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Architectural Form Generating Based on the Alternate Phyllotaxis Algorithm

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Abstract: Algorithm is the core of architectural form generating in parametric design. In this paper, the alternate phyllotaxis is studied and applied to the generation of architectural form. Firstly, based on the morphology of phyllotaxis, the principle is analysed, and then the characteristics of form generating are summarized in use of the digital diagram method. Secondly, the secondary develop has been done to Rhinoceros in use of the Xamarin to implement the algorithm. In the end, the algorithm is applied in the architectural prototype design. By comparing the prototypes of architectural design, the influence of each parameter on form generating is understood more intuitively. The accuracy and efficiency of the algorithm are improved through the secondary development of software. The alternate phyllotaxis algorithm can generate three-dimensional curves and produce varied and complex forms, which has great potential to generate and optimize architectural forms.

1. Introduction

After Modernism, architects devoted themselves to the design of diverse building designs. One important way is to learn from nature and biology. As a complex of function, technology and art, architecture has its own characteristics. It is both an opportunity and a challenge to learn from or transform natural biological forms. The current parametric architectural design combines computer technology with graphics, mathematics, biology and geometry to form a more intelligent and logical architectural design method. New architectural forms are generated based on algorithm, which can help inspire designers. The form that algorithmic logic produces leads to deeper thoughts. Algorithms become ready-made tools or instructions that provide more technical support for building design.

1.1. The principle of form generating

The integration of parametric into architectural design leads to parametric design. In the parametric design, the core is algorithm, and algorithms can translate geometric rules into different forms. The algorithm contains the logic and functional relation of the form to be generated, and determines the influences of each parameter in the algorithm, and, also, determines the result of the form generating after the calculation. A series of related researches of parametric design carried out by applying algorithm have been studied, such as DNA algorithm, cytoskeleton algorithm, and bird foraging, etc. According to Xu Weiguo, professor at the school of architecture, Tsinghua University, parametric design is to quantify parameters changes in design. Each parameter is an analysis of one or more important factors in the design process[1]. Changing the values of the parameters will leads to different design results.

It is generally believed that the utilized of biomimicry for form-generation is for efficiency, because biological forms have evolved for higher efficiency and survival over generation. To borrow biological form for architectural form generating, firstly, the characteristics of biological morphology have to be distinguished, and embody these features in the algorithm. The program is not only the simulation of the biological form, but also the generation of plenty architectural prototypes according to different parameters.

1.2. Approach

As Peter Eisenman said, as generative device in process of architecture design, the diagram is a form representation[2]. The pioneer architects combined graphic theory with digital technologies to form a digital graphic design method that integrates the graphics with algorithms in specific operations, which provides a new method and content for architectural design[3,4]. In this paper, prototype analysis and feature extraction are carried out based on the digital diagram of alternate phyllotaxis, the secondary development of a 3D modelling software has been carried out with algorithm writing in computer language, and applied the research results for architectural prototype design. The research steps of the alternate phyllotaxis algorithm, and the architectural form generating base on it, can be summarized as follows:

(1) The pattern of alternate phyllotaxis forms is extracted by digital graphic analysis.

(2) The generation rule of alternate phyllotaxis forms is translated into algorithm flow chart.

(3) A secondary development of the modelling software has been carried out based on the Application Program Interface (API). The algorithm is transformed into functions and modules written in computer language, in other words, programming.

(4) Input the key parameters, then compare and optimize the form generating results. The suitable results can be selected.

2. Prototype analysis of Alternate Phyllotaxis

The regular arrangement of lateral organs is an important aspect of plant form, known as phyllotaxis. Different position and number of organs are form on a giving point; types of different pattern can be distinguished. There are four kinds of leaf order: alternate phyllotaxis, opposite phyllotaxis, whorled phyllotaxis and fascicled phyllotaxis[5,6].

The alternate phyllotaxis always has only one organ on each node; every new leaf on a plant stem is positioned at a certain angle to the previous one. From a plane view, alternate phyllotaxis contains two sets of curves in opposite directions[7]. In the entire world of developmental biology, phyllotaxis is perhaps the most striking example of a phenomenon that can only be described by using quantitative notions of geometry[8]. The definition is determined by the recursion formula:

$$f_0 = 0, \quad f_1=1, \quad f_k + f_{k+1}=f_{k+2}$$

Simson proved that the ratios of consecutive Fibonacci numbers F_(k+1)⁄F_k convergent towards the golden mean. The Fibonacci divergence angle *α=(360°)⁄τ^2* , approximately equal to 137.5 °. This is the golden angle, which is obtained when a circle is sectioned according to the golden ratio. [9]

$$\lim_{n\to\infty} \frac{F_k}{F_{k+1}} = \tau$$

$$\tau = \frac{(\sqrt{5} - 1)}{2}$$

The tracking of organ growth points will form an Archimedes spiral. Based on the discussion above, the mathematical relationship of the alternate phyllotaxis can be summarized as below:

(1) There is only one leaf on each node[10,11].

(2) The plane projection angle of between adjacent leaves is approximately equal to 137.5°[12].

(3) Two groups of curves of alternate phyllotaxis can be described by the Archimedes spiral. The quantities of spirals are two consecutive Fibonacci number F_{k+1} and F_k.

(4) The relationship between the number of spirals formed by leaves and the leaves growing is F_{k+1}/F_k.

3. Implementation of the Alternate Phyllotaxis Algorithm

3.1. Platforms

In this paper, according to modelling requirements, Rhinoceros is used as a modelling platform, Xamarin and Visual Studio are program development platforms, and based on Rhinoceros Application Programming Interface (API), the algorithm can be developed in C# language on Xamarin and Visual Studio.

Under the OS system, the Xamarin software platform can directly call Rhinoceros in time and execute C# program scripts after the *RhinoCommon* library, including wizards and the Rhino debugger, has been loaded. To develop an algorithm, it needs to be generated a *.dll* file and manually invoke the script in Rhino. The steps are complicated and many temporary files are generated. Therefore, Xamarin on the OS system was used for development in this study.

The algorithm development in Xamarin creates Rhinoceros' Application object, establishes the root object, realizes Rhino application control and interface rewriting through the access to *RhinoCommon*, *Rhino.UI* and other function libraries, and invokes the properties and methods of the root object. The referenced library eventually implements handle the exchange.

3.2. Steps of Algorithm function implementation

(1) The first step is the establishment of the Fibonacci sequence. C# has no built-in Fibonacci function, the sequence can be implement in an iterative manner. The arithmetic progression *D_1 (0,1,⋯,n-1)* and *D_2 (b_0,b_0+d,⋯,b_0+(n-1)d)* are realized by the for loop, and the starting term *b0* and tolerance d in *D2* needs to be customized (Figure 1).

```
public static int Fibonacci(int n)
{
    if (n <= 0)
    {
        throw new ArgumentOutOfRangeException();
    }
    int a = 1;
    int b = 1;
    for (int i = 3; i <= n; i++)
    {
        b = checked(a + b);
        a = b - a;
    }
    return b;
}
```

Figure 1: Fibonacci sequence in C# script

(2) Set up the points P_m($m \in D_1$), the points' sequence number are with the arithmetic progression.

(3) The default rotation angle is accurately assigned as variable *ro_angle*, which is about 137.51°, besides, an interface is setting for inputting the rotation angle to make this parameter adjustable.

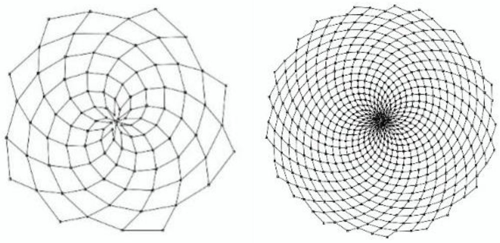
(4) Set two types of points formation rules. The distance from every point on the Fibonacci serial spiral to the central point is an arithmetic progression.

(5) Link the points to form the Archimedes curves in two opposite directions. Besides, with different mode choice, Archimedes spiral and Logarithmic spiral will be show as the result.

4. Architectural form generating

4.1. Prototype Simulation

After debugging the algorithm script, the Rhino software can be called directly by Xamarin to run the alternate phyllotaxis algorithm written by the author. The following are the morphologies of alternate phyllotaxis generated under different parameters. Based on the script the author has written, the Archimedes curves are generated with points located in polar coordinates. The following curves, from left to right, are the forms generated when the parameter rotate angle equal to 137°, 137.51°and 138°.



(Resource: Author)

Figure 2: Forms generated in Archimedes curves

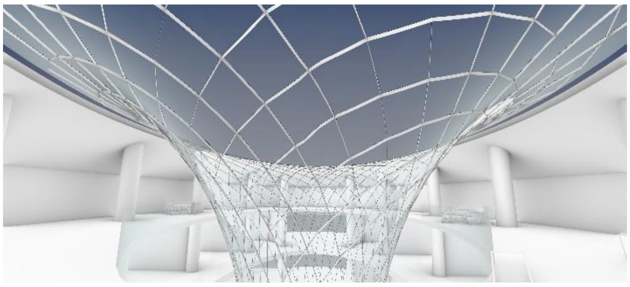
Other trials of form generating with Logarithmic helix have been done with the parameter *rotate angle* equal to 137°, 137.51°and 138°. 137.51° is the key data to this algorithm, changes to the rotate angle are subtle on the trials above to make sure shapes keep the features as bionic forms. Though big changes have been tried which change the meaning of the algorithm.

The alternate phyllotaxis algorithm helps to generate complex two-to-three-dimensional curvilinear shapes during the architectural design processes (Figure 2). The forms are diversified due to the participation of multiple factors in the algorithm, which provides abundant prototypes for analysis, deepening and application for architectural design. In the process of design, the algorithm can efficiently and easily generate curves and forms, and the shapes change when the parameters are adjusted. On this basis, the generated form can improve the function and space of the architectural scheme, the effect of light and shadow, and improve the suitability and aesthetics.

4.2. Applications of Architectural Form generating

This paper takes the design of landscape bridges in a project in Xining, China, as practice of application of alternate phyllotaxis algorithms in architectural design. The prototype of the dome on the building is generated in use the algorithm, and then the shape is optimized in the design. Levers are formed by the optimization of the curves generated by the algorithm, after projecting to the simple surface; the shape of the dome has been optimized in Rhino. The design of this project is a collaboration of algorithms and digital design tools, and it is gradually processed and refined (Figure

3).



(Resource: Author)

Figure 3: Aerial View of the project design in alternate phyllotaxis algorithm

5. Conclusion

The formation of biological forms often requires a number of relatively simple rules, while the patterns generated based on these rules can be very different. Combined with the computer's powerful computing capabilities, a large number of architectural forms can be generated. The research method and technology of alternate phyllotaxis algorithm has superiorities:

(1) The bionic form, point elements and three-dimensional curves, can be generated based on the leaf sequence shape algorithm.

(2) The alternate phyllotaxis algorithm has the potential to generate and optimize the architectural form, which can produce complex and varied forms, and also provide diversified shapes for two-dimensional plane and three-dimensional surface.

(3) With the help of Xamarin and Visual Studio software, Rhino can provide the technical support for the research algorithm after the secondary development.

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