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DESIGNING A PERFORMANCE-ORIENTED HOUSE ENVELOPE BASED ON A PARAMETRIC APPROACH

An integrated method

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Abstract. Conventional house envelope design methods often generate few alternatives related to meeting living comfort and building environmental requirements. However, these design methods are increasingly facing difficulties in following the dynamic climate change and advanced building performance conditions in the early stage of the design process. This paper attempts to introduce an integrated method for designing a performance-orientated house envelope in New Zealand which adopts the parametric approach. This approach can guide and assist designers to make a well-informed decision, which can satisfy both aesthetics and energy performance, and gain more efficiency for the design process in the early stage of housing performance simulation.

Keywords. Performance-oriented house envelope design; integrated parametric design; dynamic approach.

1. Introduction

House envelope design strategies have been given increasing attention over the last several decades. Conventional building envelope design methods always produce a small number of design alternatives. As a result, the related environmental evaluation and justification for the house envelope design has been somehow separated from the early design phases in the whole process. In practice, performance simulation is normally postponed to a later stage, which largely limits the success of the design process (Chong et al. 2009). Chong et al. conclude that “in the earlier design stage, assessing the fulfilment of design requirements relies on the insight of the designer who can focus only on a limited range of performances". It can be seen that these methods are increasingly facing the difficulties of meeting the dynamic nature of performance-oriented design (Turrin et al. 2011, Bechthold et al. 2011).

An early integration of the envelope design needs to be considered as an integral part of the whole process. As CAD/CAM gained its popularity, the parametric design approach (being flexible in nature) has been demonstrated to have complex form-making capacity. However, few have studied this integration approach (Guzik 2010). Due to the underdevelopment of the tools evaluating multiple options, with so many variables in different platforms it is still a time-consuming process. The possibility of a dynamic design system therefore emerged as a field of research for buildings. This paper attempts to introduce an integrated method of parametric approach for producing a performance-orientated house envelope in New Zealand. This research is intended to suggest an emerging design strategy for developing a dynamic envelope panelling system that is to satisfy both the visual form and energy performance. The research scope of this paper is limited and specific on study of performance-based New Zealand house envelope design. The integrated parametric approach for energy simulation is mainly focused. It is noted that this paper is just a starting part of the whole research. There is a growing need for parametric design tools that integrate energy performance feedback in the early architectural design phase (Turrin et al. 2011) to assist designers with well-informed decision-making. A real-time feedback loop between the adjustable geometric properties (windows, insulation and thermal mass) of a house envelope and its corresponding energy performance can be established and evaluated within one unified system.

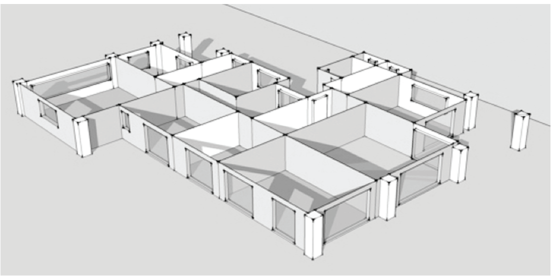

Figure 1. Sketch of the original model.

This paper describes the integrated method through the research of a case study, a one level simple house in New Zealand, based on a New Zealand template house which is defined in the book *Designing Comfortable Homes* (Donn 2010) (Figure 1). It is north-facing, 200 square metres, including four bedrooms and two bathrooms. House envelope design is selected to be explored as the starting point in this research because the building envelope plays a critical part in designing energy-efficient buildings. It functions as an energy mediator between its interior life and the environment of the external world (Lovell 2009).

2. Discrepancy between performance and geometry design

Discrepancy in the whole design process which, including performance and geometry aspects, is explored from the literature review.

A performance-oriented design plays a significant part in designing energy efficient homes in New Zealand. The book, *Designing Comfortable Homes*, established a passive design guideline for New Zealand houses based on the three most important performance factors, namely, glass, mass and insulation (Donn 2010). Glass is to collect the sun's heat; insulation is to keep the heat in; and mass is to store the heat (Donn 2010, p. 6). The three factors are tightly interconnected as each factor is dynamically influenced by the others. For example, in the day-time a bigger window contributes to more heat gain, while at night-time it causes heat loss due to its low R-value.

However, it is often difficult even for the well-intentioned designer to include such a dynamic relationship into the design process (Oxman 2008). As common practice, the fulfilment of code-compliance is the main agenda of performance-based house envelope design in New Zealand. It lacks a holistic approach for designers to design more comfortable homes (Bates and Kane 2009). The current approach has long been recognised as increasingly inefficient in meeting the dynamics of the external climate. For example, there were 27 separated simulation models in Donn's research (2010) in which a very complex process was evolved in order to calculate every possible combination between glass, insulation and mass for a single house.

Furthermore, feedback on the performance implications of design choices is normally lacking in the early stages of the design process due to tools and process limitation (Turrin et al. 2011). Considering the impact decisions made during the conceptual stage on the success of design solution, performance improvements need to be made in the early stages of design process when the building's orientation, thermal mass, materials of envelope, building systems and their properties are proposed (Turrin et al. 2011).

A dynamic system of building design is needed, particularly in the initial stage of the design process where more design options are explored and analysed with the optimised energy design scheme (Toth et al. 2011). The establishment of a feedback loop between form and performance can assist designers to make well-informed design decisions.

3. Performance-based parametric design approach

As discussed above, parametric modelling has the potential of integrating performance requirements into the house envelope design at the early stage. It can represent both geometric entities and their relationships, based on the associative geometry in a hierarchical chain of dependencies.

Parametric design, or parametric modelling, is based on the concept of rules, constraints and association between parameters. All properties of a model, or an object in a model, can be controlled through data values and numbers based on a mathematical formula (Davis 2010). The rules, or numeric values, may represent environmental data (such as solar radiation, solar angles and wind velocity), but as well many other important building geometrical properties (for example cladding panels, sizes and proportions of windows). For design disciplines the concept of parametric has been associated more generally to the notion of design variation (Hudson 2009).

Computational tools such as Maya, Grasshopper, CATIA and Bentley's Generative Components are examples of platforms that allow parametric control of model geometry through parameters and constraints. Currently, the concept of performance-oriented (also called performative) design has recently emerged, as a design method in which building performance is seen as a design driver to guide the whole design process from its inception to final completion.

The house envelope design needs to work as a holistic system to interact with the energy flows in order to create a comfortable living environment and reduce energy use of the building. It is not merely seen as a physical boundary to separate the inside and outside, but increasingly considered as a possibility for integration in a coordinated response to the issue of light, heat gain and heat loss through a dynamic design strategy.

4. An integrated method of parametric design approach

4.1. OVERVIEW

This research provides an integrated method of parametric design approach, which connects house envelope design to building performance (Figure 2). In the early design stage, performance parameters and geometry parameters are cross-examined though establishing governing models and processing models of the original house (details are explained in Stage Two and Three). Such a system enables design schemes to be easily modified in the development and detail design stages, due to its dynamic nature.

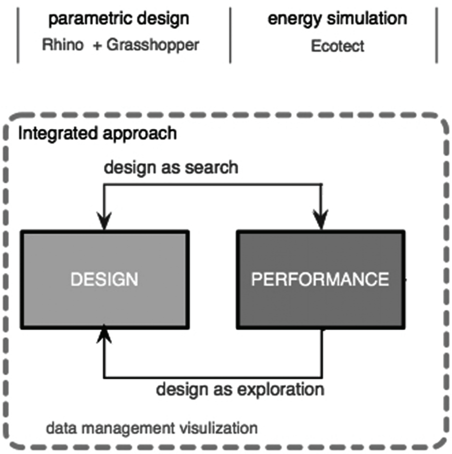

Figure 2. Overview of the method.

4.2. STAGES OF METHOD

4.2.1. Stage one: define parameters and constraints

To ensure a common understanding of house envelope design across different platforms (parametric design, performance), a collection of key performance parameters is identified and defined in line with its corresponding geometrical as well as system constraints. Due to the wide breadth of performance-based design knowledge, the proposed system has to be defined in a way that is both specific and comprehensive. The working system boundary is defined based on two groups of parameters, as shown in Table 1.

Two categories of parameters are identified as critical components for the proposed performance-oriented parametric system, namely, performance parameters and geometric parameters. The reason for the selection is discussed in Section 2. In this research, performance criteria to be evaluated are listed, including daylight factors and levels, incident solar radiation, shadow and reflections, and thermal performance (heating and cooling loads).

By assigning different values to glass, insulation and thermal mass, the values of the above performance factors are accordingly adjusted in parallel with the geometrical change of the house envelope. The change of performance factors can be visualised within the system, which assists designers to make possible the interaction between design selections and their energetic impact.

TABLE 1. Different types of parameters

Types of parameters	Parameters	Values		
Energy parameters [1]	Glass (wall WWR)	25%	40%	55%
	Insulation	Code	Better	Best
	Thermal mass	Low	Medium	High
	Orientation	Floating value		
	Solar azimuth and altitude	Floating value		
	Location	Wellington (fixed)		
Geometry parameters	Window unit size	Floating value (w×h)		
	Window distribution types	Floating value (n)		
	Wall (panel) grid	Incremental values (u×v)		
	Wall inclination angle	Floating values (d)		
	Wall curvature factor	Dependence on grid points		

[1] Key parameters as have been identified as necessary in constructing an early energy model for house envelope design (Donn, 2010).

Grasshopper is to be selected for the parametric modelling tool because of its gaining popularity in research and practice and its seamless integration with Rhino, which offers capacity of flexible modelling, rendering and design work flow. Autodesk Ecotect, an energy performance simulation tool, is selected for this research because it offers a wide range of simulation tasks and is broadly used both in research and practice.

4.2.2. Stage two: parametric governing model

Stage Two establishes a governing model based on the original model (from Donn 2010) – this model has been introduced in the early section. It is a surface-based model composed of geometric primitives (points, polygons and surface). It is to explore various possibilities of linkage and interaction between parameters though a series of tests. This stage is principally about taking the parameters defined in Stage One (detailed in Table 1) and relating them to the original model. A flexible relation between geometries and energy performance is analysed. A relational diagram is applied in mapping the full relationship of different parameters. The governing model, then, is established in such a way that it can explicitly manipulate both the geometrical and performance variables for feedback data visualisation and result comparison.

Two tests are undertaken in this stage to explore various aspects of the governing model. Figure 3 shows the schematic diagram of two tests. The various combinations of parameter setting and their interrelationship are examined in these tests. The living room of the "house model" (one thermal zone) is selected and a series of tests are undertaken against some basic environmental criteria:

- Test One explores the visual feedback of performance factors triggered by changes of performance parameters (Details of this test is listed in Table 2).
- Test Two explores the direct visual interaction between geometry and performance. Expected changes of performance results are triggered by various window distribution patterns and wall tilting angles. Test Two is based on the governing model from Test One (Details of this test is listed in Table 3).

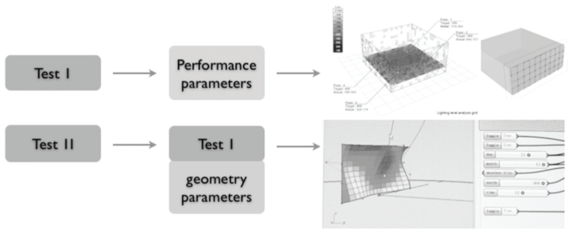

Figure 3. Schematic model of two tests in Stage Two.

TABLE 2. Details of Test One

Input	Performance parameters (insulation, glass, thermal mass, orientation, sun path)
Process	Explore the visual feedback of performance factors triggered by changes of performance parameters
Output	Data visualisation within the governing model system (daylight factors and levels, shadow diagrams, incident solar radiation)
Steps	• Translating specification from constraints defined in Stage One to relational schema (diagram) for one thermal zone • Explore various parameter combinations by changing several levels of performance parameters (including glass, insulation, mass)

TABLE 3. Details of Test Two

Input	Geometry parameters + performance parameters
Process	Explores the direct visual interaction between geometry and performance
Output	Design iterations with various geometry properties and performance data
Steps	• Modify the original model in a visually interactive way. Geometries of the house envelope is synchronised with performance criteria (for example changing size of windows can directly impact on daylight availability) • Examine the feedback loop between geometrical forms and their performance

4.2.3. Stage three: processing model: design exploration, simulation and visualisation

Stage Three is a core component of the overall research. It focuses on the full range of performance requirements (explained in Stage One) with multiple thermal zones in terms of surface subdivision.

Simulations are run for winter and summer scenarios respectively; the objectives of the optimisation are different between winter and summer. In winter, it is aimed at maximising both the daylight factor and incident solar radiation; in summer it needs to maximise the daylight factor, but minimise incident solar radiation. The conflicting objectives pose challenges for design exploration. The combination of monthly incident radiation (June and December) and daylight factors are set as performance goals for generating a large collection of corresponding geometric iterations of the envelope. The Galapagos, a plug-in of Rhino Grasshopper, is applied as a bi-directional approach aimed at tackling the multiple-objectives problem.

Based on the parametric "governing model" from Stage Two, Stage Three is to develop a processing model, which takes one step further from Stage Two (single objective in single thermal zone) towards multiple objectives in multiple thermal zones (Figure 4 and Table 5).

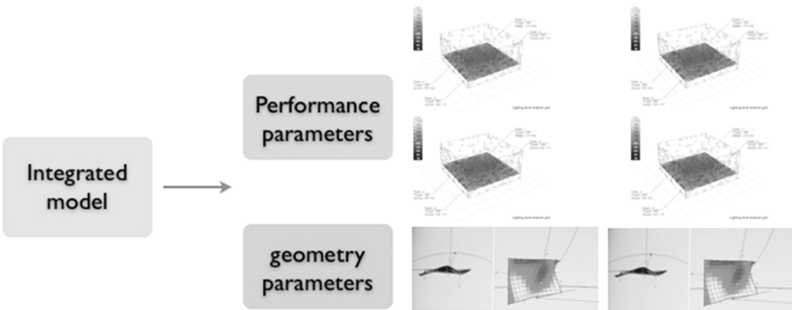

Figure 4. Schematic model of Stage Three.

TABLE 5. Steps of Stage Three

Step 1	Refining the governing model by including three groups of parameters (allow grid points movement in different directions within a given range)
Step 2	Assigning the cladding panels and glazing in Rhino and setting up platform
Step 3	Analysing and sorting the solution of fitness towards which design iterations can automatically be compared and optimised

Step 4	Automatically computing the process of searching and generating envelope geometry towards the fitness goal through the working platform; two collections of design iterations (winter and summer) are expected
Step 5	Envelope surfaces are subdivided according to assigned material constraints
Step 6	Manually analysing the outcome of geometric forms, performance data
Step 7	Setting up a database to store collection of data of design iterations; a web server is to be established at www.parametrichouse.com to host the database that will be later applied for visualised tests

5. Conclusion

This paper attempts to establish an integrated method of a parametric design approach for performance-orientated house envelope design. This approach is to assist designers to make a well-informed decision to satisfy both aesthetics and energy performance requirements, and to gain more efficiency for the design process of performance simulation in the early stage.

It found that there is a growing need for parametric design tools which can assist designers with well-informed decision-making. The advancement of Computer Aid Design (CAD) in the building industry, particularly the recent development of parametric design combined with other energy simulation tools, promises some possible directions to create and build a building envelope with complex geometry and climate-oriented adjustment in form. It provides a flexible system containing associative parameters with adjustable values. It can be explored during design through variations of performance-related parameters that meet the internal and external climate conditions.

Currently, this research investigates a conceptual view of the dynamic approach to provide a foundation for improving the understanding of house envelope design across different platforms (parametric design, energy performance). This paper is just a starting point. This whole study is intended to fill the gap for a theoretical system between the architectural, performative processes.

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