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THE ARCHITECT AS PERFORMER OF ENERGY SIMULATION IN THE EARLY DESIGN STAGE

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ABSTRACT

Despite the software developments intended to facilitate the use of energy simulation programs by architects in the early design stage, a very limited guidance is available, leading to a limited uptake. This paper investigates ways to better inform architects about energy simulation, firstly by enabling them to identify and translate the design inquiries into simulation tasks for deriving productive decision support and secondly by familiarizing them with the concepts and processes involved in energy simulation. The authors propose the development of a simulation tool independent framework to achieve the first objective. The framework will correlate simulation tasks with the performance parameters and the architectural elements to be evaluated using these parameters.

KEYWORDS

early design stage; architects; energy simulation; design decision support

INTRODUCTION

Paul Seletsky (2005), in his article ‘Digital Design and the Age of Building Simulation’ rightly expresses that with the pace of recent developments in Building Information Modeling, user friendly powerful building energy simulation and data interoperability, architecture is on the verge of a major digital revolution that can change the way buildings are designed and executed. Of these, building energy simulation is considered to be a potentially powerful tool for decision support in energy efficient building design (Henson 1994). Also, it is widely proposed that use of simulation in the early design stage (EDS) by simulation experts and non-experts like architects can influence better design of energy efficient buildings (Obanye 2006, Mahdavi et al 2003, Morbitzer 2003, Robinson 1996, Henson 1994). The latter is particularly true for smaller projects as the budgetary and time constraints can preclude the use of experts regularly performing energy simulations in the EDS and normally lead to design decisions based on prior experience of architects and rule of thumb rather than the applied performance feedback from the energy simu8lation programs (ESP’s) (Marsh 1996, Robinson 1996). However, the post design user surveys by researchers through questionnaire (Pedrini et al 2005, Mahdavi 2003, Lam et al 2004) and through interviews and case studies of buildings designed by leading designers (Morbitzer et al 2001, Trebilcock et al 2006, Wilde et al 2001) investigating simulation uptake by architects indicate that despite these developments the application of ESP’s in the EDS by the architects is very limited.

The observations of the surveys were: a) skepticism towards the potential of the ESP to provide decision support, b) lack of simulation know-how and unfamiliar working methods, c) perceived disconnect between the simulation process and the architectural design process as the simplified ESP’s meant for EDS analysis were used in the same stage as the more complex ESP’s i.e. in the detailed design stage, d) the ESP’s were used mainly for load calculations and code compliance. To experience firsthand the issues related to limited uptake within the design process, a test design was undertaken by the authors. Similar observations were experienced by the authors in addition to the facts that a) very limited guidance is available to architects for understanding and integrating simulation as a design tool in the EDS and b) selection of the ESP’s is a non-trivial task and requires better guidance. These observations are discussed in detail later in the paper.

Attempts to address the architect’s use of energy simulation are proposed by many researchers. The underlying logic behind these attempts are an in-depth understanding of: a) the architects needs and expectations (Wilde et al 2001), and b) the relationship of the design stage specific performance studies with the design inquiries (Xia 2008, Morbitzer 2001, Hayter 2000). Though the former has been researched, the later has been researched on case basis (e.g. for selection of energy efficient design strategies, natural ventilation). A case independent framework investigating this relationship between the building performance, passive/active design measures for energy efficient design and the design stage can provide a basis for architects to relate simulation to the design process. The research presented in this paper aims at the development of such a simulation tool independent framework for architects.

Finally, the user surveys (Mahdavi et al 2003) indicate that architects lack simulation know-how. Architects are usually familiar with environmental concepts, but often do not clearly understand how to translate the design and performance inquiries into simulation tasks and evaluate them using ESP's. Though researchers often propose that architects should use simulation as a design tool in the EDS, a simulation tool independent guide explaining the basic concepts of simulation, the data and process involved in preparing and simulating the design, and the output data interpretation for decision support is not available. The need for this guide is discussed in the paper and its structure is currently under development.

PERFORMANCE BASED DESIGN DECISION SUPPORT IN THE EDS

For formulating the proposed framework, it is important to look at how architects approach performance based design analysis and decision support and why ESP's finds limited use in the EDS. As Pedrini (2005) pointed out, intuition and past experience rank highest on the list of decision making techniques followed by guidebooks and rule of thumb while mathematical and simulation models rank low amongst the list of 18 decision support techniques.

The reason for the popularity of guidebooks can be attributed to the fact that they are easy to use and navigate, are time and cost effective and do not require detailed information about the design. Performance based decision support is usually provided through a list of energy conservation measures, design techniques and rule of thumb. The graphs and diagrams are used in conjunction with simple mathematical calculations for rough sizing the architectural design elements based on the performance criteria's like passive heat gains, day lighting, etc. An example is the LT method (Baker et al 2000) which can be used to determine the glazing ratio based on heat gains and day lighting potential. However, the biggest shortcoming of the guidebooks is that they are non-interactive and they fail to evaluate the climate and design specific performance evaluation and implication due to the synergistic behavior of multiple energy conservation measures usually proposed in the design.

ESP's, on the other hand, are interactive and provide climate and design specific performance evaluation. They are particularly suited to the iterative nature of the architectural design process in the EDS, where the gradual refinements of the design and its performance can be simulated repeatedly and with increasing detail. However for architects with limited background in energy simulation, defining a simulation model poses a significant challenge. The process not only requires detailed information but is also time intensive. Such detailed information is often not known or unavailable in the EDS and is typically not demanded by the guidebooks.

Most architects prefer simple ESP's that offer the flexibility to quickly model design concepts, explore 'what if' scenarios and evaluate the design alternatives in relation to performance factors like day lighting, thermal comfort, energy consumption, CO_2 emission, etc. In this design stage, absolute accuracy of simulation results is not of paramount importance to architects as compared to understanding the relative effect on performance due to changes in design alternatives (Marsh 2004). The need for a qualitative and overall design direction is more important than accuracy of detail. However, with the many simulation capabilities of the ESP's, it is difficult to decide which simulation study is feasible at a particular design stage and the need for clarifying this is often expressed by other researchers (Mahdavi 2003, Morbitzer 2003, Wilde 2002).

Finally, recent developments in the ESP's such as data interoperability (geometric and non-geometric) between ESP's and between the ESP's and building information modeling (BIM) platforms, pre-defined data defaults and the enhanced graphical user interfaces have implied and made possible the use of ESP's in the EDS by simulation non-experts like architects. However, selection of the ESP's still pose a problem as there is no support system to select the appropriate ESP (Wilde et all 2001). Many ESP's have been developed since the 1970's. They range from ESP's that simulate specific environmental issues (like computational fluid dynamics, thermal exchange) to whole building energy simulation programs. The US Department of Energy (DOE) web directory (www.energytoolsdirectory.gov) lists over 300 ESP's, providing one of the best overviews of the currently available ESP's. However, the directory neither provides guidance for the selection of appropriate ESP's for the EDS performance analysis nor does it evaluate their simulation capabilities.

TEST DESIGN

In order to frame and understand the problem at hand, the authors used the graduate design studio as a test case to investigate the integration of BIM and ESP's in the design process and identify the issues typically faced with such integration. The studio project was to design a mixed use commercial building (20,000 sq.ft.).

The following software's were selected based on a software review using the DOE website and their availability: a) *Revit Architecture* as the common BIM platform, and b) *IES<VE>* and *Green Building Studio (GBS)* as they are suitable for the EDS energy analysis (Lam 04), and *Integrated Environmental Solutions* (*IES<VE>)* as it offers a direct link with *Revit Architecture* for geometry import through the *IES Toolkits*. The simulations performed are listed in *Table 1*.

As the graduate students were inexperienced in use of ESP's, the test design enabled the analysis of a first time user experience. The experience was documented and analyzed as a part of the research methodology. Each of the three ESP's were used and compared to analyze the design and provide decision support at the different development stages. The observations based on this field study were the following;

1. Since the application of ESP's requires an understanding of the concepts of simulation, the question arose what level of understanding is necessary for architects, especially for the first time users. The graduate students invested significant time to understand these concepts through the *Ecotect* program documentation and learn the ESP's. Energy simulation has been the domain of researchers and engineers since its inception, who are more conversant with the processes involved in using simulation. However, architects are a fairly new audience to energy simulation and very limited ESP independent guidance related to simulation is available. An example can be the difference between rooms as typically understood by architects against a room or thermal zone in a simulation model. Also, a simulation model requires additional information to be defined e.g. schedules, internal gains, etc, which are not commonly used concepts amongst architects.
2. For deriving productive design assistance in the EDS, it is essential to frame a clearly defined simulation scope. It was observed that a clearly defined simulation scope can influence the modeling and simulation strategy and at the same time isolates and prioritizes the performance parameters. For example for simulating daylight, a *.dxf* file can be imported directly from *Revit* into *Ecotect* and analyzed for day lighting. However, a *.gbxml* file is required to perform thermal analysis in addition to defining thermal zones, schedules and other related details. The scope formulation requires an understanding of which design inquiries can and should be simulated and which performance parameters should be evaluated. Some ESP documentations provide information on defining the simulation model and the basic terminologies encountered in the process. However, neither do they address the issue and assist in formulating the simulation scope nor do they elaborate on how the output can be interpreted to facilitate decision support.
3. ESP's have been used mostly by engineers and experts during the detailed design stages. However, the nature of performance inquiries in the EDS is fairly different from those in the detailed stages. Typically energy conservation measures are selected and architectural design elements proposed during the EDS while system selection, sizing, and fine tuning of design elements is undertaken in the detailed design stages. For simulation to achieve more potential as a design tool in the EDS, it should be guided by some procedures or process in the EDS that acknowledge the nature of the EDS design inquiries, allow the architect to frame the simulation scope and permit flexibility in evaluating the desired energy efficiency measures.
4. The output data format and result interpretation were seen as crucial factors in evaluating the effectiveness of the ESP to provide decision support. For example, *Ecotect* allowed the weather data to be overlaid on the site while both *Ecotect* and *IES<VE>* overlaid daylight levels on the 3D model. Particularly in the EDS, where the design is continuously refined, visual data representation enables quicker data interpretation, hence saving data post-processing time for comparative design studies.
5. None of the three ESP's was alone sufficient to answer all the design performance inquiries. The potential for natural ventilation and end-use energy analysis was evaluated partially only by *GBS*, while end-use energy analysis was performed only within *GBS* and *IES<VE>*. Also, the complexity in using ESP's was a deciding factor in determining the significance of decision support. Even though *IES<VE>* provides a

broader performance evaluation scope than *Ecotect*, it has a complex interface and a steeper learning curve for first time users. This raised the question of whether single or multiple ESP's should be used in the EDS and which ESP's are appropriate for a particular task. The selection of appropriate ESP is a non-trivial task, as it depends on the scope of simulation, level of detail and the capability of the particular simulation program.

The effectiveness of performance based decision support was found limited in the early schematic design stage when the various massing options were considered. However, as the design progressed, simulations like annual temperature profile, daylight analysis and passive gain breakdown provided decision support in fine tuning the opening locations, size and light shelf's and the selection of materials for walls and windows. Apart from the software limitations to simulate natural ventilation effectively, the reason for limited initial effectiveness can be attributed to the fact that the simulation capabilities of the ESP's were not completely known by the graduate students, simulation scope was never clearly formulated and finally the absence of any standard guide to assist in formulating simulation scope and performing simulation necessitated significant time investment (considering the limited time schedule of the studio) in understanding them through the individual software help documentation.

Also, it was observed that the use of multiple simple ESP's can allow better decision support. This was observed from the fact that *GBS* allowed parametric analysis for determining optimum orientation, window-to-wall glazing ratio and construction without the need to actually modify the building model, thus saving considerable time. This capability was absent in *Ecotect* and *IES<VE>*. At the same time, *Ecotect* allowed the capability to modify the model and simulate simultaneously within the program, a capability absent in *GBS.*

The Chartered Institution of Building Service Engineers (CIBSE 1998) proposes two approaches for integrating energy simulation in the design process: the first is to apply simplified ESP's in the EDS and detailed ESP's at later detailed design stages; the other is to use a sophisticated single tool throughout the design process. Though researchers argue the validity of the former approach (Clarke 2001, Morbitzer et al 2001), simplified ESP's offer maximum potential for their use by non-experts (Robinson 1996). Morbitzer (Morbitzer et al 2001) states that using a single sophisticated program would not only allow the same model to be used for all design stages and between different team members, but also provide a common background to the user groups and eliminate errors in result analysis caused by the use of different programs. The above two approaches have been compared by Robinson (1996) and Chwif (Chwif et al 2000) and are discussed in *Table 2*.

Table 1: The ESP's used and simulations performed in the test design.

	Miscellaneous								Lighting			Thermal							Energy			
Simulations performed / ESP's used	Sun-path analysis	Wind rose analysis	Overshadow analysis	Psychometric analysis	Orientation optimization analysis	Sun/Shadow analysis	Parametric analysis		Day lighting analysis	Illuminance level analysis		Temperature profiles	Thermal comfort analysis	Insolation analysis	Passive gains breakdown	Heating/Cooling loads	Natural ventilation		end-use energy breakdown	Annual energy consumption	Heating/Cooling energy	CO2 production
Ecotect	o	o	o	o	o	o	o		o	o		o	o	o	o	o			o	o	o	o
IES<VE>	o		o			o			o	o									o	o	o	
GBS							o		o								o		o			o

APPROACHES TO RESOLVE THE BARRIERS

To facilitate energy simulation uptake and its integration in the design process by architects, researchers have proposed different solutions. These can be categorized into the following:

1. Program specific interface developments: where the program interface responds to the design process, human expertise and judgment.
2. Design process centric approaches: where simulation activities respond to decision making in the design process.

A program specific interface development approach is proposed by Morbitzer (2003) and also adopted by ESP's like *Equest*. Morbitzer (2003) proposes the use of a single sophisticated simulation engine with user interfaces customized to the different design stages instead of multiple simplified simulation programs. The pros and cons of using simple versus sophisticated tools were discussed earlier in the paper. This approach will require substantial and continual developments of the ESP. Based on the experience from the field study; expecting a single simulation program to provide decision support for all design inquiries and at all design stages is highly ambitious.

A design process centric approach is proposed by Hayter (et al 2000), Mendler (2006), Wilde (2001, 2002) and Xia(2008). Wilde proposed the concept of an assessment matrix to assist in the management of simulation output for the selection of the best performing design option and in the selection of ESP's. The assessment matrix is a co-relationship framework based on the analysis of design activities and the related performance evaluation in the design process. Though the concept of matrix shows considerable promise, it is currently focused on management of simulation output and the analysis of only specific scenarios (Mourshed et al 2003). Hayter (energy design process) and Mendler (energy optimization process) propose simulation procedures with respect to the design stages and lay out the intent of the simulation activity to be performed during each design stage. 'Parametric analysis' and 'ranking' of energy efficiency measures with respect to their effectiveness are identified as crucial steps in the programming stage. However, the simulation steps for the schematic design stage are generic. They define the intent of simulation but do not elaborate which architectural and performance parameters should be simulated. Also, both the processes are based on the use of a detailed simulation engine like *DOE2*.

Though the research approaches mentioned above address specific areas to facilitate the use of simulation in the EDS, they do not provide a framework for architects to understand how the performance related EDS inquiries are related to the architectural and quantifiable performance parameters and how to translate the design inquiries into simulation tasks for obtaining decision support. The authors expand on the concept of Wilde's assessment matrix to propose a framework for facilitating the formulation of simulation scope. A simulation framework co-relates the 'process steps' and the simulation tasks proposed in the above researches to the performance based design inquiries and the related performance parameters.

Table 2: Comparison of simplified and sophisticated ESP's.

	Simplified Simulation program likely users : architects	**Sophisticated simulation program** likely users : engineers and experts
Pros	• Lesser cost and suitable for smaller projects • Easier to implement, validate and analyze • Easier to modify and perform multiple simulation in less time	• Test both macro and micro level performance parameters (system sizing, component sizing) • Applicable in all design stages
Cons	• Used in fewer design stages and test macro level performance parameters (location, form, glazing, etc)	• Steep learning curve and time intensive application • Requires large amount of input data

CONCLUSION

A common observation from the literature review and the test design was that a very limited software independent guidance is available to assist architects in performing energy simulation in the design process. Some of the challenges identified were how to translate the design inquiries into a simulation model for obtaining decision support and for the selection of the ESP's appropriate for use in the EDS by architects. The authors thus propose formulation of a software independent guide for architects to facilitate simulation knowhow. The structure of the guide is underway. The topics identified for inclusion in the guide are: introduction to energy and environmental simulation, defining scope of simulation, selection of the ESP's, defining simulation model and performing simulation, data analysis and interpretation, program validation and quality assurance.

The importance of defining the simulation scope for guiding productive simulation activity was realized through the test design. A clearly identified scope allows translating the design inquiries into simulation tasks and identifying modeling strategies. This requires a thorough understanding of the nature of performance based design inquiry, the related performance parameters to be evaluated and the associated simulation task. Also, a need for process steps to guide architects in deriving productive information from the simulation activity was realized by the authors through the test design. The authors propose the development of a simulation tool independent framework to assist in formulating the simulation scope. The framework in its first version is shown in *Figure 1* and described below.

The framework

The proposed framework expands on the concept of the 'process centric assessment matrix' proposed by Wilde (et al 2002).

The framework is structured on the American Institute of Architects (AIA) description of design stages. Though architects follow this commonly agreed design stage descriptions and deliverables rarely in detail, the stages are universally accepted and thus the framework based on the AIA design stage descriptions can ensure better acceptance and understanding by architects. The framework co-relates the design inquiries in the EDS, the related performance parameters and the respective simulation tasks evaluating these performance parameters.

The design inquiries in this framework relate to the design activities typically involved in the AIA design phase descriptions and the energy efficient design strategies typically proposed by guidebooks. The performance parameters related to the design inquiries are extracted from guidebooks due to their clarity, familiarity and popularity amongst architects. The simulation tasks or process steps are then defined with respect to each design stage. The 'process centric simulation approach' proposed by Hayter (2000) and Mendler (2006) indicated 'parametric analysis' and 'ranking' of energy conservation measures as crucial simulation tasks in the programming stage. While these procedures are focused on the programming stage, the authors adopt these steps and focus on defining the simulation/analysis task and the related performance parameters for the schematic design stage (based on review of guidebooks).

The following representative guidebooks were selected for review; a) Energy Design Handbook (Watson 1993), b) AIA 50<<50 (ver 1, 2007), c) Green Studio Handbook: Environmental strategies for Schematic design (Kwok 2000), d) Energy and Environment in Architecture, A Technical Design Guide (Baker et al 2000). The first two have been published by AIA while the later two are chosen as representative guidebooks intended for architects.

The framework (*Figure 1*) correlates the simulation tasks with the performance parameters and the architectural elements evaluated through these parameters. For example, for evaluating daylight, the architects should do a sun path analysis and a cloud cover analysis in the programming stage, evaluate the lighting gains, daylight factor, reduction in cooling and overall energy consumption and daylight autonomy analysis in the early schematic stage and evaluate the discomfort due to glare, illuminance levels, reduction in lighting and overall energy consumption in the late schematic design stage. Though the framework does not require the architect to perform all these analyses, it presents the performance parameters that can be related to day lighting and assist in defining the scope of simulation accordingly. The framework could thus enable architects to understand and define the scope of simulation.

Future research

The success of the proposed framework in facilitating simulation knowhow and increasing simulation uptake by architects is yet to be tested and is proposed as a future research direction. Also, the authors suggest the use of the proposed framework for performing software reviews. The reviews can then identify the appropriateness of particular ESP's for EDS and for the designated performance evaluations in the EDS.

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	Process Steps	Type of analysis	Miscellaneous					Lighting					Thermal																			Energy											Architectural design parameters
			Shading Mask	Overshadowing analysis	Sunpath Analysis	Wind Rose analysis	Psychrometric analysis	Cloud cover analysis	Daylight analysis	Illuminance level analysis	Daylight autonomy	Glare index	Min/Max Temp range	diurnal Temperature variation	HDD/CDD	Balance point temperature	Incident Solar radiation	Room Temperature	Heat storage/removal capacity	Occupancy gains	Conduction gain	Direct Solar gain	Lighting gain	Heat gain avoidance by Daylighting	Timelag in heat transfer	Heat gain/Loss	Heating load	Cooling Load	reduction in Heating/Cooling load	air change rate	Infiltration gain	base case end use energy breakdown	proposed end-use energy breakdown	energy conservation measures	DL supplemented Lighting energy	Heating energy	Cooling energy	savings in Lighting energy	reduction in Heating energy	reduction in cooling energy	overall energy consumption	energy generated by PV	
A	Programming Stage	Climate analysis	o	o	o	o	o	o					o	o	o																													
		Benchmarking																													o												
		Parametric analysis																													o		o										
B	Schematic Design Stage																																											
1	BUILDING VLV	Orientation	o	o	o	o		o																					o			o	o						o	o	o		optimum orientation
		Massing		o	o																																							aspect ratio, volume
		Site form Massing																																									
		Space Zoning																		o			o																					
2	SPACE LVL																																											
	optimize envelope	Insulation													o			o			o					o	o	o	o									o	o		o	o	o		optimum U, R values, thickness
		Materials - opaque																o			o					o	o	o									o	o				o		U, R values, thickness
		Materials - glazed							o			o										o				o	o	o									o	o				o		SHGC, VT, U value, optimum WWR
		Green/Cool roof																o										o							o	o		o	o	o		U,R values, thickness
3	Passive heating	Thermal Mass																o	o						o		o	o	o												o	o	o		Area, location, thickness, heat storage capacity
		Direct heat gain	o	o	o			o	o			o	o					o	o			o			o		o	o	o												o	o	o		WWR, SHGC
		Indirect heat gain	o		o			o					o					o	o						o		o	o	o												o	o	o		thickness, heat storage capacity
4	Passive cooling	Cross Ventilation				o	o						o					o							o	o	o	o	o	o					o	o		o	o	o		Inlet/outlet opening area, location
		Stack ventilation					o											o							o	o	o	o	o	o					o	o		o	o	o		stack height, location, opening area
		Mass+night cooling				o	o							o				o	o						o	o	o	o	o	o	o					o	o		o	o	o		area of thermal mass & openings
5	Shading	Shading	o		o				o	o		o																o											o	o			geometry, location
6	Daylighting	Daylighting			o			o	o	o	o	o										o	o		o														o		o	o		optimum DF, WWR
		Light shelves			o				o	o		o																o														Glare control
		Daylight zoning									o																											o						
		Skylights			o			o	o	o		o																														optimum DF
		Daylight dimming																					o						o													o	o		
		Occupancy sensors																																					o	o	o		sensor location
7	Renewables	Solar power			o																																				o	o	panel sizing
		Wind Power																																									
		Geothermal power																																									
		Solar DHW			o																																				o	o	panel sizing

o Programming Stage   o Programing stage repeated in Early Schematic stage   o Early Schematic Design   o late Schematic Design

Figure1 : The framework