Twister

An Integral Approach Towards Digital Design and Construction

Marco Hemmerling
Detmolder Schule für Architektur und Innenarchitektur,
Hochschule Ostwestfalen-Lippe, University of Applied Sciences
http://hs-owl.de/fb1
marco.hemmerling@hs-owl.de

Abstract: The paper outlines the relevance of computational geometry within the design and production process of architecture. Based on the case study “Twister”, the digital chain - from the initial form-finding to the final realization of spatial concepts - is discussed in relation to geometric principles. The association with the fascinating complexity, which can be found in nature and its underlying geometry was the starting point for the project presented in the paper. The translation of geometric principles into a three-dimensional digital design model was followed by a process of transformation and optimization of the initial shape, that integrated aesthetic, spatial and structural qualities as well as aspects of material properties and conditions of production.

Keywords: Geometry; 3D modeling; rapid prototyping; photogrammetry; digital fabrication.

Geometric principles in computer aided architectural design

Computer-Aided Architectural Design (CAAD) enables the architect to generate complex spatial geometries. The lack of traceable relations between the different aspects and elements of architecture often 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, which 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 - Twister

The academic project “Twister” was set-up with the aim to generate a spatial design, which is inspired by fascinating structures from nature and at the same time based on traceable geometric principles and
rules. The aim was not only to generate a complex design but also to build it in scale 1:1. This approach implied that the students had to think beyond the scale of Rapid Prototyping models and develop a strategy for the production and assembly of the structure. Within the project 3D-Modeling-Software (in this case Rhinoceros) was used as a design tool from the concept-modeling to the production of digital and physical models and to generate the geometric information (e.g. developable surfaces) for the production of the building parts.

The design process can be described as a sequence of inspiration, abstraction, variation and selection. In the beginning the inspiration of a natural structure was translated into a mathematical model. Based on that 3D-Model the generative elements of the geometry - like points, edges and surfaces - were transformed in order to achieve self-similar models, with slightly different properties. In a process of selection the models were categorized in relation to their spatial and structural qualities and there ability to be represented in an appropriate geometric model for the production of large scale elements.

**Design process**

The structure of a winding nautilus-snail served as an initial inspiration for the design process. By analyzing and rationalizing the geometry of this natural structure a digital 3D-model was developed, that interconnects different arcs to an intertwining surface. The radiiues of the arcs increase from the center to the outside of the structure while the arcs are rotated by 10° in XY-direction around the center. In the preliminary design phase the arcs where connected by a continuous spherical surface.

Based on these principles accordingly the resulting surface twists in the center from the inside to the outside (Figure 1). The spatial performance can be described as an in-between of directional and centered space. The shape seemed to be ideal to function as an exhibition space that allows a seamless transformation of guided circulation while entering and leaving the space to focused concentration while being in the center of the structure.

The next step of the design process comprised the investigation of different construction concepts for the exhibition pavilion. In order to find a simple production method, from where the building parts could be derived the concept of triangulation came up. As a result the production of flat panels in wood or metal seemed to be quiet promising for the production, but failed in the aesthetic expression and the spatial representation of the intended coherent overall shape. (Figure 1)

The idea of a textile skin - supported by glass-fibre-rods, which define the geometry of the arcs - was finally chosen as a structural concept. The tent-like structure didn’t only respond perfectly to the geometric principles of the digital model, but offered also a simple production and construction method for the pavilion. Based on the translucency of the textile membrane the illumination of the structure by night became a new aspect of the design. The adaption of the material properties to the geometry of the skin finally resulted in the concept of minimal surfaces between the rods.

**From digital to physical**

In order to realize the concept of the exhibition pavilion in scale 1:1, the next relevant step was to match the digital model with the methods and conditions of production. Rapid Prototyping technology was used in a first step to translate the digital data into a physical scale model. The Rapid Prototyping-modell helped to understand the spatial qualities and was at the same time the base to study production methods for the 1:1 scale. (Figure 2)

For the realization of the exhibition pavilion with a radius of approx. 6 meters and a height of 3 meters obviously other methods had to be developed. For the building process of the low-budget project a common tent structure based on carbon-fibre rods for the arcs and a textile membrane for the minimal surfaces spanning between the rods was chosen. Within the further planning process the conditions
of production (fixtures, element sizes etc.) and the material properties were investigated and implemented into the digital model.

By using the principles of reverse engineering the digital 3D-geometry was adapted to the parameters of production. The geometric deviations of the rods in relation to the digital model of the arcs was analysed in a test-assembly of each arc. With the help of Photogrammetry (Figure 3), that relates the lines of the digital model to the orthoscopic foto of the rods, the physical geometry of the rods was ascribed to the Rhinoceros-Model. Based on this analysis the digital model was adapted to the material conditions from the survey of the rods. The blanks and
physical methods resulted in a precise description of the building parts. From this point on the production of the building parts started.

The further process of production and assembly took almost 80% of the total amount of time spent on the whole project. Due to the various steps of production – assigning the geometry, cutting and sewing the textile – the imprecision of the membrane increased. (Figure 4)

sizes for the rods and the membrane where finally taken from the so updated model in Rhinoceros into the realization process. (Figure 3)

The double curved geometry of the minimal surfaces was unfolded by using approximation methods after generating a polysurfaces from the NURBS-model. The different shapes of the developed surfaces where then used as a layer for tailoring of the membrane. The dialogue between digital and
principles, the developed model delivers a resilient and at the same time adaptive base for the process of manipulation and optimization.

Secondly the extension of the digital chain from the architectural design process to the architectural production in this project showed the relevance of integrating material properties and production conditions into a the digital design process in order to achieve an accordance between the digital model and the physical result. Extending the digital technology to the production and assembly process will definitely increase the level of efficiency and precision.

Next to its use for the development of spatial concepts and the form-finding process, computational geometry is a relevant medium to integrate the assembly of the exhibition pavilion “Twister” was finally based on traditional methods of membrane constructions using sewing-technologies and knot-fixtures. After setting out the rods, that defined the basic geometry, the tailored membrane was applied to the line-grid of the rods from the bottom to the top, with resulting deviation at the top of the structure. (Figure 5)

**Conclusions**

Two relevant aspects for the process of digital architectural production in relation to geometry could be taken from this project. The methods of digital form-finding within the design process extend the repertoire of spatial concepts. By referring to geometric

Figure 5
Assembly of the rods and central knot-structure
parameters of the realization into the architectural design process. (Figure 6)

**Future work**

Further research covers the implementation of digital tools into the production and assembly process. Besides the integration of material properties into the digital model the rethinking of production methods and their implications for the digital design process will be in the focus of the next academic projects.

**Acknowledgements**

The project “Twister” was conducted with the support of Ulrich Knaack, Jens-Uwe Schulz and David Lemberski at the University of Applied Sciences (Hochschule Ostwestfalen-Lippe) in 2008.


**References**


