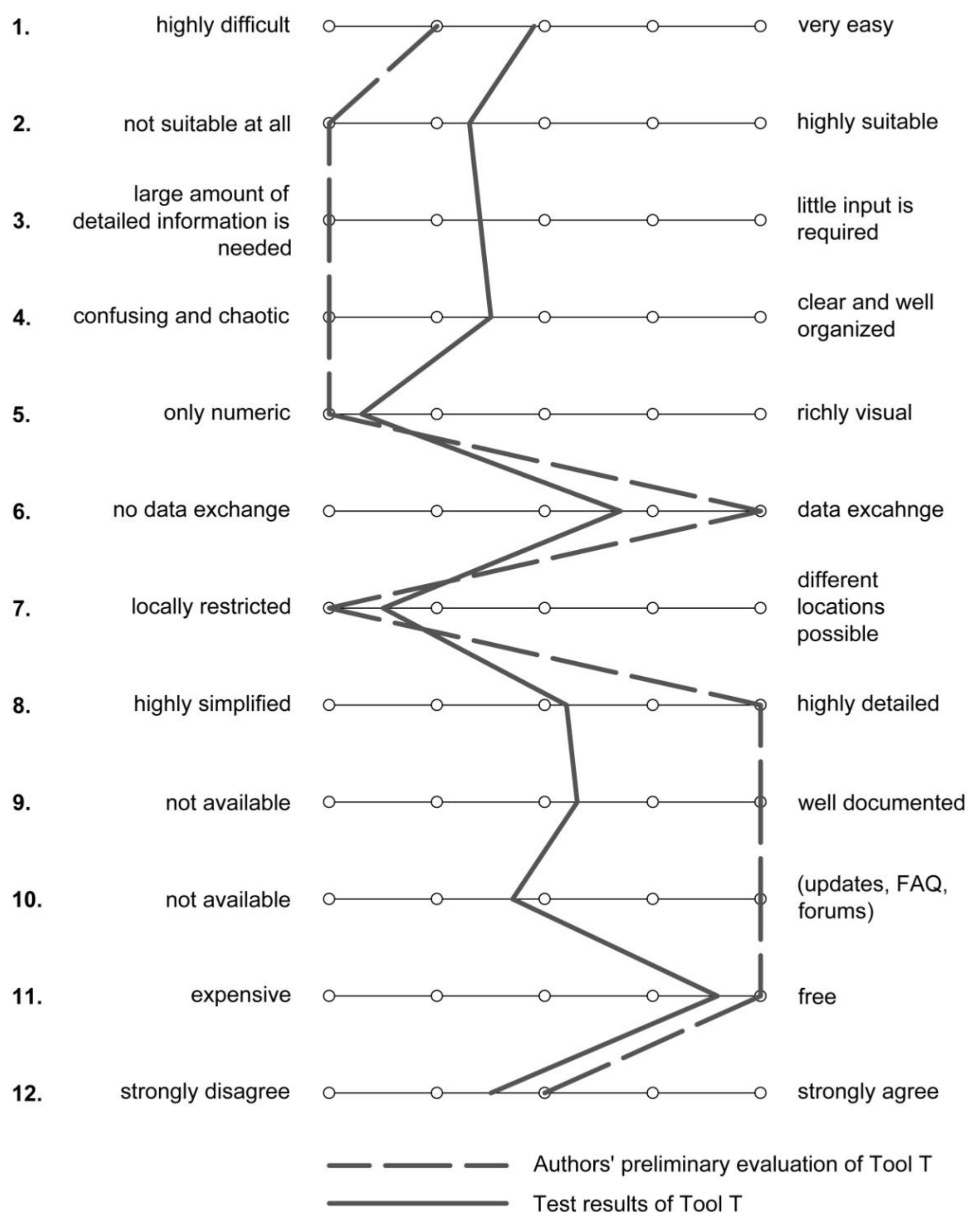

Figure 16 *Comparison between authors' preliminary evaluation and test results of Tool T*

Table 14 *Analysis of the test results*

QUESTION	ANALYSIS
1. Ease of Use	***I*** requires less input data and provides default settings, hence it was found easy to use. ***M*** has a friendlier user interface as compared to ***T***.
2. Early design stage suitability	Contrary to the authors' conjectures, they found ***I*** more suitable then the other two. The reason seems to be that users focused on the fact that ***I*** requires less information, not that this information is not necessary available at the early stages of design.
3. Input data amount/ resolution	Similar to authors' conjecture, ***I*** was seen as requiring the least amount of data input and ***T*** has the highest.
4. Quality of output data	***I*** offers users a combined view of the results of different design alternatives, explaining users' preference. Users agreed with the preliminary evaluation in finding ***T***'s output confusing.
5. Visualization of the results	Since ***T*** does not provide charts or graphs for results, it received the lowest evaluation.
6. Data exchange with BIM or CAD	***T*** was the only tool that enables the users to import files with BIM extensions.
7. Local – Global applicability	Even though ***I*** offers a variety of locations, it received a lesser evaluation than expected: users implied that the locations were not distributed well enough. ***M*** is available only in Denmark and ***T*** in New Zealand.
8. Algorithms	Users' views confirm the preliminary evaluation.
9. Documentation	Users' views confirm the preliminary evaluation.
10. Support	As opposed to our conjecture, ***T***'s support function was not considered high, as the users could not access forum, due to the tool's GUI.
11. Price	All tools are free in principle. But the registration requirement of ***M*** and the report cost for ***T*** appear to have affected participants' judgment.
12. Satisfaction	All tools were found modestly satisfactory.

3.3.4. Comparison of the group results

We conducted the test with 2 separate groups. First group tested the tools in a sequence of ***I,M*** and ***T*** while the second did it like ***M,T*** and ***I***. The goal was to eliminate the perception that would be possibly created by the test order. In figure 13 the results of the two groups are provided and compared regarding with the weighting scheme (table 7).

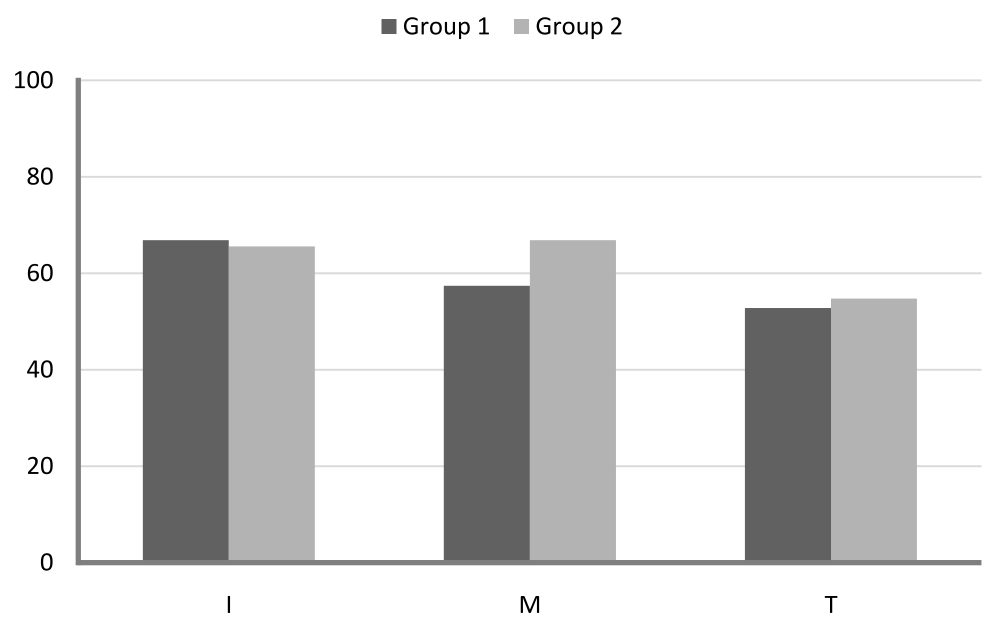

Figure 17 *Comparison of the two group evaluation*

First group began the test with tool ***I*** and end with ***T*** while the second started with ***M*** and the evaluation lasted with ***I***. In the first evaluation participants in both rated the items slightly higher than the second and third tools. On the contrary for the lastly evaluated tools the comparisons are slightly lower in both occasions. A closer interpretation would be the sequence of the test affects the results negatively to avoid this effect it is necessary to conduct the test in groups.

4. DISCUSSION

4.1. Survey

For this framework, 141 tools were classified and mapped depending on their simulation type and domain. Tools vary, even in the same category by their approaches and diverse audiences. Correspondingly diverse inputs, outputs and methods are required. To explore these tools it would be necessary a detailed pursuing way within the framework.

As it is stated in table 5, compared to the classical tools (56%) the number of the RSVs is still less (39.7%) and their structures are simplified. Moreover the most remarkable feature of RSVs is ease of use. The LSVs are mature and require detailed inputs. The tools with hybrid structure are considerably fewer in numbers (4.3%), although they hold a promising future by combining the best features of classical and web-based tools (figure 14).

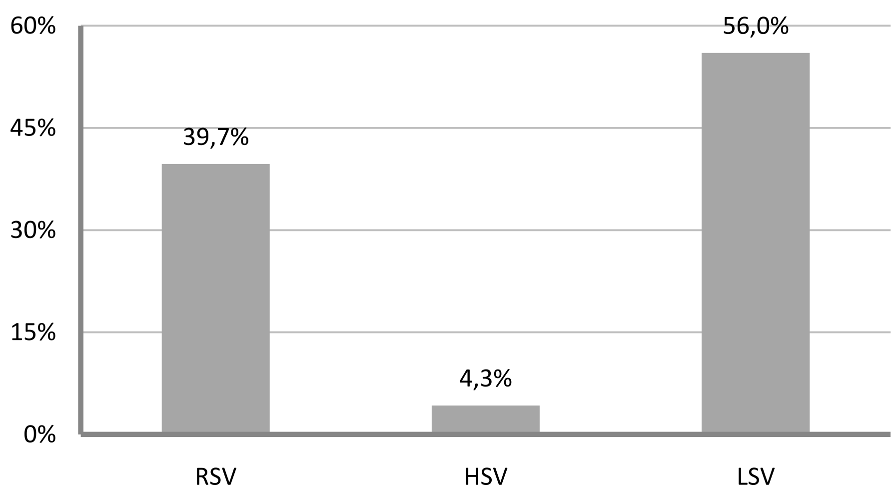

Figure 18 *The percentage of the simulation types overall 141 tools*

In all of the three simulation types, the majority of the tools perform thermal-energy calculations (31.9%) (Figure 15). By way of inference the need for thermal- energy calculations appears to be greater than the others. Correspondingly tools in with thermal domain have more complex structures.

Code compliance offers simulation for completed designs or existing buildings. That means orientation of the building and building geometry have to be decided; building materials have to be selected and zones have to be defined before running simulation. The users have not a direct impact on the design process. Their priority on employing BPS tools is mostly to improve the building performance.

Despite the fact that tools with active energy systems domain are presented in the same quantity as the code compliance tools, active energy systems consists of various minor topics (i.e. PVs, solar collectors and air conditioning systems).

Lighting is another of the major domains in this framework. Only three of these applications are entirely internet driven and they support either daylighting or artificial lighting design. Tools with local simulation approach support more complex designs. They also offer simulations for both daylighting and artificial lighting design. They can be applied generally in the last stages of architectural design.

Tools that we listed under the topic of others are mainly supportive applications for building design or construction.

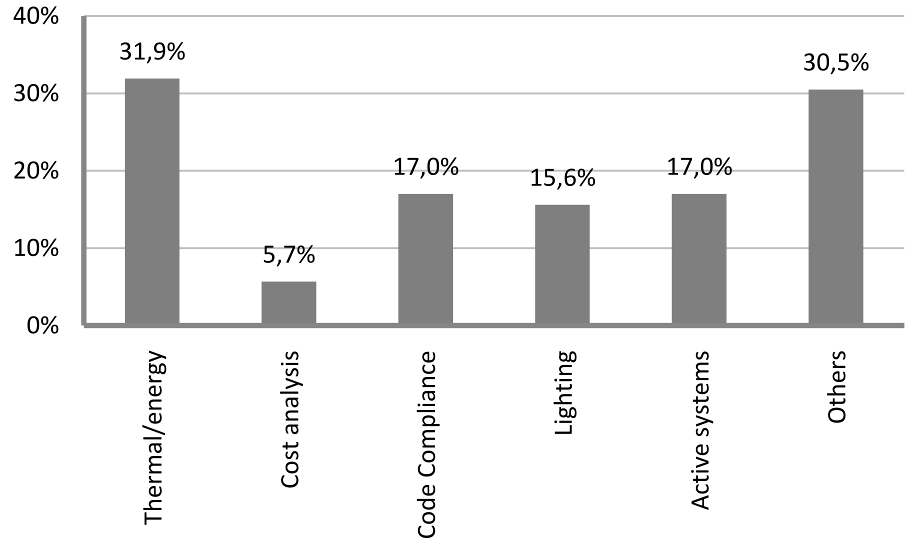

Figure 19 *The percentage of the domains overall 141 tools*

4.2. Preliminary Evaluation

Even the tools with the same simulation domain vary in many ways. It is not possible to infer that two specific tools have entirely the same features. It is due to their diverse audiences correspondingly diverse approaches.

More than half of the evaluated tools were developed for the utility of users like the facility owners or contractors who are not experts in this field. Because of developing tools for various range of users reduces the complexity of the tools and requires less expertise. Thus the majority of the tools are easy to use. Similarly most of the tools offer more visual and well organized results regarding with a better graphical layout.

A great number are not suitable for use in early design stages. They require inputs of utility bills, historical/ real time energy measurements or detailed information of the building construction.

Data exchange capability is a rare feature in this sub-set which is employed by only two tools in this list: ***I*** and ***M***. However ***I*** offers only the import function of files with *.gbxml extensions and ***M*** exports *gbxml file too but it doesn't perform as it is expected.

To calculate thermal energy performance it is indispensable to provide weather data. Running a simulation remotely doesn't perform always very effectively due to the great variety of locations. The historical weather data has to be provided for each location. Similarly some of the tools were designed to provide code compliance and each country developed its own codes. Therefore the availability is reduced and most of the tools were not able to expand the borders of certain countries.

Depending on the commercial and residential use the price of the tools differs, but both of them have mostly reasonable charges compared to conventional tools.

Considering the variety of the target audiences they are either relatively easy to use with no requirements of expertise or hard to use without a technical background. The second type of tools mostly provides simulations for specific purposes but not for the "whole-building" performance. In addition to that most of them do not provide model reuse. It is possible to infer that the evaluated tools don't comply entirely the demands of an architectural design process.

4.3. Test

It is necessary to indicate that the small user group has a technical background of building physics. Therefore while we were observing the results, it has to be taken into consideration that the ease of use item is evaluated by the participants who are familiar with the content.

It is possible to infer that the tested programs have a variety of features. Various audiences have different demands and correspondingly the approaches are changed by this fact.

Beginning with ***I***, it mainly supports the decision making in architectural purposes. Therefore comparisons of different alternatives are provided. The climate zone, building geometry, orientation of the building, occupancy, window type, lighting and HVAC system information are taken into consideration. The results consist of: energy consumption, cost analysis, thermal comfort in a sample room, natural ventilation and daylighting. Since our test participants are architecture and engineering students they were more satisfied with ***I*** than the other tools (**figure 9**). The user comments of ***I*** summarized as following:

I. Ease of use, visualization of the results and wide availability were the features that affect the level of satisfaction positively.

II. The default settings don't adapt the changes. The program crashed in several occasions and the results took long time to proceed.

III. The required information is not detailed, so most of the participants questioned the reliability of the software.

On the other hand ***M*** is developed for the use of home owners who possess mainly low-rise buildings. Generation of the building geometry with a user-friendly interface is offered. The location is defined via virtual maps so the orientation is set automatically. The other requirements are the appliances, lighting, heating and cooling information which are all supported by a richly visual interface. Thus the complexity of the simulation inputs is reduced for the users who have no technical background. Although the generation of the building model created a positive impact on the users, the level of satisfaction was selected as medium, because:

I. To reduce the simulation effort data exchange capability is provided, but it didn't perform very well during the test sessions.

II. The selection of the locations is restricted within a country.

III. It simulates only residential buildings.

IV. Comparisons of different design alternatives are not supported. Registration for another account is required to simulate another building.

V. The users didn't find it reliable while some of the inputs which are essential for conventional tools are not supported in this tool (i.e. the information of building materials). Furthermore the heating and cooling system information are found simplified.

Since ***T*** is a code compliance tool, the users are mainly facility owners, contractors or various engineering and architectural firms. The detailed information of building geometry and materials has to be provided in order to run the calculations. This fact limits the audience range to the users with technical backgrounds. Although the data exchange capability improved the level of satisfaction, it has the lowest mark (figure 9). According to the user comments:

I. User interface was found deficient and unorganized, thus it isn't easy to use and easy to navigate in the program.

II. It wasn't considered as suitable for use in early design stages due to the detailed input data.

III. Selection of the locations is restricted within a country.

IV. The results are verbal and numerical.

To make a general observation of the test results regarding the user comments, it is possible to say that these three tools didn't fulfill their expectations entirely. To summarize the user comments:

- Ease of use: it created a double-sided effect on users. While the tools were considered as easy to use, it was found also the source of unreliability.

- Design integration: it is possible to use ***I*** and ***M*** in early design stages but on the other hand they don't support data exchange with BIM or CAD file extensions. They expected more data integration of overall design stages.

- Data exchange capability: ***T*** supports data import of a building information model. The data are consisted of only numerical information and to edit the model, user has to memorize the building geometry. If a preview was provided, navigation would have been easier. The visualization of the import file doesn't exist.

- Wide availability: the number locations were limited. Even though ***I*** supports numerous locations, most of the countries are absent in the dropdown list. They expected more variety of options.

4.4. Conjecture: Discussion of overall the study

In the light of the whole study web-based BPS tools are still in their infancy, they must be enhanced in many aspects. Despite the advantages over classical tools, web-based BPS simulation is deficient in many characteristics:

- First of all there is no such tool that comply the demands of the architectural design processes entirely. Only a few are suitable for use in conceptual design stages.
- Most of the existing tools were developed for the non-expert users. They achieved designer friendly software by reducing the data input or simplifying the algorithms. For instance, most of the tools with thermal-energy domain don't require the building information model or the orientation of the building which are essential inputs to perform reliable simulations. There are a few examples which attach importance to the enrollment of the specialists.
- Although web environments are highly interoperable, web-supported BPS technologies are not performing in this aspect very effectively.
- Remotely controlled simulation has delays in feedbacks during the instant access of multiple users. Network traffic can cause loss of speed and data.
- Especially the RSVs are simplified in algorithms. The features that they offer are limited with the server load, thus they are prone to error.

4.5. Recommendations for future tool developments

Future trends in building simulation field cannot be considered without the existence of web integration because of promising features: wide availability, platform independency, low-maintenance options, progressive collaboration between the design team members, and etc. However, to meet the future requirements a comprehensive understanding on this new breed of simulation should be maintained.

The current web-based BPS tools should be enhanced in many aspects. A number of recommendations are listed after the observations of the overall study:

I. **Optimization of user friendliness:** ease of use is one of the features that enhance the deployment of tools. Even if it's desirable attribute, to make the software's easy to use; most of the tool developers prefer to reduce the amount of input data. This can affect in some occasions the accuracy of the results.

   The lack of information may interpret results wrongly. Instead of making the software simplified, the features of mature tools have to be preserved. On the other hand the GUI must be enhanced and documentation should be more visual for a better navigation and use. The preferable tool engages the user requirements with effective, efficient, error tolerant and easy to learn tool design (Quesenbery 2001). The better solution would be, without compromising any data, more visualization which allows the user navigate effectively.

II. **More integration in early design stages:** in order to perform energy efficient design, BPS tools has to be integrated in all phases of design process beginning with early design stages. Data exchange capability and comparisons of design alternatives has to be supported.

III. **Inclusion of multiple locations:** The current tools don't reflect the web nature very effectively in terms of serving information to geographically distributed users. To support simulations for certain locations, the databases (historical weather data, material libraries etc.) have to be provided by taking into consideration that larger geographical range increases the workload on the server. To overcome this difficulty, instead of running the whole simulation remotely, some of the data libraries could be downloaded to the client side.

IV. **More efficient data exchange capability:** the tools which offer the data exchange function don't perform very well in practice. Either import or export function of the building geometry is supported by only a few applications. Data import from BIM and CAD tools has to be enhanced.

V. **Provision of design optimization:** the web environment should be supportive in generating simulations for multiple designs. Thus the consequences of the design variants will be compared simultaneously. This feature will educate the user and help to be specialized.

VI. **Project management:** The challenge of integrating web environment is to provide an efficient collaboration between the members of a design team. Only then the involvements of the specialists become easier. Most of the tools must be enhanced within this objective.

VII. **Provision of databases** (qualitative material and weather libraries): the materials are limited with certain data's. The user input for generating new materials has to be provided. The variety of materials enhances the accuracy of the results.

VIII. **Inclusion of multiple domains:** As no application was detected that offers acoustical performance simulation and there is no multi-domain tool supported by the web environment.

IX. **Addressing the audience background:** the majority of the tools are developed for the non-expert users. They are mainly facility owners, contractors etc. who employ this simulation technologies only in late design process or after the construction. No doubt with the enrollment of the specialists, more energy efficient buildings will be emerged.

X. **Reducing the server loads:** due to the instant access of numerous users, simulation procedure is often interrupted or crashed. Remote simulation and visualization (RSV) faces often loss of speed and data during the simulation process. A good alternative for RSV would be hybrid simulation and visualization (HSV) which combines the best features of classical tools with RSVs (Myers 2004). To reduce the workload in HSV the animation engine is downloaded to the client side and the simulation runs remotely. Therefore the simulation takes advantage of the more powerful hardware (Byrne et al. 2009). Building up the simulation, provision of data libraries is supported by a desktop application and in the meantime a concurrent simulation and collaboration between the team members would be achieved. In addition to that, comparisons of design alternatives and design optimization will be enabled rapidly.

5. CONCLUSIONS

5.1. Contribution

This thesis contributes to the web-based building performance simulation field:

- A framework for the currently available tools is provided. It is composed of remotely controlled applications which are considerably low in price and local simulations which are free of charges. One of the features of this study was to explore alternative simulation technologies for the firms in developing countries, smaller firms and architecture/ engineering students. Therefore there is a possibility that the employment of BPS in building design field would be enhanced and more energy efficient buildings would be constructed.
- With the provision of the framework the myriad BPS choices has been categorized and a better framework for tool selection is offered.
- State of the art, availability and usability of web-based BPS tools were explored.
- The problematic features of the current tools were discussed and recommendations for future tool developments were made.

5.2. Future Research

Web adapted BPS environments are still immature while other web-based simulation technologies are developing rapidly. Especially web hosted game development tools have recently become more popular. Enabling of everyone to create high-quality 3D interactive content and even publish them to smart phones demonstrates the benefits of instant accessibility very effectively. Then why the rest of the applications are still lacking behind? According to Kuljis

(2001) it is due to the fact that "there are no real applications and no real users who are pushing for more adventurous approach."

The existing web-based BPS environments did not fulfill the expectations of the potential users, particularly the ones with technical backgrounds. Most of them are deficient in algorithms, in design integration capabilities and in availability. It is possible to infer that the distributed nature of BPS is still in its infancy and they do not have the capability to compete with conventional tools yet. In the previous sections, we provided recommendations in order to support the subsequent development of the future web-based BPS tools. If designed properly, the web-supported BPS tools can be expected to become progressively more common.

To maintain the advantages of WBS tools in terms of instant accessibility, simple user interaction features and low costs, but to provide, at the same time, sufficiently detailed and reliable results, tools with a hybrid structure may offer the best opportunity: they combine the best features of local and remote simulation (Byrne et al. 2009). The workload on the server is reduced (as compared to conventional WBS approaches) by exporting the animation/visualization functionality to the client side (Myers 2004). Thus, BPS tools with a hybrid approach could offer the same features as the conventional tools in terms of data interoperability and provision of a database. It would be interesting to explore further these tools in terms of usability and/or accuracy.

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7. APPENDIX

7.1. Appendix A

Complete list of 141 surveyed WBS tools

	Web-based simulation (RSV: remote simulation and visualization)	HSV: Hybrid simulation and visualization	Classical Tools (LSV: Local simulation and visualization)
Thermal- Energy Performance	- ArchiPHYSIKwebPRO - Acuity Energy Platform* - Building Advice* - Building Greenhouse Rating* - Building/ Green Energy Performance Compass - Clariti - MIT Design Advisor - Home Energy Saver* - Home Energy Suite and Commercial Energy Suite* - Green Quest* - Rehab Advisor (residential) - Cal-Arch (California) - Energy Profile Tool - Energy CAP Benchmark (energy use-in5 steps) - Energy Work Site (Energy Expert)* - foAudits (for PDA) - SMEasure (UK) - My e-Home (Danmark) - H1 Code Compliance* - COM check (IECC-USA)* - IC3 Code Compliance (Texas)* - REscheck*	- Autodesk Green Building Studio - e-Bench - GenOpt - EnergyCAP Enterprise - Green Space Live*	- Energy Plus - Easy Energy Plus (Chinese) - eQuest - Demand Response Quick Assessment Tool - DeST* - DIN V 18599 - ESP-r - EPB Software (Flemish region) - ENVSTD and LTGSTD* - Federal Renewable Energy Screening Assistant (FRESA) - HOT2000 (Canada,USA-low rise buildings) - HOT2XP (quick analysis) - HOT3000 (Canada-construction industry, zero houses) - Visual Spark - RETScreen* - ISE (single zone simulation) - SBEM (UK)* - SolArch
Lighting	- Sustainable by design products (Sun Angle, Window Shading, Panel shading, climate data-USA) - Commercial Lighting solution (USA) - SunPosition Calculator		- Dialux - Building Design Advisor - Compulyte - Daylight - DAYSIM - DeST* - ENVSTD and LTGSTD* - HiLight (for Hawaii)* - Daylighting 123 (early design) - Quick Calc - Quick Est - Radiance - Radiance Control Panel - RadOnCol - Sky Vision - Solar-2 - Solar-5 - SPOT - SuperLite
Active Systems (PV, Solar collectors etc)	- CPF Tools - Heat Pump Design Model - PV potential and Insolation (solar resource maps of Canada) - Photovoltaics Economics Calculator - Roanakh (PV) - Roof Air Conditioner Cost Estimator - Solar Estimate.org - Solar Design Tool - CtrlSpecBuilder (HVAC controls) - Energy Periscope	- Eff Track (Chiller Performance- installing devices for measurements)	- BLCC (PV cost estimation) - GS2000 (Geothermal Heat Pump) - HOMER (PV,wind tribune, generator..etc.) - RETScreen* (renewable energy) - WATSUN (Solar water heating) - Enerpool (Solar collectors for swimming pools) - SWIFT (Solar wall) - HPSim (Heat pump) - HVACSIM+ - Panel Shading (PV,solar collectors) - ParaSol(PV,solar collectors) - PVcad - RETScreen*

	Web-based simulation (RSV: remote simulation and visualization)	HSV: Hybrid simulation and visualization	Classical Tools (LSV: Local simulation and visualization)
Cost Analysis	- Acuity Energy Platform* - Home Energy Saver* - Home Energy Suite and Commercial Energy Suite* - Energy Profile Tool*		- BEES - HEED (energy savings) - RETScreen* - EnCalcEU (for non-commercial use)
Code Compliance	- Building Greenhouse Rating (ABGR-Austraila)* - Green Quest* (energy star) - REscheck (available for USA: IECC,MEC, IRC, state codes)* - Energy Star Home Advisor - Energy Work Site* (energy star) - COM check (IECC-USA)* - IC3 Code Compliance (Texas)* - Building Advice* (Energy Star) - H1 Code Compliance*	- Green Space Live*	- ABACODE (for IECC) - Athena model (life-cycle assessments) - COMcheck (For IECC& ASHRAE) - Czech National Calculation Tool - ENVSTD and LTGSTD* - HiLight (for Hawaii Model Energy Code) - HOT2EC (MNECH) - HOUSETRAD (Canada- MNECH) - EE4 (Canada- MNECH) - EE4 Code (Canada- MNECH) - EE4 OBC (Canada- MNECH) - BILDTRAD (MNECH) - REscheck (available for USA: IECC,MEC, IRC, state codes)* - SBEM (UK)*
Others	- Construction R-Vlue Calculator - Degree Day Forecasts - Degree Day.Net - Degree Day Reports - Tariff Analysis Project (bill calculator) - ThermoSim (thermal bridges) - R-Value Calculator - DOE Cool Roof Calculator - Maintenance Edge (Management Tool) - School Dude Products (Management Tool) - Water Calculator - ZIP-Code Insulation program (in USA) - eGRIDweb (gas emissions) -Calculators (appliance calculators) - Appliance Calculator - Radon risk analysis - BPE Interactive Calculators* - Energy Calculator - ArchiPHYSIKweb		- 3E Plus (insulation thickness for pipe/duct equipments) - CHP Capacity Optimizer (proper installed capacity for heating,cooling and electricity) - Climate Consultant - COMIS (indoor airflow) - CONTAM (indoor airflow) - Cool Roof Calculator - DAVID-32 (thermal bridges) - HAMLab (Heat air & moisture) - Envi-met (Fluid dynamics and therrmo dynamics) - BASECALC (Basement energy calculations) - MOIST (heat & moist flow) - OHVAP (venting & oil fired equipment) - Psychometric Analysis - RESFEN (Fenestration) - Opaque (envelope features) - SolarShoeBox (interface for Energy Plus) - Therm (thermal bridges) - TOP Energy (energy systems-German) - UNORM (thermal bridges) - Pentuar (envelope features) - Convection (calc. for risk of convection - Pipestag (heating-cooling of pipes) - Watergy (water-energy savings) - Window (fenestration) - WUFI-ORNL/IBP (indoor airflow) - BPE Interactive Calculators*

* : the tools that exist in the table more than once

7.2. Appendix B

Overview of the preliminarily evaluated tools

Code	A	B	C	D
Web-address	www.agentisenergy.com	ic3.tamu.edu/login	homeenergysaver.lbl.gov	www.apogee.net
Tool Name	**Acuity energy platform**	**International code compliance calculator**	**Home Energy Saver***	**Home Energy Suite and Commercial Energy Suite***
Simulation Domain	Energy managment tool	Code compliance	Cost/energy and saving estimation	Cost/energy estimation
Availability	*requires installation of sensors *available in US *1st year $1999, 2nd $999	*free *available in Texas	*free *available for US	N/A
Algorithm	*intermediate	*intermediate	*simplified	*simplified
Ease of use	*expertise not required *for the sensor installation technical support is needed	*background is required	*expertise not required	*expertise not required
Suitable for use in early design stages	*for existing buildings	*no integration	*for existing buildings	*for existing buildings
Data input	*historical data (provided by the utility), *real-time data *location	*location *building Parameters (floors, walls, roof, window/ shadings, insulation) *HVAC system information	*location *building elements information *HVAC system details *electricity/ energy use	* building information *system information (simple) *saving scenarios
Data output	* Energy use/ cost/ demand charts and benchmarking	*IECC code compliance *debug	*cost analysis *saving opportunities and recommendations	*combined energy/ lighting/ electricity cost analysis
Interaction with BIM/ CAD	*no interaction at all	*no interaction at all	*no interaction at all	*no interaction at all
Exporting file formats	*.csv	N/A	N/A	N/A
Notes	*electricity/ energy management *mainly for commercial buildings			

Code	E	F	G	H
Web-address	www.web-planquadrat.at/de/planquadrat.html	www.psdconsulting.com/software/buildingperformance	poet.lbl.gov/cal-arch/start.html	www.energyclariti.com/index.html
Tool Name	**ArchiPHYSIKweb Pro**	**Building/ Green Energy Performance Compass**	**Cal-Arch**	**Clariti**
Simulation Domain	Energy estimation and code compliance	Energy use and savings, CO2 emissions	Energy use	Energy management
Availability	*for customers of Planquadrat firm *available in Italy and Austria	*available in US *pay per building	* free *available in California	*Available in Australia
Algorithm	*intermediate	*energy use and improvement tracking	*simplified	N/A
Ease of use	*background is required	*Expertise not required	*Expertise not required	*Expertise not required
Suitable for use in early design stages	*for existing buildings	*for existing buildings	*for existing buildings	*for existing buildings
Data input	*location *definition of the materials (building element information for walls/ floor/ ceiling) *HVAC system information	*utility bills *location *the number of occupants *building parameters *system information	*annual energy use *floor area *system information	*real time data
Data output	*energy use *energy certificate	*energy use/ savings reports *heating/cooling load, CO2 emissions *annual energy cost	*energy use/ electricity/ natural gas use	*heating/ ventilation/ electricity energy use *daily reports *comparisons * CO2 emissions
Interaction with BIM/ CAD	*no interaction at all	*only treat *.xml files is possible to import	*no interaction at all	*no interaction at all
Exporting file formats	*.pdf	*.xls	N/A	*.csv, *.pdf
Notes		Building energy compass is for large facilities, green energy compass is for one family houses	*Berkeley lab	*data collection process is not accurate

Code	I	J	K	L
Web-address	designadvisor.mit.edu/design/	www.energycap.com/benchmark/	www.energyprofiletool.com/subscription/default.asp	www.foaudits.com
Tool Name	**MIT Design Advisor**	**Energy CAP Benchmark**	**Energy Profile Tool**	**foAudits**
Simulation Domain	Energy use, daylight	Energy use	Energy use, cost estimation, CO2 emissions	Energy use (PDA or Palms)
Availability	*free *available for 30 countries	*free *available in US	*$30 building limit: $500/year *available in US and Canada	*$50 annually
Algorithm	*simplified	*highly simplified	*intermediate	N/A
Ease of use	*Expertise not required	*Expertise not required	*Expertise not required	*Expertise not required
Suitable for use in early design stages	*intermediate suitability	*for existing buildings	*for existing buildings	*for existing buildings
Data input	*location *building parameters *system information *building elements information	*orientation/ region/ type/ sq meter of the building,	*location *building system information (HVAC/ hot water/ lighting) *floor area *utility bills for electricity and natural gas *building element information (window/ roof/ orientation)	*HVAC system details *Heating/ cooling
Data output	*Energy use * the level of thermal comfort * indoor temperature *daylighting *energy cost analysis	*electricity and energy use	*energy use/ cost (detailed heating, cooling, lighting, hot water, HVAC) comparing with the region standards *gas emissions	N/A
Interaction with BIM/ CAD	*no interaction at all	*no interaction at all	*no interaction at all	N/A
Exporting file formats	N/A	N/A	N/A	N/A
Notes	MIT			

Code	M	N	O	P
Web-address	www.savingtrust.dk/consumer/tools-and-calculators/my-home	rehabadvisor.pathnet.org/index.asp	www.smeasure.org.uk	www.airadvice.com
Tool Name	**My e-home**	**Rehab Advisor**	**Smeasure**	**Building Advice**
Simulation Domain	Energy use	Energy savings calculations	Energy use and green house gas emissions	Energy use and savings, code compliance
Availability	*free *available for Denmark	*free *available for US	*free *available in UK	*requires installation of sensors *available in US
Algorithm	*detailed	*simplified	*simplified	*intermediate
Ease of use	*Expertise not required	*Expertise not required	*Expertise not required	*Expertise not required
Suitable for use in early design stages	*possible to implement	*for existing buildings	*for existing buildings	*for existing building: based on collecting data and manage it via web
Data input	*the floor plans *location *heating/ cooling/ electricity equipment and furniture *utility bills	*location and type/age of the building	*location *building parameters *regularly meter readings (manually edit)	*building parameters (ventilation, general, system, humidification, possible pollutants) * utility bills *HVAC system information *real time measurements
Data output	*energy use/ cost (detailed heating, cooling, lighting, hot ater,HVAC) *gas emissions *saving opportunities	*saving opportunities	*energy use *gas emissions *degree day analysis	*Benchmarking Report, Energy Savings Assessment, and Energy Savings Audit *indoor air quality
Interaction with BIM/ CAD	*exporting and importing file of .*meh extension	*no interaction at all	*no interaction at all	*no interaction at all
Exporting file formats	N/A	N/A	*.csv	*.doc
Notes	*for residential buildings *supports camera surveillance *exports gbxml file but it is not working		*Environmental Change Institute at Oxford University	

Code	**Q**	**R**	**S**	**T**
Web-address	www.abgr.com.au	www.energyworksite.com/corporate/default.asp?cwnpID=90	www.mygreenquest.com	www.design-navigator.co.nz/DNProcessProject.php
Tool Name	Building Greenhouse Rating*	Energy Work Site (Energy Expert)*	Green Quest*	H1 Compliance Calculator
Simulation Domain	Energy use and savings, code compliance	Energy use, cost estimation, code compliance	Energy use, cost estimation, CO2 emissions, code compliance	Energy use, code compliance
Availability	*free *available in Australia	*$.... *available in US	*free *available in US	*free *available in New Zealand
Algorithm	*simplified	*intermediate	*simplified	*intermediate
Ease of use	*Expertise not required	* training is required	*Expertise not required	*intermediate
Suitable for use in early design stages	*for existing buildings	*for existing buildings	*for existing buildings	*for existing buildings
Data input	*location *building parameters *energy use *recycling	*location *real time data	*location *utility bills and meters (electricity/ energy/ water) * saving projects	*location *floor/ roof/ wall building elements information
Data output	*green house rating *CO2 emission *energy use *water rating *indoor environment rating	*energy cost/ use *predicted energy consumption *gas emissions *energy savings analysis *energy star rating	*degree day forecast *energy use /cost *gas emissions *energy star rating	*NZBC Clause E3 Code Compliance *Heat loss details
Interaction with BIM/ CAD	*no interaction at all	*no interaction at all	*no interaction at all	*.gbxml *editing the building parameters is possible
Exporting file formats	N/A	N/A	N/A	*.pdf
Notes				*importing *.csv file is possible

Code	**U**	**V**
Web-address	energycode.pnl.gov/COMcheckWeb	energycode.pnl.gov/REScheckWeb
Tool Name	**COM Check web**	**REScheck**
Simulation Domain	Code compliance	Code compliance
Availability	*free *available in US	*free *available in US
Algorithm	*intermediate	*intermediate
Ease of use	*information of the R values of the building elements	*information of the R values of the building elements
Suitable for use in early design stages	*no integration	*no integration
Data input	*location *selecting the code *building elements parameters (roof, wall, floor, window, door, basement) *internal lighting parameters	*location *selecting the code *building elements parameters (roof, wall, floor, window, door, basement) *internal lighting parameters
Data output	*checking the code compliance	*checking the code compliance
Interaction with BIM/ CAD	*no interaction at all	*no interaction at all
Exporting file formats	*.pdf	*.pdf
Notes	*for commercial use	*for residential use

7.3. Appendix C

Sample of the questionnaire

USER PROFILE

The software that you are testing:

- My e-home
- MIT Design Advisor
- H1 Compliance Calculator

Last 2 digits of the matrikelnummer*:* __ __

Gender:

- Male
- Female

Learning style preference (Select the most appropriate 1 option for each group)

Group 1

- Trial and error
- Consult with others
- Read documentation

Group 2

- Use then read
- Read then use
- Learn by doing

Attitude towards technology

- Don't install the new version unless it is necessary
- Follow the updates and install always the latest one

Which operating system are you using?

- PC- Microsoft Windows
- PC- Windows Vista
- MAC OS
- Linux

Task:

1. Try to evaluate a house with a simple geometry for example 12x 10 with 2 storey's
2. Define/ assign the building elements
3. View the results
4. Create an alternative and try to compare the outputs. (Change the dimensions of the building or assign different materials that make sense…etc. *the software may not have a comparison function)

Satisfaction:

(Fill this part in the end of the questionnaire)

Strongly disagree				Strongly agree
O	**O**	**O**	**O**	**O**

1. Ease of use

highly difficult — very easy

Comments:

2. Suitable for use in early design stages

not suitable at all — highly suitable

Comments:

3. Input data amount/ resolution

large amount of detailed information is needed — little input is required

Comments:

4. Quality of output data

confusing and chaotic — clear and well organized

Comments:

5. Visualization of results

only numeric — richly visual

Comments:

6. Data exchange with BIM/ CAD systems

no data exchange — data exchange possible

Comments:

7. Local- Global applicability

locally restricted — different locations possible

Comments:

8. Algorithm

highly simplified — highly detailed

Comments:

9. Documentation

not available — well documented

Comments:

10. Support

not available — (updates, FAQ, forums)

Comments:

11. Price

expensive — free

Comments:

General Comments: