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INFORMATION DEPENDENCIES BETWEEN ARCHITECTS AND SERVICES ENGINEERS FOR EARLY DESIGN EVALUATION

A framework for an energy design tool for architects

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Abstract. Effective strategies for the design of efficient and environmentally sensitive buildings require a close collaboration between architects and engineers in the design of the building shell and environmental control systems at the outset of projects. However, it is often not practical for engineers to be involved early on in the design process. It is therefore essential that architects be able to perform preliminary energy analyses to evaluate their proposed designs prior to the major building characteristics becoming fixed. Subsequently, a need exists for a simplified energy design tool for architects. This paper discusses the limitations of existing analysis software in supporting early design explorations and proposes a framework for the development of a tool that provides decision support by permitting architects to quickly assess the performance of design alternatives.

Keywords. Performance-based design; energy simulation; decision support; design process; information dependencies.

1. Introduction

Contemporary awareness of global environmental concerns reinforces the imperative to construct buildings that minimise energy consumption and associated carbon emissions. Consequently, there is an increasing pressure on architects to be more environmentally responsible in their designs. Despite this, building services, one of the largest contributors to energy usage, complexity and cost, are rarely considered in the conceptual design phase, let alone conceived of as potential driving influences behind architectural form.

Presently, on a global scale, the buildings sector is responsible for 33% of all energy-related carbon emissions (Intergovernmental Panel on Climate Change, 2007). Furthermore, in Australia, 18% of the nation's emissions can be attributed to commercial buildings (Intergovernmental Panel on Climate Change, 2007), with the ongoing operation of heating, ventilation, and air-conditioning (HVAC) systems accounting for over 60% of the energy consumption responsible for these emissions (Department of Sustainability and Environment, 2006). However, it is atypical for the performance implications of thermal comfort strategies to be explored in any detail in the early modelling of a building proposal, despite the potential environmental and financial benefits that stand to be gained from this approach (Drogemuller et al., 2004). If more sustainable built environment outcomes are to be achieved, then performance-based strategies that integrate architecture and services must be implemented in order to generate building designs in response to considerations of energy efficiency.

This paper reports on findings from the first year of embedded-practice Ph.D. research being undertaken within Project Services, a building design and project management division of the Queensland Government's Department of Public Works. As such, the conclusions are not yet finalised. Rather, this is a work in progress that summarises the explorations to date and outlines the developments to be embarked upon over the next two years.

2. The need for an energy design tool for architects in early design

Decisions made in the conceptual phase of architectural design have the greatest impact on building performance outcomes, as they determine the flexibility, effectiveness, and efficiency of the design solution (Hensen, 2004). During this earliest stage the general form, orientation, and construction of the building are defined, from which all subsequent decisions are derived (Ellis and Mathews, 2001). Consequently, while these decisions initially provide direction for the project, they simultaneously generate constraints that become difficult and costly to alter as the design progresses (Maassen et al., 2003). This can jeopardise the viability of a project if a poorly made decision needs to be rectified late in the design.

Frequently, these early decisions are based on information that is complex, incomplete, and, at times, incorrect (Maassen et al., 2003). Design solutions are often guided by experience and intuition, rather than based on quantitative prediction of multidimensional performance indicators such as operating costs and energy consumption (Struck and Hensen, 2007). While these decisions have implications for all disciplines involved in the design, the decision-making process is conventionally led primarily by architects, usually without an adequate decision support environment to effectively evaluate multidisciplinary criteria (Bleil de Souza and Knight, 2007). Often choices are made with limited comprehension of the impacts that alternatives have on the design's performance (Flager and Haymaker, 2007).

Ideally, all the design professionals required to complete a project would be appointed at the same time. This, however, does not typically fit within the scope of current design practice (Ellis and Mathews, 2001). It is therefore essential that architects be able to quickly and accurately evaluate the energy performance of their conceptual designs without the need for expert assessment.

3. Problems with existing energy analysis tools

Presently, there is a lack of tools that have the capacity to support the rapid interactions between architectural design and services engineering needed early in the design process (Flager et al., 2009). Traditionally, services engineers have not been involved in building projects until the documentation stage of the design process, and subsequently, the majority of energy simulation tools that do exist have been developed to support tasks associated with this phase of development (Maassen et al., 2003). As a result, performance evaluations are generally time-consuming and complicated to carry out, requiring detailed information about the building construction and services before a simulation can be performed (Ellis and Mathews, 2002). To undertake even an indicative energy analysis requires information for inputs that may not yet be available during the preliminary design stages, which is paradoxically when the evaluation is most influential (Punjabi and Miranda, 2005).

In addition to the complexity of the software acting as a deterrent to its use by architects, the interface for these tools is typically cumbersome, non-visual and unintuitive (Punjabi and Miranda, 2005). The inputs and outputs are largely numeric, and, consequently, the translation of model descriptions and simulation results is a non-trivial task that often constrains the designers' ability to understand and decide between design alternatives, as well as consuming large amounts of time and effort (Prazeres et al., 2009). While there is some capacity to map design representations into the required domain representations in certain energy analysis applications, these transformations are highly limited, and the reverse process of mapping performance solutions to design models is largely unsupported, leaving iterative explorations to be undertaken manually (Kolarevic, 2003).

The energy simulation tools available do not successfully reconcile the relationships between design actions and performance outcomes, rendering them incapable of supporting design decision-making in any significant manner (Attia et al., 2009). As such, they have largely failed to be incorporated into general design practice (Warren, 2002). What is instead needed is a performance evaluation process that parallels the characteristics and logical relationships of the design process, and permits smooth transitions between domain-specific representations (Yan and Jiang, 2005).

4. Performance-based decision support in early design

There is a compelling rationale to overcome these obstacles impeding the use of building simulation tools for decision support in early design. The spate of energy codes and rating schemes emerging, such as Section J of the Building Code of Australia (Australian Building Codes Board, 2009) and Green Star (Green Building Council of Australia, 2009), along with their equivalents in other countries, are creating common objectives for architects and engineers. In addition, recent improvements in both modelling and simulation software are giving rise to more tangible opportunities for direct links between design and analysis processes (Attia et al., 2009). At present, however, there is very little guidance available to architects for understanding and incorporating energy analysis as a decision support tool (Bambardekar and Poerschke, 2009).

Defining the criteria and procedures necessary to connect these design and evaluation activities is very much a human problem of process and understanding, independent of specific modelling or analysis tools (Bleil de Souza and Knight, 2007). While architects are typically familiar with general environmental concepts and rules of thumb, methods for structuring the data and process necessary to perform simulations have not been formalised into common standards (Bambardekar and Poerschke, 2009). In order to successfully bridge this gap, a unified framework that identifies and redefines key simulation parameters as design-related criteria must first be established, so that information crucial to determining performance outcomes is placed in a context easily understood by architects (Ellis and Mathews, 2002).

A modified version of the design approach suggested by Todesco (1996) is suggested here as the structure by which to develop an energy-based design strategy (Figure 1). As well as an example of a clearly formalised process that is reflective of common opinion within recent research (Ellis and Mathews, 2001), Todesco’s approach is also well aligned with the sustainability initiatives of Project Services. Minimising building loads is the first step in this approach. Since building loads are largely affected by building shape, spatial organisation and thermal characteristics, architectural decisions can consequently be directly translated into the inputs required for early performance evaluations (Ellis and Mathews, 2001). Engineering decisions tend to then be concerned with the steps following.

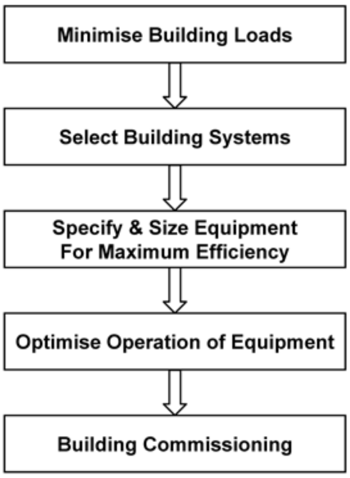

Figure 1. Design approach for energy-efficient buildings, based on Todesco (1996).

In this approach, it is important that architects recognise the building envelope as being either a barrier or a filter (or a combination of both) moderating the effects of weather, surroundings, and internal occupancy (Bleil de Souza and Knight, 2007). The objective is then to design a building envelope that offsets as much of the energy transfer through it as is appropriate, responding to and accommodating variations in external and internal conditions (Bachman, 2003).

In order to gain a better understanding of this construct of the building and its envelope, the software eQUEST was recently employed as an evaluation tool on a live project within Project Services. In spite of the program being intended for use in an American context, eQUEST was chosen due to its implementation of design wizards for the preparation of analytical models, which clearly lay out the minimum information required to perform a simulation. From this demonstration, seven groups of parameters have been identified as necessary in constructing an early energy model. These are defined to reflect an architectural perspective, as follows:

- *Thermal Zones:* are used as the geometric construct rather than rooms, characterised in terms of shape, orientation and program, and grouped and positioned to minimise thermal loads that require mechanical offsetting to maintain interior comfort.
- *Construction Types:* are selected and located according to their conductance to moderate the energy flows between thermal zones and the external environment.

- *Glazing and Skylights:* are selected and positioned to permit natural light internally while avoiding undue solar heat gain.
- *External Shading:* is positioned to shield glazing and highly exposed external walls from excessive solar radiation.
- *Internal Heat Gains for Occupancy, Equipment and Lighting:* are determined for each thermal zone by both a load and a schedule of operation associated with the allocated program, which are derived as constant values from building codes and rating scheme guidelines.
- *HVAC systems:* are chosen in collaboration with a mechanical engineer, in order to determine the type of system best suited to the building form and function and the architectural implications of this system, then set as a default, to maintain focus on the performance impacts of the architectural decisions.
- *Weather and Surrounds:* are independent of the building, and set as constants throughout the performance evaluation.

The performance impacts of these seven parameters are highly interdependent, and must be recognised as a dynamically interconnected system if they are to be evaluated adequately (Bleil de Souza and Knight, 2007). Although it has been shown that performance outcomes are particularly sensitive to the factors of orientation, window area, wall construction and roof properties (Ellis and Mathews, 2001, Attia et al., 2009), it is vital to recognise that simulation results will not directly point to a single building element to adjust for better results (Sanguinetti et al., 2009). Rather, all parameters must be considered in combination to gain a complete understanding of building performance.

5. Requirements of an energy design tool for architects

In order to successfully make use of energy analysis as a decision support tool in early architectural design, simulation must be recognised as a social discipline, as it involves both human-computer interaction and knowledge processing, while simultaneously facilitating the definition and exploration of design space (Attia et al., 2009). From this perspective, not only must an energy design tool support the proposed framework to successfully target use by architects, but it must also address issues of interaction and understanding specific to this design discipline.

As Pedrini & Szokolay (2005) have revealed in recent research, architects rank experience and intuition as their preferred decision-making techniques, followed by guidelines and rules-of-thumb, while the use of simulation models ranks amongst the lowest methods used. Despite lacking the capacity to evaluate climate and design-specific idiosyncrasies, resources such as guidebooks are favoured because they are simple to navigate and require little detail about the design, making them time and cost effective

(Bambardekar and Poerschke, 2009). What is therefore needed is a simulation-based tool that combines its inherent analytical capability to handle dynamic and iterative design investigations with the ease of use associated with resources like guidebooks. The operation of such a tool should not necessitate that architects learn a new skill set, but rather be intuitive and reflective of the design process.

A number of criteria for 'architect friendly' simulation tools have been identified by both the architecture and simulation communities in recent years (Attia et al., 2009, Warren, 2002, Crawley et al., 2008, Maassen et al., 2003). The following features have been the most frequently suggested:

- A user-friendly interface that represents simulation inputs and outputs graphically, allowing for simple navigation and flexible control.
- The ability to quickly compare and track design alternatives and 'what-if' scenarios, as well as visualise the potential impacts that different design decisions have on energy performance.
- A design knowledge base that facilitates learning by supporting users with the following - tutorials; online help; assistance in recognising and modifying conflicting criteria; and a library of case-based example buildings for reference.
- Default templates and parameter values to facilitate data entry, combined with the flexibility to control whether parameters are set or variable.
- Links to building codes and rating schemes, to check code compliance and energy credits, respectively.
- The capacity to build the simulation model in a 3D environment by linking the energy simulation tool directly to an existing 3D modelling program, through the use of an automated bidirectional mapping procedure to transform between design and analysis representations.

This last point is particularly important, as one of the main challenges in achieving the integration of simulation with design lies in how to formulate associative interconnections to current building information modelling processes. Current implementation of the Industry Foundation Class (IFC) export is not conducive to an interactive concurrent design environment as its "top-down" hierarchical structure necessitates the transfer of the entire model file rather than permitting the selective export of only required building elements (Dong et al., 2007). Additionally, the semantics of IFC exchange are too ambiguous to allow for seamless integration between design and analysis representations (Petrinja et al., 2007), and very few energy simulation programs support it as a file format for this reason. Instead, Green Building XML (gbXML) is the preferred file format for the exchange of data between CAD and energy analysis software, as it is an extensible and robust non-proprietary format that expresses building geometry as rectangular surfaces, the representation required for energy simulation (Dong et al., 2007). It is therefore anticipated that future development of the framework will be based upon the gbXML schema.

In addition to these features, the performance of individual scenarios needs to be accounted for in absolute terms, to allow for quantification against energy rating scheme criteria, as well as in relative terms, to compare design alternatives (Donn et al., 2009). This suggests the use of a single, robust performance evaluation tool throughout the design process, to eliminate inconsistencies in results caused by the use of different methods of evaluation (Morbitzer, 2003). A single tool approach allows the same model to be progressively refined throughout the different design stages, providing a common construct to support the integrated development of both the architectural and services designs from the outset of the project onwards (Maassen et al., 2003).

Project Services have recently demonstrated the practical benefits of engaging in energy simulation early in the design process with their Joint Call Centre (JCC) project, a 5100m² office building located in Brisbane for non-emergency police calls and general government services. This project has been awarded the highest Green Star rating ever given to an office building in Australia, achieving 92 points out of a possible 105. The exceptional outcome can largely be attributed to the fact that the services engineers were heavily involved in the early design process, performing numerous simulations (each one having to be modeled individually) to explore tradeoffs required between spatial organisation, and HVAC and lighting systems, to obtain an optimal design solution. Due to the expert nature of the analysis and interpretation required, the architects had minimal involvement in this process, making apparent that the tools being used did not adequately support an interactive concurrent design environment. Despite these obstacles, however, this strategy demonstrated the effectiveness of integrating simulation in the early design process as means by which to improve building performance.

6. Conclusion

While the range of available performance analysis tools is increasing, there is no single program that meets the needs of architectural users. This paper presents a framework for an energy design tool that will address these needs, the development of which will be undertaken in future work. The next stage in this process will be the selection of a simulation program on which to base this development, a non-trivial task that will involve consideration of how different software might be adapted to accommodate the Australian climate and regulations, which is largely unaddressed in the current research and development concerned with energy design strategies. We will assess

Ecotect, IES Virtual Environment and Energy Plus, amongst others, for their potential to be extended to accommodate the front end of the design process, as well as for the accuracy of the results that they generate.

Energy simulation is a potentially powerful decision support tool for architects that offers a new frontier in the exploration of design processes affecting more energy efficient design solutions. By reducing the complexity of simulation tools and simultaneously improving their ability to accommodate performance enquiries typical to the early design stage, energy design processes will begin to present themselves as potential generators of innovative and sustainable building solutions, rather than acting as deterrents to their own use. This will open up a dialogue between architects and services engineers and assist in the development of mutually responsive objectives and processes that have the capacity to resolve design and performance constraints simultaneously and subsequently result in a more sustainable built environment.

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