Experimental Design-Build

Teaching Parameter-based Design

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Abstract: *We present a student design class, in which experimental full-scale parametric objects are planned and built. The class explores the possibilities of digital production chains in which CAAM techniques driven by parametric modeling can expand the range of possibilities for designing and producing architecture. We show how those possibilities and techniques can be integrated into architectural education in facilitating a transition from digital design to actual object. The didactic challenge represents teaching a methodological approach towards parameter-based design, its transfer into a software program and the choice of construction and production method.*

Keywords: *Prototyping; parametric design; student design build projects; CAAM methods; evolutionary optimization.*

General statement

We believe that using digital planning and fabrication methods, not only more complexity in built structures, but also reaction to environmental parameters and specific adaptation to external parameters is being made possible. Digital software using parametric modeling and scripting tools are introduced to convey parameter-based design. Numerically controlled manufacturing processes enable via rapid prototyping the fast analysis of physical models.

In most German universities though, the design approach is often still analog and algorithmic, rule-based approaches are mostly unknown.

In 2007 to 2009 we conducted several design studios and workshops at the Technische Universität Darmstadt to communicate the new way of thinking and designing to architectural students of the 3rd and 4th year. The focus was not on the generation of the most spectacular geometry as “l’art pour l’art” objects, but on the methodology of designing user-defined parametric architecture and the understanding of the potential of generative planning and CNC-manufacturing.

Figure 1
Cardboard wave: 1st experimental parametric exhibition stand

Figure 2
Moebius strip: 2nd experimental parametric exhibition stand

Design-build projects

The design-build projects we present focus on a scale that can be handled in a university context. Despite a high geometric complexity, the number of different crafts could be limited to 3 to 4. Since at our school the capacity of the CNC-tools is currently limited to model-making size, an extra challenge constitutes the realization process: a close cooperation with innovative regional firms forces the students to work under "real" conditions and enable the experimental buildings to be successfully realized.

In the process of developing the experimental structures we exchanged knowledge on digital production technology with colleagues teaching at the ETH Zürich and invited guest critics from the Royal Academy of Arts Copenhagen.

Teaching generative design

In generative design, an algorithm can reproduce a scheme with changes to its dimension or configuration and thus create forms both of great complexity and with responsiveness to conditions and environment. The potential drawback of the generative approach lies in the abstract and distinct nature of the procedural structure. This may lead the designer to a form that makes sense only virtually.

Therefore, the method of working taught in our design studios is procedural rather than geometric: Instead of designing a final form of a geometry the steps to generate this form are conceived. Hereby, every step has to satisfy internal and external factors of the project and consider the logic of the design on the level of use and practicability, material and construction.

Our teaching method focuses on a close connection between the procedure of form generation and the realization of the design. Hereby, we use methodologies of construction logic and building performance: The performance of a design is being optimized via simulation of the behavior of the virtual model for ideal geometric integrity, structural efficiency or energetic performance. The interconnection of the initial parametric scheme with repeated simulation leads via feedback loops to the final form that meets the specified goals.

Case study objects

The methodology and potential of parametric design is tested on different design tasks and scales. To really check the impact of mass customized design, objects have to grow out of model-size into real-life usable objects. Also, it confronts students with realization processes beyond usual university limits of mere planning processes.

We present the planning and fabrication process of two exhibition stands for the department of architecture built in 2008 and 2009, the "cardboard wave" (Figure 1) and the "moebius strip" (Figure 2).

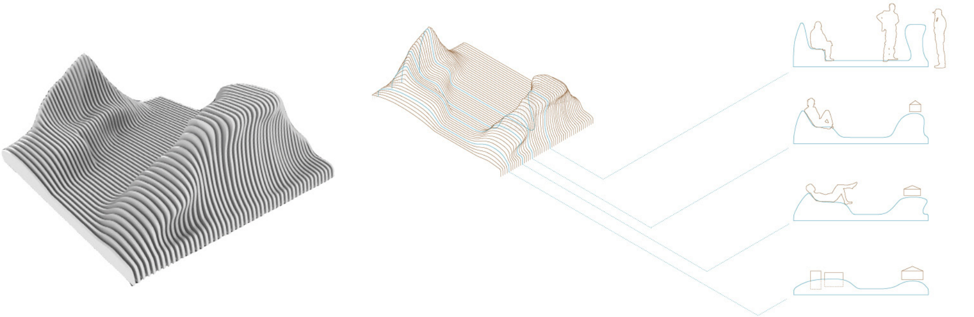

Figure 3
Cardboard wave: 3d model of parametric topography and sections for specific uses

Using digital fabrication methods as well as new materials, the stands demonstrate new technologies in architecture.

From design to program: Parameter-based design

The design task was to conceive a singular object that would fulfill a multiplicity of needs: act as counter, information display and furniture landscape. The object had to be adjustable via several parameters to accommodate changes in envelope dimension, arrangement of functions, size and number of functional areas. Through this, each of the designs would be applicable to a huge number of different situations as it would change with the changing parametrized conditions (Figure 3).

The initial designs were purely conceptional and did not necessarily already have to be implemented in a parametric modeling software. Two different groups of designs were detected: those that stem from solid objects and those that are subdivided into smaller parts. From the feasibility of being modelled digitally and built using CAAM, one design from each group was chosen to be digitally modelled and actually built by the whole group.

Both parameter-based designs are digitally modelled in Rhino 3D. The solid object of the cardboard wave consists of a miniature topography forming a complex geometry that accommodates the functions described above. Each task is associated with a specific section and an extrusion depth

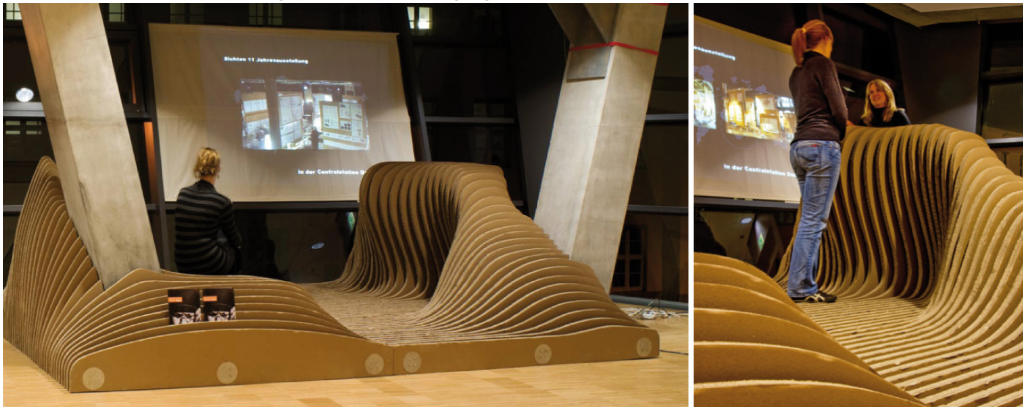

Figure 4
Cardboard Wave forming parametric topography

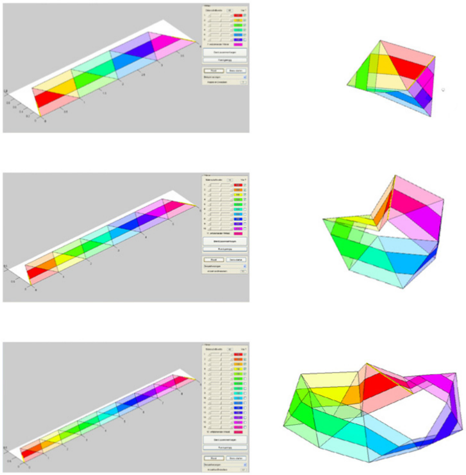

Figure 5
Moebius Strip geometry: optimizing process in MatLab using a different number of segments

and path for that section. The extruded sections can be placed freely within a predefined boundary to reflect the desired configuration and are then joined smoothly by the software Rhino forming a complex surface shape. This procedure can be repeated until the optimized geometry for the specific exhibition stand is found (Figure 4).

Similarly to the cardboard wave, the second design, the moebius strip, is shaped so as to

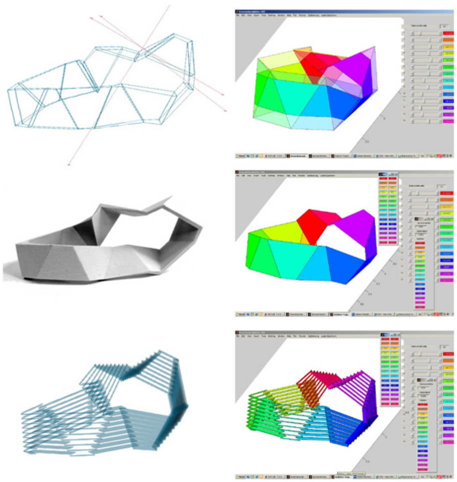

Figure 6
Moebius Strip geometry optimized in MatLab and checked in digital and physical models

accommodate display, information counter and seating possibilities. The moebius strip is formed by a string of planar segments that twist before connecting end to beginning. The mathematical shape proved quite complex to model – and more importantly – to define as adaptable parameter-based object, whereas its mathematical code is fairly simple. Through a cooperation with the department of mathematics, a program was written within the software MatLab. Here, the whole range of possibilities of geometric arrangements can be tested and geometrically optimized (Figure 5). Also, in order to build, the division into smaller parts, size and number of the ribs, are parametrically defined and can be adapted to the construction requirements (Figure 6).

From model to object: Digital fabrication

The two exhibition stands were both built by students in consecutive years. The process of actually building something at university – rather than just planning it – constitute after the parametric design approach a second, more practical and team-building one, that is indispensible in architectural curriculum, but rarely realized and no fixed and continuous class within the German university system. Furthermore, the situation of CNC-tools at our university requires even more initiative from the students. Lacking CAAM machinery within the university, the students have to investigate which CAAM techniques are available to them from professional contractors and to secure sponsoring. To set up a digital production chain, they have to manage interfacing between the modeling and production softwares, monitor and participate in the production process of the stands' components, and finally build the stands themselves.

Both projects used the digital data exported from the parametric models in Rhino or MatLab. For the cardboard wave, the contours of the two-dimensional elements of the segments forming the topography define the cutting path of the machine. Using

Figure 7
Production process: waterjet cutting cardboard

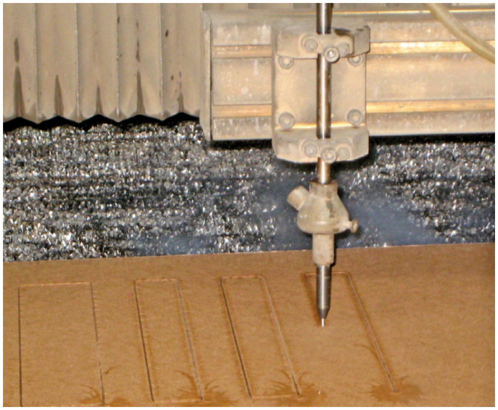

Figure 8
Cut-out Elements of cardboard wave

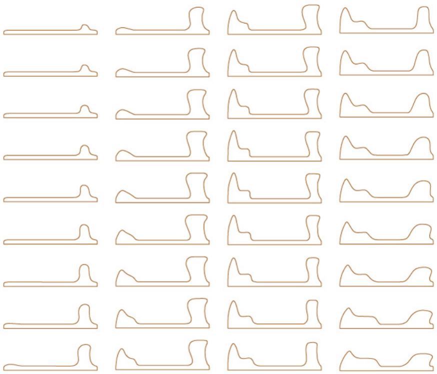

Figure 9
Moebius strip with ribs within planar trapezoids

cardboard as material, the CNC-cutting method had to be carefully tested. Whereas CNC-milling proved to produce a too rough border and CNC-lasercut jeopardized to set the material on fire, only CNC-waterjet showed desirable results (Figure 7 and 8).

The moebius strip consists of not only two-dimensional, but also three-dimensional elements. For both a suitable CAAM method had to be found according to the materials used. The two-dimensional segments made of plexiglass and timber were cut out by a CNC-lasercut machine from a local joiner (Figure 9). The three-dimensional interspace elements between the ribs were cut out from a simple PVC-pipe (Figure 10). The specific geometry of the spacers was produced by a 5-dimensional CNC-milling. The data for both elements was generated in Rhino. The transfer to the lasercut was handled through AutoCAD; the transfer to the milling-machine through the mechanical engineering file-format Parasolid.

Review

In both case study projects the designs consisted not only of one specific object: the design being parametrized meant that a whole family of related objects was designed. Together with a fully integrated digital production chain, this would in principle allow for the production of a large number of fair stands, all stemming from the same design, but adjusted to situational specifics like place, size, arrangement of different functions. The production process of both objects was similar – however the path that led to the generation of the production-data was completely different.

Realizing design-build projects in a non-CAAM environment constitutes a big challenge for all participants: knowledge of different software packages and readiness to quickly familiarize with unknown data formats, flexibility in the time schedule and disposition to transport the material to the machinery.

The project not only introduced the students to the possibilities of designing with parametric modeling software, but also familiarized them with the

Figure 10
Detail joint of Moebius strip geometry

initial difficulties and the following large payback in employing them for actual production. The finished stands went far beyond what they initially had believed possible.

Outlook

In the future, we intend to continue our exploration and step beyond what has already been achieved in two ways:

Firstly: So far, the stands were assembled from similar but nonequal planar elements that had been cut out from larger sheets. We intend to manufacture more massive parts, comparable perhaps to individualized building blocks, but much more diverse in shape and material.

Secondly: So far, in each case only one instance of the designed parametrized group of objects has been realized. With the next project, we intend to produce more than one instance and indeed build a small family of similar objects so that the productive power of the digital chain becomes more apparent.

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Figures

The photographs in figure 4 are by Thomas Ott and the ones in figure 9 and 10 are by Stefan Daub.

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