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Performance-driven architectural design and optimization technique from a perspective of architects

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ABSTRACT

Performance-driven architectural design emphasizes on integrated and comprehensive optimization of various quantifiable performances of buildings. As the leading profession of a project team, architects play a vital role in guiding and conducting the performance-driven design. Methodology and techniques start emerging both in literature and practice. However, architects often find them difficult to use for various reasons. Therefore, developing an effective technique to conduct performance-driven design and optimization from the perspective of architects is necessary. This paper starts from discussing the concept of performance-driven architectural design. Existing methodology and techniques are reviewed. The focus is on selecting a basic platform suitable for architects, upon which the technique can be developed. Rhinoceros, an architectural modeling program, is used, along with its graphical algorithm editor Grasshopper, to establish such technique by incorporating three performance simulation programs, namely Ecotect, Radiance, and EnergyPlus. Design cases are presented to demonstrate the technique and its effectiveness.

1. Introduction

Performance-driven architectural design emphasizes on integrated and comprehensive optimization of various quantifiable performances of buildings. It is an important research subject and a design philosophy being practiced by many architects and design firms [1]. Compared with the conventional architectural design methodology, which focuses on space and form, performance-driven design takes a holistic view towards ecological and environmental performances of buildings while ensuring that the functions and esthetics of the design are not overlooked. It is particularly important in countries undergoing fast urbanization such as China [2] since the performance of many newly built buildings affects the overall quality of urbanization.

A major boost for performance-driven architectural design is the implementation of green building standards internationally such as LEED in the US [3], BREEAM in the UK [4], and the newly launched green building evaluation standard in China [5]. These green building standards establish many quantifiable performance requirements to guide and control the design. Thus, performance-driven design is encouraged and more rational thinking and scientific analysis are brought into the field of architectural design. As more and more green buildings emerge, architects, the leading professional of a building project team, urgently need to study and grasp the new design philosophy and the supporting technique to ensure the design quality while keeping the good essence of the conventional design.

1.1. Green buildings and architects

Reviewing the history of green buildings shows a clear pattern that it is largely the research, development, and utilization of new materials and/or mechanical equipments that lead the progress of the field. As a consequence, the green building is gradually becoming a high-tech architectural machine and architects, the supposedly leading professional, are somewhat lost. The conventional architectural design methodology is often powerless facing the scientifically rigorous and quantifiable performance criteria. The implementation of green building standards exacerbates this problem. Two kinds of so-called green architects can be identified.

- The first kind is an architect who follows the conventional design approach to complete the conceptual design. He then turns the work to other professionals such as consulting engineers or mechanical engineers to apply various green technologies. In this way, the green building is designed by rigidly adding technologies without adequate integration and optimization.
- The second kind is an architect who aims at designing a green building in the conceptual stage. Due to the lack of specialized knowledge and technique, he uses conceptual, non-quantifiable,

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and sometimes even vague methods to design. The end result is a quite subjective design which may or may not be truly green.

The first kind of green architects already loses control of the design. The final quality and the performance achieved are determined primarily by the effectiveness of technology summation. The cost is significantly higher and more importantly, no integration or optimization of technologies is conducted. The second kind of green architects is still the leading professional in the design team. However, since the design methods he applies are conceptual and non-quantifiable, he has no real control over building performances. His interpretation of the design can only circle around ideas and/or concepts. Performance criteria cannot be rigorously checked, not to mention satisfy green building standards.

Therefore, what architects urgently need is a new methodology and the supporting technique of performance-driven design which can be applied in the early conceptual design stage and are reasonably precise, efficient, and dependable.

1.2. Conventional methodology and performance-driven architectural design

The conventional architectural design methodology is, in essence, an approach involving some basic design principles, mainly based on functions and forms. The driving force is the combination of the architect's rationality and sensibility. When performance criteria must be met, this design methodology is facing unprecedented challenges. Architects have to deal with the following three problems.

- The prerequisite for performance analysis is a building model that can be analyzed. However, the complexity and variance of buildings make an analyzable model quite difficult to obtain. The current practice usually involves setting up a model using design software and then importing the model into performance simulation programs. This process is time-consuming and labor-intensive.
- The model created in most modeling programs only contains geometric information (the latest development and application of building information modeling might change it). Many non-geometric parameters have to be input in the simulation program. This, combined with the previous point, discourages the engineer to use the architect's model for performance simulation purposes. Rather, he prefers to directly set up the model in the simulation program for he can input both geometric and non-geometric information at once.
- However, the modeling capability of most simulation programs is not on the level of commonly used architectural modeling programs, especially when dealing with complex shapes and forms. Here a dilemma arises, i.e., the engineer does not want to use the architect's model because he has to import it and add many parameters before a simulation can be run; on the other hand, the architect is not satisfied with the engineer's simplified model and believes that it lacks details and is not esthetically pleasing.

These three problems are difficult to overcome using conventional design methodology. New approaches and techniques must be developed to assist the architect to carry out performance-driven design.

An architectural design process can be divided into three steps, namely, conceptual design, detailed design, and construction document design. It is widely agreed that design decisions made in the conceptual stage have the largest impact on the final overall performance of the building. Guillemin and Morel conducted a survey on 67 buildings and found that 57% of technological decisions were made in the conceptual design stage, compared with only 13% in the detailed design stage [6]. Therefore, the methodology adopted by the aforementioned two types of green architects clearly has limitations. The right paradigm is to incorporate performance analysis into the early conceptual design stage so that right technical decisions can be made. The performative outcome of different designs should be quantifiable and visible to the client and the architect.

1.3. Performance-driven design and digital technology

Conducting performance analysis and optimizing the design effectively and efficiently used to be challenging. Lately, the rapid progress of digital technology and its application in architecture have changed the field dramatically. The emergence and development of performance simulation tools make rapid performance analysis possible. More and more architects and engineers become familiar with these tools and proactively use them in the design. More powerful personal computers shorten the time needed for analysis. In recent years, building performance simulation has become a very active research field. On one hand, researchers and specialists are studying and producing more powerful simulation tools. On the other hand, practitioners start realizing the value of incorporating them into the design process. This combined force pushes performance-driven architectural design to the forefront.

This paper aims to analyze the concept of performance-driven architectural design and its current status. We argue that the performance-driven architectural design is a design philosophy that must be supported by effective and efficient design technique. Equally important, the technique should be viewed familiar and practical from the perspective of architects. First and foremost, the technique must involve a modeling platform that architects feel comfortable with. Secondly, the simulation tools that can be integrated into the design flow should cover the most important performances that architects need to consider. Last but not least, the optimization algorithms should be readily available. Very few architects can and want to write their own codes for optimization. Such performance-driven design flow and technique can assist the architect to explore many design possibilities and their corresponding performances in a convenient way. The end result is a design that is esthetically pleasing, spatially efficient, and performatively sound.

2. Literature review

Many architects, engineers, and researchers have aimed at achieving performance-driven design. Research works conducted by different professionals show distinguishable features. Analyzing these features helps us understand what kind of approach and technique architects need. The following section presents a short literature review on performance-driven architectural design. The literature is grouped into three categories based on who the leading professional is.

The first category of the research work is led by computer scientists or software engineers. Performance-driven design is achieved by developing source codes from the very bottom. Very few architects are involved since they don't possess the special knowledge and skills to write a significant amount of computer codes. For instance, Ellis et al. [7] developed an automated multivariate optimization tool to perform energy efficient building design. The tool employs multiple modules, including a graphical user interface, a database, a preprocessor, a simulation engine, an optimization engine, and a simulation run manager. All modules are customer written.

The second category of the research work is led by consulting professionals. The framework is to use commercially available optimization program and integrate building performance simulation tools to conduct performance-driven design. Some computer code writing is usually needed to set up the design flow. Shi [8] used modeFRONTIER, a commercially available optimization program, and integrated energy simulation program EnergyPlus to study the optimal insulation strategy for an L-shape, one story building. Also using modeFRONTIER, Manzan and Pinto [9] integrated ESP-r, an energy simulation program, and Radiance, a lighting simulation program, to design an external shading device in an office with a window and different glazing