Abstract. We employ the possibilities of parametric modeling software and customized mass production machinery to develop a design for adaptable multifunctional temporary medium size buildings made from recyclable lightweight materials and built a prototype from cardboard. We developed a grasshopper script that controls the geometry of a self-supporting arc made from a folded plane. The project is conducted as an experimental design-and-build university course that familiarizes students with parametric thinking and designing and with carrying out a project from initial concepts through to building a 1:1 prototype. This project is part of an ongoing series of investigative design & build courses integrating current design possibilities and construction methods.

Keywords. Parametric Design; Grasshopper Script; Temporary low-cost buildings; Student design build projects; CAAM methods.
Developing the initial design: Parametric Origami

The design is based on an arc and employs origami principles to create a lightweight yet stable structure (Figure 1). Variations in the folding create different pieces that can be combined into larger assemblies.

We developed a Grasshopper script that describes a Yoshimura folding which leads to an arc (Figure 2). This Grasshopper script allows for easy geometric adaptation, and the folded segments are combined to form a self-supporting structure. Folding the segments creates structural stability and reduces the required mass. Using cardboard reduces costs and facilitates ease of use.

We augmented the original Yoshimura folding...
Figure 3
Folding technique including fold-back with stiffening elements.

Figure 4
Building example using Yoshimura folding: market hall.

Figure 5
Building example using Yoshimura folding: shelter housing.
through the addition of connecting elements that fold back onto themselves and their neighbors and thereby stiffened the structure substantially (Figure 3).

The parametric Grasshopper script makes it easy to adapt the basic model to many different situations (Figures 4-6). Size and shape are flexible (Figure 7). The script partitions the basic shape into a controllable number of foldable building components. The components can be cut out and subsequently folded from cardboard - either by machine or by hand.

**Design Course**

We arrived at the Yoshimura folding by conducting a design competition in which the students had to develop principles for lightweight adaptable enclosures. The enclosures furthermore had to be described parametrically. This type of thinking is despite its capabilities and its growing importance not very prevalent at all in many architecture schools and therefore unfamiliar to the students. For this reason, we prepared the design competition by starting with a purely geometric exercise to design a geometric object that was to be adaptable through the change of various parameters.

Developing the initial principle into a buildable design required several steps of feedback between physical and digital models. Physical prototypes were used to test manufacturability and structural stability.

Once the design had been successfully stabilized and described in a parametrically adaptable Grasshopper script, we explored the space of possibilities...
by producing alternatives through varying the parameters to test and show how the design might be applied to different uses and contextual situations.

**Building a 1:1 prototype**

After the design had been scripted, the structural stability tested in physical models and the applicability of the design proven through CAD studies, we began preparing to build a physical 1:1 prototype. The specific function and also the funding came from the need for an annual trade fair stand to represent the architectural faculty at a fair where all university faculties present themselves through their work to potential students. In addition to the university's own funding, we secured sponsoring for the construction.
Figure 8
Building process of the prototype: Preassembly

Figure 9
Building process of the prototype: Final Assembly
Figure 10
Prototype as trade fair stand representing the Department of Architecture, TU Darmstadt

Figure 11
Prototype: View of the inside.
material and the production of the individual pieces themselves. We then used the script to produce first a 3D model that fit both the functional requirements for the faculty’s exhibition and the site. From the 3D model we derived files that controlled a CNC cutter.

As material, we selected corrugated cardboard because of its light weight, its availability and low price. As cutting technology, we selected the cutting-plotting technique where a cutting-knife oscillates at the tip of a plotting head comparable to a standard 2D plotter and which can cut any contour from soft materials. It is limited to minimal radii of 4 mm and material thicknesses of 20 mm maximum. For the prototype, building elements of 8 mm corrugated cardboard were produced in pieces of 1.60 x 1.90 m to meet the cutting capacity of the machine available to us. The elements were then folded and glued to shape and assembled into transportable units of 10-20 elements each (Figure 8). These pre-fabricated elements were transported to the site where they were assembled into the final construction and connected via Velcro (Figure 9).

**Evaluation**

Overall, the project’s aims were achieved: the students were introduced to parametric thought, design and production, an adaptable parametric design was developed, alternative were derived and tested and a 1:1 prototype successfully built (Figures 10-11).

We encountered difficulties in the conceptual phase and with regards to the applied software tools: Most students were initially unfamiliar with parametric thinking and parametric design software and associated parametrism only with complex shapes. To understand how a design can be formulated as a set of rules that are controlled by parameters, and the power deriving therefrom, meant an enormous effort for the students. Most commonly architects shy away from making the structure that underlies their designing explicit as they tend and are mostly taught or conditioned to think intuitively without much rationalization or post-rationalization. This conditioning could be overcome, though, through starting with simple geometrical exercises.

Translating ideas that could be visualized manually through drawing or model-making into scripts driving Rhino also proved to be difficult. Again, rationalizing intuitive findings was the main hurdle, together with the requirements of a computer language where even things that are usually self-explicit have to be stated precisely.

**Outlook**

In the future, we aim to build more large-scale models and 1:1 prototypes all based on the same parametric model to demonstrate its capabilities for adaption to different situation in terms of site conditions and functional requirements. We especially look at temporary roofs for public functions like markets, assemblies, chapels, provisional hospitals and shelter.

We aim to study the possibilities of foldable materials like cardboard or metal and, in addition to that, how materials can be strengthened further and their performance improved by coating them with functional layers. Furthermore the connection principles and methods offer many more possibilities to increase stability and span.

Most importantly, we strive to make more of the possibilities of folding. Origami has undergone an enormous development in the past two decades due to much improved understanding of the underlying mathematics and computer software based thereupon. Our project for us is a first step in harnessing these developments.

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References


[1] www.grasshopper3d.com