A shape-grammar for double skin facades

A basis for generating context sensitive facades solution

Negar Ashrafi¹, José Pinto Duarte²
¹,²SCDC, School of Architecture and Landscape Architecture, The Pennsylvania State University
¹,²{nza119|jxp400}@psu.edu

Double skin façade (DSF) is considered one of the best envelope systems in terms of energy efficiency. However, designing an energy efficient DSF system depends on different factors, such as climate, DSF shape and how the air flows in that system. This study presents a methodology to assist design decisions regarding the DSFs shapes. For this purpose, shape grammars was used as a generative design system to generate alternative DSF shape designs. Results of this study can be integrated with an energy simulation tools to calculate the energy demand of each design and consequently design the most efficient DSF system for each context.

Keywords: building envelope design, double skin façade, generative design system, shape grammars

INTRODUCTION

In developed countries, energy saving is a high-priority concern. Therefore, an extensive set of energy-efficient measures and features are being increasingly implemented in all areas. The building sector is not exempt from this concern as it is responsible for an important part of the overall energy consumption in the world. One of the most important methods of energy saving in a building is to carefully design its façade. A ‘double skin façade’ (DSF) is considered one of the best options in managing the interface between the outdoors and the indoor spaces. It also provides some architectural flexibility to the design. Recently, it has attracted more attention as an alternative solution to the more traditional glazed curtain wall. This is due to its ability to efficiently reduce energy consumption, which decreases building operation costs. The amount of energy saved depends on the climate and on the selected design. The specific configuration of DSF systems can vary, but generically these systems consist of few basic parts, including exterior glazing, interior glazing, and the airflow cavity between them, where shading devices are usually placed (Uuttu 2001). The design of the DSF involves decisions regarding on different parameters such as geometric parameters, glass selection, ventilation strategy, shading, daylighting, aesthetics, wind loads, and maintenance and cleaning cost expectations (Kim et al. 2013). Combination of these different parameters may result in the creation of multiple types of DSF. The motivation for this research is the need for a system that can present all of the design alternatives, so that it can be used in dif-
different analytical studies (e.g., energy analysis or cost analysis).

This paper aims to use shape grammar as a methodology to assist designers in the design of DSFs. In this study, two of the most common ways of classification of DSFs (i.e., based on geometry of the air cavity and on ventilation mode) are used as a basis to develop a shape grammar, capable of generating alternative DSF designs. The results can be integrated with energy simulation to calculate the energy demand of each design and ultimately results in selecting the most efficient DSF system for each context.

PRECEDENTS

Double skin façades

The term double skin façade (DSF) covers a wide range of façade systems and types from narrow fully sealed assemblies to systems with fully operable external louvers or shading devices (Arons 2000). Although different definitions of DSFs exist, the basic concept is a façade system that is comprised of an external and internal glazing system separated by a ventilated cavity hosting an operable blind or shade. The main advantage of DSFs is the greater control that they provide over the thermal/ fluid exchange between the perimeter zone and the outside environment (Doebber and Mcclintock 2006).

According to Author and Pollard (2000), there is no accepted standard for grouping or defining the different types of DSF. The literature reviewed in their report found multitude ways to classify them. Some of the most popular methods for classifying DSFs are based on the geometry of the air cavity, as well as on the ventilation mode. For instance, Compagno (1999) provided a comprehensive review of

Figure 1
Classification of Double Skin Facades (DSF) based on the geometry of the air cavity. (a) Building high double-skin façade, (b) Story-high double-skin façade, (c) Box double-skin façade, and (d) Shaft façade

Figure 2
Classification of Double Skin Facades based on different airflow possibility and geometry of the air cavity
Figure 3
The proposed grammar rules based on the geometry of the air cavity and different air flow pattern

DSF and stated that double-skin façades can be divided into four categories based on the geometry of the air cavity: building high double-skin façade (multi-story window), story-high double-skin façade (corridor window), box double-skin façade, and shaft façade, as shown in Figure 1.

Loncour et al. (2004) added an additional type of DSF to the above typology called the louvers façade. Recognizing the advancements made in the industry over the years, Knaack et al. (2014) further developed this typology with two additional types: alternating façade and integrated façade. It is notable that some of the types of DSFs mentioned are quite similar with small differences, which was not in the scope of this study, so they were considered to be in the same category. There are also some other classifications based on the ventilation mode of the DSFs and the air flow pattern, as shown in Figure 2. Airflow pattern describes the air movement into and out of the cavity, which is considered the main difference between double-skin façade and single-skin façade. The three modes of airflow include outside-ventilated, inside ventilated, and hybrid ventilated (Arons 2000).

**Performance-driven generative design**
Shape grammars and other generative and parametric design tools can affect architectural design in early stages of the design process. These tools can predict the design solutions by analyzing and optimizing early design alternatives through parameter control.
There are several examples of using generative/parametric design tools in order to assist design decisions that have been made with different purposes. Monks et al. (2000) applied optimization techniques to a generative acoustic simulation system through an interactive approach of acoustic design. Shea et al. (2005) used a preliminary integration of a generative structural design system (eifForm) and Generative Components through the use of XML models. Caldas (2008) used GENE_ARCH, which is an evolution-based generative design system assisting designers to achieve energy-efficient and sustainable architectural solutions. For this purpose, she combined a genetic algorithm (GA) as the search engine with the DOE2.1E building energy simulation software as the evaluation module. Moreover, Granadeiro et al. (2013) integrated shape grammars as a generative envelope shape design, parametric design, and energy simulation to calculate the energy demand of each design solution, hence, assisting designers in decision making in early design stages.

**METHODOLOGY**

In this study, shape grammars was used for encoding and developing a generative design system. According to George Stiny who co-created the concept of shape grammars, shape grammars are systems containing an initial shape and transformational shape rules. By applying shape rules to the initial shape recursively, a set of shapes that are part of the same family or belong to a certain style can be generated.
Therefore, in this study it was attempted to develop a grammar for DSFs by:

- Analyzing the selected classification of DSFs (based on the geometry of the air cavity as well as the ventilation mode);
- Extracting the rules that are embedded in the structure of DSFs based on the aforementioned classifications;
- Applying those rules to the initial shape (in this study the initial shape is a single pane window that is considered as a baseline) to generate all design possibilities.

**The grammar**

As already mentioned, there are four main types of DSF based on the geometry of the air cavity: box windows, shaft windows, corridor windows, and multi-story windows. Moreover, in this study three main air flow patterns (i.e., Outside-ventilated, inside ventilated, and hybrid ventilated) were combined with different types of air cavity geometry to produce twelve different types of DSF system. These different classifications of DSFs are depicted in Figure 2.

In generic terms, a grammar is a production system that consists of “if-then” rules. Geometric operations-translation, such as rotation, reflection, and scale can be applied to match the “if shape” of the rule to a shape in the evolving design, and substitute it for the “then shape”. In shape grammars, rules can be potentially applied an infinite number of times (Granadeiro et al. 2013).

In order to extract the rules from available DSFs, we started with a single pane window as the initial shape (from which all DSFs were generated) and tried to re-create all possible air cavity geometries, step by step. It should be noted that, as the section of the DSF system is the best view to describe the details and differences of the various DSF configurations, the extracted rules were defined in this view. Figure 3 presents the extracted grammar rules base on the geometry of the air cavity and different air flow patterns. In the first step, the air cavity boundaries are created by applying rules 1 to 6, thereby creating the geometry of the air cavity. These rules recreate different types of interior and exterior glazing system (single pane or double pane), the vertical partitions position, and the pivot point of the interior window. Rules 7 to 31 define different configuration for the openings in the interior and exterior glazing systems. Rules 32 to 50 describe the possible direction of the air flow in each of the created air cavity geometries. Figure 4 shows some of the derivations of DSF designs using the proposed grammar rules.

In the next stage of our research, to explore the potential of the proposed shape grammar-based methodology for designing DSFs, we considered a case study. As shown in Figure 5, this case study was a DSF system formed by 4 by 5 modules, totaling 20 modules. Each of these modules, has two different
sections (section A-A, and section B-B) and the proposed shape grammar rules can be applied to each of these sections, independently. Different design variations for one module were generated as discussed in the next section.

RESULTS
The results of the study indicated that, based on the rules extracted from existing DSF designs, there are 20 different design variations for section A-A and 27 design variations for section B-B. Some of the design variation of section A-A and B-B are illustrated in Figure 6. As a result, there are 540 (20 x 27) different design possibilities for each module in the DSF.

Considering that each of these 20 modules could approximately have the same number of design possibilities, the potential of using this methodology in the design of appropriate DSF designs for different contexts is clear.

SUMMARY AND FUTURE WORK
In this paper, we propose a shape grammar-based methodology to assist designers in the design of DSFs. The development and application of the shape grammar is based on two of the most common ways of classification of DSFs (i.e., based on geometry of the air cavity as well as ventilation mode).

For future work, this design system can be implemented as a parametric design system, and coupled with other analytical tools to search for the design solution with best performance for a given context. For instance, it can be coupled with Ecotect and SAP SE to find the solution with the least energy consumption. In this scenario, different design solutions produced by the shape grammars can be analyzed in different contexts with regard to their energy consumption. The outcome of this study, provides a framework for decision making in early façade design stages.

REFERENCES
Arons, DM 2000, Properties and applications of double-skin building facades, Ph.D. Thesis, Massachusetts Institute of Technology
Verkerk, NM 2014, A general understanding of shape grammar for the application in architectural design, TU Delft, the Netherlands