REVEALING PATTERNS

Using parametric design patterns in building façade design workflow

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Abstract. The objective of this paper is to provide a way of viewing design knowledge imbedded in the design workflow. By reviewing known design projects, we have observed common occurrences of design patterns in different stages of parametric façade design workflow. We demonstrate the application of parametric design patterns in practices as preliminary studies of forming a pattern language of parametric design.

Keywords. Design pattern; parametric design; façade design.

1. Introduction

Using parametric design tools to generate building envelopes is becoming a common practice. Parametric modelling plays an important role in the façade design workflow through stages of conceptual design to construction. We are interested in documenting the knowledge of building façade designs. Design patterns have been shown to be a good way of recording knowledge of parametric modelling (Qian et al, 2007; Maleki and Woodbury, 2008; Woodbury, 2010). By tracing the design patterns used in known cases and by testing patterns in our own practices, we demonstrate a way of viewing a design project and its workflow.

Design projects benefit from a fabrication-informed design process where an early integration of construction concerns is emphasized. In a fabrication-informed digital design process, methods of pre-rationalization and post-rationalization have been widely discussed (e.g., Attar et al, 2010; Dritsas, 2012; Vrouwe and Van Swieten, 2013). Rationalization is a key task in architectural design workflow. In the conceptual design stage, before rationali-
zation, schematic designs are often created from unlimited conceptual and geometric explorations. After rationalization, designs are modified to fit in known geometric principles and construction techniques. By observing the process of rationalization, we hope to obtain design knowledge and relate the rationalized design outcomes to their initial schematic designs.

This paper presents a midterm result from an ongoing research. We have implemented a pattern-based knowledge repository of parametric design (Chien et al., 2015) and are continuously collecting examples and cases to illustrate applications of design patterns. We envisage the formulation of a pattern language of parametric design by means of identifying design patterns used in known design projects, as well as demonstrating their applications in our own practices.

2. Background

Woodbury and his colleagues pioneered the research on design patterns for parametric modelling (e.g., Qian et al., 2007; Maleki and Woodbury, 2008; Woodbury, 2010). Referencing on their works, Hudson (2010) demonstrated through uses of design patterns for different design stages. Caetano, Santos and Leitão (2015) presented a framework with various strategies for façade designs. Design patterns offer potentials for parametric design strategies and in building façade design workflow. Moreover, design patterns provide opportunities for forms of motifs or ornaments that may emerge from the subdivided or modular in construction of building façades or cladding systems.

The power of design pattern methodology, beyond individual design patterns, lies in the formation of pattern languages. A critical point of forming pattern languages is the relationships between patterns (Zimmer, 1995, Noble, 1998). Kruschitz and Hitz (2009), Schobert and Schümmer (2006), and Schümmer (2003) illustrated various ways of visualizing the relational structure (or network) within a pattern language to assist designers navigating in the network and search for relevant patterns. We see the visualizations of pattern network a key step to turn parametric design pattern collection into a pattern language. Our research team has tried to illustrate pattern-network of a design project with an overview diagram showing the evolution of parametric models driven by applications of design patterns (Chien et al., 2015).

3. Building façade design workflow

In a digital design workflow, parametric design patterns can be used repeatedly and varyingly in stages of concept development, design development and design documentation. The concept development stage involves form finding from site context to explore ideal designs. The design development
stage includes surface representations and rationalizations. Rationalization is a parametric task and plays an important role in design problem solving. During rationalization, parametric modelling is a powerful tool to generate design alternatives and conduct quick evaluations. Selections of solutions are based on criteria related to performance, ease of construction, budget requirements, aesthetic principles and so on. The results then drive the revision towards a rationalized design rapidly. Lastly, in the design documentation stage, information management is important since the construction materials for parametric façades are usually more complex than those of conventional façades.

4. Applying parametric design patterns

To investigate the application of parametric design patterns, we have conducted studies of parametric design patterns in known design cases, by recreating parametric models of building façades through deliberate uses of design patterns. Figure 1 illustrates a result of our studies.

![Diagram](image_url)

*Figure 1. An overview diagram of patterns used in a case (Hangzhou Stadium).*

Among the cases we studied, three of them were investigated extensively because we have acquired more design workflow data. The cases are Wulai Parking Structure (WPS), Swiss Re Building (SRB) and Hangzhou Stadium (HS). We have observed common occurrences of design patterns in different
stages of parametric façade design workflow, as well as common combinations of design patterns (Table 1).

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In the form-finding stage, the *Jig* and the *Controller* pattern (Woodbury, 2010) are applied in all cases. The combination seems to be a common way to relate and translate abstract concepts to geometries. Using geometries derived from a controlled system is a basic practice of parametric design. For example, the façade of WPS took shape through three principle horizontal curves, and its form is enclosed by vertical bars. We employed *Jig* (using the silhouette of the mountains as the jig) to guide the formation of the three principle curves.

The *Place Holder* pattern (Woodbury, 2010) is often applied in the early design development stage (Hudson, 2010). Before rationalization, an ideal design using *Place Holder* can easily express continuous differentiations, which is the main feature of parametric design (Jabi, 2013). However, its related pattern, *Jig*, can be further applied at the rationalization stage. The *Jig* pattern serves a model with preciseness and associated construction techniques.

The *Extraction* pattern (Lai, 2011) and the *Point Collection* pattern (Woodbury, 2010) are key patterns when working on building façade subdivision at design development stage. Based on intention, different surface information is first extracted and then *Point Collection* is used to re-order the extracted data to fit various situations. Therefore, an architectural surface representation is basically implemented.

The *Extraction* pattern (Lai, 2011) and the *Reporter* pattern (Woodbury, 2010) are usually used in making design documents. Therefore various data
for prefabrication and construction can be extracted and generated separately to spread sheets. In the case of City Hall in London, this technique is used to layout the glazing panels in a flatten pattern, scheduling areas and listing panel node coordinates (Whitehead, 2003).

The Recursion pattern (Woodbury, 2010) can be applied when working with hierarchies in design. It may appear not only in the programming interface but also the visual order in model. The façade design for Dongdaemun Design Park and Plaza in Seoul demonstrates the recursive grid visual order which is derived from both aesthetic principles and engineering constraints (Schumacher, 2014).

5. Parametric systems in building façade design

Besides recreating parametric models of known projects, we deliberately employed parametric design patterns throughout our own projects. Here, we report, in depth, on the façade design of Project Grand Stage (PGS). PGS is a double-skin façade renovation project. The Controller, Mapping (Woodbury, 2010), and Point Collection patterns were used in the concept development stage for form finding (e.g., Area 1 in Figure 2). The Extraction, Reactor (Woodbury, 2010), Mapping, Selector (Woodbury, 2010) and Reporter patterns were used for processing of surface information (e.g. Area 2 in Figure 2), while the Recursion, Controller, Point Collection, Selector, Extrace-
tion and Reporter patterns were repeatedly used for rationalization in the design development stage (e.g. Area 3 in Figure 2). The Extraction, Point Collection and Reporter patterns were used in the design documentation stage.

5.1. FORM FINDING IN DATA SPACE

During the concept development stage, the Controller pattern was used to set up a friendly interface to manipulate light sources in clusters or individually. We envisaged a surface that is deformed by lights. A parametric system was developed to simulate how the surface can be pulled by two opposite forces, that is, the intensity and the condition of lighting from the external environment and the internal spaces.

The lighting conditions of external environment were formulated from the location defined by azimuth, altitude, and orientation, as well as reflectiveness of surrounding buildings. The lighting conditions of internal space were derived from the volume and utility of each space (Figure 3, left). Sunlight is the primary lighting source externally, in particular, from south-western direction with the given PGS site. From internal spaces, for each volume, a representative light source, based on illumination requirements of proposed utility of each space, could be turned on or off.

The Mapping pattern was always used in the process of abstraction and simplification. The Point Collection pattern was used for sorting data in various ways to address different needs. These patterns provided us the ways to work on numerical data calculations and transmissions that were initially vague and complicated. In PGS, we simplified the façade plane into an image of 5400 pixels arranged in 60 rows and 90 columns. Different types of data, such as solar radiation, artificial illumination and collision status with existing façade, were processed separately. The façade of PGS was deter-
mined with the consideration of streetscape, self-shading during day, and light effect at night (Figure 3, right).

5.2. REPRESENTATION OF SURFACE INFORMATION

In the design development stage, the Extraction, Reactor, Recursion, Mapping, Selector and Reporter patterns were used for representations of surface information. These patterns afforded different ways of extracting information from the façade surface. For PGS, we used cellular automata to generate perforation patterns (Figure 4, right). The Selector was used for deciding the distribution of perforation densities. Three zones were defined by filtering values of lighting intensity related to the solar radiation, existing façade opening and proposed average illumination (Figure 4, left).

By setting attractors and using Reactor, we could visualize the gradient in multiple ways. The gradient trails and contour lines were further developed into carving texture. Colors from bright to dark were picked from site photos and mapped to the surface based on slope gradient to emphasize the mountains and valleys on the surface. Contrast is an important element when people perceive geometries. We kept the maximal and minimal brightness at the same time. But the steps in between were decided through the process of rationalization at later stages.

5.3. RATIONALIZATION

The Recursion, Controller, Point Collection, Selector, Extraction and Reporter patterns were repeatedly used for rationalization during the design development stage. For PGS, after considering manufacturing constraints, options for panel assembly system were investigated. To ensure the feasibility of manufacture and construction, panels were designed to be planar and the
size was limited 340 mm in length and 236 mm in width. We used Jig (instead of Place Holder) to create a seamless modular assembly on the PGS façade. We designed universal joints on edges of the panels so that they could be assembled into large size units.

We used Recursion to perform uneven subdivisions (Figure 5). There were two goals in the subdivision stage: to reduce the number of assembly units; and to reduce deviation gap. Using a larger assembly unit could reduce the total number of units. However, using a larger planar unit to compose the free form surface might cause larger deviation gap. So the size of a unit and the number of units were decided by these relevant considerations.

![Figure 5. Uneven recursive subdivision based on slope gradient of the surface.](image)

5.4. DESIGN DOCUMENTATION

In the design documentation stage, the Extraction and Reporter patterns were used. When continuous differentiation and mass-customization took place in practice, designers and fabricator face many complicated tasks. We managed to extract the geometry and categories of items data, exported to spread sheets and delivered to the fabricator. For PGS, selected samples from design documents were sent to the fabricator for prototyping, and feedbacks of prototyping informed further adjustments of detail designs to fit in construction constraints but without changing the overall design.
6. Discussions and conclusion

We tried to identify the parametric design patterns used in design workflow from cases, and applied them in our own practice. We found that a pattern may appear repeatedly in different design stages; a composite of patterns may be often used together. We demonstrated the uses design patterns from concept development, design development to design documentation. In our own case of PGS, more design patterns were used in design development stage (Figure 6). In this stage, the tasks of synthesizing an ideal design and rationalizing it require lots of design efforts. Documenting of these design efforts could not be obtained from case studies of known projects.

There are compositional uses of design patterns re-occurring in our studies. For example, in Table 1, the Extraction and Point Collection patterns are repeatedly used together to serve the intension of new creation from existing. In Figure 6, there are design patterns used across early design stages and others for later design stages. The figures seem to hint at a form of grammatical rules.

In summary, we believe there are potentials to turn parametric design pattern collection into a pattern language. We see our demonstrations of using parametric design patterns in practices as preliminary studies of forming a pattern language of parametric design. We hope to reveal more patterns of compositional uses of design patterns in parametric modelling to identify a pattern language of parametric design through our continuing research.
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References


