

Adaptive Façade: Variant-Finding using Shape Grammar

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Abstract. Modular façade construction has never been better since the birth of computer-aided manufacturing which bridges the modeling phase into the manufacturing phase for escalating the mass production. This comes to a result that the identity of a product or a building façade will commonly generate in the same way that the initial design was intended to. Rectifying the early model will then greatly impact the process later. The aim of this paper is to propose a way to solve these two challenges, without risking the manufacturing process, but more to explore the potential designs. Shape grammar is used to conceive more designs in the early stage, derived from the initial product – the modular adaptive façade system. The derivations are then tested through simulation to state the efficacy of the models. We find that the workflow somehow contributes to the better design and engineering process as well as the solution allows diversification in the façade expressions.

Keywords: shape grammar, adaptive façade, energy efficient, design tool

1. Introduction

People tend to spend almost 90% of their life in a shade [1], thus the building is meant to be built safe and secure, and as comfortable as can be. Building skins contribute to cover and protect the inhabitants from the negative impact of unpredictable external conditions. In the other side, extreme natural lighting and hardworking HVAC system are popularly adopted in the 20th century. Therefore, building skins lose their role as an energy controller and as a shade from vigorous sun radiation. This condition makes the energy consumption in the building is reaching the level of industrial and transportation consumption [2]. Moreover, built environment produces one-third of the CO₂ emission on a global scale.

Buildings are characterized as one of the causes of global warming and all its implications. However, these conditions provide challenges for designing a better system in terms of building skins. The International Panel on Climate Change states that buildings are the highest potential sectors that can mitigate negative impacts, UNEP [3] emphasizes efforts to be more significant than before pressing these issues. A new paradigm for defining energy efficiency requires a transformation. The act is meant to be the norm in every building rather than a prescription, whether it is an old building or a new construction [4]. Innovation and technological proliferation in building skin designs must be a catalyst for this great leap in change.



2. The Design Research

2.1. Secondary Skin Design

The development of adaptive secondary skins to raise the energy efficiency and building performance [5], and adaptive system using parametric camshaft mechanism [6] so far have built a prototype as shown in Figure 1. The further development of the research was to develop the skin into a SOHO building as a case study [7]. The mechanism somehow creates a boundary to formulate multi-expressions. Then, the latest study was giving some ornaments as an aesthetic expression [8] to create a distinctive feature.

To excel in building an identity, previous models need to be redesigned to have sufficient flexibility. We need to admit, however, that there will be some new adjustments to the mechanical system, but this will increase the productivity of finding new variants. At the same time our effort is to improve the design-manufacturing process chain to be more efficient. Variations should not cost the manufacturing process to be more complex. Shape grammar is used to search the language of design of this existing design.

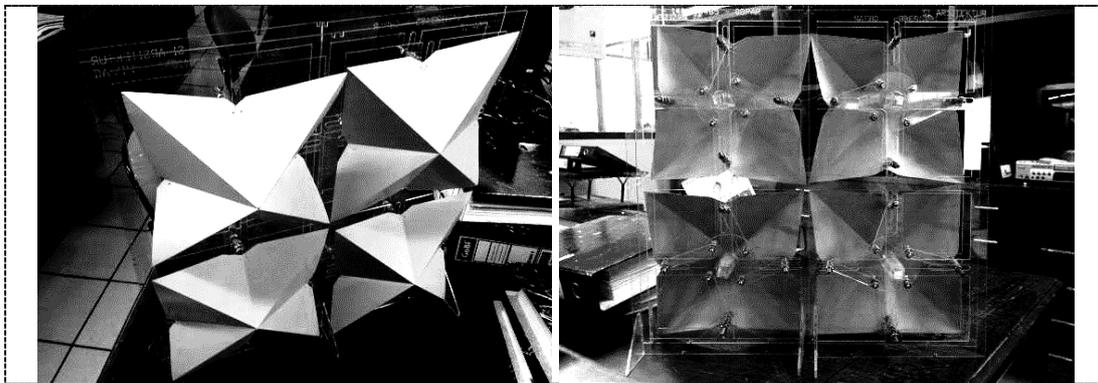
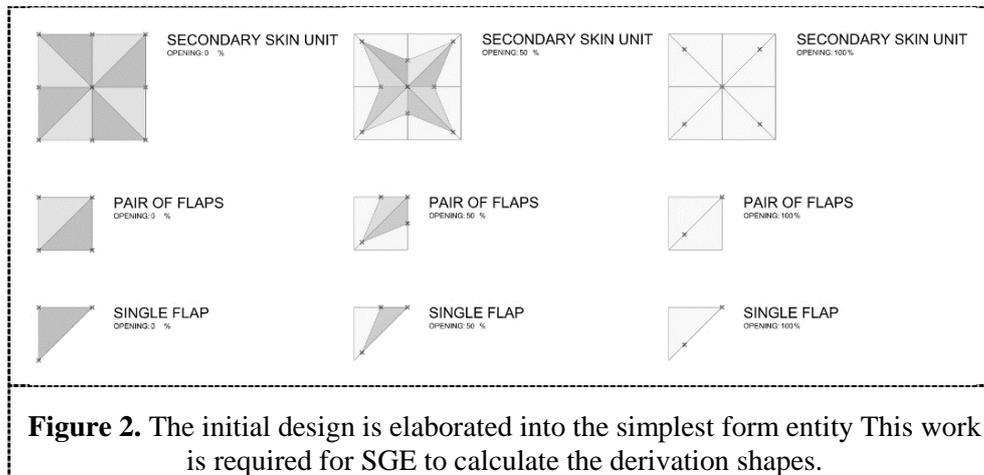


Figure 1. A prototype of the skin module from the development of the adaptive system.

2.2. Shape Grammar as a Tool

Shape grammar is used as a design tool [9], to figure design variant that might not have conceived. In fact, the exploration was not as simple and practical as that. Initial design decomposition requires intensive attention because of its unique mechanism, as shown in Figure 2. Furthermore, shape grammar interpreter has not reached its mature development. Thus, additional research was run to develop workflows in support of variant-finding. Nevertheless, shape grammar as computational method helps to understand better about the design itself, the design and the manufacturing constraints.

This design tool introduces the idea of preparing initial shape and rules by reversing the design process. The focus is highlighting the left-hand side of the rules, which is the result of the elaboration process of the existing design. While elaborating manually, this retrograde thinking process or a de-transformation could be prepared in an algorithmic method, because somehow it has a systematic protocol. The approach seems feasible, based on the conducted workflow using *Rhinoceros 3D* and *Shape Grammar Environment v1.0* (SGE), but additional research is needed. Then, the variant-finding method basically follows the shape grammar previous studies [10, 11, 12].



The original idea of shape grammars that Stiny introduces, is how geometrical shape can be elaborated and then be constructed by ruling the transformation of its lowest constituents. In this case, the initial design of the adaptive skin is expounded into a simplified 2D shape as shown in Figure 2. Within its basic form, 12 initial shapes were recognized. The experiment conducts all the transformation methods to be applied on those initial shapes.

In the transformation method, a transformation subtype is created to find more possibilities in obtaining a new form. After extensive exploration, the internal shape editor interface at SGE-Rhino itself is a constraint by nature, in the end. The editor is a square area in the plan view, also a box in 3D view. However, this constraint provides an opportunity to think of ways to differentiate more shape rules. The square or box delineation have special nodes and axes, which help determine the transformation. Therefore, the possibilities are explained in Table 1, which illustrates this reasonable approach. More opportunities can be achieved by exploiting delimitation. Additionally, the additive subtype is intended to implement the transformation without deleting the initial shape.

Table 1. Transformation expansion possibilities.

Transformation	Non-additive Subtypes	Additive Subtypes
Translation	1-unit axial move ½-unit axial move 1-unit diagonal move ½-unit diagonal move	1-unit axial move ½-unit axial move 1-unit diagonal move ½-unit diagonal move
Rotation	90° rotation, centroid axis 180° rotation, centroid axis 270° rotation, centroid axis 360° rotation, centroid axis 90° rotation, corner axis 180° rotation, corner axis 270° rotation, corner axis 360° rotation, corner axis	90° rotation, centroid axis 180° rotation, centroid axis 270° rotation, centroid axis 360° rotation, centroid axis 90° rotation, corner axis 180° rotation, corner axis 270° rotation, corner axis 360° rotation, corner axis
Reflection and Glide Reflection	Sectional reflection at Horizontal axis Sectional reflection at Vertical axis Sectional reflection at Left side diagonal axis Sectional reflection at Right side diagonal axis Full reflection at Horizontal axis Full reflection at Vertical axis Full reflection at Left side diagonal axis Full reflection at Right side diagonal axis	Sectional reflection at Horizontal axis Sectional reflection at Vertical axis Sectional reflection at Left side diagonal axis Sectional reflection at Right side diagonal axis Full reflection at Horizontal axis Full reflection at Vertical axis Full reflection at Left side diagonal axis Full reflection at Right side diagonal axis
Scale	Scale 2X	Scale 2X

To simplify the creation and list, 512 form rules created in this project are combined in a matrix format. Presentations easily show the rule of duplicate form, which is found in many regulatory generations. This problem leaves room for an exciting future study that can examine duplicates. However, the next closest development will study the extension to create styles in search of shape rules transformation. This interesting field will likely lead to a creation of a transformation style. Calculating shapes is a common task in practicing parametric shape grammar, moreover in generating new shapes, but this form of rule-making will give new ways to approach new design languages.

2.3. Design Exploration

The novelty of the design built with the shape grammar depends on the initial shape statement, preparing a set of shape rules, mixed by the designer's intuition and interpreter's ability - as Li calls *designerliness*, and certainly all involved in most of our design process. In this experiment, exploration scope is limited by existing design mechanical constraints as well as design timeframes.

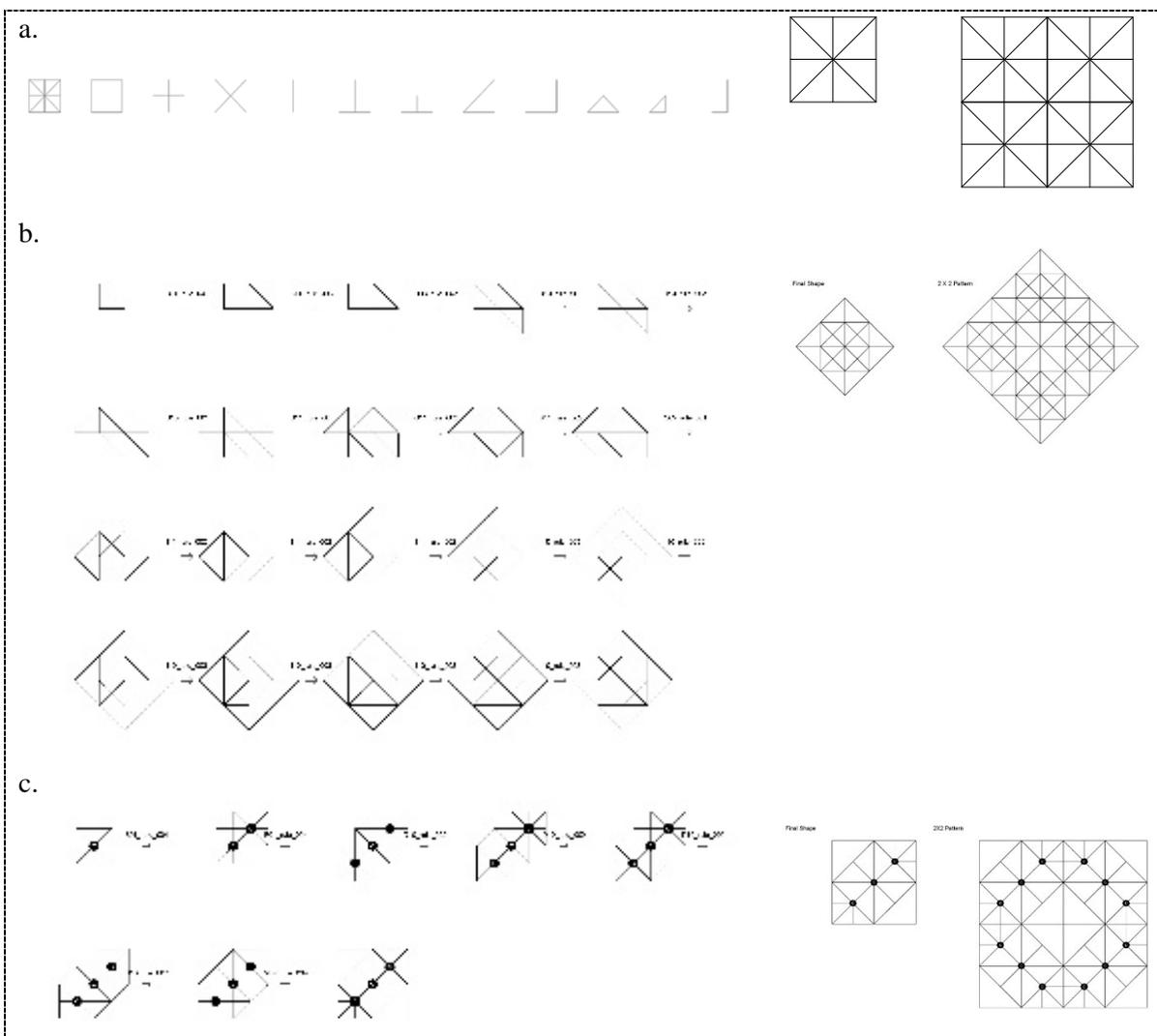


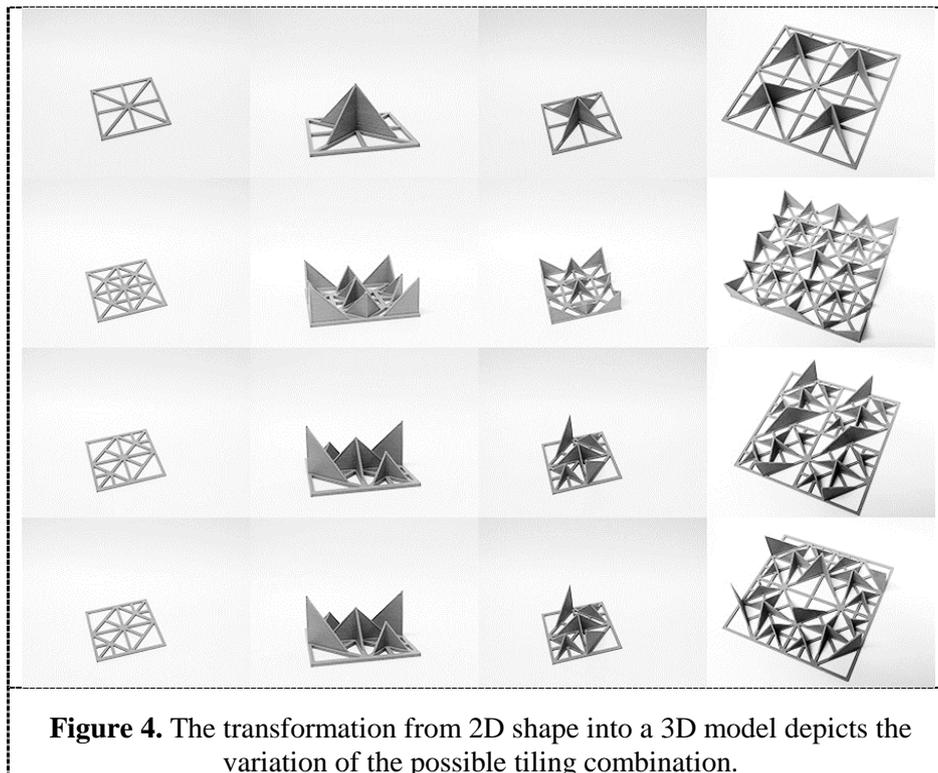
Figure 3.

a. Simplified (2D) design from initial adaptive façade design unit;

b. Derivation design 01;

c. Derivation design 02.

After several experiments, it ends in the result of two derivation designs, both of which have different characteristics in the interconnection as shown in Figure 3. The derivation design 01 (Fig. 3.b) has a palindromic tile, which means the placement only creates a homogeneous pattern. While the derivation design 02 (Figure 3.c) has different corner details. Therefore, the design will create variations in tiling, for example, 2x2 tiles at least produce 3 different variations. They are: continuous arrangement of tiles, mirroring 1 tile module and 2 tile modules mirroring. This less symmetrical module has the opportunity to get more tile designs on the facade.



2.4. Simulation

To express the resulting design efficacy, simulation procedures and variance comparisons are performed to help determine and justify the design. In Table 6, all simulation models are described, including basic models that represent only simple spatial objects, to describe the original characters of radiation that hit buildings on the site. The Widjodo Center building is also included, as a benchmark. The building has a unique skin design that helps the building lower the energy consumption of its interior space.

Table 2. The simulation models of the existing and the designed skins.

Model	Descriptions
Base Model	Simple spatial object without any shading devices
Widjodo Centre Building	One of the best designed building skin façade in Jakarta
Default design	The Sjarifudin's initial adaptive façade design
Design 01	Design derivation 1
Design 02 A	Design derivation 2, tiling type A
Design 02 B	Design derivation 2, tiling type B

The simulation is looking for the overall thermal transfer value (OTTV) for all 4 side walls on each box model, oriented to 4 different directions, North, East, South, and West. For this simple analysis, the *Glass Box Method* [13] is used to illustrate the ratio of solar thermal radiation to the walls, and its value is predictive only. However, the visualization of Figure 4 shows that each model simulation that uses an additional building cover, its value being under the 45W/sqm national regulation, as required for green building purposes. The Widjojo Center building gets the lowest score, while the Skin Designs 01 has the lowest average with little difference among the other derivation designs, and surprisingly better than the existing design.

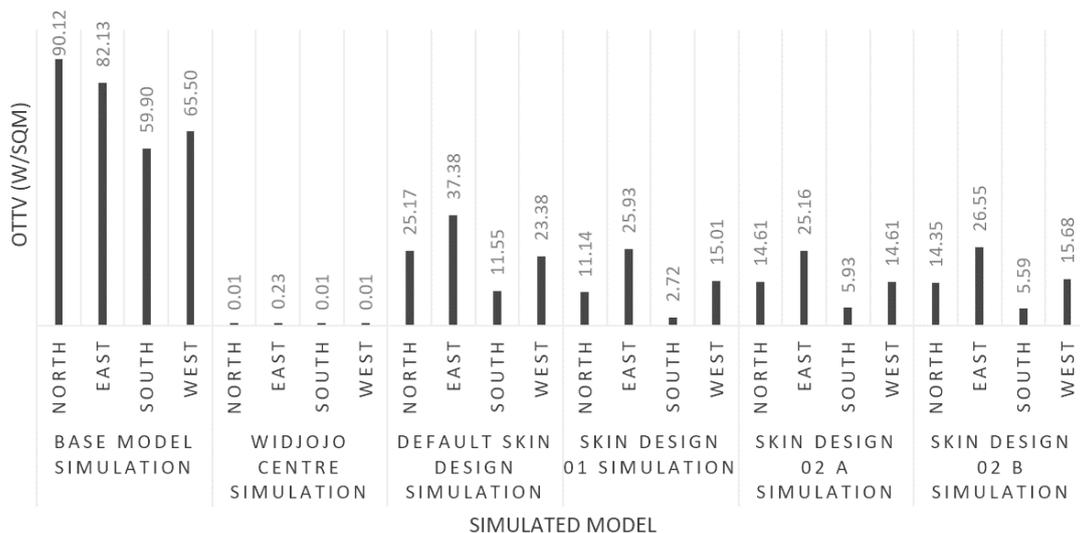


Figure 5. The OTTV simulations result in some acceptable differences. Meaning all the designs are still in a good performance, which is under 45W/sqm.

3. Discussion

Research on building skin has been our concern in the last 5 years. Efforts and results significantly educate our understanding of energy-efficient building approaches. This paper is the result of continuous development in the discourse which aims to strengthen the diversification of the building skin design. The absence of a variant in the model created before will have bad implications for future markets, where each building needs an identity expressed on the outermost layer of the building.

Thus, the analytical shape grammar has demonstrated the ability to produce many design variants. In addition, this analytical process provides important clues that the derivation can produce better designs, which are associated with better performance. In addition, variants with identical mechanisms will be more efficient. This diversified optimism will not only help create a variant in the market but also contribute to an efficient manufacturing process. Thus, the identity requirement of the building façade should not sacrifice the enormous energy use since design and manufacturing, while the goal is to reduce its consumption.

On the other hand, the use of shape grammar has not achieved ideal performance for the designer. There is room for improvement, both for interpreters and interoperability, to support the process of seamless design decomposition into the design process itself. At least, there are three potential future developments noted in this study.

First, the process of decomposition of existing designs still relies on the perception of designer's eyes. This means the process can be subjective, which is also limited by the designer's ability. It can cause

failure to see a shape that has never been conceived. Although the initial form is not something we need to collect in large quantities to make shape grammar work. However, our idea comes from the concept of mathematical equations, which can be reversible. If we realize that the transformation of the form occurs on the right side, then the process should be reversible, by parsing the existing form by applying a reverse transformation of the design.

Secondly, we see that the workflow to create the form rules can be less tedious. Creating a parametric rule-making process has the potential to be done, which we think will result in a rule-making style, using shaped editor border, in 2D and 3D spaces. Obviously, there are some things that will be ignored and there need to be some adjustments, but surely this will make a lot of variety in creating shape rules.

Thirdly, because of the vigorous exploration in the making of shape rules, there are many excessive formulations that need to remove afterward. These excessive shape rules will slow the calculation process and will limit the output. Frankly, we are still looking for an elegant solution to tackle this issue. Nevertheless, the process of searching for this variant is a wild exploration to reach the edge of the Shape Grammar Environment ability.

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