Sparkler

The Vitruvian Man vs. Buckminster Fuller

1Marco Hemmerling, 2David Lemberski
1,2Hochschule Ostwestfalen-Lippe, University of Applied Sciences; Detmolder Schule für
Architektur und Innenarchitektur, Germany
1,2http://www.hs-owl.de/jb, http://www.m-cdc.de
1marco.hemmerling@hs-owl.de, 2david.lemberski@hs-owl.de

Abstract. Every production technique requires a focus on their specific demands and
possibilities. This paper shows the whole design, optimization and production process
including preliminary studies, preliminary design, form-finding and assembly based
on a case study. All needed data for optimization in external software and for digital
production is derived from a central parametric model programmed in Grasshopper.
The result in a collaborative process between theory/practice, human/machine, software/
hardware and analogue/digital is the Sparklerpavilion.
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INFORMED ARCHITECTURE
Since several years computational design enables the architect to generate complex spatial geometries based on the principles of parametric design thinking. The new freedom leads to an increasing number of arbitrary shapes that promise spectacular spaces on the computer screen, but they often fail in the finally built architecture. The lack of traceable relations between the different aspects of architectural production results in complicated, rather than complex structures. Complexity though, as an intelligent connection of elements to (in)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 and manipulated as well as enriched and expanded in the further process. The knowledge of geometric principles, and the underlying logic, forms an essential base for the design and realization-process of complex spatial concepts (Pottmann and others, 2005). Starting from the initial form-finding strategy, geometry guides the project through the optimization of the form, the integration of various demands and elements up to the implementation of parameters from production and assembly in the realization phase.

But the adaption and variation within the design and production processes generates a new freedom and different demands at the same time. Next to the possibilities of individualized manufacturing we can observe a shift from a result to process-oriented design as well as a change of design strategies from top-down to bottom-up. Digital form-finding strategies, parametric design and digital fabrication technologies allow today for the direct translation of the digital model into the physical world – a powerful toolbox in the hands of architects that needs to be reflected as well in the CAAD curriculum (Hemmerling and Tiggemann, 2011).
**Case study Sparkler**

Against this background the academic project Sparkler tries to connect digital design strategies with appropriate construction principles and methods of assembly as well as a worthwhile material usage to achieve significant architectural results. In this respect the role of computation can be seen more as a connector and amplifier rather than a form-generator of digital architecture.

The crystal-shaped structure of the pavilion is a three-dimensional interpretation of Leonardo Da Vinci’s Vitruvian Man, showing a man bound within a square and a circle (Fig. 1 left). The definition of the geometry is based on two primitives, an inner sphere and an outer cube, which are connected by the extruded edges of an Archimedean solid - the truncated icosahedron, also known as buckyball, named after Richard Buckminster Fuller (1967/2008). Starting point for the form-finding process was the initial idea to use a Boolean operation for the generation of the basic shape by subtracting a sphere from cube (Fig 1 right). After testing different variations of the penetration the question of the production method and materialization was implemented in an early stage of the design, reflecting additive and subtractive fabrication methods on the campus (3D-printing, laser-cutting and CNC-milling) to produce the building parts in scale 1:1.

Within the further design process two strategies were brought forward simultaneously: The first approach focused on an irregular structure based on a triangulated geometry, while the second approach was based on the regular geometry of the truncated icosahedron (Fig. 2 left). After evaluation both strategies were superimposed and brought together in a parametric model, programmed in Rhinoceros/Grasshopper (Fig. 3 right). While the angle of all faces were kept the same, based on the regular geometry of the Archimedean solid, the size of the faces varied within the model. This decision lead to a clear separation of the constructive elements, taking the fabrication possibilities and assembly method into account: regular steel knots (serial production) vs. irregular wooden panels (customized production).

The parametric model allowed for a holistic transformation of the overall shape by individually redefining the three geometric descriptions (sphere, cube, Archimedean solid). Based on that the design process was brought ahead by generating numerous variations of the design concept (Fig. 3 left). In order to support the idea of a transforming structure the outer cubic shape is cut by seven planes. As a result the final geometry of the Sparkler pavilion allows for a varying positioning on each of the seven outside faces.

Inside Grasshopper, each of the three determinant intersecting geometries (crystalline outer cut, buckyball structure and spherical inner cut) could be changed in scale and position parametrically and independently. A 3D human was set inside the virtual pavilion model to remind the scale and proportion in the real world. At the beginning of the GH working stage all panels were only treated as extruded surfaces without thickness to allow the fastest pos-

![Figure 1](image)

*Inspiration: Leonardo Da Vinci’s Vitruvian Man (left), sketches from the early design process (right).*
sible computation and interactivity. Disregarding the knots at this time was also needful because the knot’s design and the structural simulation were still ongoing. To help estimate weight and costs of the project, GH was programmed to always show the total area of all panels.

Next to Rhinoceros/Grasshopper, Sparkler was developed using also Dlubal R-Stab/R-FEM during the planning phase to verify the structural concept as well as CNC-technologies for the production of the different building parts, in this case: wooden panels by CNC-milling and steel knots using water jet cutting. (Hausschild, Karzel 2010). The material dimensions and the construction principles were finally implemented in the parametric model as well to prepare the production of the building parts.

The panels have been transferred via DXF as 3D objects from Grasshopper to Dlubal R-Stab/R-FEM in order to simulate structural and tipping behaviour (Fig. 4). An optimum balance between panel thickness, knot dimensioning and knot distance had to be determined. These parameters were interdependent, a change on one of them would affect the total weight and stability and thus require a change on the others. These alternating process of changes and calculations requires a loop which can only be left after reaching the equilibrium.

The resulting values like panel thickness, knots dimensioning and minimum knot to edge distance have been integrated as parameters into the GH programming once the structural simulation was finished. There were two spherical layers of knots, mak-
ing a total of 120 junctions. Because all knots were planned to be equal in order to reduce production time and costs the knot detailing was done in 2D to further simplify the design process (Fig. 5 right).

Since every of the 90 wooden panels had an individual shape all slots of the outer knots had a different distance from the center. To ensure final fitting accuracy the slots has been calculated in 3D (Fig. 5 left). Especially on the interface between design and construction it was helpful to realize a physical model in scale 1:10 to understand and test the assembly of the building parts and connections. Therefore the different panels were developed from the 3D-model as planar polygons, using the Grasshopper-logic.

In order to optimize the cutting pattern and minimize the material use for the panels the polygonal shapes were nested. Subsequently the scale model was produced with a CO2-lasercutter (Fig. 6). Next to the testing of different building methods, e.g. bottom-up or by elements (hexagonal and pentagonal shapes) the scale model was also used to evaluate the spatial and structural performance.

The cutting pattern for both the scale model 1:10 and the final 1:1 pavilion has been derived from the same Grasshopper parametric model. At the beginning this model had only few parameters but during the design process more and more parameters has been added resulting in over 20 at the end.
This amount of adjustment options allowed to fine-tune the model, recalculate it within two minutes without remodeling it by hand and adapt the output data to different production techniques with little effort. To transfer the 2D cutting pattern from Grasshopper to the lasercutting and CNC-milling machine again DXF was used.

Within the digital design course the students were not only asked to design a summer pavilion but also to construct and realize the design in scale 1:1, using digital design and fabrication tools. Against this background the digital workflow including parameters of production, construction and material became key issues of the further process that was carried by involving different disciplines and experts (e.g. department of structural engineering and building materials). Due to the experience with the scale model and the reverse engineering to the digital model, according to the demands of fabrication, the production process of the building parts and the assembly of the pavilion went smoothly. While the shapes of the plywood panels are all different the steel knots are all similar due to the regular geometry of the Archimedean solid. The appearance of the pavilion changes not only due to the seven possible positions, but also related to the perspective from where Sparkler is experienced. The inner space appears in contrast to the outside of the pavilion very open, which goes along with the central focal point of the geometry (Fig. 7). Looking from inside out no faces, only the edges are in the view of the beholder.
CONCLUSION AND OUTLOOK
The integral and collaborative approach within the design and construction process proved to be indispensable for the realization of the experimental pavilion. Due to a consistent digital process the pavilion has been realized from the initial idea to the final assembly in only two months. The expertise from different professions (architecture, building engineering and material science) was important for a holistic understanding of the relevant parameters in the project. The data-exchange between Rhinoceros/Grasshopper and R-Stab/R-FEM via DXF –Format worked out well and the results of the structural engineering software could be implemented in the form-finding process. A better integration of material properties, cost calculation and life cycle evaluation would definitely enrich the planning process. The step towards a Building Information Model (BIM) that can be shared by all partners (architect, structural engineer, contractor…) via the IFC –Format (Industrial Foundation Class) will be the focus of future projects.

Against this background the new post-graduate Master-program Computational Design and Construction (www.m-cdc.de) was set up at the Hochschule Ostwestfalen-Lippe University of Applied Sciences in Detmold, that focuses on the interdisciplinary field between Architecture, Design Engineering and Informatics. The international study program incorporates the professional qualities of a higher architectural education together with the theoretic and operative aspects of civil and mechanical engineering as well as information technology.

REFERENCES