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TOWARD A PERFORMANCE-ORIENTED ARCHITECTURE

An integrated design approach to a real-time-responsive structure

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Abstract. This paper started from the study of "performance-oriented architecture" for the purpose of developing a real-time-responsive prototype that can enclose large expansive interior space. Questions regarding the relationship between the structural arrangement of systems and the natural environment initiated an investigation in Phyllotaxis. It has been found in plant systems for the optimisation of photosynthesis with harvesting maximum amounts of solar energy. In the design of a real-time-responsive prototype, an algorithmic approach is introduced with the mathematical interpretation of Phyllotaxis and its translation into the global geometry of the prototype. Also, the usage of a Voronoi diagram is parametrically configured to form the local geometry of the prototype. The interactive mechanism of the prototype was achieved with an assorted computational application. Furthermore, with the demonstration of the aforementioned prototype in both digital and physical environments, its implementation process is explained.

Keywords. Performance-oriented architecture; phyllotaxis; Voronoi diagram; real-time-responsive structure.

1. Introduction

The concept of "Performance-oriented Architecture," originally proposed by Michael Hensel, is based on the term 'performativity' in which all elements in both the built and natural environment are heterogeneous and in constant response to one another as well as external stimuli. Hensel (2010) employs the term 'performance' to address the limitations of 'representation' and 'meaning' in reference to the central issue of post design optimisation (the functional issues that arise toward the later stages of the design process which result in the alteration of initial design intentions). Among the many milestones that were used as a foundation to ‘performance-oriented architecture’, the themes that are significant to the development of this research are ‘performativity’ and complex biological systems. In this paper, an integrated approach between botany, specifically Phyllotaxis, and architecture is developed in the process of making a kinetic system that encloses large unencumbered spaces through real time environmental response.

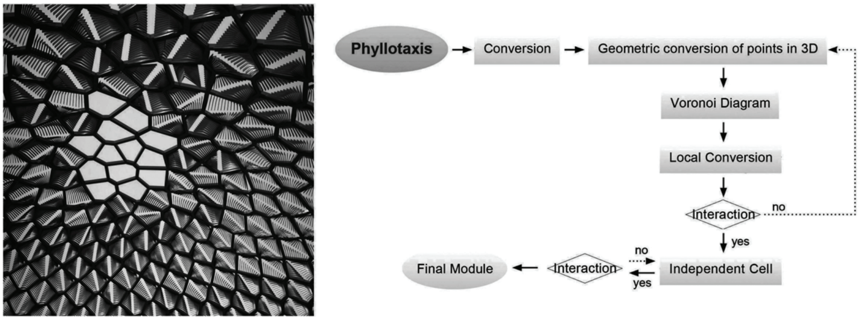

Figure 1. An integrated approach of a real-time-responsive structure.

Phyllotaxis provides architects with the opportunity to achieve maximum uniformity for infinite planar surface areas. The maximum uniformity is employed as a method of optimising the interaction between the prototype and external stimuli in the concept of “performance-oriented architecture.” Uniformly arranged points in Phyllotaxis show their potential as the regulating positions to configure a global geometry and the center points of individual cells within the global geometry of the prototype. Here, the individual cell is regarded as a local geometry of the prototype. However, the study of Phyllotaxis was limited to its two-dimensional configuration in theory, so its usage was not fully developed in practice that requires its three-dimensional application. In this paper, the three-dimensional configuration of Phyllotaxis is developed in Rhinoceros 3D and Grasshopper. The boundary condition of each individual cell that has a Phyllotaxis point as its center provides optimised distribution of real time interaction with the stimuli within the proposed responsive prototype. In this paper, a Voronoi diagram was employed for the design of the boundary condition and implemented in Rhinoceros 3D and Grasshopper. The kinetic mechanism of the responsive prototype was tested and developed with the combination of various computational applications including Arduino, Firefly, Grasshopper and Rhinoceros 3D. Environmental data communication was made seamlessly in real time through the use of photo sensors, motors, and Arduino microcontrollers. Through the combination of these applications, digital and physical environments are fused together to provide real time interaction by elongating the experience of the users and enhancing the spatial quality of the prototype. In this paper, the assorted computer application of the prototype was developed for demonstrating a performance-oriented architecture that responds to the changes in environmental stimuli in real time with the employment of Phyllotaxis and a Voronoi diagram. Furthermore, the physical implementation of an individual kinetic module is inserted in each local configuration of the prototype.

2. Phyllotaxis: configuration of global geometry

Phyllotaxis was first coined by botanist Louis Bravais and explorer Auguste Bravais in 1837. During this time, the development of a two-dimensional optimisation scheme began to turn toward mathematical and systemic rather than observational studies (Adler et al. 1997). These mathematical and systemic studies in the 1830's led to a formula designed by Roger V. Jean, where the common divergence angle (*d*) in the arrangement of leaves found in plants is related to the Fibonacci sequence (1, 2, 3, 5, 8…) (Jean 1994) as below.

$$d = 360^\circ \left(2 + \left(\frac{\sqrt{5}+1}{2} \right)^{-1} \right)^{-1} \tag{1}$$

The design of the proposed real time interactive structure begins with converting the two-dimensional scheme designed by Jean into an algorithm that serves as the foundation to parametrically determine a globally distributed set of uniform points in three dimensions. The following formulae shows uniform points generated in x, y, and z directions where n is the number of points.

$$F(x) = \cos(\pi(\sqrt{5}+1)n)\sqrt{(n)} \tag{2}$$

$$F(y) = \sin(\pi(\sqrt{5}+1)n)\sqrt{(n)} \tag{3}$$

$$F(z) = \frac{n}{70} \tag{4}$$

Based upon the formulae, a set of generative algorithms for the globally distributed uniform points in three-dimensions is developed in Grasshopper as shown in Figure 2.

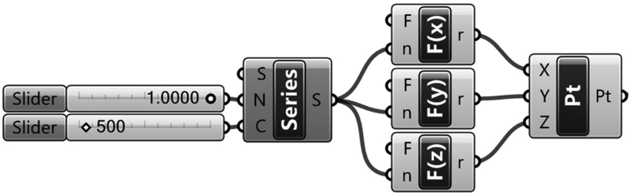

Figure 2. A set of generative algorithms in Grasshopper.

The output of the above algorithms shows their potential to generate an infinite expansion with the increase of the number of points (n) as below.

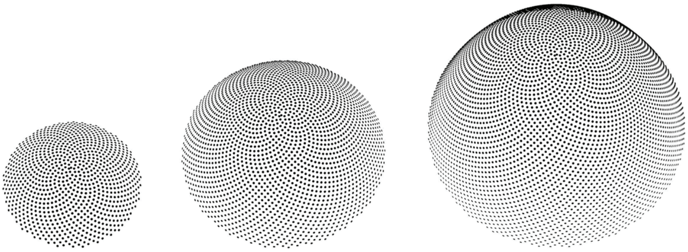

Figure 3. Growth of globally distributed uniform points in three-dimensions.

3. Voronoi diagram: configuration of local geometry

The configuration of local geometry is developed within a parametric Voronoi diagram by optimising the distribution of boundary conditions based on the globally distributed points in three-dimensions. By doing so, an optimised distribution of independent cells fit within the globally distributed geometry.

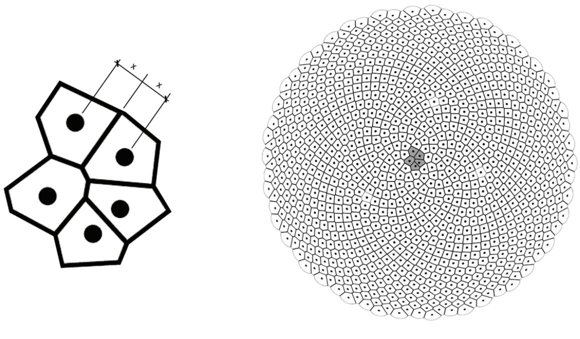

Figure 4. Configuration of local geometry within a parametric Voronoi diagram.

The configuration of the local geometry is generated through an algorithm in the environment of Grasshopper, as shown in Figure 5.

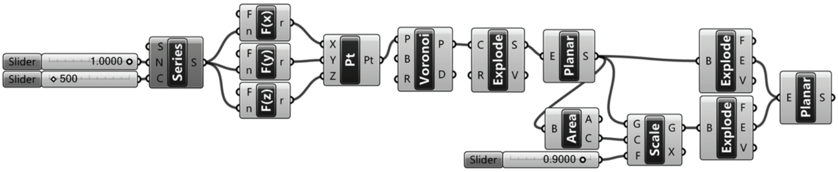

Figure 5. Generative algorithm for configuring the Voronoi boundaries of local geometry.

4. Real-time-responsive system

The design of a real-time-responsive system is initiated from developing various computer applications to produce interactions with environmental stimuli. The integrated configuration is defined through the use of Firefly and the generative algorithm within Grasshopper in connection with an Arduino microcontroller and a photo sensor. The diagram in Figure 6 illustrates how the real-time-responsive system is configured with a photo sensor, an Arduino microcontroller, a breadboard, a resistor, Firefly algorithm in Grasshopper, and motor.

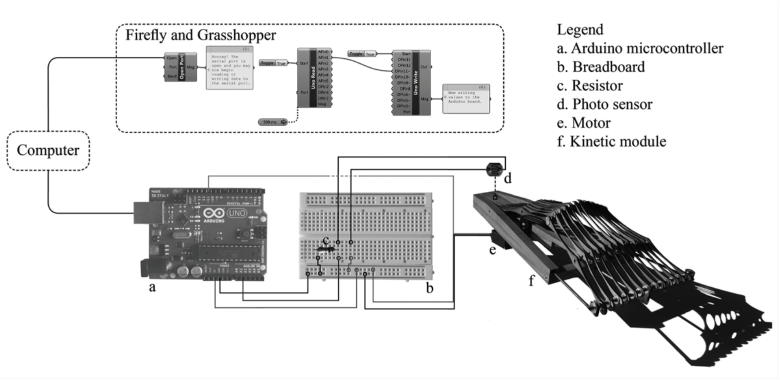

Figure 6. Diagram of real-time-responsive system.

The real-time-responsive system guides the configuration of the global and local geometry of a prototype. Based upon the amount of the changes in photons in sunlight controlled by the user as stimuli, the photo sensor attached to an independent kinetic module sends a signal to the Arduino microcontroller. Real time photo sensory response refers to a one second response time that is needed for the sensor to read the changes in daylight (Johnson and Andrew 2011). The signal from the microcontroller is converted into data information within Firefly and Grasshopper. The information is used to control the overall size of the global configuration and the number of local geometry based upon the Voronoi diagram generated within Grasshopper as shown in Figure 7.

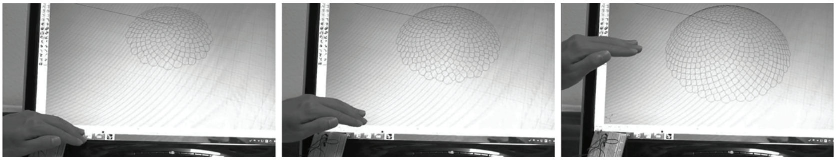

Figure 7. Real time interactive changes of the configuration of global geometry.

Furthermore, the information is used to inform the motor that directs the movement of an independent kinetic module inserted in each local configuration of the prototype as below.

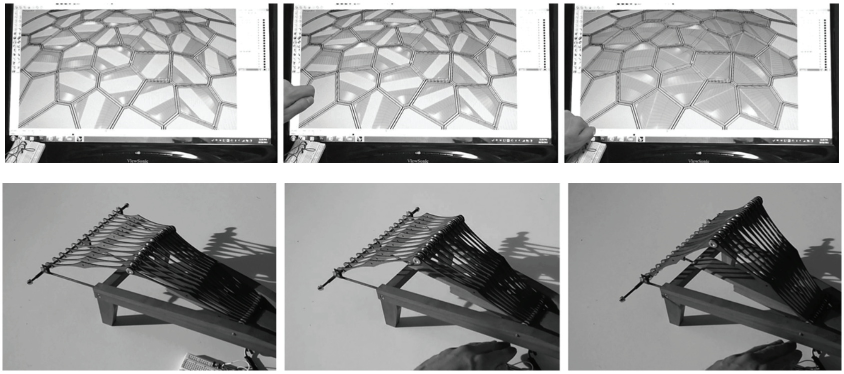

Figure 8. Real time response of individual kinetic module in digital and physical format.

5. Development of individual kinetic module

As for mechanical response, especially regarding the 'performance' of the module, concern is placed on separating the main force from the upper components to reduce rotational stress and the amount of friction caused by the motor. In order to attempt this issue, investigation is placed on the use of a rack and pinion system connected with a motor to provide an immediate response and uniform motion throughout the entire module. The use of this particular system creates a force shown as an arrow in Figure 9 to open and close the upper components. The rotational stress and friction are dampened in the steel rod of the rack and pinion allowing the independent module to perform in response to the environmental data information sent from the real-time-responsive system. Figure 9 shows the exploded diagram of the individual kinetic module.

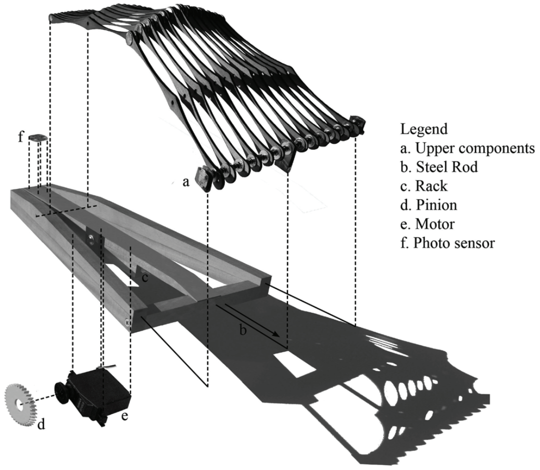

Figure 9. Exploded diagram of individual kinetic module.

The physical implementation of this individual kinetic module with the real-time-responsive system is based on knowledge stemming from multiple fields, including electronics (circuits), mechanics, engineering, and carpentry. The implementation was achieved with the help of machine cutting technologies and the usage of various mechanical parts as shown below.

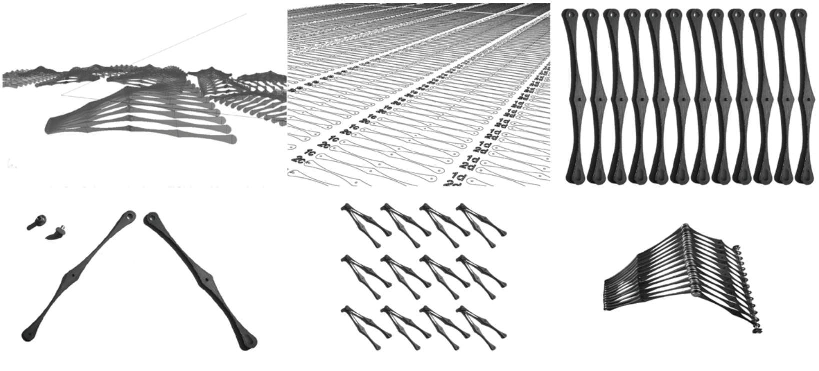

Figure 10. Machine cutting fabrication process.

6. Conclusion and future development

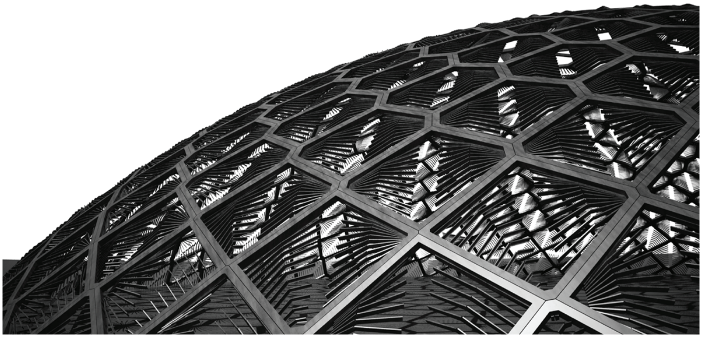

Figure 11. Exterior perspective of the prototype.

A real-time-responsive prototype from the integrated approach provides architects with the potential to develop a "performance-oriented architecture" where an independent kinetic module within a local geometry responds to environmental stimuli in real time. The prototype based upon Phyllotaxis and the Voronoi diagram enhances the quality of its internal space and increases the degree of user interaction. The uniform distribution of points employed in the design of the global and local geometry of the prototype provides structural advantages in the construction of the members.

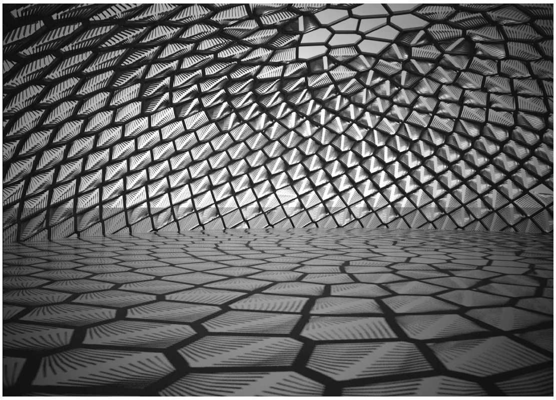

Figure 12. Interior spatial qualities of the prototype.

The development of a real-time-responsive prototype was successfully completed through the proposed integrated approach toward a 'performance-oriented architecture'. The three-dimensional configuration of Phyllotaxis and the Voronoi diagram illustrates a promising solution to the initial hypothesis regarding the relationship between structural systems and the natural environment. It is evident that the generative algorithms used for the interpretation of Phyllotaxis and the Voronoi diagram can be applied for the construction of various large expansive systems in the early design stage. At the same time, the real-time-responsive system of the prototype becomes the source for developing various practical applications, not limited to a building, in interaction with daylight, wind, rain, people, or other various stimuli. These include the skin of a skyscraper, the shell of an emergency deployable or nomadic structure, a responsive landscape, or the fabric of a real-time-responsive clothing as shown below.

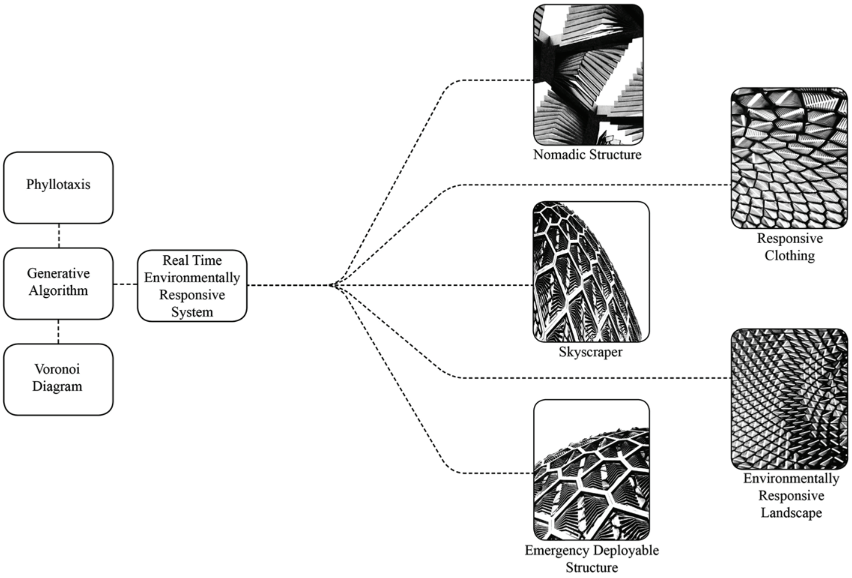

Figure 13. Possible variations of the proposed prototype.

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