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Rule Based Design Workshop at the TU Berlin

Christophe Barlieb, Kristoffer Josefsson, Sven Pfeiffer, Ines Putz, Dimitrie Stefanescu, Norbert Palz, Martin Tamke

A new cluster of a possible series of digital design & digital fabrication workshops held at the Berlin University of Technology (TU Berlin), Department of Building Design, School of Architecture, explores teaching and learning Rule Based Design. The first workshop introduced computational logical and design concepts to lead into a second workshop further exploring digital design and fabrication tools. The goal is to produce a full-scale prototype to test the ideas, methods and materials. This paper focuses on digital design & fabrication via a pedagogical exploration between academics and practitioners.

Introduction

Crafting sensitive architectural solutions requires extensive management skills on all fronts. Controlling and communicating the architectural geometries, programs and construction methods is essential to a successful project. Flexibility in thought and expression is vital to all creative fields. The power of a new generation of parametric and bespoke CAD tools lies in the ability to negotiate and communicate the design intent clearly. This streamlining saves time as well as materials while integrating architecture, engineering and fabrication over the course of the entire architectural design process. The goal of the new series of workshops at the TU Berlin School of Architecture is to introduce Rule Based Design (RBD) strategies and CAD/CAM to “open up new horizons for architecture” (Pottmann, Kilian and Hofer, 2008). The workshop exposed the students to the fundamental changes in the building industry and the greater Building Information Modelling (BIM) network. It aimed at introducing basic principles of parametrically driven architecture via a small scale installation speculating on the relevance of the introduced methods for other architectural tasks.

Pedagogical Background

As in many other Architectural Schools, at the TU Berlin there exists a gap between the teaching of design methodologies and the teaching of digital tools. Whereas the students at the TU are introduced methodologies in the Design Studios of the various chairs, separate courses are offered that teach CAD as a drafting tool via commercial CAD packages like AutoCAD® and SketchUp®. The department’s title, “Technische Architekturdarstellung” (Technical Architectural Description) underlines the focus on the aspects of description and presentation of a finished design project. Based on a set of plans, the students create a digital model in order to develop visualizations. Parallel to these CAD courses, the chair of “Darstellende Geometrie” (Descriptive Geometry) introduces the students to fundamental techniques of perspective drawing in analogue drafting exercises.

In the newly established Bachelor and Master system these courses are being taught throughout the semester on a weekly basis and are completed by a final submission at the end of the term.

The goal of the series of RBD workshops at the school is to

- confront students not only in the later semesters but rather at the beginning of their studies with digital tools that are fundamental to develop their projects.
- shift the digital design curriculum from drawing and modelling to the understanding of organizational principles and systems with a specific behavior.
- use the energy and focus of a workshop with limited time instead of a once-per-week course.
- introduce RBD strategies and CAD/CAM to the design studio curriculum and to feature these systems as an integral part of the architectural design process.
- create a network among students, faculty and to interact with academic and professional practitioners.

Assignment Description

The first day of the workshop introduced Scripting & Outputting via Grasshopper (Geometrical Relationships & Parameterization). The goal was to produce a series of individual hats (as a fashion accessory) made from developable surfaces. The second day, the design challenge to create an intervention for the TU Berlin School of Architecture's (IfA) main lobby was introduced. Ten teams (groups of two - four) were formed in order to produce a spatial element made from developable surfaces and a possible sub-frame. The function of the intervention was left to the team's discretion. Nevertheless, we recommended keeping the function to a bare minimum i.e. a screen, a landscape, etc. The dimensions of the intervention should not exceed 4m³. The purpose of this exercise was to implant a meaning into the exploration: What is the intent of our proposal? What do we wish to convey? How could we get there? Etc.

The following rules had to be observed:

- Only developable surfaces were acceptable.
- A parametric based geometry or framework had to be considered.
- Components had to be parametric, simple and to display richness when assembled.
- The choice of materials was decisive as the project is to be built 1:1.
- Connection details had to be considered, but not completely designed at this stage.
- All the designs had to be plotted on a laser cutter and assembled in order to explore the design process.
- The available tools were: Rhino3d/Grasshopper, Processing, the laser cutter, and student self-developed tools with the aforementioned or external scripting languages.

- The work had to be uploaded to a blog.
- The designs had to be presented and reviewed.

Scripting in Architecture

The digital medium (or computer) can be fully understood (and in the same time meaningfully used as tool) through a scripting based approach – this is especially true when relating to the field of architecture. This technique permits the architect a much more intimate communication with the computer and thus enables him to escape visual mannerisms or other drafting banalities that are otherwise so easily pursued with today's ready-available design software.

One of the big changes that scripting has brought on in architecture is the possibility of creating one's own tools, designed specifically to respond to various problems (posed by different aspects - conceptual or pragmatic - of the overall project) or designed to enable new artistic expression on behalf of the architect.

The RBD workshop focused on introducing students to scripting via visual programming (a graphical way of scripting which requires less familiarity with code yet provides and exposes the full logical mechanisms of this technique). The conceptual background was the well-defined mathematical group of developable surfaces. This provided a coherent framework that helped focus creative forces within the constrained timeframe of the workshop. The software most employed was Rhino's Grasshopper plug-in due to its flexible and open nature (allowing both traditional and visual scripting).

Students were able to define their own parametrically controlled developable shapes over the course of the workshop working under a clear mathematical and architectural framework.

5 Mathematical Aspects

There are many ways to characterize developable surfaces mathematically, for example: by prescribing Gaussian curvature $K = 0$, as an envelope of moving planes or as a ruled surface with extra conditions on the rulings. The first lead to solving a PDE, the second lends to a dual description in a quadric in Plucker space (Wallner, Pottmann). We chose to work with the third description, since the *directrix* of a ruled surface (a space curve) is a suitable design tool in CAD programs. Typical representations include NURBS-curves, splines and so on.

With this description, the surface describes a surface that is possible to build without creases, for example out of paper - as long as we restrict ourselves to the area outside the *edge of regression*. This is a space curve associated to the surface where the description breaks down.

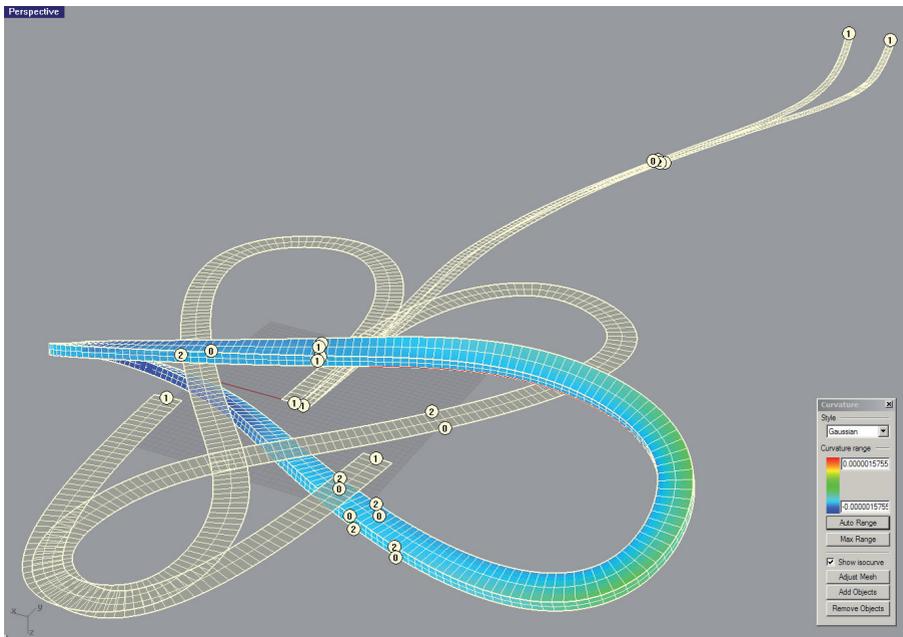
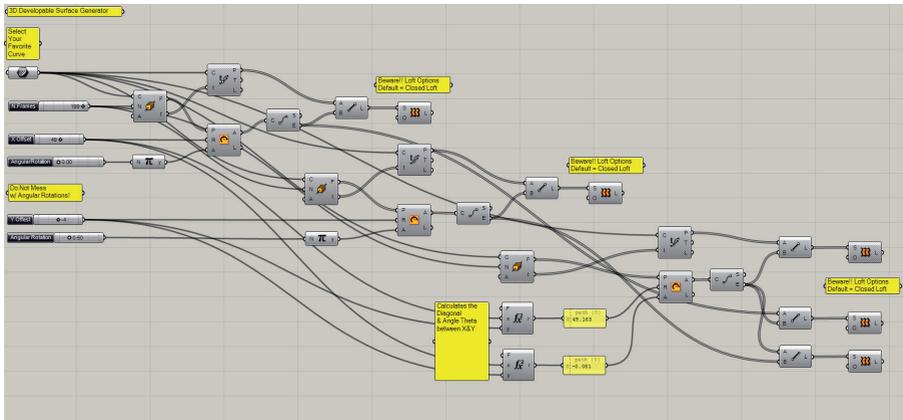


Figure 1: (Top) Grasshopper definition to parametrically control a (Bottom) Bishop developable sets of surfaces.

A special case of a ruled developable surface is the *tangent developable*, where the rulings are given by the tangents of the directrix. It is a mathematical theorem that each developable surface (locally) is described by a tangential developable of *some* space curve, not necessarily lying on the surface. Degenerate cases correspond to the plane, cylinder and the cone. One advantage with this description is that the directrix coincides with the edge of regression, and hence it is easy to stay outside this area. On the other hand, it may lead to rather unpredictable surfaces, since one has to work with a curve either outside, or on the edge of the surface and not a curve on it.

Other examples of developable surfaces that lend to a directrix based modelling include the *rectifying developable* and what we call the *Bishop developable* (Fig.1). We can describe these by using the Frenet frame (Struik) of the curve as following: In the first case, the rulings are given by the Daroux vector, expressed as $D = \tau T + \kappa B$. The rectifying developable has the property that the directrix gets unrolled to a straight line.

In the second case, which seems not to be described in the literature, the rulings lie orthogonal to the osculating plane, and are given by $R = \sin(\int \tau + \alpha) + \cos(\int \tau + \alpha)B$ where α is an arbitrary constant.

Other methods included intersection of primitive developables (such as cones, cylinders) to generate more intricate surfaces. This also provided a good interface to the CAD programs in way of manipulating the surface with control points and so on.

Grasshopping

Grasshopper is a graphical algorithm editor, integrated into the 3D-modelling software Rhinoceros® via a plug-in. It is built for designers who want to develop a wider variety of shapes and to control the modelling process using generative algorithms.

Using the implemented functionality of Grasshopper requires no knowledge of programming or scripting, but allows designers to build form generators in a very intuitive way from simple to highly complex descriptions. For advanced users Grasshopper provides support for C# and VB scripting to adjust and enlarge the tool to specific and more individual concerns. During the workshop we used the *Work in Progress Version 0.6.0012 of Grasshopper* (<http://grasshopper3d.com/>)

Giving a complete Grasshopper tutorial was not our intention, rather using it as a tool to serve a more experimental purpose. Therefore we decided to introduce only the very basic concepts and the user interface of Grasshopper at the beginning. The next step was to let the participants familiarize themselves with the visual scripting tool by addressing a small exercise - the design of a simple developable hat. By translating the introduced mathematical concept of developable surface creations

into Grasshopper we generated a basic script the students had to enhance. This enabled us to determine the current students' skills, to adjust further steps in order to reach more advanced levels.

At first this approach led to certain conceptual problems, since we found out that the proposed Grasshopper scripts did not result in developable surfaces (Koschitz, Demaine, Demaine, 2008). So we introduced a definition to reverse engineer an imaged design, which can be understood as a certain kind of backdoor procedure (Fig.2).

Nevertheless the out coming approaches were very satisfying and they clarified the problems encountered by creating designs constrained with developable surfaces.

Since further studies required a more fundamental understanding of Grasshopper, an introduction into its data management structures - i.e. lists and data trees was given. Taking into account its very theoretical but nevertheless most useful aspects, we confined this to a general level. By giving only needed overall information, we maintained a certain freedom of mind, especially to encourage and not to restrain the creative design process. Specific problems were solved in small groups regarding the students' personal ideas and skills with the tutors' assistance.

Alternating from general and common to particular and individual instructions promised as well as proved to be a considerable way of a didactic method getting involved with new design strategies.

Production phase

One of the goals of the workshop was to introduce the concept of material behavior in parametric models. To link the physical with the virtual reality, an understanding of material properties has to be generated first. The found properties can later be transposed into parameters within a model (Tamke, Ramsgard, 2009). The knowledge of the materials behavior and the ability to abstract this into rules determines the success of this endeavor. We assumed that for this workshop and the precision needed, rough approximations would be sufficient.

The workshop started right away with cutting models out of the unrolled developable surfaces. Laser cutter and paper gave the necessary ease of use as well as speed and resembled the model of the developable surfaces in the best possible way. This approach allowed an experience of the possibilities and limits of paper folding and developable surfaces and the care needed, when producing them. The direct link of the parametric tool with a drawing tool allowed the use of well established production processes and high precision. The models produced were of good quality, taking into account that none of the students had worked with paper folding, bending and creasing beforehand.

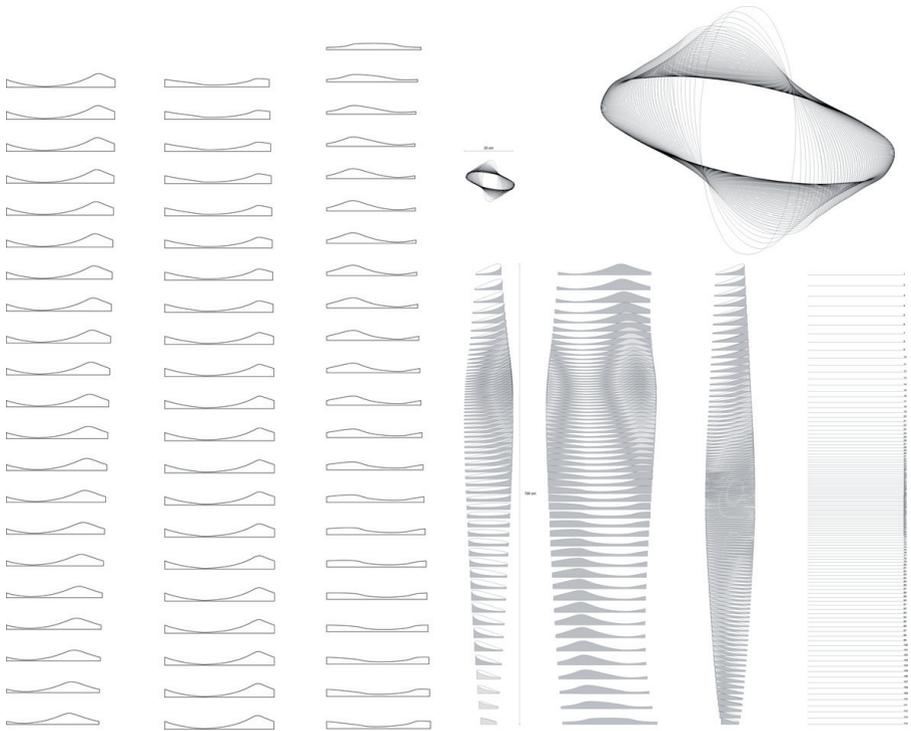


Figure 3: Developed surface of the proposed light column, elevations and plans.

The further course of the workshop intended to establish a link between the students custom made parametric models and fabrication. Whereas the assignment was heading into this direction the time needed to develop an architectural concept and to set this up in a parametric model set a time constraint. The transformation of the threedimensional parametric model into cutting pattern created a burden the students weren't able to overcome in the given time. Yet all developed their models having production based on developable surfaces in mind. Some of the groups produced handmade models, which served well in evaluating design decisions and a possible later production. Their rough nature allowed for further speculation.

The workshops manifold directions made it hard to pursue the digital fabrication. As this part is the last in a design process it is the one that is skipped first. Yet, the overall concept of developable surfaces should allow a later production. Linking material behavior into parametric models demands good knowledge of the scripting environment and production tool. Gaining this knowledge requires time, patience and a constant hands-on dispute with the material itself.

Results & Evaluations

The intensive five day workshop concluded with a presentation of design proposals for the lobby area of the architecture department at the TU Berlin. The different teams presented their individual solutions that showed the impact of the software on varying scales and intensities. Two models were selected for an investigation on a potential future fabrication:

Screen: The team proposed a linear arrayed set of vertical wooden plates with specific rotation angles assigned to upper and lower pivots attached to a load bearing rectangular frame structure, allowing for a gradient differentiation of individual screen configurations.

Column: The author developed a design for a cylindrical column (Fig.3). The surface of the 7,00m high object consisted of an array of parametrically controlled horizontal rings that had gradually deformed lens shaped openings through which an internally projected diffuse light source could shine (Fig.4).

A two week timeline would be desirable for future workshops to be able to integrate material and machine constraints into the initial steps of the design process. An artistic dialog between the potentials of the machine and materials allow a more vivid and multilayered language of expression. Hereby the fabrication technology subsequently exceeds a purely manufacturing role but can become an active player in the design process. Del Campo and Manninger (Del Campo, Manninger, 2007) described the application of the manufacturing traces of the milling machine for the three dimensional ornamentation of the surface.

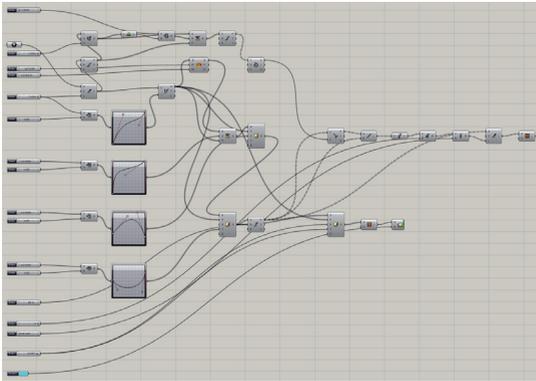


Figure 4: (Top) Grasshopper definition of the column (Bottom) Photomontage into the IfA lobby.

A mixed media approach that combines these analogue and digital tools seems to be promising in order to avoid a design output that overuses the obvious tools of the software. The ability of the student to adjust or even create their set of tools to the required architectural demands requires an overview of the potentials and limitations that are connected to material, matter and software.

Conclusions and Outlooks

The workshop demonstrated that students are capable of rapidly grasping complex concepts and modelling strategies without introducing traditional tutorial based pedagogical methods. By introducing mathematical and geometrical concepts, digital design tools and fabrication methods early on in the design process the students had a better understanding of how to deal with the complexities they were encountering. This resulted in more precise and directed form making processes leading to meaningful solutions and thoroughly developed concepts.

A second workshop will be based on this experience and feature more complex RBD systems, tools and fabrication possibilities. The students will refine the selected proposals and research directives between the workshops and tools. Furthermore they will be encouraged to intertwine the digital design and fabrication processes while building in limited degrees of freedom to keep their designs under control. The set of rules developed in the first workshop will act as mediators between the inherent properties of the materials, geometries and external functional requirements. It will constantly be updated during the materialization process. The goal is to construct a 1:1 design prototype. The final piece will be exhibited along with selected works in the school's main foyer in 2010.

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