A STUDY OF THE USE OF PERFORMANCE-BASED SIMULATION TOOLS FOR BUILDING DESIGN AND EVALUATION IN SINGAPORE

Khee Poh Lam, Nyuk Hien Wong and Feriadi Henry

Faculty of Architecture, Building and Real Estate

National University of Singapore

Singapore 117592, Republic of Singapore

ABSTRACT

This paper provides an overview of the usage of performance-based simulation tools for building design and evaluation in Singapore based on an extensive industry survey. It highlights the status and difficulties encountered in the usage and the needs of the industry for such tools. Recommendations are also given to promote the pervasive use of such simulation tools.

INTRODUCTION

The design and performance evaluation of buildings has become increasingly complex over the past decade. Such complexity arises from the rapid advances in technology, changing perception and demands of building owners, operators and tenants as well as the increasingly importance of the building as a facilitator of human control, productivity and information interchange [Tham 1992]. One of the challenges is to understand the interaction between various aspects of building performance and also their implications on complex control. The over-reliance of mechanical systems to achieve the required comfort and health has also obscured the inherent performance implications of other critical building design decisions. As a result, the decision on mechanical systems and controls was frequently decoupled from the building design. The dynamics of the organisational workplace as well as the flexibility of the building infrastructure also have important impacts on the environmental and technical quality of the offices [Tu and Loftness 1998]. Over the past few years, the pressure for competitive differentiation is also leading property developers and designers to include novel and innovative design features in the core design work. Unfortunately, there is considerable uncertainty in assessing the performance of such designs if the dynamic and integrated response of the building and its environmental systems is not taken into account. The aspiration of designers to create a sustainable built environment for the future by consciously taking into consideration issues such as energy efficiency, passive building and ecologically friendly design has further added to the complexity of the design process.

With such increasing complexity involved in building design and performance evaluation of buildings, the need for the use of computational building performance evaluation and design support tools throughout the process is recognised. Such tools allow the building designers to evaluate the impact of design on the various performance mandates such as thermal, air, acoustic and visual quality [Hartkopf, et al. 1986]. To some extent, they are able to replace expensive and time consuming field tests and provide a comprehensive range of test conditions. They can also lead to an improved understanding of the behaviour of various climatic agents and thus provide confidence in design. They are also especially important for making preliminary evaluation of complex design strategies [Mahdavi and Lam 1991].

THE DESIGN SUPPORT TOOLS

Despite the proliferation of many performance-based simulation tools and their increasingly usage for building design and evaluations especially in North America, their usage by architectural and engineering consulting firms in Singapore has not been very encouraging. The traditional approach of relying on accumulated experience of the building designers is still prevalent. Rule-of-thumb solutions developed over time were motivated by the need for compliance with codes of practice and very often were applied rigidly without considering the overall design context. Such decision tends to be uni-disciplinary since most of the codes of practice were developed to fulfill one particular aspect of the building performance. For example, the OTTV requirement was developed taking into consideration only the heat transfer process through the building façade for air-conditioned buildings. The implication of such requirement on other building performance such as the potential for the utilization of daylight was not considered.

In order to provide a better understanding of the extent in which performance-based simulation tools are used in building design and evaluation, a survey was conducted among the architectural and engineering consulting firms in Singapore. The survey also serves to identify the problems and difficulty encountered by them and the needs of the industry for such tools.

STATUS OF USAGE

Methodology

A self-administered questionnaire was sent to the architectural and engineering consulting firms in Singapore. The questionnaires were structured in such a manner that would provide information regarding:

- performance-based simulation tools commonly utilized in building design and evaluation;
- educational background of the software users;
- the stage of design process where the software were utilized;
- reasons for the usage of such tools and the problems encountered;
- reasons for not utilizing such tools;
- perception of integrative design support environment and
- suggestions towards the enhancement of such software utilization

The survey was conducted for a period of 1 month from early December 1998 to early January 1999. A total of 584 firms were surveyed, comprising 440 architectural firms, 134 engineering consulting firms and 10 government statutory bodies. Approximately 28% of the questionnaires sent were completed and returned (Figure 1).

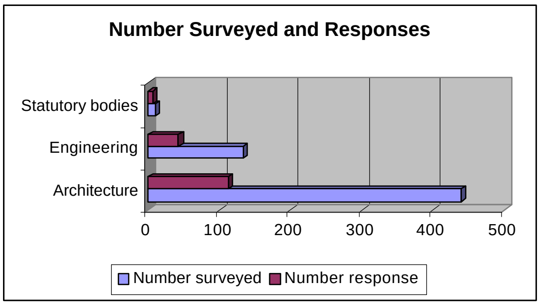

Figure 1: Response rates from the various groups

Use of Performance-based Simulation Tools

Table 1 shows the usage of various performance-based simulation tools by the firms surveyed. The results revealed that the usage of energy and HVAC sizing software by architecture firms was extremely low. Most architecture firms indicated that they were not aware of the existence of such software tools and that the usage was beyond the scope of their work. Though 46.4% of the engineering consulting firms surveyed were using the software, majority of the software were supplied by the HVAC manufacturers, which served to assist them in the design and selection of HVAC systems and components. The usage of generic energy and HVAC sizing software such as DOE-2 was very limited. 11.3% of the architecture firms were using the lighting software. However, the software were used mainly for rendering to enhance the visual impression of the design. They were not used specifically for the design of artificial lighting or daylighting. About 25% of the engineering consulting firms were using the lighting software supplied by the lighting manufacturers for the design of artificial lighting. In most cases, daylighting was not considered in their design. Again, the usage of generic lighting software such as Radianc or Lightscape was very limited. The survey also revealed that software for the analysis of acoustics, ventilation and indoor air quality were not used at all by the firms surveyed. Most firms surveyed expressed that they had not come across any of such software and felt that such software should only be used by the specialists.

Table 1 Percentage of the firms surveyed using various performance-based simulation tools

Response Group	Percentage of Firms Surveyed (%)	
	Energy and HVAC Sizing	**Daylighting And Electric Lighting**
Architecture	1.6	11.3
Engineering	46.4	25.0
Statutory Bodies	16.7	0.0
Combine	15.6	14.6

Table 2 revealed the educational background of the software users. Majority of the energy and HVAC sizing software users were mechanical engineers and building services engineers. For the daylighting and electric lighting software, 71.4% of the users were electrical engineers and about 28.6% were building services engineers. The usage by architects was about 14.3%.

Table 2 Educational background of the software users

Educational Background	%	
	Energy and HVAC sizing	**Daylighting and Electirc Lighting**
Architecture	0.0	14.3
Mechanical Engineering	69.2	0.0
Electrical Engineering	7.7	71.4
Building Services Engineering	38.5	28.6

Table 3 reveals the frequency of usage of the various simulations tools. 46.2% of the energy and HVAC sizing software users utilized the software frequently with 30.8% indicated that they seldom used it. For daylighting and electric lighting software, 66.7% of the software users utilized the software occasionally.

Table 3 Frequency usage of the various software tools

Frequency Of Usage	%	
	Energy And HVAC Sizing	**Daylighting and Electric Lighting**
Seldom	30.8	16.7
Occasionally	15.3	66.6
Frequently	46.2	0.0
Always	7.7	16.7

Table 4 shows 53.8% of the energy and HVAC sizing software users utilized the software during the design development stage. For daylighting and electric lighting software, 80% of the users utilized the software from beginning of the schematic design as well as during the design development stage.

Table 4 Design stages where the various software tools were utilized

Design stage	%	
	Energy and HVAC Sizing	**Daylighting and Electric Lighting**
From beginning of schematic design	15.4	40.0
During design development	53.8	40.0
After the design is completed	7.7	20.0

Reasons for Using Simulation Tools

Figure 2 shows the major reasons for the usage of performance-based simulation tools. 69% of the firms surveyed utilize the tools to enhance the design in terms of providing better understanding of impact of design on building performance. 58.6% felt that the tools speed up the design process as well as provide confidence in the design. Only about 35% expressed that the usage is to fulfill the client's requirements. Some firms also expressed that the adoption of such simulation tools will enhance the image of their companies and thus increase their competitiveness in securing projects.

Reasons for Not Using Simulation Tools

Figure 3 reveals the major reasons for not using the simulation tools. 70% felt that most clients do not stipulate the employment of such tools as an essential requirement. Most firms viewed the use of simulation tools as involving extra cost and effort but with little recognition and appreciation from the clients. Very tight project schedule and budget further aggravate this problem. Other major reasons include staff lacking the skills and training in the usage, the high cost of simulation tools and the belief that the use of such tools would incur more design time in the process. 50% also expressed that most of the tools have very steep learning curves and not user-friendly. Most firms surveyed also felt that the usage of such simulation tools was beyond their scope of work. The opinion is that such tools should be utilized only by the specialist consultants or the suppliers. The lack of "suitable projects" further hampered the regular utilization. The lack of support from the local software developer is another obstruction since such software was not easily available and those developed in US or Europe may not be suitable for local use. The output generated from the simulation tools could be extremely difficult to interpret and utilize for design decisions. It could also be difficult to justify cost savings in the design to the clients. Their basic objective of the design was to fulfill the requirement as specified by the codes of practice; thus the usage of complicated simulation tools was not essential. Of greater concern is perhaps the apparent lack of awareness of the existence of such tools.

Figure 4 shows the barriers encountered in the usage of simulation tools. About 64% felt that the main barriers were the high cost of maintaining and upgrading the software. The lack of training facilities and that staff did not see the usefulness of such tools are other major factors. Figure 5 shows the perception of the limitations of current simulation tools by firms surveyed. 69% felt that the main limitation is the very extensive data input required. This can indeed impose a very serious problem especially during the initial design stage where design information is very limited. Another hindrance is that, simulation tools are largely platform-dependent requiring firms to possess specific computer systems. The tools do not match the existing design process and there is no integration with CAD tool. Only about 35% felt that investment in this technology is expensive. This is because of the tremendous improvement in the computer technology and the drastic reduction in the price of computer memory.

WHAT CAN BE DONE TO ENHANCE THE USAGE

The above survey results confirmed the general feeling that the usage of performance-based simulation tools for building design and evaluation in Singapore was very limited. The main reasons for the limited usage of such simulation tools can be summarized as follow:

- Inherent system limitations of current simulation tools.
- Structure of existing building delivery process.
- Prescriptive nature of the building legislation.

Development of Integrative Design Support Environment

To ameliorate the inherent system limitations of the current simulation tools, concerted efforts have been made by researchers to effectively incorporate performance simulation within computer-aided design environments. Some of these research efforts include STEP [ISO 1992] COMBINE [Augenbroe 1992], ICADS [Pohl and Reps 1988] and SEMPER [Mahdavi et al. 1996].

Figure 6 shows the perception of the firms surveyed on the enhancement of the design process offered by an integrative computational design support environment. 82.3% felt that such an environment will certainly enhance the design process, particularly in achieving Total Building Performance and Systems Integration [Hartkopf et al. 1986]. It will also provide a better understanding of the impact of the design decisions on multiple performance mandates, as well as enhancing the evaluation of the complex design strategies. Such an environment will ultimately improve the total design coordination resulting in eco-friendly energy efficient buildings. It will also enhance contact between design consultants in various disciplines and will improve the cost effectiveness of the design solution.

Figure 7 shows the perception of the firms surveyed on the elimination of the limitations of current simulation tools with the use of an integrative computational design support environment. Most firms felt that such an environment will certainly provide a better integration of CAD tools with performance based simulation tools. It would also facilitate the data input and interpretation of the output and is more user-friendly. It also has the advantage of having shared database for multiple simulation domains.

Co-evolution of Building Delivery Process and Simulation Tools

The hindrances caused by the existing structure of the building delivery process for the effective usage of simulation tools for design evaluation are well documented [Mahdavi 1998]. The predominant factor is the emphasis on cost, specifically the initial and capital cost. Building projects are generally characterised by tight schedules and budgets. This problem is further compounded by the current project development trend where the completed buildings are not occupied by the building owners but are leased out. As such, the developers may have minimum interest in the ultimate performance of the buildings. However, the unwillingness to invest in preliminary investigative studies using simulation tools may result in remedial or abortive work as well as higher operating and maintenance cost.

The building industry is a fragmented industry and the building delivery process has invariably remained as a discrete and sequential set of activities. This is due to the necessity to organize the activities for the purpose of establishing a professional fee structure that is commensurate with the scope of work and level of accountability or responsibility. However, with rapid changing technologies, production processes as well as knowledge explosion, the existing framework no longer seems effective or capable of meeting the increasingly complex demands associated with the creation of the built environment. Thus, it is eminently necessary that a co-evolutionary development of process and tool be encouraged. The critical evaluation of the shortcomings of the existing process implies the need for enhanced tools and the introduction of new technologies will trigger reevaluation of and improvements in the existing structure and process [Mahdavi 1993].

The Use of Performance-based Regulatory Systems

To encourage the usage of performance-based simulation tools, it is essential to shift the current regulatory systems from prescriptive to performance-based approach. This shift is not a recent phenomenon as the evolution of building legislation from the practice of prescriptive requirements to performance based solutions has taken place over the last 10 years or so in countries such as Australia [Chang 1998]. Though the traditional prescriptive approach is relatively simple to understand, and the requirements are treated as 'rules' to be compiled with, its provisions are often regarded as "cumulative, conservative in nature and in reality only suitable in relation to 'standard' building configurations" [Hatton 1996]

On the other hand, the basic concept of a performance-based approach is not to prescribe solutions but rather to demonstrate that the proposed design meets defined objectives. This approach may result in alternative designs which are more flexible, rational, innovative as well as cost effective. This approach can also be multi-disciplinary, consciously taking into consideration the implications and synergistic effects of the various performance mandates. A comprehensive performance-based approach necessitates the ability to translate the objectives into quantifiable parameters, to set limits for these parameters and to have means of estimating performance of proposed design to validate compliance with the required performance parameters [Beck 1997]. In this respect, simulation tools should be able to play vital roles in achieving such objectives.

CONCLUSION

The increasing complexity in the design and performance evaluation of buildings has resulted in the need for the use of computational building performance evaluation and design support tools throughout the process. However, the survey results as shown in this paper reveal that the usage of performance-based simulation tools for building design evaluation in Singapore is still very limited. The limited usage of such simulation tools arises mainly from the inherent system limitations of current simulation tools. Emphasis on initial or capital cost by the clients, coupled with the fragmented building delivery process has resulted in little progress in the augmentation of simulation tools for design evaluation. The prescriptive nature of the current codes of practice and design guidelines also does not promote its usage. With the move towards the development of an integrative computational design support environment where there is effective integration of CAD system with various performance-based simulation tools, it will enhance the design process as well as eliminate the major limitations of current discrete simulation tools. It is hope that this development will become an impetus for building designers to utilize the tools for performance evaluation of their design. The shift from the prescriptive nature of the building legislation to performance-based approach will further enhance such usage. It is also essential to provide the necessary conditions for a positive co-evolutionary cycle of process evolution and tool development; achieved through a critical review of the status quo and in-depth reflections on the dialectics of process and tools.

REFERENCES

Augenbroe, G, 1992: Integrated building performance evaluation in the early design stages. *In Build. Environ 27(2) 149-161*

Beck, V., 1997:Performance-based fire engineering design and its application in Australia. Fire safety Science-Proceedings of the Fifth International Symposium of the International Association of Fire Safety Science, pp23-40

Chang W., Lim B. and Williamson J., 1998:Fire Legislation Reform and The Architect, *in Royal Australian Institute of Architects (Queensland Chapter) Seminar, October, 1998*

Hartkopf, V., V. Loftness, and P. Mill, 1986: The Concept of Total Building Performance and Building Diagnostics. *ASTM Special Technical Publication* - Building Performance: Function, Preservation, and Rehabilitation. STP pp5-22.

Hatton, T., 1996:Problems of the Prescriptive, in Fire Code Reform. National Seminar Series: Performance-based Approach to Building Fire Safety Design. August, 1996, Adelaide

ISO, 1992: Product data representation and exchange. Part 1: Overview and fundamental, *STEP Document ISO TC184/SC4/PMAG*

Mahdavi, A and K P Lam, 1991: Performance simulation as a front-end tool for integrative conceptual design evaluation. *Proceedings of Second International Conference of the International Building Performance Simulation Association (IBPSA), France pp 185-192*

Mahdavi A., Hartkopf V., Loftness V., Lam K.P., 1993:Simulation-based performance evaluation as a design decision support strategy, *Proceedings of Third International Conference of the International Building Performance Simulation Association (IBPSA), Australia pp 185-192*

Mahdavi, A., Mathew, P., Lee, S., Rohini, B., Chang, S., Kumar, S., Liu, G., Ries, R., Wong, N.H., 1996 : On the Structure and Elements of SEMPER. *In Proceedings of the 1996 ACADIA conference. Tuscon, Arizona. pp 71-84*

Mahdavi A., 1998:Computational decision support and the building delivery process: a necessary dialogue, *Automation in Construction, Vol 7, pp 205-211*

Pohl, J., Reps, I.,1988 :An integrated intelligent CAD environment. *In Proceedings, 4th International Conference on Systems Research, Informatics and Cybernatics. Baden-Baden, Germany*

Tham, K.W. , 1992: Intelligent buildings – concept, technology and perceptions, *Professional Builder, Vol 6 No 4 pp 3- 10, Singapore*

Tu K.J. and Loftness V. , 1998: The effects of organisation workplace dynamics and building infrastructure flexibility on environmental and technical quality in offices, *Journal of Corporate Real Estate, Vol 1 No 1, pp 46-63*

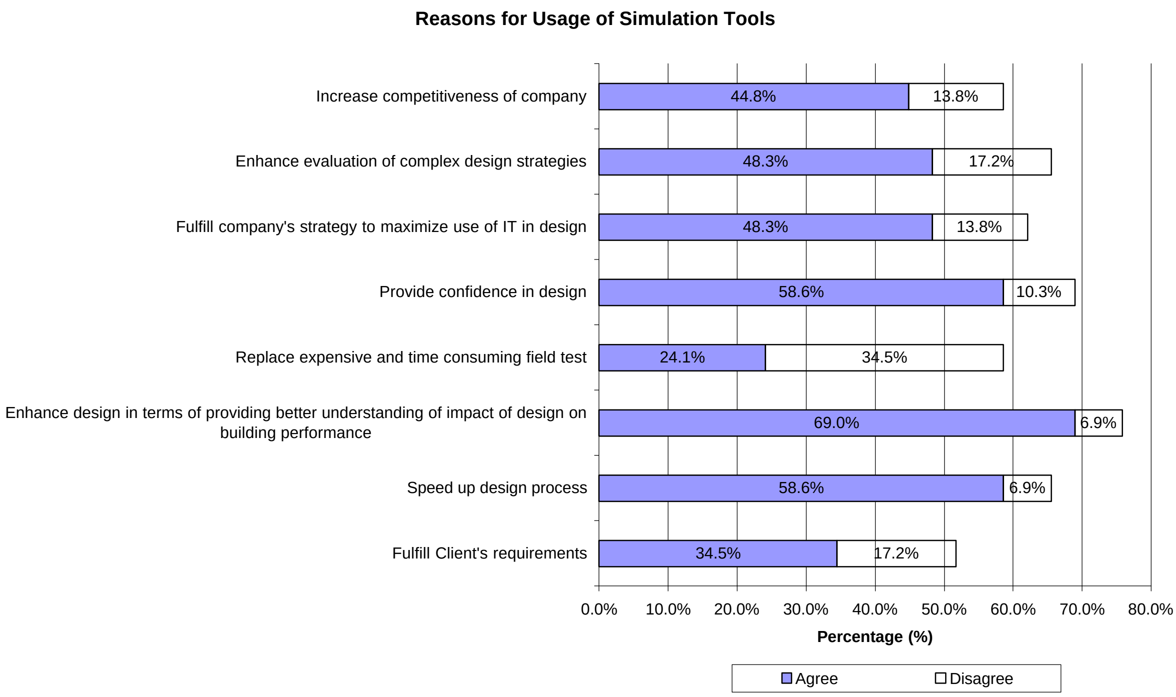

Figure 2: Reasons for using simulation tools

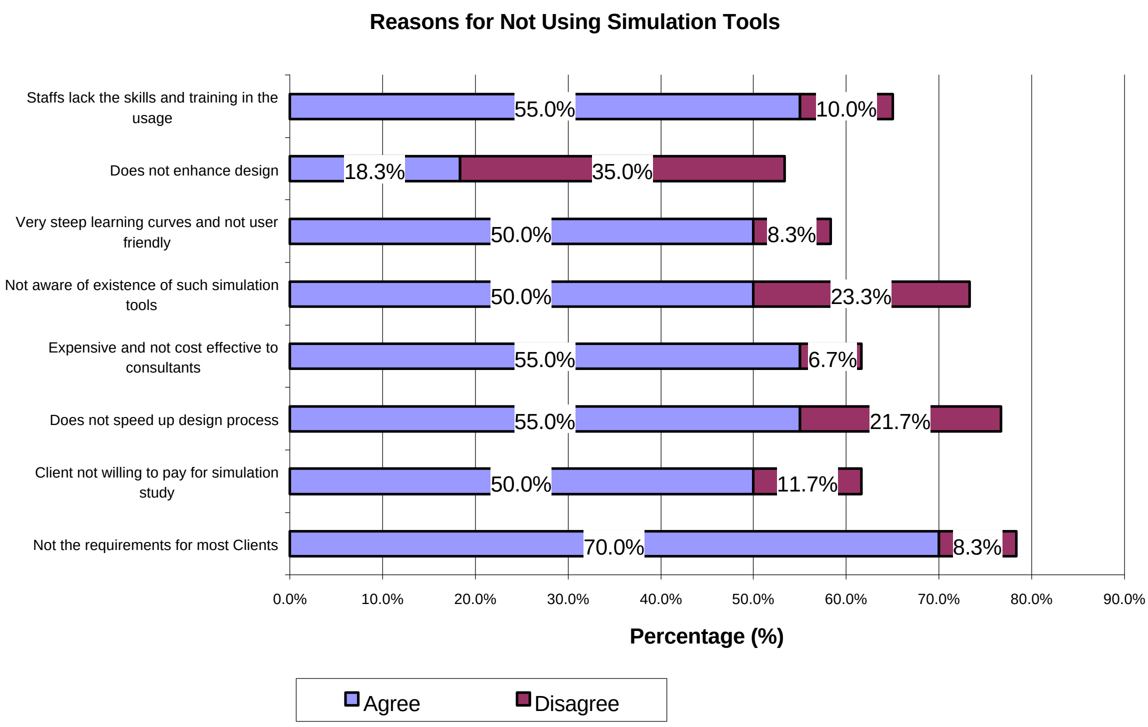

Figure 3: Reasons for not using simulation tools

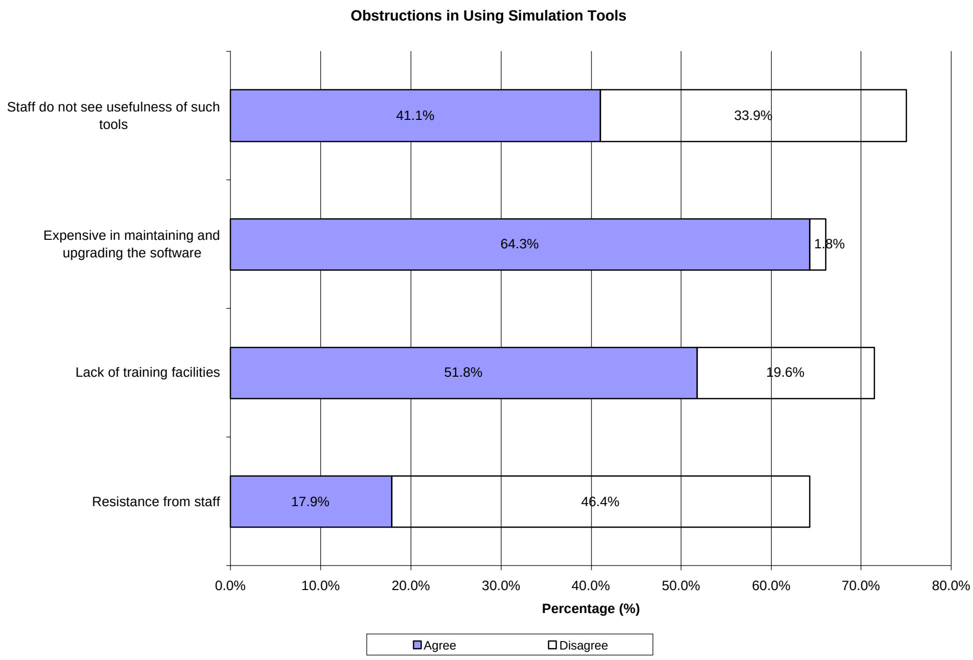

Figure 4: Obstructions in Using Simulation Tools

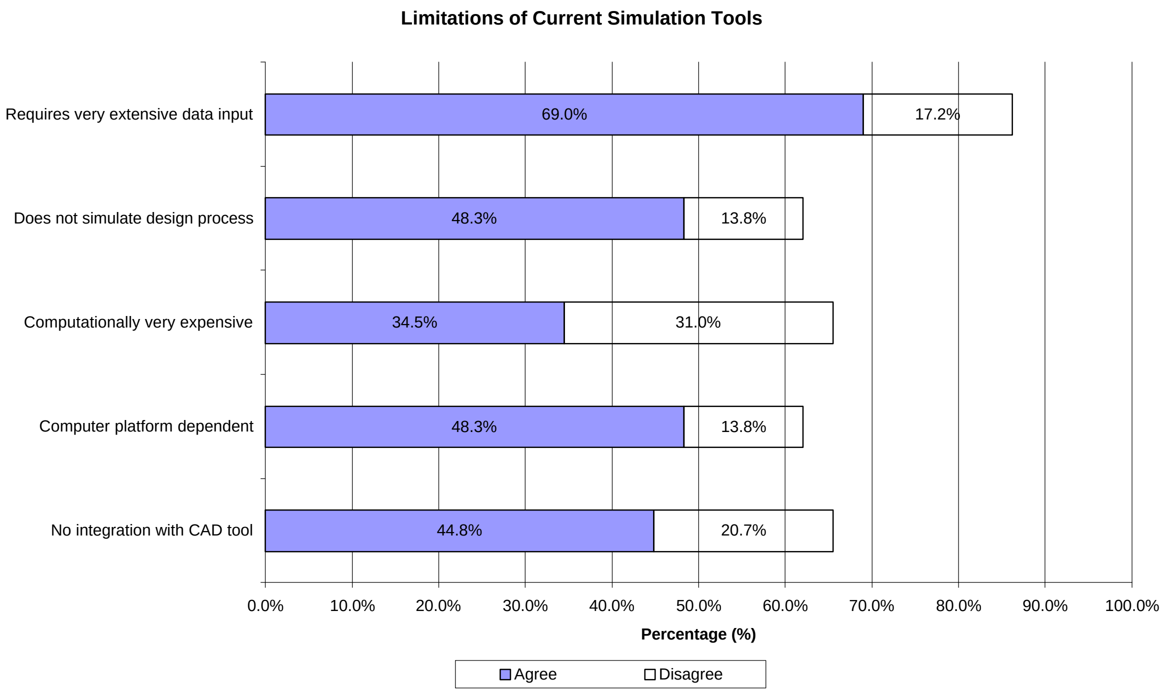

Figure 5: Limitations of Current Simulation Tools

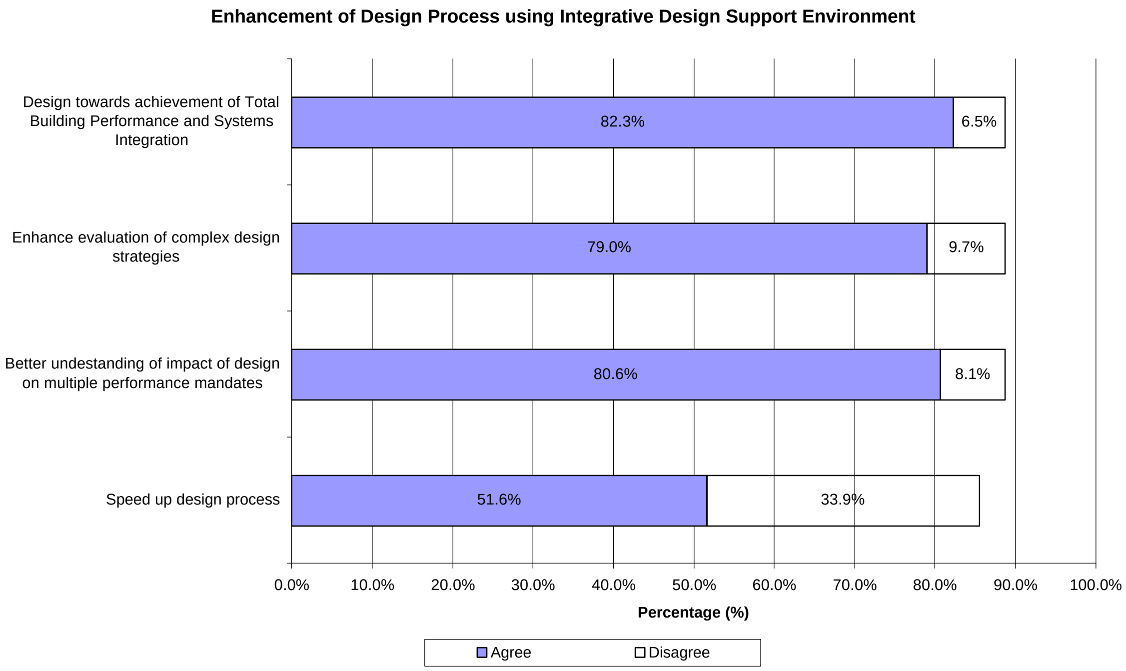

Figure 6: Enhancement of Design Process Using Integrative Design Support Environment

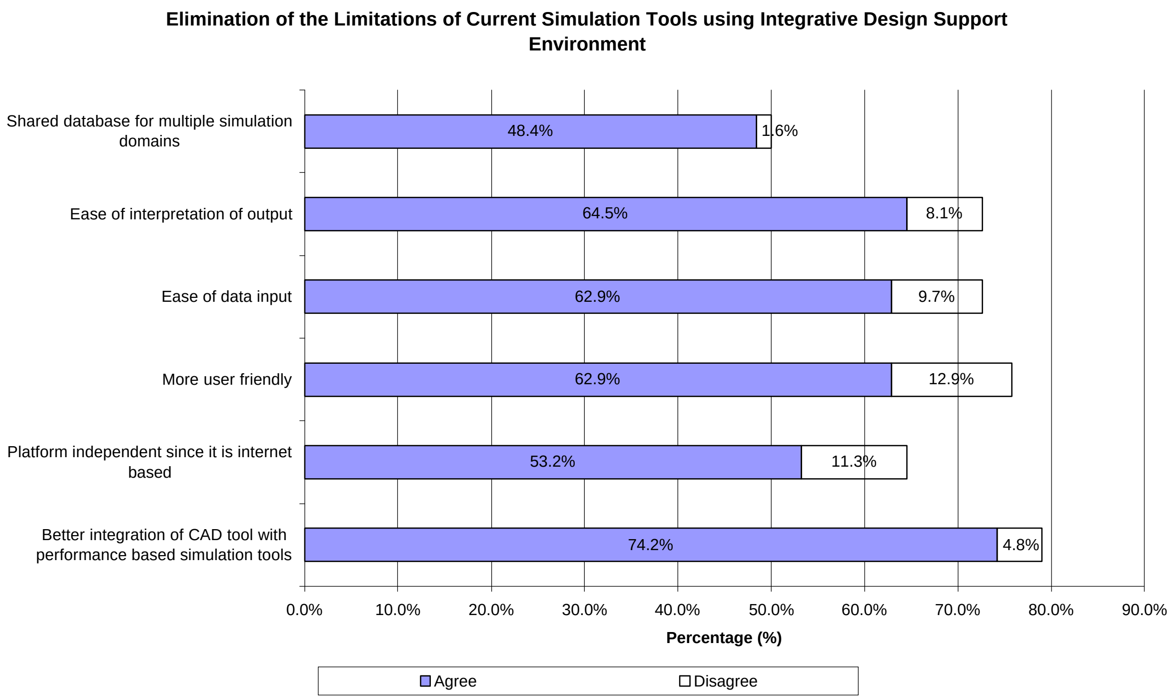

Figure 7: Elimination Of the Limitations of Current Simulation Tools