Complexity in Digital Architectural Design

Abstraction, Optimization, Mutation and Interpretation of Complex Geometric Structures

Marco Hemmerling 1, Ulrich Knaack 2, Jens-Uwe Schulz 3
1-3 Detmold School of Architecture an Interior Design, Hochschule Ostwestfalen-Lippe, University of Applied Sciences
http://www.hs-owl.de/fb1
1 marco.hemmerling@hs-owl.de, 2 ulrich.knaack@hs-owl.de, 3 jens-uwe.schulz@hs-owl.de

Abstract. The association of complexity and geometry was the starting point for an academic project at the chair of Computer Aided Design in Detmold. The students were asked to analyze a complex structure - taken from nature, art, technology or society - regarding the underlying geometrical rules and principles. The translation of these abstract geometric principles (logarithmic spiral, polyhedron, rotational solids, mesh-work, double helix...) into a three-dimensional structure was then realized in Rhinoceros. The 3D-modeling was followed by a transformation- and optimization-process of the initial shape by using the evolutionary principles of mutation and selection. The set-up for these variations followed predefined rules and principles for the manipulation of the original structure.

Keyword: Geometry; Complexity; Computer Aided Design; Architecture.

Introduction

The connection of architecture and computer science generates manifold possibilities for the development of new products and services. The computer is certainly the most comprehensive and dynamic medium ever available to architects for developing and realizing spatial concepts. Exploiting this potential requires the ability to use the computer as an interactive instrument and use its artificial intelligence as an expansion of possibilities. Developments over the past 20 years in computer aided architectural design and production show the steadily growing influence of digital media on the work of architects. Processes for developing architectural concepts and formal designs, and even the way architecture is perceived, have evolved considerably through the implementation of computer technology.

Geometry an complexity

Computer-Aided Design (CAD) enables the architect to generate complex spatial geometries. The new freedom leads often to an increasing number of
arbitrary free-from-shapes that promise spectacular spaces on the computer screen but often fail in the final built project. The lack of traceable relations between the different aspects and elements of architecture result in complicated, rather than complex structures. Complexity though, as an intelligent connection of elements to form an integral overall structure, is one of the main characteristics of architecture. In this respect geometry delivers a perfect toolbox of various principles to organize a flexible pattern, that can be transformed, manipulated and expanded in the further process. The knowledge of geometric rules and principles is the essential condition to develop a solid base for the design- and realization-process of complex spatial concepts. Starting from the initial form-finding, geometry guides the project through the optimization of the shape, the integration of various elements and the implementation of parameters regarding manufacturing and assembling in the realization-process.

**Case Study - Printables**

The Printables-Project was set-up with the aim to generate complex objects that are inspired by fascinating structures from various fields (nature, technology, art ...) and at the same time based on traceable geometric principles and rules. Within the project CAD-Software was used as a design tool from the early form-finding to the final production of the digital and physical models. The design process can be described as a sequence of inspiration, abstraction, manipulation, variation, selection and association. A possible function is associate with the resulting shape only at the end of the design process and is not, like in a normal design process, given from the beginning. In that respect the immanence of the geometry is the determining factor for the designs identity.

**Radiolaria**

The structure of a radiolaria served as an inspiration for the design of a free-form structure. The fantastic drawings by the scientist Ernst Haeckel from the beginning of the last century show the complexity of these uni-cellar organisms, that live in the ocean. The structure is mainly based on hexagonal pattern, that uses a minimum of material to generate a maximum of stability. Based on these principles the aim of the design was to develop an optimized structural element, that could be assembled to a bigger free-form shape.

The hexagonal geometry was used as a self-refering system to work top-down as well as bottom up. As a result the 120° knot, that is based on many 120° knots, is able to form an even bigger hexagonal structure. In the optimization phase the geometry was simplified in order to have as many similar parts as possible to generate diverse free-form structure. In the end only four different modules were used to build up a complete construction set. The different parts were fabricated by rapid prototyping (fused

![Figure 1](successive modelling process of the hexagonal structure)
deposition modelling) and subsequently used as a reverse-mould for aluminium casting to produce a half-dome structure with a span of 16 meters.

**Meshwork**

The translation of a braid system into a digital design process was the starting point of the meshwork project. After the investigation of different principles for braid systems the concept was applied to a digital 3D-model by sweeping circular sections along an intertwining rail curve. Three identical strands were shifted along a central line with an offset in relation to the frequency of the sweeping rail. The intersection of the resulting linear structure was geometrically optimized by adapting the radius of the section profile to a minimum distance between the three strands - regarding the deflection of the amplitude.

In a next step the linear structure was transformed to a circular structure by generating an endless loop of the three intertwining strands. By applying the principles of braiding to the braid itself a self-referring structure evolved based on traceable geometric rules. The final rapid prototyping model proved that the intertwining strands do not touch each other while generating the continuous and complex geometry.

**Nautilus**

The nautilus shell presents one of the best natural examples of a logarithmic spiral. The logarithmic spiral...
is a self-similar spiral curve, in which the distances of the turnings increase in geometric progression [2]. It can be found in variations in many natural phenomena (galaxy-configuration, hurricane, flowers or the approach of a hawk to its prey).

Starting with a line drawing of the basic geometric rule, the project developed to a surface model by connecting the progressively growing sections of the spiral with a loft surface. In a further manipulation the geometric relation of the logarithmic spiral was applied in X and Y direction at the same time. As a result a self-congruent volumetric model emerged, that appears in „floorplan“ and in „section“ as a logarithmic spiral. In a final step the generative curves were rotated within the same principle to form a spiral in X, Y and Z. The measurement of the resulting model ranged from 8 millimeters to 80 meters diameter by combining only 10 logarithmic spirals to a three-dimensional object. The model of the X-Y configuration was in the end reproduced as a scale model by rapid prototyping and serves as a design study for a lounge chair, that is supposed to be developed in the next academic year.

**Physalis**

Physalis is a genus of plants in the nightshade family, that grows in subtropical regions. The fruit was used as a reference for a digital form-finding process, that focused on the inherent features of convolution and decomposition.

The abstraction of the double curved surface of the Physalis resulted in a regular spherical geometry.
and was represented by a polyhedron with triangulated faces in the next level of abstraction. In the further design process the digital 3D-model was manipulated by varying the number of faces in order to generate a representative number of variations to select from. The tiling followed the principle of triangulation, starting with an icosahedron (20 faces) to polyhedrons with more equilateral triangular faces. The process of deconvolution was integrated by unfolding the structure stepwise along the edges and the aspect of decomposition was implemented by dissolving the faces gradually from the center to the edges. The variations of the three major processes (formal abstraction, deconvolution and decomposition) were superimposed and assembled to a final model that inherits a balanced aesthetic relation regarding the immanent geometrical rules.

**Conclusion**

Geometry is an inherent aspect of many fascinating natural structures and constitutes at the same time the base for the design and development of architecture and space. Knowing about the principles of
geometric composition the architect is not only able to generate various spatial ideas but also to apply them to a specific design task and implement the relevant parameters into an architectural overall concept. The Understanding of sustainable geometric principles of nature reopens manifold possibilities for a translation to contemporary architecture. A major principle that can be found in natural geometries is the self-referring and self-congruent character of these structures. The concept of generic connections that form an immanent whole is perfectly transferable to architectural design. Against this background of emergence Computer Aided Design enables the architect not only to investigate these principles playfully but also to transform them creatively and generate new ideas based on these mutual interconnections.

**Acknowledgements**

The Printables-project was conducted with the support of David Lemberski and Marcel Bilow at the Detmold School of Architecture and Interior Design. Participating students: Roberto Almeida (Araucárias), Fernanda Cardoso (Favelas), Yalcin Dündar (Croissant), Kamil Ertürk (Graffiti), Benjamin Gerner (Radiolaria), Jakob Heining (Meshwork), Matthias Kemper (Nautilus), Frank Püchner (Physalis), Manuel Welsky (Spiral).

**References**

Wilson, J.: 1999, Equiangular Spiral and Its Related Curves, University of Georgia.