Parametric Design and Fabrication Strategies by Practice

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Abstract
The rapid development of parametrical tools for architectural design has implicated a big challenge for contemporary architectural education. In the last years many universities have been introducing digital design and fabrication in their syllabus to provide and teach a broader understanding of parametrical design. In order to make virtual parametrical models also buildable for architectural usage a huge amount of knowledge and skills are needed, which induces a big task for teachers and a big challenge for students. Mathematics and geometry play again an important role in order to understand these new tools.

This paper presents our teaching approach to the design process through parametrical modelling to realisation in scale 1:1 strongly based on geometry and mathematics. With the design project “Wooden sleeper”, which is made from solid wood, we will present our teaching line. The core of this is the geometrical understanding of the different relations between the involved objects and its translation into a geometrical and mathematical language in terms of computer algorithms, including the mathematical transformation of building materials behaviour.

1. Introduction
For many years wood was treated as material for traditional and temporary architecture. Due to the development of digital tools for CAD programming and CNC fabrication the tendency for experimentation with wood has been growing intensively for the last ten years. Additionally, wood is an economical and natural substance which is very popular for experimentation and can be easily machined. Furthermore, the interest and courage to build extraordinary and novel architecture and constructions made of wood is increasing [1], [2]. Confidence and trust in wooden architecture is coming back, although governments are sometimes very frightened to accept and allow novel approaches.

The tendency for experimentation is currently strong promoted by the schools of architecture in terms of small architectural structures or temporary art projects (Figure 1 and [3]).

In such projects, wood is used as a linear element, self-supporting, or as fill material. Manifold possibilities result from using different types of wood, different structures, like solid wood, laminated wood or bended wood. Wood processing ranges from manual workmanship to the use of all kind of CNC machines. Centuries-old knowledge on wood processing can be now adapted and brought to new prospects given by the digital age. The age of digital fabrication of wooden elements and the process automation from design to fabrication has brought two significant changes in architecture. On the one hand, an unprecedented precision and level of detail in the machining of wood elements arose by the use of CNC machines. On the other hand, a formal freedom in the design of linear and curved surface elements emerged. A very significant contribution to the formal freedom of the design is due to the use of computer programming and algorithms already in the design stage. In addition to the use of CAD programs for 3D modelling and visualization of architectural objects, algorithmic software supports the...
Figure 1. Experimental wooden architecture

Figure 2. Some of the students’ competition projects

Figure 3. Scale models of the winner project “Wooden Sleeper”
approach of the individual architect and broadens the perspective. Depending on the skills and the capability of the architect, these algorithms can be implemented in the architectural design at different levels - from conceptual design to the optimization of the form with respect to static behaviour up to the details of individual architectural elements.

The use of algorithms and parametric design is very important in our approach and algorithms, from the initial design, to model making and eventually to the real scale production, support many processes in the project described in this paper [4].

What makes our project unique is the parametric connection between the architectural design and the static behaviour of the form. Both affect each other.

2. Teaching, design and research

The course “Design of specialized topics” hold in the summer semester 2015 featured the so-called project “Wooden canopy”. The task for the students was the conception design for the future use of Park Lackenbach and a design of a canopy for the entrance of a rail-cycle draisine station into the park. Park Lackenbach and castle Lackenbach are located in the eastern part of Austria.

Since the main goal of this course was to develop one project from the design stage to the realisation, all students were very motivated to be part of it. The challenging task was that the whole project should be developed in a short time (one semester) and be assembled by the students themselves. In order to achieve this aim it was necessary to use all possible digital tools for the design and the fabrication process.

In the first stage we made a competition and all students made their individual designs (Figure 2). A jury chose one design, based on different criteria such as visual identity, feasibility, costs, realisation, etc.

In the second stage the winner project called “Wooden sleeper” (Figure 3) was developed further by all students. In the third stage they assembled and built the project all together in scale 1:1 guided by qualified persons.

At the end of the semester, all competition projects were exhibited for three months in castle Lackenbach next to the site of the winner project open to public view.

Important for our teaching approach was the fact that after jury’s decision the students should work together as a team and collaborate in one project. All work was divided into several parts handled by small students’ groups, including detailed planning, 3D modelling, cooperate design, model making, etc.

In the following paragraphs we will give a detailed description of this work and the winner project.

3. Geometry

The geometrical shape of the “Wooden Sleeper” consist of three conoidal surfaces [5]. The surface $c_1$ is on the left side, $c_2$ on the right side and $c_3$ acts in between as the canopy (Figure 4). A conoidal surface is a ruled surface whose rulings are parallel to a director plane.
For the further definition of the conoidal surfaces we have four curves, the bottom curves b₁ and b₂ and the curves t₁ and t₂ at the top of the building, between the canopy part and the side parts.

In the real project we had to discretise the conoidal shapes, and so the rulings were represented by wooden bars.

4. Static behaviour

With the geometrical rules of a conoidal surface it is possible to design a wide range of structures. The challenging task in our approach was to choose an optimum shape solution based on statical conditions and constraints.

One of the main characteristics of our project is that we included statical calculations at the early stage of the design. We programmed an interactive statical calculation that provided an optimal geometrical solution for the shape of our structure. The basic statical system is defined as a three sided frame (Figure 5). The whole structure consists of twenty one different frames. All frames have the same topology but all bars are different in length with different angles in between.

The goal of our statical system was to minimize bending moments in supports by proper positioning the bars in each frames accordingly. To achieve that the resulting forces representing the vector P/2, F (support forces) need to meet in one point M (Figure 5). This special situation results in zero bending moments in support.

For the calculations the support points 0 and 3, the bar S₁ and the direction of S₂ were given. The bar S₂ was then defined through the calculations shown on Figure 5 right.

In order to stabilize the frames in the direction perpendicular to each other we used threaded bars along the lines L₁, L₂, L₃ (Figures 4 and 6B).

Since the lines L₁, L₂, L₃ can be seen also as generatrices for the conoidal surfaces c₁, c₂, c₃ they are also called conoids.
5. Parametric modelling

In order to have an optimal way of freedom we pushed the students to establish a parametric model of the project. Therefore we used the CAD program Rhino and its plugin Grasshopper.

In a first step, we setup the main geometry. This included the geometry of the bars and their connectors and joints, where every part is different. After this, we incorporated the static model into the geometric one. Every change in the static calculations influenced directly the geometry and vice versa. With this model we optimized the static behaviour and the forces. To link the beams to the concrete fundament we modelled steel connectors.

With the parametric model we defined the positions of all connectors and the whole 3D geometry of the bars. The 3D data of the bars could be directly sent as an output of the model to the Hundegger-CNC-machine for fabrication without any further change. For welding the steel connectors (Figure 6C), which was done manually and very challenging, we exported blueprints from the parametric model for the welder.

6. Assembly

The assembly was done by the students themselves supported by some experts (Figure 7). All of them, including the women, got an introduction in handling the tools we used. This was a very interesting experience for everybody, especially the use of the angle grinder. For almost everybody the assembly of this structure was the very first manually work they have ever done in this size.

The final project can be seen in Figure 8.

7. Conclusion

The realisation of a real project is very rare and challenging for bachelor students of architecture and their teachers. Fortunately, the students at our university had this possibility, and they were very grateful for this experience.

The project named “Wooden Sleeper” was designed in SS2015 with parametrical tools, fabricated by a 5-axes CNC cutting machine and built as a canopy and entrance for Park Lackenbach in Austria. The main objective of the “Wooden sleeper” project was to include structural behaviour and material properties already in the parametrical mathematical model. For this project a deep understanding of the structural system and the geometrical properties was the challenge for the students. The second objective was to connect geometrical properties with the building materials and fabricate a wooden structure in scale 1:1. For this project, all building parts were parametrically designed and a direct file export for the CNC machine was provided.
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The experience “from design to production” that student got in this course showed us that this kind of teaching is very motivating and supports new competences for the future generation of architects. Due to the very professional work of the whole team we have got the opportunity to continue the cooperation with Park Lackenbach and to plan a new project for the upcoming year.

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References


