CLOSING THE LOOP OF DESIGN AND ANALYSIS

Parametric modelling tools for early decision support

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Abstract. There is a growing need for parametric design software that communicates building performance feedback in early architectural exploration to support decision-making. This paper examines how the circuit of design and analysis process can be closed to provide active and concurrent feedback between architecture and services engineering domains. It presents the structure for an openly customisable design system that couples parametric modelling and energy analysis software to allow designers to assess the performance of early design iterations quickly. Finally, it discusses how user interactions with the system foster information exchanges that facilitate the sharing of design intelligence across disciplines.

Keywords. Parametric; performance; analysis; integration; energy.

1. Introduction

While parametric modelling is becoming an increasingly integral part of many computer-aided design (CAD) tools, its potential to provide dynamic and responsive performance analysis, through integration with building simulation, has long eluded the architectural domain. Pioneers of CAD predicted a design process that exploited the analytical powers of the machine to enhance the creative powers of the designer (Coons, 1963). They portrayed a system based on associative modelling, where designers refine digital concept sketches iteratively in response to feedback obtained from analyses carried out by the computer (Sutherland, 1963). However, while parametric modelling systems today have succeeded in establishing associative methods for defining and exploring design constraints, few have been developed to incorporate performance feedback into this design process.

Limitations in both tools and process pose challenges to the integration of simulation in early design. The conversion of 3D models between design and analysis representations is not well supported by existing data transformation mappings, and typically requires expert translation and interpretation (Augenbroe et al, 2004). Furthermore, most simulation tools necessitate detailed information about a building's construction and services before even an indicative analysis can be performed; information that may not be available at the conceptual design stage (Ellis and Mathews, 2001). These incompatibilities inhibit the development of an interactive information exchange network where design and analysis processes are active simultaneously, and serve rather to reinforce conventional practice where one domain is active and the other reactive (Nicholas and Burry, 2007). What is needed instead is a dynamic and concurrent performance evaluation process that parallels the characteristics and logical relationships of the design process, and permits smooth transitions between domain-specific representations.

While strategies for integration are often seen to revolve around software interoperability, design communication networks also play a critical (yet sometimes forgotten) role in establishing clear relationships between design and performance constraints. This paper therefore examines not only *how* data is exchanged, but also *when* and *what* information is shared between disciplines. It focuses on the interaction between architectural design and energy analysis to demonstrate how integration can be achieved in domains where geometry is not necessarily a common foundation.

2. Open versus closed circuits

The industry's preoccupation with software interoperability over the last two decades (Boddy et al, 2007) has led to the development of 'open circuit' practices that do not support responsive feedback between domains. As a result, designers rely predominantly on intuition and rule-of-thumb to make decisions, despite these techniques lacking the capacity to quantify the performance impacts of design decisions against the complexity of project constraints (Bambardekar and Poerschke, 2009). Subsequently, rather than playing a role of decision support in the design, analysis is used primarily to verify and rationalise decisions already made (Hopfe and Hensen, 2009).

These open circuit processes can be seen in Figures 1 and 2, which illustrate the two most commonly adopted methods for exchanging information between domains. Both are based on a strategy of *data model interoperation* and rely on programs sharing information at the level of the product model (Citherlet et al, 2001). Model exchange achieves this via a neutral file exchange format that serves as a generic common representation, while model sharing involves a single data management system that contains the entire building description from which domain-specific applications can extract required information (Citherlet et al, 2001). In both cases, design and analysis models are developed separately, which often results in data redundancies and inconsistencies between representations (Schlueter and Thesseling, 2009). Additionally, neither scenario can support the rapid and interactive transformations required to generate responsive performance feedback.

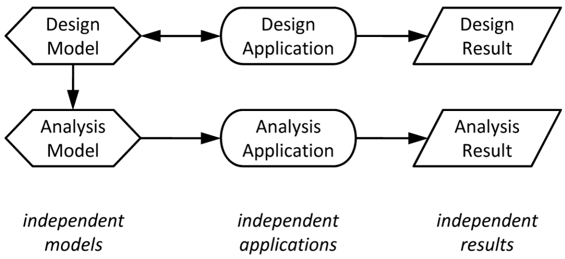

Figure 1. Data model interoperation: model exchange.

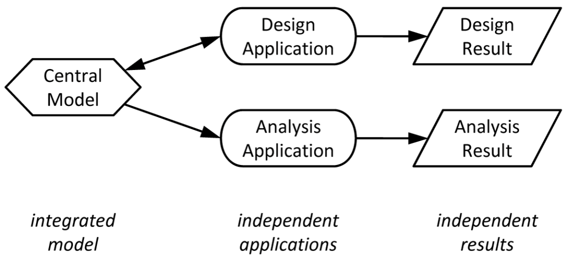

Figure 2. Data model interoperation: model sharing.

What is needed instead is a closed circuit approach that allows information to be dynamically exchanged in a feedback loop throughout design exploration (Janssen et al, 2002). A *data and process model cooperation* approach is currently emerging as an alternative strategy for information exchange that enables this feedback. In this scenario, programs are effectively coupled by providing the facility to link to other applications at run time (Hensen, 2004). As illustrated in Figure 3, one program controls the evaluation process and invokes other applications as required, automatically generating necessary analysis models and performing simulations (Hensen, 2004). As a result, information is able to be cooperatively exchanged during the design process in a manner that is readily customisable. This research finds the cooperative approach to be vital to the development of performance-oriented design tools for early design.

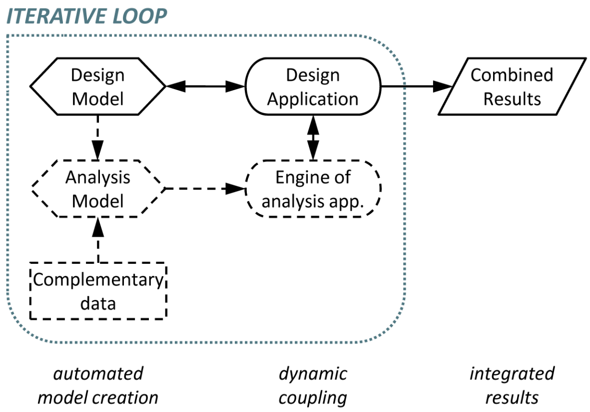

Figure 3. Data and process model cooperation.

3. Energy-oriented design in practice

Despite the proliferation of energy simulation tools in the last decade, few connect to the actual analysis needs of the designer. The majority that attempt integration, such as IES Virtual Environment and Trace 700, typically implement model exchange or model sharing strategies to achieve information transfer with BIM (Building Information Modelling) software, in a manner that is not customisable, and are more suited to the late stages of the design process. Those applications that do target early design often engage a program coupling approach, usually in combination with 'push/pull' modelling techniques, however, pose their own obstructions to integration. Many, such as Autodesk's Project Vasari, employ simplified simulation tools that engineers regard as too unreliable for use in systems design, and subsequently inhibit collaboration between disciplines. Others, like the OpenStudio plug-in for Google's SketchUp, use validated simulation tools, but are incomplete in a collaboration sense as the coupling link deals only with the translation of geometry between programs, and not material properties, building systems, or occupation. Additionally, none of these tools implement parametric modelling capabilities to explore design constraints.

Recent research from Stanford has demonstrated that when a program coupling methodology is combined with parametric geometry definition, a greater number of design iterations and improved performance outcomes result (Flager et al, 2009). Further building on this research is Arup's DesignLink (Arup, 2010). This domain-independent platform uses customised plug-ins to couple parametric modelling and performance analysis applications, subsequently generating trade-off evaluations of constraints (Holzer and Downing, 2010). At present however, there is a predominantly structural flavour to the analysis software that has been linked to the platform, and a focus on the translation of geometry between domains. This research therefore seeks to build on this existing knowledge by examining how representational frameworks can extend beyond a geometric understanding of a building to include the association of behavioural attributes.

4. Parameters and representation

To ensure a common understanding across domains, a unified conceptual framework that identifies and redefines key performance parameters as design-related criteria must be established. From recent investigations into energy analysis undertaken by the primary author, seven groups of parameters have been identified as necessary in constructing an early energy model (Toth et al, 2010). These are as follows:

1. Thermal Zones (used as the geometric construct rather than rooms);
2. Glazing and Skylights;
3. External Shading;
4. Construction Types;
5. Internal Gains for Occupancy, Equipment and Lighting;
6. HVAC Systems; and
7. Weather and Environment.

Rather than following the existing trend of high resolution BIM data structures, a simplified representation schema that connects these seven parameters must be developed to achieve a greater degree of integration with the analytical domain and a level of detail suitable to early design. Energy simulation requires building geometry to be expressed as a series of zones defined by closed sets of planar surfaces, to which performance attributes are attached (Dong et al, 2007). This surface-based representation is considered suitable for conceptual design when architectural considerations are limited to basic form and spatial organisation. Since parametric design environments do not recognise the constructs of 'zone' and 'surface', new representations must be created to ensure semantic compatibility. Each 'surface' is based on the geometry of a polygon, with the addition of a ‘construction type’ property to allocate conductance values. A ‘zone’ adopts a solid geometry to represent its volume, and requires the properties of ‘activity’ and ‘HVAC system’ to determine internal gains and equipment loads respectively.

To avoid overcomplicating input requirements, the designer must be able to simply tag the geometry within the model to indicate the required attributes, and have these tags translated to the relevant numerical values when the analysis procedure is invoked. The system must therefore be able to populate the simulation model automatically with detailed building schedules, thermal conductivity properties, and systems profiles. This requires the development of detailed support databases containing values derived from guidelines and regulations that are well accepted within industry (Morbitzer et al, 2001). These databases enable a system to be developed that allows design representations to be transformed into analytical models and evaluated through simulation, without the need for expert interpretation and translation.

5. Proposed design system

This research proposes an energy-oriented design system that couples GenerativeComponents (GC) and EnergyPlus (EP) to create a decision support tool for early design. The structure for this system (which is currently under development) is illustrated in Figure 4.

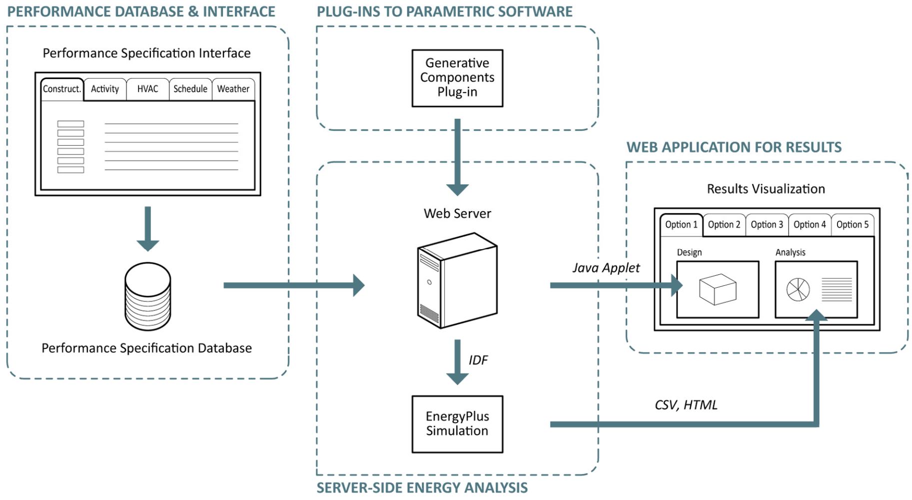

Figure 4. Proposed energy-oriented design system.

This system does not seek to provide exact estimations of operational energy consumption, but rather to offer a reliable means of comparing early design options. By ensuring that a high level of consistency is maintained in the structuring of the analytical models, designers will be able to directly observe the impacts of their decisions by comparing the performance of different design alternatives. The openly customisable design environment establishes a dynamic and cooperative performance evaluation process by linking the modelling application to the analysis procedure through a server-based specification database. Evaluation occurs in close to real time, with results being pushed to a web application that displays design options and performance outcomes side-by-side.

The system consists of four key components, which are discussed in the following subsections.

5.1. CUSTOM PLUG-IN FOR PARAMETRIC SOFTWARE

Additional features must be embedded inside GC to ensure that design models contain geometric and behavioural data suitable for energy analysis, as discussed in the previous section. As well as generating simple planar surfaces, these features are designed to accommodate quite complex geometry through approximations using surface faceting techniques. When the energy simulation procedure is invoked from within the modelling software, the plug-in then sends a query to the database to retrieve the relevant attribute data for each property tag, as well as additional information concerning weather and building scheduling. This information, along with the geometric data from the model, is then forwarded to EP to be analysed.

5.2. PERFORMANCE SPECIFICATION DATABASE

A Graphical User Interface (GUI) is used for populating, viewing and editing the performance specification database, which contains the non-geometric data required for energy simulation. This separates the numerical representation of data from the design model, allowing designers to focus on the manipulation of form and space. The database is hosted on a web server, but can also run as stand-alone. Users can work in connected or disconnected modes, depending on the availability of internet connection. In addition to this, the simulation process can also be invoked from within the database, so that building attributes can be further refined once a design is selected.

5.3. SERVER-SIDE ENERGY ANALYSIS

EP performs analysis on a text-based representation of the building data known as an Input Data File (IDF), which is automatically created when the simulation procedure is invoked. Analysis results are generated as CSV and HTML files, so that they can be displayed directly in the results interface. At the same time, the geometry from the parametric model is stored in the database for on-demand visualisation of the three-dimensional data. This ensures that a snapshot of the design is captured for every simulation performed, to facilitate the tracking of design options and their performance outcomes.

5.4. WEB APPLICATION FOR RESULTS VISUALISATION

As well as displaying the results of the energy analysis, this web application is embedded with a Java applet that displays the stored geometry, so that design options and performance outcomes can be viewed side-by-side. Simplified simulation results are also returned to GC to provide the designer direct access to the performance outcomes within the design environment.

6. Circuits of use

This system aims to create an integrated and interactive design process that facilitates the sharing of design intelligence across disciplines, so that the impacts of design decisions on performance can be clearly understood. It necessitates that common objectives be established upfront so that systems and scheduling appropriate for the spaces of the project can be defined, which creates opportunity for discussion and collaboration between disciplines. Architects and engineers are then able to work concurrently within the system, as illustrated in the use case diagram in Figure 5.

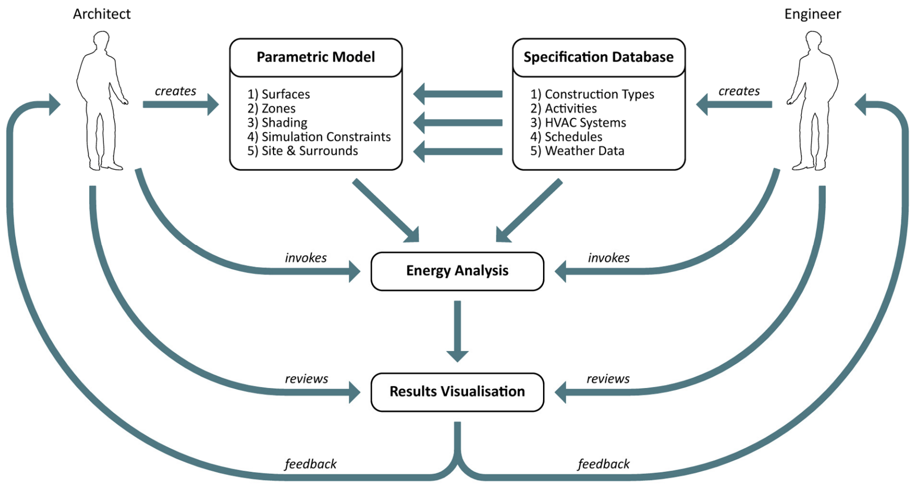

Figure 5. User interaction with the proposed design system.

As can be seen, the different disciplines are able to work in parallel, with the architects undertaking the modelling of different design options, using input from the database that is manipulated and refined by the engineers to ensure accuracy in results. This integrates the typically separate tasks of design and specification to produce a holistic representation of the building, while mimicking the workflows of each discipline. Energy analysis can be invoked from either the modelling or database interfaces, to ensure that both disciplines are able to investigate building alternatives. With the outcomes being published to a common web application, team members are able to review the options simultaneously and make decisions collaboratively.

Typically, one of the primary downfalls of simplified energy analysis applications is that the default simulation data is largely hidden from the user, and often does not reflect the specifics of a project. In response to this, the ability for the user to customise the design environment is a key characteristic of the proposed system. As well as having the freedom to define the non-geometric building attributes through the performance specification database, users are able to extend the actual coupling link as required to include further capabilities such as code-checking. The system is also scalable and accommodates various usage scenarios, from a single user working on a local computer to multiple users accessing the database, server, and results, and can swap between modes of operation at any stage in the design process.

7. Conclusions

While parametric modelling tools have undoubtedly been successful in establishing methods for the rapid generation and flexible exploration of design alternatives, few extend to address performance considerations in early design. This paper presents the framework for a performance-oriented parametric modelling tool that will address this need to facilitate an integrated design process that is *collaborative*, *iterative*, *customisable* and *scalable*.

By linking analysis applications to parametric design software, and simultaneously reducing the complexity of simulation inputs to suit early design enquiries, new decision-support tools can be developed that enable designers to assess the performance of design alternatives quickly and iteratively. It is anticipated that the establishment of flexible and concurrent design and analysis environments, such as the one presented in this paper, will open up a dialogue between architects and engineers and strengthen design communication networks. This will support the development of more integrated design practices that facilitate a shared understanding and knowledge between disciplines, which is of as great a benefit to the design process as the performance evaluation capabilities that the system provides.

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References

Arup: 2010, "DesignLink SDK". Available from: Open Source Repository <http://arupforge.arup.com/wiki/index.php?title=DesignLink_SDK> (accessed 29^{th} November 2010).

Augenbroe, G., de Wilde, P., Moon, H. and Malkawi, A.: 2004, An interoperability workbench for design analysis integration, *Energy and Buildings*, **36**(8), 737-748.

Bambardekar, S. and Poerschke, U.: 2009, The architect as the performer of energy simulation in the early design stage, *11^{th} IBPSA Conference*, Glasgow, 1306-1313.

Boddy, S., Rezgui, Y., Cooper, G. and Wetherill, M.: 2007, Computer integrated construction: A review and proposals for future direction, *Advances in Engineering Software*, **38**(10), 677-687.

Citherlet S., Clarke, J. and Hand, J.: 2001, Integration in building physics simulation, *Energy and Buildings*, **33**(5), 451-461.

Coons, S.: 1963, An outline of the requirements for a computer-aided design system, *Spring Joint Computer Conference*, Detroit, 299-304.

Dong, B., Lam, K., Huang, G. and Dobbs, G.: 2007, A comparative study of the IFC and gbXML informational infrastructures for data exchange in computational design support environments, *10^{th} IBPSA Conference*, Beijing, 1530-1537.

Ellis, M. And Mathews, E.: 2001, A new simplified thermal design tool for architects, *Building and Environment*, **36**(9), 1009-1021.

Flager, F., Welle, B., Bansal, P., Soremekun, G. and Haymaker, J.: 2009, Multidisciplinary process integration and design optimization of a classroom building, *ITcon*, **14**, 595-612.

Hensen, J.: 2004, Towards more effective use of building performance simulation in design, *in* J. Van Leeuwen and H. Timmermans (eds.), *Design and Decision Support Systems in Architecture and Planning*, Eindhoven University of Technology, Eindhoven, 291-306.

Holzer, D. and Downing, S.: 2010, Optioneering: A new basis for engagement between architects and their collaborators, *Architectural Design*, **80**(4), 60-63.

Hopfe, C. and Hensen, J.: 2009, Experiences testing enhanced building performance simulation prototypes on potential user group, *11^{th} IBPSA Conference*, Glasgow, 1976-1982.

Janssen, P., Frazer, J. and Tang, M.: 2002, Evolutionary design systems and generative processes, *Applied Intelligence*, **16**(2), 119-128.

Morbitzer, C., Strachan, P., Webster, J., Spires, B. and Cafferty, D.: 2001, Integration of building simulation into the design process of an architecture practice, *7^{th} IBPSA Conference*, Rio de Janeiro, 697-704.

Nicholas, P. and Burry, M.: 2007, Import as: Interpretation and precision tools, *12^{th} CAADRIA Conference*, Nanjing, 249-257.

Schlueter, A. and Thesseling, F.: 2009, Building information model based energy/exergy performance assessment in early design stages, *Automation in Construction*, **18**(2), 153-163.

Sutherland, I.: 1963, Sketchpad: A man-machine graphical communication system, *Spring Joint Computer Conference*, Detroit, 329-346.

Toth, B., Drogemuller, R. and Frazer, J.: 2010, Information dependencies between architects and services engineers for early design evaluation: A framework for an energy design tool for architects, *15^{th} CAADRIA Conference*, Hong Kong, 313-322.