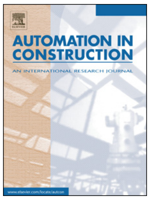
Automation in Construction xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon



An exploratory model on the usability of a prototyping-process for designing of Smart Building Envelopes

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ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form 26 December 2016
Accepted 15 March 2017
Available online xxxx

Keywords:
Virtual Model (VM)
Smart Physical Model (SPM)
Smart Building Envelope (SBE)
Prototyping
Sketch

ABSTRACT

The Smart Building Envelope (SBE) is an interactive system which is adaptive to environmental conditions by transforming its shape and functions. The success of the SBE depends on elaborate interactions among the various building components. The acutely challenging issue is to design the SBE not only to satisfy multidisciplinary requirements but also to orchestrate the technical functions of components. The research objective is to propose an exploratory model on the usability of a prototyping process for SBE design. So the research is related to the conceptualization of the prototyping process model based on complementary use of the Virtual Model (VM) and Smart Physical Model (SPM). The conceptual prototyping process model is appropriate for consideration of the characteristics of the architectural design, the resources of the educational environment and the limitations of the novice designer. Furthermore, the prototyping process model in this research will help in the formulation of guidelines for the educational process, which in turn will help not merely to make intricate engineering products but also to introduce observed results into the architectural design process.

1. Introduction

A building system largely consists of 4 sub-systems including the load-bearing structure, technical service (heating, ventilation, air-conditioning), the spatial sequence (interior walls) and the building envelope. The building envelope is influenced by both interior and exterior environments and is directly linked to the performances of the other sub-systems [1]. The building envelope is required as an up-and-coming architectural strategy that minimizes the effects of surrounding environments and responds to emerging issues such as energy depletion and climate change [5,25]. The building envelope, via the integration of smart technologies, is becoming a nearly automated system for responding to environmental alterations, whose function is balanced with those of the other sub-systems.

In this context, the Smart Building Envelope (SBE) is defined as a system for adaptation of shapes and components to environmental changes and user behaviors. The SBE, also known as 'responsive facade' or 'intelligent facade,' is an interactive building envelope that adapts to environmental conditions by transforming its shape and functions. It is a kind of machine operating based on multiple interactions between sub-components, the optimum motions or shapes of which are not easy to explore by means of the conventional design process applied in general building projects [16,18,20,31]. Technological advances in computational intelligence have enhanced SBE performance [27]. The SBE is typically adopted in facilities integrated with networks of sensor and actuators to predict requirements between buildings and users (Fig. 1). The SBE, compared with general building envelopes, is sometimes considered overkill due to its high-investment cost, but can be rather beneficial in its contribution to energy saving or the control of occupants' comfort, thus reducing life-cycle or social cost.

The tolerance of architectural design tends to be relatively high as the margin of error in building design used to be accepted through changing user activities and controlling system capabilities [13]. The success of the SBE, however, depends on elaborate interactions among the various building components. In designing the SBE, heterogeneous technology such as robotics, smart materials, IoT (Internet of Things) and architectural design needs to be incorporated so that design reliability, geometric constraints, robustness of structure and safety of movements are all actively considered and accounted for [15]. This is why the SBE is a low-tolerance design. The acutely challenging issue is to design the SBE not only to satisfy multidisciplinary requirements but also to orchestrate the technical functions of components. Designing an SBE is finding the optimum interactions among numerous building components corresponding to the given design requirements. More specifically, it is the orchestration of the functions of building components by consideration of their integrated engineering [12]. Therefore, when applying smart building technologies for buildings, design errors that would have counterproductive effects on overall building performance need to be detected in the initial design phase.

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http://dx.doi.org/10.1016/j.autcon.2017.03.012

Please cite this article as: D.-Y. Kim, S.-A. Kim, An exploratory model on the usability of a prototyping-process for designing of Smart Building Envelopes, Automation in Construction (2017), http://dx.doi.org/10.1016/j.autcon.2017.03.012

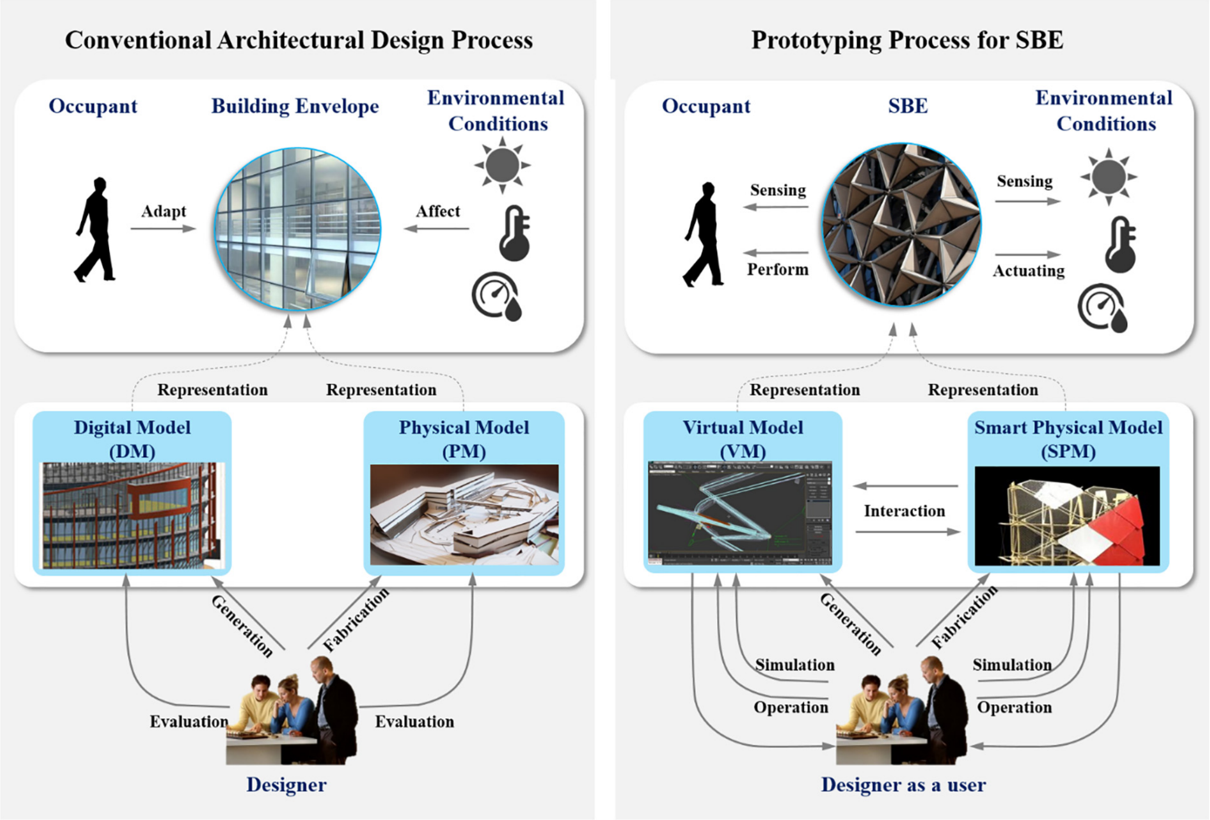

Fig. 1. Roles of VM and SPM in designing SBE.

Currently, smart technologies are generally introduced in the final phase of the contemporary architectural design process [29]. Smart facilities are not orchestrated based on the overall performance of buildings, but are adopted regardless of the spatial design. Indeed, focusing only on the specific technological establishment quickly runs up against the problem of obsolescence. For proper design, the SBE needs to identify whether or not the applied technology will have negative effects on the surrounding environment and user behaviors from the early stage of design. Prototyping is considered a reasonable method to deal with the SBE design in this context.

Prototyping is the process of building a model that represents design ideas (principles) for end-users and explores possible design errors. It has been generally used in the manufacturing industry, for example aircraft or automobile design. Contemporary prototyping is classified into two methodologies: digital prototyping and physical prototyping. Digital prototyping utilizes a 3D product model based on Computer Aided Design (CAD) techniques. It creates shapes, puts them together, and tests overall performances, all without manufacturing physical models. Physical prototyping, by contrast, manufactures and tests physical mock-ups in the real world. Therefore, it is influenced by material properties and deformation, and as such, it has to filter incorrect assumptions or improper values and then eliminate drawbacks via the process of constructing an assembly and testing it for realistic performance. Recently, a complementary digital-physical prototyping strategy has become a mainstream method in manufacturing design. It helps to achieve highly specific building-system performance goals by fully taking advantage of each prototyping methodology (Z [34]). The digital model, harnessed with parametric technologies and integrated simulation tools, empowers the designer not only to investigate various possibilities and evaluate performances, but also find the optimum designs among the parametric variations. However, the digital model cannot offer full real-world support in terms of complex environmental conditions and user sense, perception, cognition and behavior. On the other hand, when using the physical model, designers can detect design errors intuitively by responding to physical conditions. Therefore, if physical computing devices are integrated into the physical model, the Smart Physical Model, thus evolved, will prove useful for in-depth investigation of real-time operations. Despite its advantage of the physical model, the greatest barrier to the utility of the physical model is the great time and cost incurred in fabrication or assembly. Furthermore, complementary digital and physical prototyping is required for designers to be able to fully maximize the advantages of both the digital and physical models: the digital model's reduction of repetitive workflows and rapid discovery of various alternatives in terms of target performances; the physical model's elaborate design scheme and utilities for resolution of problems not investigated in the digital model.

In particular, SBE design needs to be enhanced in consideration of the processes of engineering product development. If the complementary prototyping methodology is applied in SBE design methodology, a system not only can be created for explaining design strategy but also can be elaborately improved in its composition and movement. It is fundamentally different from the nature of traditional architectural design which has been rather prescriptive. The complementary digital-physical model allows for three advantages in SBE design. First, using the digital model, parametric variations are generated based on the equivalent design scheme and evaluated in relation to the target performance to facilitate discovery of the proper design for users (occupants or clients). Second, using the digital model with digital fabrication tools, the system can be developed quickly from the free-form shapes to the intricate details. Third, the interaction between the digital and physical models using sensors, processors, and actuators means that movement and shape become adaptive. An adaptive system makes possible real-time response to the physical environment. In this paper, such real-time-response-enabled digital and physical models are referred to as the Virtual Model (VM) and the Smart Physical Model (SPM), respectively. However, whereas previous studies have analyzed affordance (i.e., the

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