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PARAMETERISING PINECONE NASTIC MOVEMENT FOR ADAPTABLE ARCHITECTURE DESIGN

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Abstract. This study investigates a digital modelling process that aims at achieving architectural flexibility and adaptability. Inspired by the pinecone nastic movement, a flexible modular design is proposed and evaluated through various methods including a mathematical parametric generator and origami-based fabrication simulation. The modular design system was applied to a specific chosen site with its environmental and contextual requirements. The results show how the pinecone-like nastic movement may be translated into design and fabrication of adaptive architecture. We discuss the likely impacts of the kinetic features on architectural sustainability as well as the effectiveness of parametric modelling.

Keywords. Flexibility, adaptability, pavilion, design, pinecone, parameter, movement, interactive.

1. Introduction: dynamic architectural adaptability and flexibility

The development of digital applications has informed a new understanding of architecture design, in which building structures and building elements are no longer permanent, fixed or immobile (Schumacher, 2010). As dynamic architecture becomes more popular and applicable, there have been immerging questions about its purpose and effectivity. One of its typical employments is to respond to changing functional and environmental requirements. Although this viewpoint has potentials in creating more sustainable and fascinating architecture, it requires careful researches and suitable strategies during the design process, to achieve meaningful mobility and efficient controlling mechanism (Megahed, 2017).

This study proposes a design process that can be suitable to dynamic architecture. Developed from a dynamic component design, the process explores the balance between architectural adaptability and flexibility. While an architectural component needs to be flexible to be applicable to different environmental and functional requirements, the adaption process applied to a specific site transforms it and limits its flexibility. Therefore, the parametric tools were used in both ways: to generate flexibility as well as to limit it to gain adaptability. In other words, the design process becomes an information feedback loop between idea development and (site-specific) possibility evaluation (Figure 1). The paper is organised in two parts. The first half is the flexible component design, in which a process of finding the efficient movement and control mechanism is proposed. The second half describes the method to adapt and apply that component into a specific site with its own contextual and environmental requirements. A conclusion and further developments are proposed at the end of the paper.

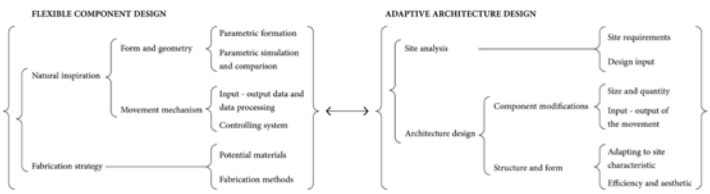

Figure 1. Overview of the design process – flexibility and adaptability.

2. Flexible architectural component design

2.1. PINECONE NASTIC MOVEMENT

As living organisms, plants are strongly dependent on their surrounding environment, because of their limitation in mobility. Therefore, the ability of adaptation to environmental conditions becomes one of the most important factors affecting their survival rate (Darwin, 1880). Since there are similarities of passive adaptation between plants and architecture, many studies have considered this phenomenon and tried to find their applications in architectural design (Hugh, 2004). However, there is one spectacular vegetative reaction which could be better modelled as a source of inspiration in the making of digital interactive architecture: nastic movement.

This reaction is defined as the movement of plant parts, which is caused by an external stimulus but unaffected in its direction (Braam, 2004). In this study, we investigate the mechanism of pinecone nastic movement as a reference model to design a kinetic architectural system which can interact with its surrounding. To maximize the survival rate of its descendants, the pine tree developed a structure to safely protect and distribute its seeds, which is the pinecone (Harlow, 1964). This structure contains different arrangements of fibre which reacts differently to environmental conditions, thus makes sure that the pinecone only opens and spreads its seed in the suitable warm and dried weather (Dawson, 1997).

The mechanism of pinecone scale movement is complex, involving different materials at a micro scale, which has been studied and applied into material science (Reichert, 2014). However, in this study we propose a simple parametric model that provides a mechanical-based bio-mimicry in the form of a kinetic single-material architectural system, taking in the same inputs (i.e., environmental conditions such as light, temperature, humidity, etc.) and giving out a similar output (i.e., the movement of open and close).

2.2. PARAMETRIC MODELLING OF A PINECONE INSPIRED KINETIC STRUCTURE

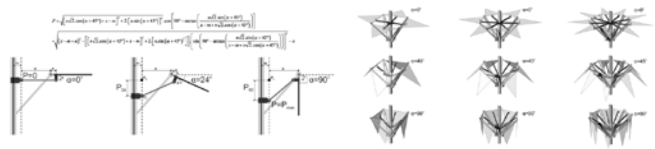

Figure 2. The mathematical formula calculating the position of the control point P given constraints from the movement angle α and other structural variables (m, n, x) and different variations of the component generated by the parametric model

The central to this parametric system is to control the open-and-close movement by a single-directional control point moving along the centre axe. We developed a mathematical formula to specify the location of the main control point (Figure 2) given constraints from the angle of open-and-close (α) and other values defining the structural size (x, m, n)

- α: the relative angle of the wing (leave) comparing to its initial stage (horizontal to the ground)
- x, m, n: values that define the sizes of the various structural parts

The output of the mathematical expression is P, the coordinate of the control point, representing the relative distance of movement comparing to its initial position. By implementing this mathematical formula in the Rhino-Grasshopper environment, a parametric system was created. This system can generate potentially an infinitive number of architectural structures employing the same mechanism, thus maximizing adaptability.

2.3 ORIGAMI PATTERN DEVELOPMENT

To simplify the structure and to achieve an easier controlling mechanism, we designed a new origami pattern for the component. This pattern allows all structural elements to be interconnected in one folding surface, while still following the same calculating method. Benefits from this new design include: (1) Lightweight material and less structural elements required; (2) easier controlling method due to homogeneous movement; (3) providing more aesthetic and attractive architectural shape; (4) larger and continuous shading area.

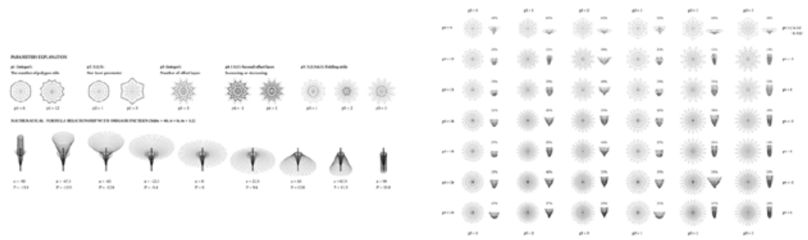

Figure 3. Five input parameters for pattern generating and relationship to the mathematical formula and origami patterns comparison by F% value, folding angle = 5π/6

To choose the best origami pattern, a parametric function is developed. There are five input values (p1 to p5) used to modify the shape and complexity of the planar pattern (Figure 3). All generated patterns are then virtually folded by kangaroo at the same folding angle (5π/6) and then compared based on their F% value, or folded size percentage (the width after folding / the flatten width %). The pattern with the smallest F% value (12%) is chosen, since it will provide more efficient controlling and faster movement.

3. A test case for the component's adaptability

3.1. THE CHOSEN SITE AND ITS REQUIREMENTS

The chosen site for this design is an old canal basin in Sheffield, England, called Victoria Quays. The basin was a cargo port in late 20th century, which is now transformed into a site of business and leisure spaces. With notable quantity of tourists and citizens going to the location daily, the proposed design is a dynamic pavilion used for semi-outdoor activities and is also expected to be a new tourist attraction.

Table 1. Site analysis and design inputs.

Site characteristics	Design requirements	Design inputs
Site for outdoor activities on land and on water with canal boats	Servicing human activities on multiple environmental context	A pavilion half on land and half on water
Dynamic behaviour of tidal river	Adapting to different water levels	Movable pavilion structure
Site for leisure activities	Providing playful experience	Possibilities of interacting with users

Site characteristics	Design requirements	Design inputs
Lack of outdoor shelter and shaded spaces	Adapting to weather conditions	Dynamic architectural movement adapting to weather data
Big plaza beside the river without energy source	Self-generated power from renewable sources	Possibilities of using hydropower and solar power

3.2. ADAPTABLE DESIGN FOR TOPOGRAPHICAL AND ENVIRONMENTAL ELEMENTS

Based on the previous parametric modelling system development and site analysis, we carried out a test case study by applying these components to the chosen site. The idea here is twofold: (1) to test the flexibility of the structure if it can adapt to different topographical requirements, and (2) to preserve its kinetic characteristics through an interactive installation at upper layer.

Figure 4. Testing the adaptability of the pavilion on different water level and structure behaviour of the super-structure layer.

A hexagonal grid structure is chosen due to its compressive and tensile strength also its resemblance to the cell system (Her, 1995). To test the structure's adaptability, a parametric function using Grasshopper and Kangaroo is introduced to simulate different topographical conditions, which is, in this case study, the changing datum of each column base as presented by the water level (Figure 4). Specific input values such as the number of cells, the limit of cells' deformation and the maximum rotation angle between each cell edge, are also used in the test function.

Figure 5. Perspective renderings of the final design.

While the super-structure layer plays the main role in site-adaptability, an upper layer of the pavilion can be interactive to users and the contextual environment, either manually (open-and-close by users' pushing and pulling the pavilion's 'scales'), or automatically (open-and-close by powered-actuation driven by environmental input, such as solar and temperature sensing).

4. Conclusion and further developments

The study proposed a new design process that started from architectural flexibility and developed the adaptation to the specific contextual conditions. Since kinetic architecture requires complex engineering task and integration of different disciplinary (Megahed, 2017), this design process allows a mobile component to be applied in different conditions and requirements. While parametric function provides dynamic flexibility to the structural form and function, contextual characteristic limits its possibilities and increase adaptability.

To extend the scope of the design process, we will further address environmental elements to the movement controlling system. This step can be considered as a development to increase the architecture's adaptability. An application of the Internet of Things is proposed to collect weather data, as well as to process them into the component's movement with parametric mathematical tools. A user-interactive behaviour system is also expected to be integrated into the design, to provide playful activities to the chosen site.

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