

## **EXPERIENCES TESTING ENHANCED BUILDING PERFORMANCE SIMULATION PROTOTYPES ON POTENTIAL USER GROUP**

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### **ABSTRACT**

Previous work involving literature review, simulation tool analysis and interviews with world leading building performance consulting engineers and designers has shown that building performance simulation (BPS) is mostly limited to code compliance checking of the final building design whilst it could provide useful information and guidelines throughout the entire design process [Hopfe et al., 2005/ 2006].

It is aim of this research to enhance the current use of building performance simulation (BPS) in practice and therefore to build up a multi-aspects prototype simulation-based design environment for optimization of buildings and systems among others.

For that reason, three prototypes were developed in the past addressing simple uncertainty/ sensitivity analysis, decision making under uncertainty/ sensitivity, and the use of optimization techniques for multi-objective optimization.

An online survey was prepared to check how designers feel satisfied with the different prototypes, the guided set-up and the varying outcome. This paper summarizes the results of the user reaction to the three approaches.

*Keywords: Online Survey, Case Study, Multi-Criteria Decision Making, Multi-Objective Optimization, Building Performance Simulation, Usability in Practice*

### **INTRODUCTION**

Despite nearly 40 years of research and development in building assessment it is still the fact that developed methods/ ideas etc. are not yet implemented, difficult to manage, too time-consuming or not applicable [Preiser et al., 2004].

The overall aim of this research is to improve the use of building performance simulation in the final stage of the design process.

Therefore three prototypes were developed. The general approach is based on the integration of uncertainty/ sensitivity analysis (UA/ SA) into building performance software and to provide useful information of the impact on different design alternatives, changes in scenario conditions, and the uncertainty of physical parameters in the building layout.

Further, the problem is tackled from two different directions: providing multi-criteria and stakeholder decision analysis and multi-objective parameter optimization.

Therefore, a commercially available, industry strength, and extensively used, BPS tool is coupled with two external research type software tools, enabling uncertainty and sensitivity analysis and design parameter optimization.

Furthermore, analytical hierarchy process (AHP) a protocol supporting multi-criteria and stakeholder decision making was applied.

However, all three approaches aim to support the designer in the detailed design process. Nevertheless, the prototypes differ in several perspectives as e.g. guidance through the design process, fulfilling the requirements for building performance simulation, supporting the decision process among others.

The experiences testing the usability of the prototypes on a potential user group is summarized.

### **USABILITY TESTING**

During a conducted usability testing one or multiple users are supposed to access a prototype whilst possibly an observer follows the work- through.

Mills et al. (1986) for instance define usability as the ease with which an application can be used.

The empirical testing seems advantageous because feedback from many users can be collected. By running through the program, feedback from practise is achieved by the intended user group. Drawback on the contrary is that the rapidly developed prototypes don't provide an applicable user interface so far that would it make possible to let users test it self-contained.

Preston (2009) summarizes a range of methods for usability testing:

- Interviews and observations: These are one-on-one sessions with designers, asking questions like what they do, want, prefer in building assessment.
- Focus groups: Focus groups are meetings with multiple attendees from the specific target group. Although it is a promising method especially for initiating discussions, it was not possible to apply due to the difficulty of bringing professionals together at the same time and location.
- Questionnaires: A formal questionnaire is an instrument for gathering information from a group of people. Advantage is that it is not influenced by the interviewer. It is easy to conduct if online spread, and implies therefore less effort than interviews. Besides, a bigger number of respondents can be covered. The answers can be gathered standardized which makes the data analysis easy as well.

The usability testing in this research comprises an online survey that was conducted after the development of three different prototypes.

The key questions asked before the experiences testing were: "How much interaction is too much?"; "How much influenced/ affected is the provided answer by the question?"

However, intending to avoid the risk of interpreting behaviour and thus, influencing the interviewee, an online survey was developed.

The setup needs to be exemplified, as the survey questionnaire comprises of several modules: an introduction page followed by three scenarios dedicated to three prototypes.

#### Structure online survey

1. Introduction with general questions about state of the art in building performance, user satisfaction etc.
2. Representation of scenario 1 including uncertainty/ sensitivity analysis
3. Representation of scenario 2 including decision making uncertainty/ sensitivity analysis
4. Representation of scenario 3 including parameter optimization
5. Summary and conclusion part

#### Participants

In the first step, seven online studies with building services professionals were conducted: four mechanical engineers, three building physicists: all of them holding positions in industry, having high to very high experience in the use of building performance simulation. Further on, they frequently participate in design team meetings, are due to that experienced in the communication with other design team members.

#### Directions to be addressed

Different categories were addressed in the survey:

1. the requirements fulfilments for BPS in the final design stage
2. the appreciation and traceability (comprehension) of the results
3. the support of the design process in terms of communication and guidance
4. the usefulness of the integration in BPS, an added value?

Results presented comprise answers to closed-ended questions where the respondent can easily select the preferred answer in selection of possibilities with radio buttons or check boxes.

Typical response scales for closed-ended questions are Thurstone or equal appearing scaling, Likert or summative scaling, and Guttman or cumulative scaling [Trochim, 2006].

Likert scale developed by Rensis Likert in 1932 is the mostly applied scale in questionnaires. Respondents e.g. specify the level of agreement or importance to a statement. Very often five level scales are used, but it also varies from 3 to 7 level answers. If the intention is to force the respondent to give an answer and to avoid "neither nor" replies, no middle number is provided (4,6,8 etc.)

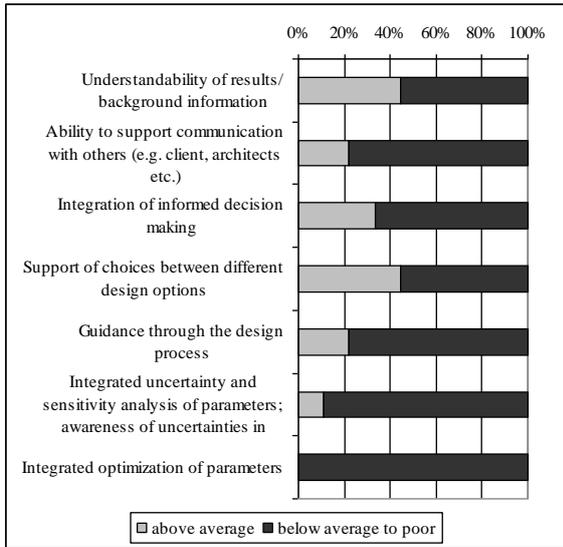
The Likert terms selected in this questionnaire are mostly forced choice scales stating the importance (very important to unimportant), agreement (strongly agree to strongly disagree), standard (very high to very low), or quality (excellent to poor) of a question/ graphic.

## DISCUSSION

### **Introduction**

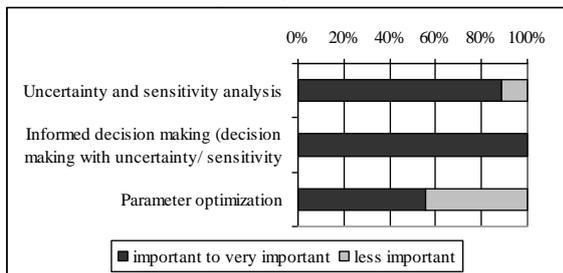
The aim is to encourage the use of BPS in the final design stage. In the introduction part of the survey the background of the participants is assessed. Furthermore, it is evaluated what need and satisfaction level they have considering guidance through the design process, ability to support communication, integration of informed decision making among others (see table 1).

*Table 1*  
*Current satisfaction level in BPS*



To conclude, it is questioned what need they see in the integration of uncertainty/ sensitivity analysis, informed decision-making, and optimization (see table 2).

*Table 2*  
*Need of integration in BPS*



**Prototype 1: Integration of uncertainty/ sensitivity analysis in building performance simulation**

In the first scenario the necessity of the integration of uncertainty analysis (UA) and sensitivity analysis (SA) in building performance simulation is found out. Besides, the achievement of different outputs is tested.

It is distinguished between three different sources of uncertainty: physical, scenario and design uncertainty:

1. Physical uncertainties: uncertainty in physical properties as conductivity, thickness, density of the different material layers etc..
2. Scenario uncertainties: influence of infiltration rate (the operation of window openings), climate change (for instance due to global warming), lighting control schemes, and other occupant related unpredictable use of the building.

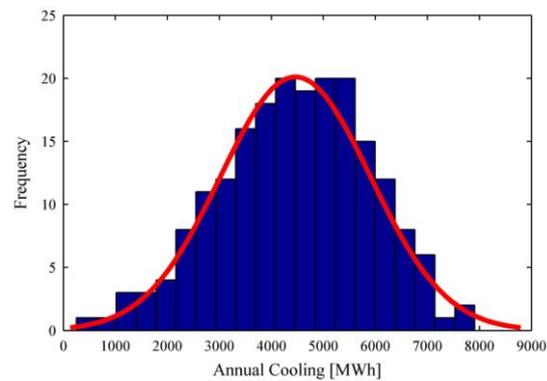
3. Design uncertainties influenced by the designer in type of glazing, glass surface, geometry.

Table 3 shows the perception given by the participants about what group plays a role in what phase of the design process.

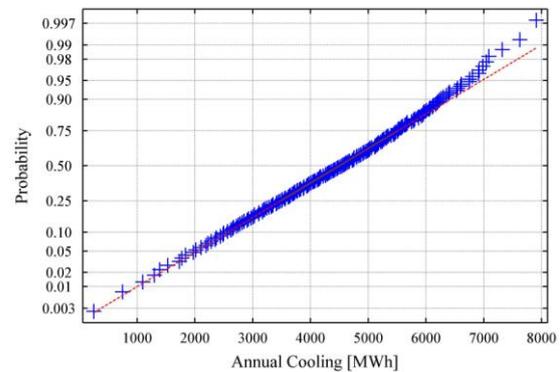
*Table 3*  
*Correlation group of uncertainties in design process*

	physical uncertainties	scenario uncertainties	design uncertainties
Conceptual design stage	28%	35%	35%
Preliminary design stage	25%	43%	31%
Final design stage	37%	25%	37%

In the following, two different uncertainty outputs and two different sensitivity outputs are presented. Figure 1 and 2 dedicated to uncertainty analysis, showing the frequency and the probability distribution.



*Figure 1 UA 1 frequency*



*Figure 2 UA2 probability*

Table 4 and figure 3 for giving an insight in the sensitivities. Table 4 shows the four most sensitive parameters for different criteria like annual cooling/heating and weighted over- and under heating hours:

Table 4  
SA1 table

nr	ENERGY		THERMAL COMFORT	
	Annual cooling	Annual heating	Weighted overheating	Weighted under-heating
1	Infiltration rate	Infiltration rate	Infiltration rate	Infiltration rate
2	Size room	Size room	Loads equipment	Loads equipment
3	Conductivity floor layer 4	Switch single double glass	Size room	Size room
4	Switch single double glass	Loads equipment	Loads lighting	Switch single double glass

	physical uncertainties
	scenario uncertainties
	design uncertainties

In figure 3 the order of the most sensitive parameters is shown graphically ordered. The longer the bar the more sensitive is the parameter.

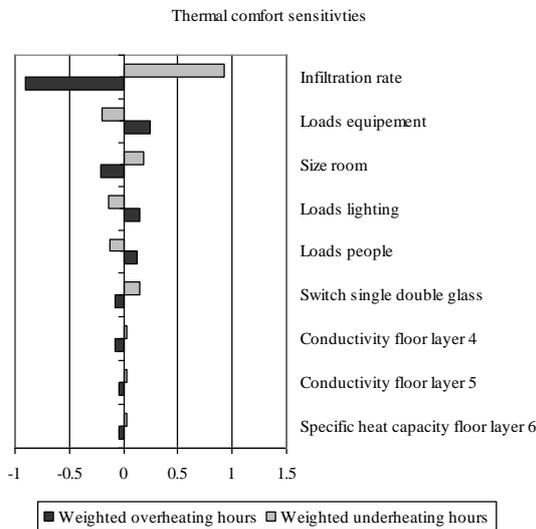


Figure 3 SA2graphic

The Table 5 – 8 summarize the feedback to uncertainty/ sensitivity analysis from the practitioners.

Table 5

Appreciation as a basis for communication with others

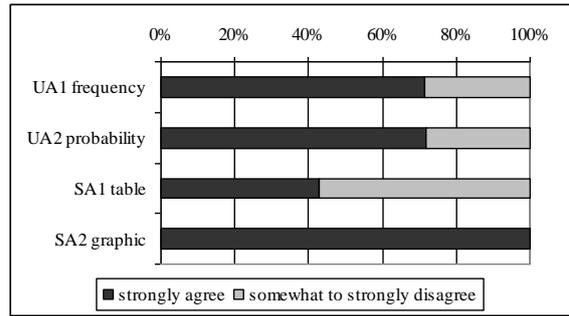


Table 6

Perception of being intuitively understandable

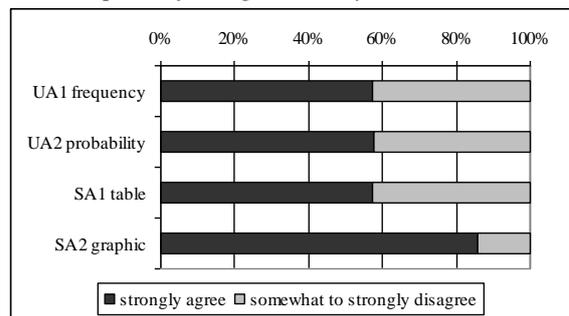


Table 7

Appreciation to support the design process

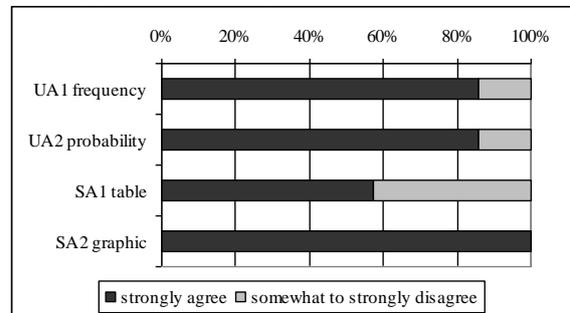
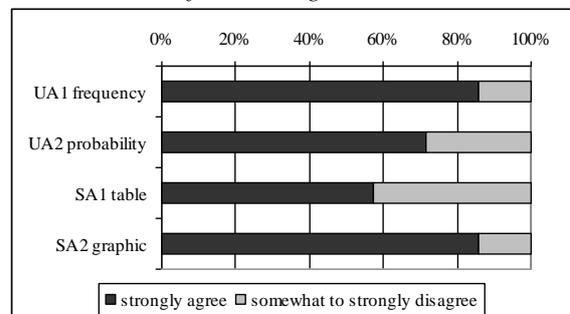


Table 7

Wish for the integration in BPS



### Prototype 2: Decision making with uncertainty/ sensitivity analysis

In the following section, a decision-making protocol is described for achieving informed decision-making.

A case study is taken with an additional option. The first option represents a mainstream standard solution: a conventional heating/ cooling system. The second design option represents a novel, “risky” design, incorporating heating/cooling storage in combination with a double façade.

The treatment of the case follows mainstream rational decision theory and hence assumes that the decision process is purely rational and that stakeholders pursue no other agenda than choosing the best performing design option, influenced only by the objective probabilistic predictions of the relevant performance measures, their (subjective) importance ranking and the risk attitude of each stakeholder. The decision problem thus falls in the standard category of multi criterion decision making under uncertainty.

Three members of the design team were asked separately to make a list with the most important performance aspects of the building. Performance aspects as initial costs, architectural layout, image/ symbolism, energy consumption and thermal comfort were mentioned by all participants although with varying statements of significance, importance, or influence across participants.

Figure 4 shows the result for three decision makers for the two options. The normalized performance (sum of aspects as comfort, aesthetic etc) of both options compared to a normalized cost factor (energy costs, investment costs). The range indicates the risk that is in performance due to comfort and in costs due to energy consumption (see figure 4).

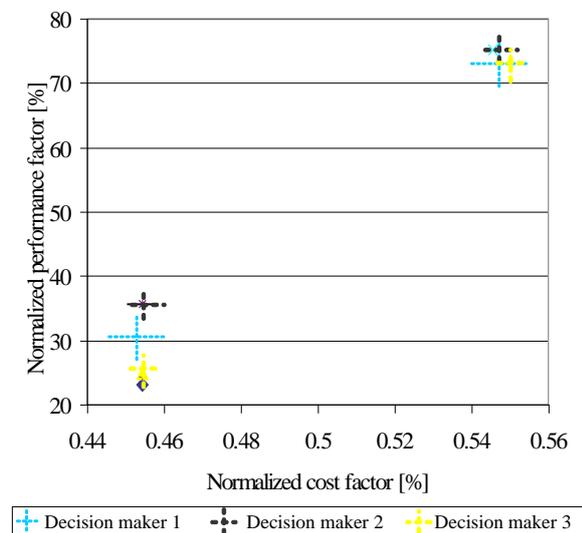


Figure 4 Outcome informed decision making

The graphic shows that the higher the performance, the better the option; the higher the cost factor the worse (more expensive) the option. It can be seen that option 2 (right) is better performing but also more expensive than option 1 (left).

An uncertainty analysis is conducted in addition and results are presented in figure 5 for criteria as annual cooling and heating as well as weighted over and under heating hours.

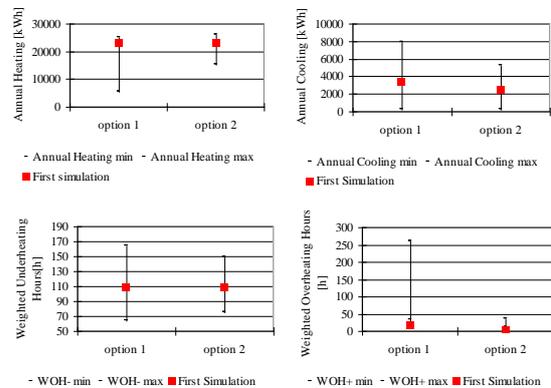


Figure 5 Uncertainty analysis- range of outcome

The uncertainty analysis shows that for the most preferable option 1 the weighted overheating hours are exceeding the limit of 150h.

In a conducted sensitivity study (figure 3) the infiltration rate is identified as being the most sensitive parameter. Looking deeper into the correlation of the infiltration rate to the weighted over heating hours (figure 6), it can be seen that it is almost linear. Limiting the risk of exceeding the overheating hours meaning setting fixed limitations to infiltration rate turns option 1 indeed into the better option by eliminating the risk.

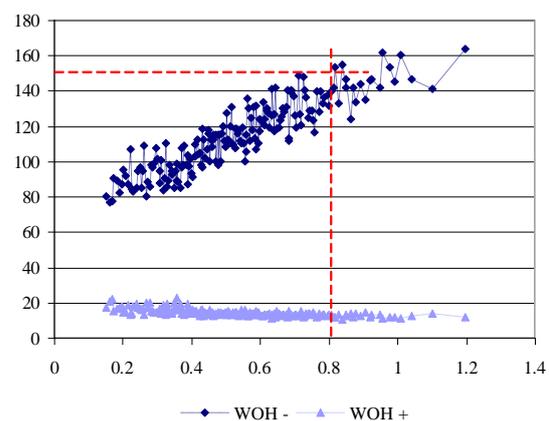
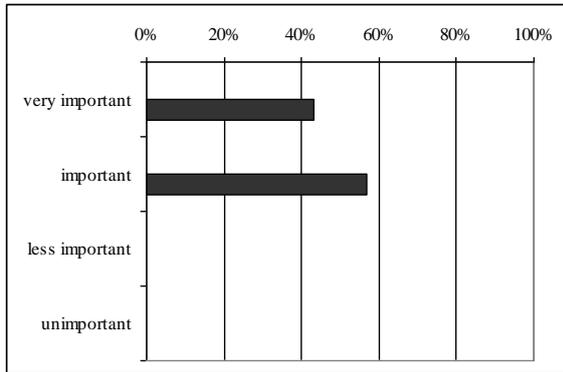


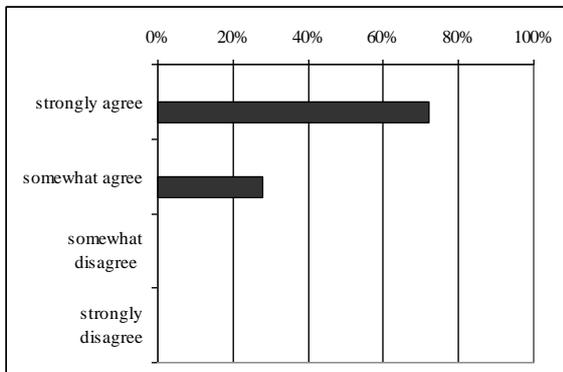
Figure 6 Infiltration rate compared to weighted over and under heating hours

The perception of the participants to informed decision-making and the prototype is summarized in table 8-11.

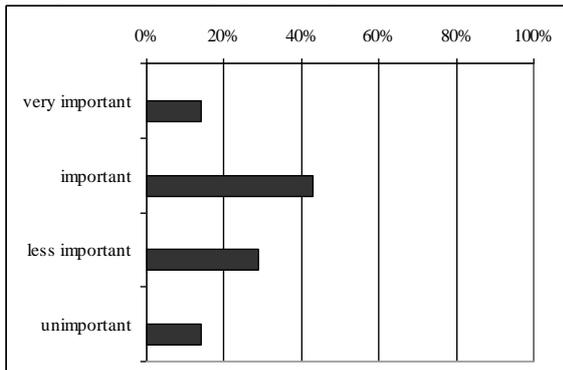
**Table 8**  
*Perception of the importance of communication in the design process*



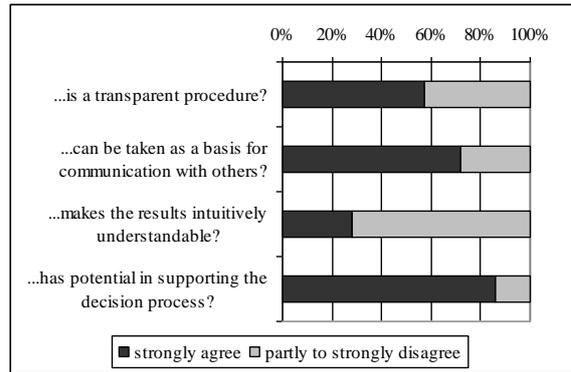
**Table 9**  
*Importance for BPS to provide the possibility to support communication with other design team members*



**Table 10**  
*Importance that preferred option is without risk*



**Table 11**  
*To conclude: the prototype "decision making with uncertainty and sensitivity" ...*

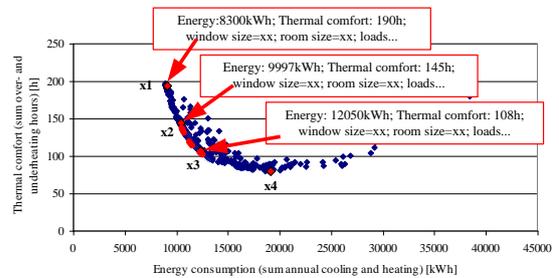


**Prototype 3: Parameter optimization**

In the third scenario, an office building is given. The objective is to optimize parameters as geometry, window size, loads etc. resulting in a better comfort and energy demand.

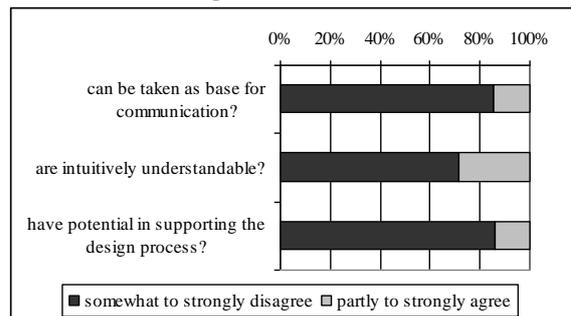
In the graphic below the trade off curve (Pareto front) is shown for a room for thermal comfort (the sum of weighted over and under-heating hours) and the energy consumption (annual cooling plus annual heating).

In the figure 7, x1 and x4 are ideal/ extreme solutions considering one objective (comfort or energy). Opposed to that x2 and x3 lie in the area/ region of good compromise solutions (knee points). The dashed line between x2 and x3 shows the fair trade-off where the obtained solutions can be found.



**Figure 7** Pareto front

**Table 12**  
*To conclude: the results of the prototype "parameter optimization" ...*



## CONCLUSION

To sum up, the three approaches are compared with each other considering following categories:

1. reliability of results
2. supporting the decision process
3. guidance through the design process
4. fulfilling the requirements of BPS in the final design
5. usefulness/ importance of integration in BPS software

Table 13

*Comprehension/ reliability of results*

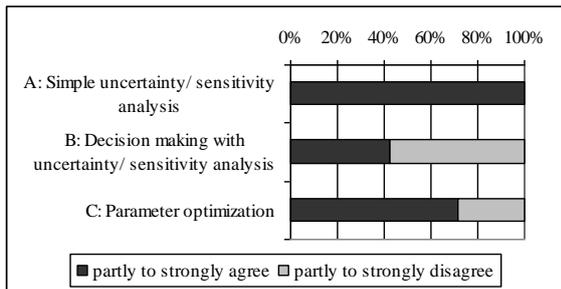


Table 14

*Supporting the decision process*

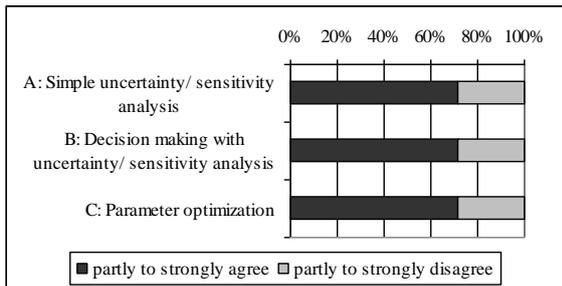


Table 15

*Guidance through the design process*

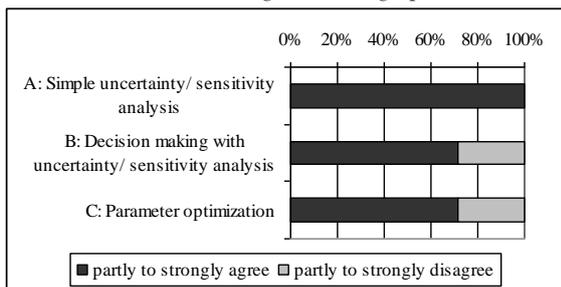


Table 16

*Fulfilling the requirements of BPS in the final design*

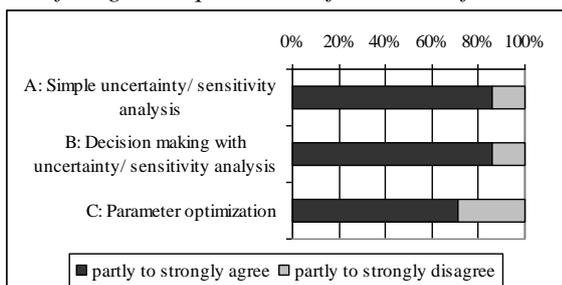
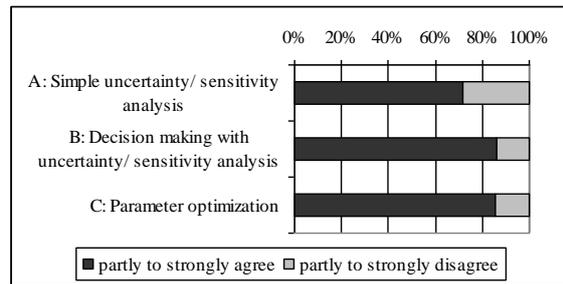


Table 17

*Usefulness/ importance of integration in BPS software*



## ACKNOWLEDGEMENT

We would like to thank K. and S. Mast, E. Nelissen, E. Rooijackers, H. Rucht, P. Stoelinga, J. Wiedenhoff, and A. Wilson (alphabetically ordered) for their participation and professional knowledge in the experiences testing.

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