DIGITAL METHODS OF ABSTRACTING FORMS FROM NATURE

KAMON JIRAPONG
Faculty of Architecture, Sripatum University
61 Phaholyothin Rd., Jatujak, Bangkok 10900 Thailand
Email address: jirapong@spu.ac.th

AND

ROBERT J. KRAWCZYK
College of Architecture, Illinois Institute of Technology
3360 South State Street, Chicago, IL 60616 USA
Email address: krawczyk@iit.edu

Abstract. Using mathematics and digital methods as a tool of investigation in both the natural and architectural form gives us a flexibility of exploring multiple forms and allows us to implement new parameters into the mathematical framework to generate rather more complex architectural geometry. The method of generating architectural forms in this research is developed by selecting seashell as natural object and investigating its mathematical description then abstracting each mathematical parameter with others possible mathematical functions. Each selected mathematical function represents a mathematical abstraction of a specific seashell parameter as it occurs in nature. These enable the exploring of new mathematical relationships to generate a variety of architectural forms. In the seashell form these mathematical functions are limited to those that appeared in the actual geometry of shell such as logarithmic spiral, circle and ellipse. However, in the architectural form the limitations are less.

1. Seashell Form Generating Process

The study of seashells has a long history, starting with Henry Moseley in 1838 and followed by many researchers such as Thompson (1961), Raup (1961, 1962), Cortie (1989), and Dawkins (1997). These researchers have outlined in a number of forms the mathematical relationships that control the
overall geometry of shells. Our interest centers on an investigation of natural forms as a starting point to generate architectural forms.

As documented by prior researchers, the seashell geometry can be expressed by four basic parameters.

As shown in Figure 1a, A is the shape of the aperture or the shape of shell section, B is the distance from the coiling axis to the center of the shell section, C is the section radius, and D is the vertical distance between sections. To understand the mathematical relationship of these four parameters, one coiling shell of the gastropods class in the mollusk classification was selected for measurement and reconstruction. Its digital geometry is illustrated in Figure 1b.

Each seashell can be reconstructed in a digital form with variations of the mathematical relationships among the four parameters. The result of a specific mathematical combination reflects the shell form for specific seashell specie. In this study, the concept of creating architectural form originating from seashell geometry can be accomplished by applying these same parameters to an architectural form interpretive exploring process.

2. Architectural Form Generating Process

This process adopts the four parameters from the seashell form generating process and implements additional conditions based on architectural and structural properties into one mathematical framework. This mathematical framework, Figure 2, then generates the result of the architectural form. The interpretation of each seashell parameter and the mathematical curves enable
architectural forms to be generated within various combinations of those mathematical functions.

Figure 2. Architectural Form Mathematical Framework and Mathematical Curves

The seashell parameters; path, section, growth, and vertical displacement, become major parameters in architectural form generating process that is similar to the process of generating seashell. The difference is the use of mathematical functions that are extended beyond the actual seashell geometry. The definitions and discussions on utilizing all parameters involved in the architectural form generating process are as follows.

2.1. PATH

In the seashell this parameter exhibits a curvature close to the one plotted by logarithmic spiral based on prior study of the seashell geometry. There are many reasons in biology study of natural growth objects in which many of them exhibit this mathematical quality. In architectural form, the path will not be limited only of the spiral mathematical functions due to the different environment and limitation.

2.2. SECTION

In seashell geometry, a smooth section curvature is perfectly suitable for a soft-body animal to live tightly inside the shell. An architectural section, however, has other different functions besides providing the similar enclosure
and protection. Humans live inside architecture with a certain three-dimensional volume of space around the human body: width, length, and height. The scale of this space varies on a number of criteria such as the type of function, and the number of people. This specified volume between architectural enclosure and the human body allows more alternatives of architectural sections to be generated.

2.3. GROWTH

This parameter indicates the change in size of the architectural section along the path. The difference between the growth parameter in the seashell and the architectural geometry is that the growth in architecture can be more than increasing. In architecture, growth parameter can be ignored to get the same size of sections throughout architectural form, increased or decreased to suit each interior space volume, and mathematically generated to express the mathematical quality in the form.

2.4. VERTICAL DISPLACEMENT

In an architectural form, this parameter has more limitations in architectural form than in seashell geometry. The limitations came from the building environment, material, and construction technology. In the seashell, the shell grows by the animal adding material at the edge of the opening regardless of environmental forces. On the other hand, these environmental forces become major limitations to the architectural forms. They prevent architectural forms from floating above the ground without proper supports. To recognize these limitations, this research has set the assumption for this parameter. The assumption is that every section always has its curve touch the ground plane and will be oriented vertically.

2.5. ARCHITECTURAL AND STRUCTURAL PROPERTIES

This additional parameter is developed and applied with reasonable conditions for an architectural form. The research explores the architectural properties with certain major conditions for example ground and orientation condition to recognize basic architectural orientation that ground plane is in X and Y-axis while vertical displacement is in Z-axis, human scale to develop adequate usable space, enclosure to create building space or shelter, and supports to transfer all loads to the ground. The study on seashell structural properties which is not included in this paper, however, provides the assumption of structural properties that can be implemented as one of the architectural form generating parameter. Those properties are the ground support, the compressive section shape, and the overlapping sections.
2.6. SECTION TYPE AND MANIPULATION

This additional parameter is implemented in the generating framework based on properties found only from some mathematical functions. Section type is categorized into three possible types of shapes. Each shape originated from the same basic section mathematical function. These types of sections are continuous, segmented, and overlapping. Additionally, manipulation is possible when, first, a rotation of the same section suggests a new shape, second, a section change its shape along the path which can be done by changing the individual values of parameter in mathematical functions.

3. Abstracting Diagrams of Architectural Forms

To illustrate the many possibilities of architectural forms generated in this process, the abstracting diagrams of basic architectural forms are developed. Figure 3 to 11 explain each possible configuration by using the same sample of path as Archimedes spiral with a simple section shape as ellipse for general section and hippopede for morphing feature.

Once path was assigned to be the same mathematical function, the rest of parameters can be implemented to generate many architectural forms.

![Diagram of Form Generated by Path and Section](image)

*Figure 3. Diagram of Form Generated by Path and Section*
Figure 4. Diagram of Form Generated by Path, Section and Increased Growth

Figure 5. Diagram of Form Generated by Path, Section and Math Function of Growth

Figure 6. Diagram of Form Generated by Path, Section and Increased Vertical Displacement
Figure 7. Diagram of Form Generated by Path, Section and Math Function of Vertical Displacement

Path: Archimedes Spiral  
Section: Ellipse  
Growth: None  
Vertical Displacement: Math Function

Figure 8. Diagram of Form Generated by Path and Rotated Section

Path: Archimedes Spiral  
Section: Rotated Ellipse  
Growth: None  
Vertical Displacement: None

Figure 9. Diagram of Form Generated by Path and Morphing Section

Path: Archimedes Spiral  
Section: Morphing Ellipse  
Growth: None  
Vertical Displacement: None
To illustrate the possibilities of architectural forms generated by exploring though diagrams above, samples of the resulted forms are presented in Figure 12 to exhibit the idea of how these forms can be used as architectural applications.

Each form displays a virtual quality of architecture and is ready to be developed further to a real architecture with proper material and structural system selection.
Figure 12. Sample of Generated Forms
4. Exploring Architectural Forms and Applications

The following is an example of form developed by this process and applied for architectural enclosure.

**Figure 13.** Diagram of Generating Form with Assigned Mathematical Functions

- **Section:** Ellipse
  - Function: \( x = a \cos t \), \( y = b \sin t \)
  - Factor: \( a \) = adapting the growth value
  - \( b = 20.0 \) ft.
  - Range: 0-180 degree

- **Path:** Archimedean Spiral
  - Function: \( x = a \cos t \), \( y = a \sin t \)
  - Factor: \( a = -10.0 \) ft.
  - Range: 0-360 degree

- **Growth:** Increase radius-\( x \) (a)
  - Rate: start 10.0 ft. – end 21.6 ft.

- **Vertical Displacement:** Circle
  - Function: \( x = r \cos t \), \( y = r \sin t \)
  - Factor: \( r = 10.0 \) ft.
  - Range: 0-360 degree

---

**Figure 14.** Top View, Elevation View and Exterior View

- Overlapping surfaces result from section's radius-\( x \) increasing along spiral path.
- Courtyard
- Glass wall on the inside (See interior views)
- Sloping enclosures result from vertical displacement
- Entry
- Sloping enclosures result from vertical displacement
The overlapping feature not only provides an interesting slope for exterior enclosure but also generates practical division of interior spaces as shown in interior view-A.

Interior view-B indicates the changing height of the building form that affects the interior space volume.

**Figure 15.** Key Plan Indicates the Direction of Interior Views

**Figure 16.** Interior View-A and B
5. Observation and conclusion

This research concluded that the value of the study of nature is not only for its power of inspiration and influence, but also for its abstract geometric properties. If the abstract properties can be described by the as mathematical relationship, they can then be developed into a built form. The translation of abstracted nature in conjunction in concrete mathematical terms and by applying prerequisite architectural considerations is the fundamental concept of this form development.

The value of this research is the process of developing mathematically definable models into an architectural form. The process is flexible enough to be adjusted to a variety of parameters according to the specific requirements of each architectural project. The results are a family of architectural forms based on one simple mathematical comprehensive relationship.

References

Moseley, H.: 1838, On the Geometrical Forms of Turbinated and Discoid Shells, Philosophical Transactions of Royal Society of London
Raup, D. M.: 1962, Computer as Aid in Describing Form in Gastropod Shells, Science, July-September.