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Two Spatial Experiments based on Computational Geometry

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***Abstract*—**The paper outlines the relevance of computational geometry within the design and production process of architecture. Based on two case studies, 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 that can be found in nature and its underlying geometry was the starting point for both projects presented in the paper. The translation of abstract geometric principles into a three-dimensional digital design model – realized in Rhinoceros – 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*—**Architecture, Computer Aided Architectural Design, 3D-Modeling, Rapid Prototyping, CAD/CAM.

I. 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.

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.

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II. Two Case Studies

A. Twister

The Twister-project was set-up with the aim to generate complex spaces, that are inspired by fascinating structures from nature 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, 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.

The structure of a winding nautilus-snail served as an initial inspiration for the design process. By analysing and rationalizing the geometry of this natural structure an abstract digital 3D-model (using Rhinoceros) was developed, that interconnects different arcs to an intertwining surface. The radius 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. The different arcs are connected by minimal surfaces in order to generate an optimized coherent overall shape. Based on these principles accordingly the resulting surface twists in the center from the inside to the outside. 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.

Fig. 1 Digital 3D-Model of the twisted exhibition space

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. The use of Rapid Prototyping technology was well known from the “Printables-project” [1] in 2007 that investigated production methods of complex geometry by using a 3D-printer in order to produce generic scale-models out of digital data. For the realization of a pavilion with a radius of approx. 6 meters and a height of 3 meters other methods had to be developed. For the building process of the low-budget project at the University of Applied Sciences in Detmold we chose – after looking at various options, like triangulated wooden or aluminium panels - a common tent structure based on carbon-fibre rods for the arcs and a textile membrane for the minimal surfaces in-between. Within the planning process the conditions of production (fixtures, element sizes etc.) and the material properties were investigated and implemented into the digital model.

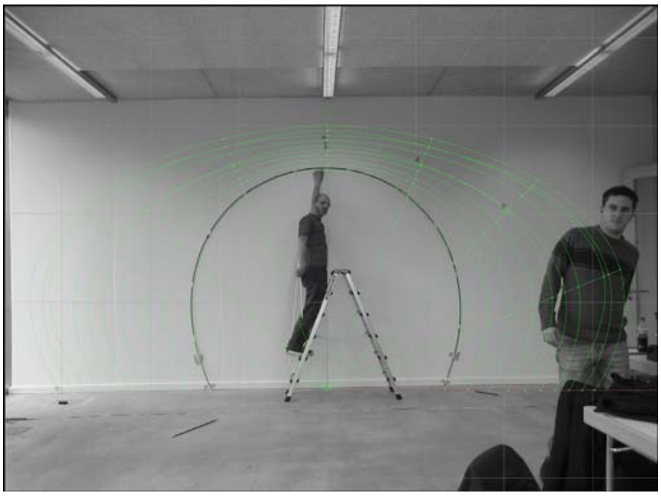

Fig. 2 Reverse Engineering: Photogrammetry of the physical rod-structure in relation to the digital arc-structure

By using the principles of reverse engineering [2] 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 the geometry of the rods was digitalized and implemented into 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 sizes for the rods and the membrane where finally taken from the so updated model in Rhinoceros into the realization process. The assembly of the exhibition pavilion “Twister” was based on traditional methods of membrane-constructions using sewing-technologies and knot-fixtures.

Fig. 3 Illuminated exhibition pavilion “Twister” in Detmold, Germany

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 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.

B. Corpform

The Corpform-project is meant to demonstrate analogies with living organisms. Using geometric, chemical and physical modifications, the building’s envelope and structure can adapt to changing climate and weather conditions. Opaqueness, maintained temperature as well as acoustics, light ambiance and the overall form of the structure ca be manipulated. The pneumatic load-carrying structure contracts and relaxes, during which the fragile glass-fiber structure takes over the support function while the shape of the installation changes. Reservoir pads with Phase Changing Materials [3] are build into the load-carrying structure, which activate thermal mass in order to regulate the climate condition of the experimental building. In addition a textile membrane with ceramic layer serves an isothermal function. The constantly changing illumination that is created by a layer of over 300 glass fiber strands visualizes the adaptive properties of the experimental structure.

Fig. 4 Corpform (structure partly relaxed) at the Entry 2006 in Essen, Germany

Even though the final shape of the experimental building seems not be directly linked to a traceable geometry, the form-finding process was relevantly influenced by the relation of geometry and material properties. The major problem we were facing within the design process was based on the contraction and relaxation of the pneumatic structure. The change of the geometry within these two conditions is related to the pressure ratio, the material properties of the membrane and the blanks that form the shape. Taking into account these parameters we developed different 3D-Models in Rhinoceros that simulated the behavior of the geometry in the particular conditions – both for the inside and outside layer of pneumatic cushions.

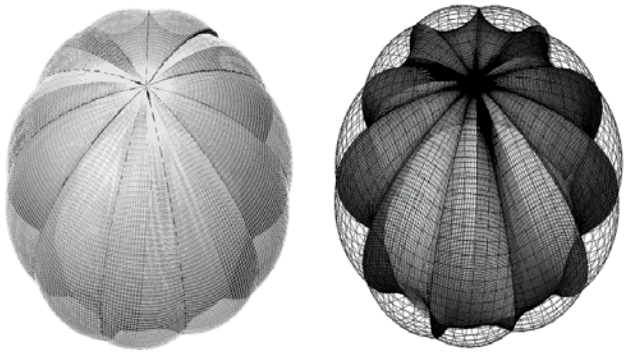

Fig. 5 Outside (left) and inside layer of the pneumatic structure

The inside layer of the pneumatic structure is generated as a set of minimal surfaces that are connected to the outside layer along a linear seam. The outside layer vaults towards the outside in a way that a convex shape for the cushion arises. The Geometry of the seams was developed in the beginning as a row of ellipse-like basket-arcs. Next to the pneumatic system a secondary load-carrying system - in the form of a glass-fiber structure – was introduced along the seams in order to avoid that the systems collapses if the pressure ratio falls below a certain degree.

Adaptivity is the major property of the installation Corpform. Next to the changes in chemical and physical performance also the geometry adapts to external influences. The manipulation of the form is based on a geometrically defined system. The underlying principles of the geometry were used as a flexible guidance within the design process and were well connected to other project-relevant parameters for the realization, such as pressure ratio and material properties.

III. 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. Next to its use for the development of spatial concepts and the form-finding process, computational geometry is a relevant medium to integrate parameters of the realization into the architectural design process.

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REFERENCES

[1] M. Hemmerling, "Geometric Complexity in Computer Aided Architectural Design" in *Proceedings* of the 13th ICGG 2008 in Dresden.

[2] R. Vinesh; Reverse Engineering - An Industrial Perspective; Springer Verlag; 2008.

[3] C.v. Uffelen, "heart cahmber" in *Pure Plastic – New Materials for Today's Architecture*, Verlagshaus Braun; Berlin; 2008.

Marco Hemmerling studied Architecture and Interior Design at the Bauhaus-University in Weimar, Germany and at the Politecnico di Milano, Italy. From 2000 – 2005 he was project architect at UN Studio van Berkel & Bos in Amsterdam and Stuttgart where he was jointly responsible for - among other projects – the design and realization of the Mercedes-Benz Museum in Stuttgart. In 2005 he established his own office for architecture and design in Cologne and completed in 2006 his postgraduate Master of Arts in Architecture and Media Management at the University of Applied Sciences in Bochum. Since 2007, he has been teaching and researching as Professor for Computer Aided Design at the "Detmolder Schule für Architektur und Innenarchitektur"; University of Applied Sciences Ostwestfalen-Lippe.