

Escaping the Model's Scale

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ABSTRACT

Over the last five years, the use of computer-controlled machinery in the building process has expanded immensely. With the help of parametric software, it has become possible not only to manage ever more complex structures but also to realize them using digital fabrication processes. These increased possibilities in turn place new demands on architectural teaching and its underlying didactic concepts. Taking the “WAVE 0.18” project as an example, this paper demonstrates the possibilities as well as the challenges of new didactic concepts and their practical application at the Chair for Architectural Informatics at the TU Munich.

KEYWORDS: didactics, parametric design, digital fabrication, CAM, Scale 1:1.

Form Follows Computability vs. Form Follows Producibility

The aim of planning is ultimately to produce an end result. Given the vast number of highly complex architectural designs—a product of parametric design software—this paradigm is more relevant than ever.

The use of digital fabrication machinery is becoming ever more important. Famous examples, such as the Mercedes Benz Museum in Stuttgart or the Centre Pompidou in Metz, demonstrate the new design possibilities that can be realized through the use of CNC-machinery, which are becoming available to us as architects, as well as to future generations of architects. In light of the broad appeal of this new formal language, architecture schools are called upon to critically examine this topic in their teaching. If one takes a look at the work undertaken in design studios in universities around the world, one can see that parametric programs, such as ParaCloud, Processing, Grasshopper and Generative Components, are being employed in many different areas. Very often, this results in designs whose forms follow purely formal criteria. As a result, internet platforms are awash with countless lavishly rendered digital utopias.

But once one has understood the basic principles of the digital design chain, it becomes evident that parametric design tools and computer-controlled machinery are in fact well suited for planning as well as realising complex forms. The challenge of digital building is the development of new systems; it is the design of joins and connections between elements that is the key to complex structures. The connection between elements influences the structural capacity, constrains the final form and determines the complexity of computer-generated structures, as well as the degree of prefabrication, of transportability and the ease of construction. Fundamentally new forms can only be realized through new systems.

If we wish to realize complex forms, more than proficiency in computer use, we require an understanding of space and a good architectural concept. If we want to create new digital architecture that can be realized, we also need to question our design methods. In contrast to the conventional approach taught in architectural studies, which begin with urban contexts and later progress to detail design, these new kinds of complex systems require that we start with details and connections. The material and how we work with it can serve as an inspiration for a new formal language.

New Challenges in Architectural Teaching

Our teaching methodology takes a holistic approach aimed at teaching students the ability to use computers to develop complex structures in such a way that they can ultimately be realized using computer-controlled machinery.

Along with the communication of parametric design skills, our teaching concept also examines CAD-CAM concepts with a particular focus on a bottom-up approach: the students should learn how to make material choices appropriate to the digital manufacturing process. They need to acquire an overview of construction details and be in the position to develop an optimal solution with regard to computer-aided manufacturing, logistics and assembly. To do this students need a broad knowledge of industrial tools and their areas of application as well as a fundamental understanding of the systematics and kinematics of computer-controlled machine tools.

This provides a foundation for understanding current developments in the field of mass-customization and one-of-a-kind production methods and how these can be applied to realize architectural construction concepts. A further aim of the teaching program is to enable students to develop a continuous digital data chain from the CAD-data of the design to CAM (Computer Aided Manufacturing) to the CNC data used to control the NC machines.

Through the above, students should acquire a greater awareness of industrial production methods in the planning process. This includes the actual use of relevant machinery such as laser cutters and rapid prototyping approaches in the production of scale models.

Finally, a central aim of our teaching approach is that students experience the consequences of their planning decisions in the building of a 1:1 life-size prototype.

Design and Production | Teaching Architecture CAM

In the winter semester of 2009/2010, a course entitled “Design and Production” that implemented a newly designed didactic concept was offered at the Chair for Architectural Informatics at the TU Munich. As described above, it represents an attempt to implement a bottom-up approach. Accordingly, the first step was to introduce the technical principles of materials, tools and machinery. The second stage then examined IT principles and the digital chain from parametric modelling and CAD data to CAM data and finally to CNC-data, all explored through a series of short exercises.

Only once this foundation had been prepared were students asked to develop digital design and production concepts presented in the form of a scale model. Finally, one of the projects entitled “WAVE 0.18”, was jointly realized at a scale of 1:1.

Technical Principles

What materials are available for digital production methods? One of the first stages in the design and production of complex structures is to determine the boundary conditions. A fundamental aspect of this process is the choice of the construction method which, in turn, is a factor of its intended function and the material used.

To ascertain which materials are appropriate for a particular purpose it is necessary to correctly address the problem at hand. Depending on the area of application, the following criteria are of key importance:

- Structural behaviour
- Weather resistance (e.g. moisture, solar radiation)
- Fire performance
- Sustainability
- Available dimensions of raw material
- Working techniques

In the course we analyse six of the most important building materials in detail using actual examples from digital production. In our examinations, wood has proven to be particularly interesting. Wood is in many respects especially suited for machine production. It can be easily machined with CNC tools and, aside from the many different kinds of sawn wood, a wide range of wood-based composite materials are also available. Alongside the many different variants of the materials and their properties, there are also a wide range of means of joining them. A further advantage is that many innovative carpentry workshops and universities now use CNC machines for processing wood.

In addition to the choice of an appropriate material, students need to acquire an understanding of suitable tools. While it is not possible to enter into a detailed examination of all the possible production methods in the scope of the course, it is possible to broaden the students’ horizons and simultaneously reactivate their cognitive understanding of existing approaches so that they are able to combine these to critically assess, and ultimately employ, production processes in a structured manner. Here we overlap with the field of mechanical engineering, where tools are divided into six principle categories:

- Primary forming | creating cohesion
- Forming | maintaining cohesion
- Joining | increase cohesion
- Coating
- Separating | decrease cohesion
- Changing material properties

To enable students to be able to assess the state of the art in the field of robotics and CNC machine tools, we begin with a chronologically structured categorisation of the machines. According to the technology historian Akos Paulinyi, tools can be categorised into three archetypal groups (Paulini, 1989):

- Hand tools – held and directed by people;

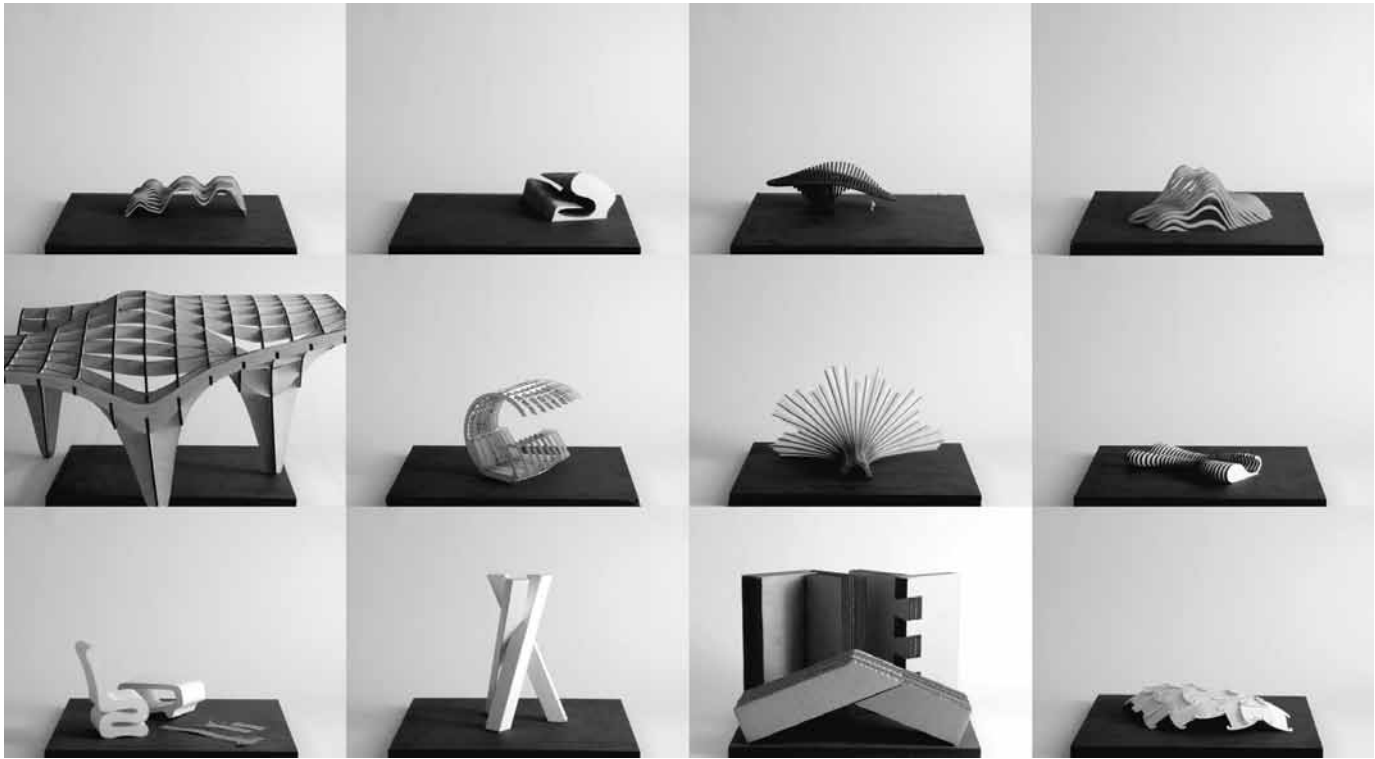


Figure 1. Student work

- Machine tools – where the tool and the item to be tooled is held and driven by a technical apparatus, but the direction of the machining process is still controlled by people;
- Information tools – in which the tool and the item to be tooled are held, driven and also controlled by a machine. CNC machines are information tools. They can process materials at high speeds with a high degree of precision (Kief, 2005) by moving a tool with the help of kinematics.

CNC machine tools vary widely in terms of mechanical structure and the possibilities they offer. The following criteria are of relevance:

- Number and direction of axes
- Type of movement
- Form and size of the working envelope

Concept Development

After establishing and exploring all the key principles for digital fabrication in small exercises, the students were asked to develop concepts of their own. In our case, we knew that the result would be shown in an exhibition at the Pinakothek der Moderne in Munich, one of the most important art galleries in Germany. The context was an exhibition entitled “Wendepunkte im Bauen” (Turning Points in Building) presented by the architecture museum on the topic of prefabrication and the new paradigm of digital fabrication. A spatial sculpture needed to be designed and built for an area of the interior (10

x 20 x 5 meters) that showcases the new possibilities of digital planning and fabrication to create authentic architectural solutions. All the concepts, therefore, needed to respond to local conditions such as the size of the room, the path of visitors and the changing daylight conditions.

The results of the concept phase were very varied: a parameterised expanded metal wall, a parameterised wooden baldachin-like canopy and a multi-dimensional metal frame structure based on the simulation of a swarm.

The 1:1 Prototype | WAVE 0.18

From this point onwards we had just six weeks to complete the project. In addition to the time frame, all technical and financial boundary conditions were also fixed. Our research focused on the development of an easy-to-assemble solution for the junction at the orthogonal intersection of the timber rib sections.

Graphic-Visual Programming

Only by creating a complete parametric model was it possible to model the complex interrelationships within the structure and accordingly to be able to react flexibly to changes that arose during the design process. The programming was undertaken in Grasshopper and VBA-script. The following parameters were taken into account during programming:

- Length and width
- Grid dimension / structural module
- Column position
- Material
- Oscillation amplitude
- Structural depth
- Dynamic cantilevering – according to distribution of forces
- Detail articulation
- Tenon placement
- Arrangement of the element layers
- Channel for tensioning band
- Weight optimisation
- Position of fixing dowels
- Element numbering

The programming resulted in a fully parameterised model in which all parameters—design, structure and production—can be adapted easily. The program produces a three-dimensional model in real time as well as all outlines for the panel production including their dowel joints. This information can be passed directly to the CNC fabrication machinery. This made it possible both to intuitively develop a number of alternatives as well as to remain able to react flexibly in real-time to necessary changes to the design, for example in response to input from the structural engineer.



Figure 2. WAVE 0.18

Fabrication

Due to these complex preparations, the entire structure could then be manufactured and assembled in just six days. Over 1,100 individual elements were fabricated together with students at the Hundegger workshops in Hawangen, Germany, a manufacturer of computer-controlled machinery for timber construction.

Over a period of 2 days, 6 m³ of pine plywood was milled using a Hundegger SPM2 portal-type milling machine.. With the help of the parametric model, it was possible to undertake product-specific adaptations at the beginning of the fabrication process. The milled pieces were then laminated watertight under pressure and heat by the students under the direction of a master joiner. After transporting the individual items back to Munich, the individual elements were then assembled within a period of just 8 hours. The disassembly took just 4 hours.

Measuring 13.5 x 4.5 x 4 meters, WAVE 0.18 embodies the design and thematic principles of a digital turning point in building construction. The following facts underline the efficiency of the optimised production and assembly system:

- Human resources: 5 people
- Manufacture: 5 days

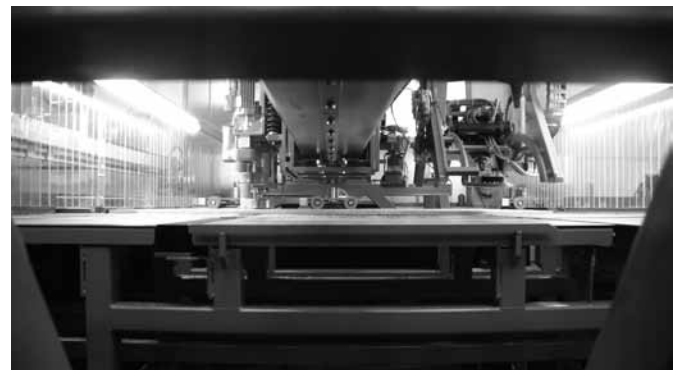


Figure 3. Hundegger SPM2



Figure 4. Assembly

- Assembly: 1 day
- Structure: 192 ribs made of 1,100 individual parts

The result is a high-precision, stable structure.

Conclusions

For Architecture Students

Overall we can conclude that we achieved the objective of our studies. The students acquired an overview of the main principles of digital production and learned how to use parametric software and computer-controlled production techniques as a means of realising their own architectural concepts. The condition that the end result had to be realized meant that students were not able to conveniently ignore apparently secondary aspects such as manufacturer research, craftsmanship, resource management, storage, machine loading, logistics, assembly and disassembly, to name just a few. The students now have a better overall understanding of the processes involved in planning. In addition to the new, more complex architectural formal language that digital production makes possible, the students who took part were also exposed to new fields at the intersection of architecture, informatics and manufacturing that will in the future become ever more relevant. Due to the large amount of time needed for the course—a vast amount of material was covered in the course—as well as the small time frame available for realisation, the students formed competence teams. Unfortunately, this meant that not all students were able to learn all aspects of production to the same degree.

For Teaching

For us, the course proved to be particularly challenging, in particular in its pressure to realise a good quality, representative structure on time. In a comparatively short period of time we learned competencies in everything from materials science to programming, and over the course of the project, probably learned more than our students. The building of WAVE 0.18 was

particularly positive, a unique shared experience that has had a lasting, positive effect on ourselves and our students, more so than from previous courses. In our view there is no better way to communicate skills and knowledge. Naturally, we invested a lot of time in the course and had to undertake large parts of the programming and detailing ourselves. In later projects we will therefore try to reduce the size of the projects.

For Research

Despite the tight time frame, together with our students we were able to develop and put fully into practice a new parameterised timber construction system. Taking into account as many boundary conditions as possible, we developed an intelligent system that optimises both the planning process as well as fabrication and assembly. From the viewpoint of our research, the course represents an important step towards the intelligent use of computer-aided fabrication for the realisation of complex structures in timber construction.

Outlook

At present the Chair for Architectural Informatics offers several independent as well as interdisciplinary courses on the topic of digital planning and production. In the current summer semester for example, we used the same didactic model for projects related to the topic of daylight. Among the designs that resulted is a novel kind of umbrella construction, that has since been developed and submitted as a patent application. At present a 5 x 5 meter prototype of the umbrella principle is currently being built.

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