Parametric Origami

Adaptable temporary buildings

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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 build 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.*

Introduction

Our project has architectural as well as educational goals. In terms of architecture, we aimed to design a building system for temporary mid-scale buildings that can be constructed by unschooled personnel from cheap, easily available and transportable material that is also lightweight and recyclable. The system should also allow for adaptation to different situations and sizes. This adaptability should be built into the fabrication intelligence so that it does not have to rely on construction intelligence. We rely on the power of parametric modeling, more and more easily available with parametric design software running on everyday laptops.

In terms of education, we aimed to introduce parametric designing and building tools, and most of all parametric thinking: how to formalize a design into explicit rules that are dependent on changeable parameters and thereby define not one specific object but a large family of similar but still different objects. Furthermore, we aimed to familiarize students with the complete process of designing and building starting with initial concepts via dealing handling the intricacies and difficulties of construction technologies and logistics and ending up with a built 1:1 prototype.

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

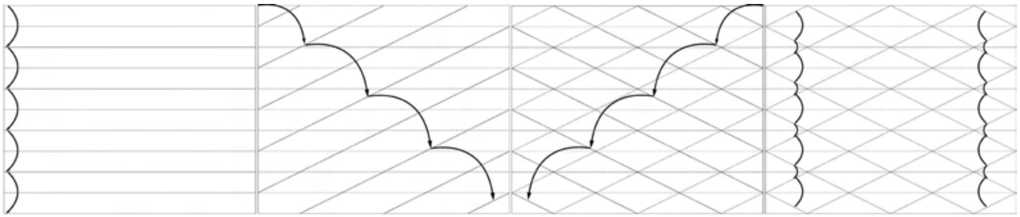


Figure 1
Folding principles.

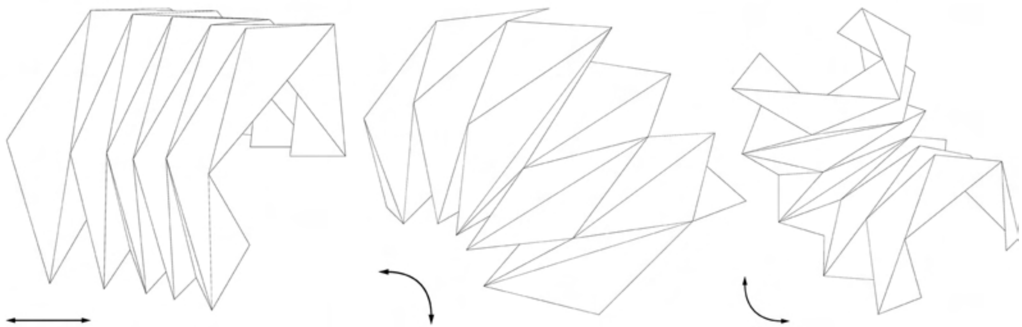


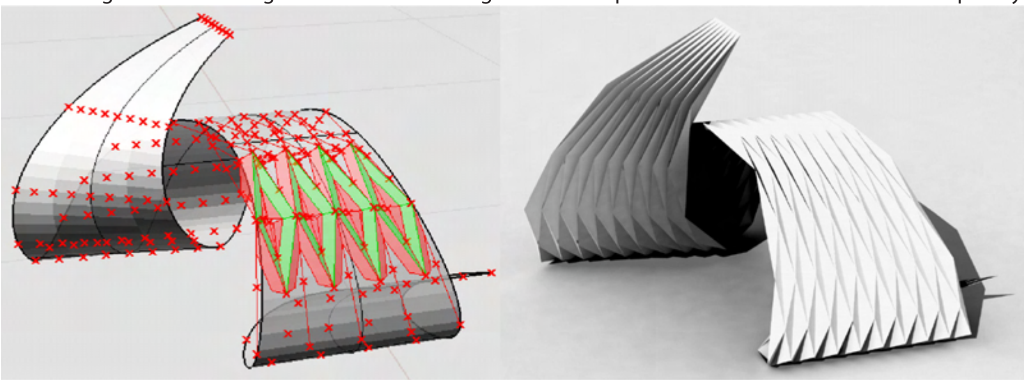
Figure 2
Yoshimura folding forming arc shape.

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 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



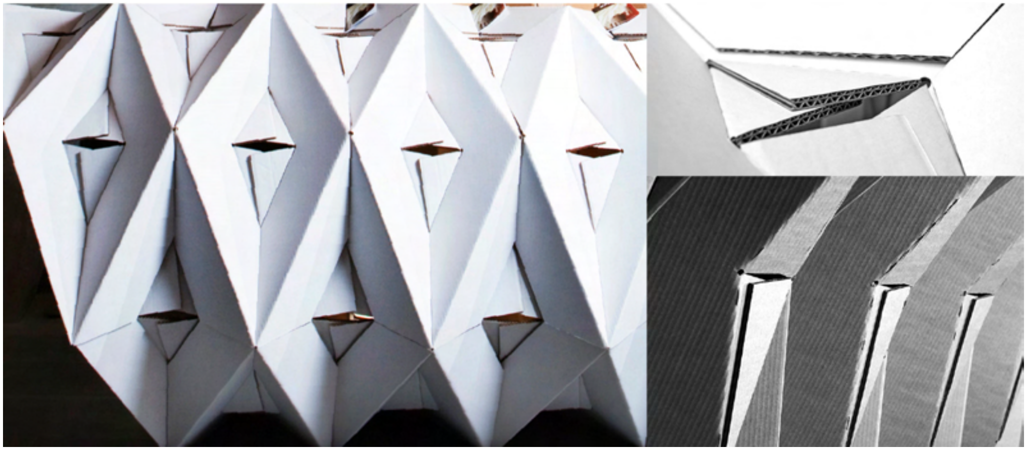


Figure 3
Folding technique including fold-back with stiffening elements.

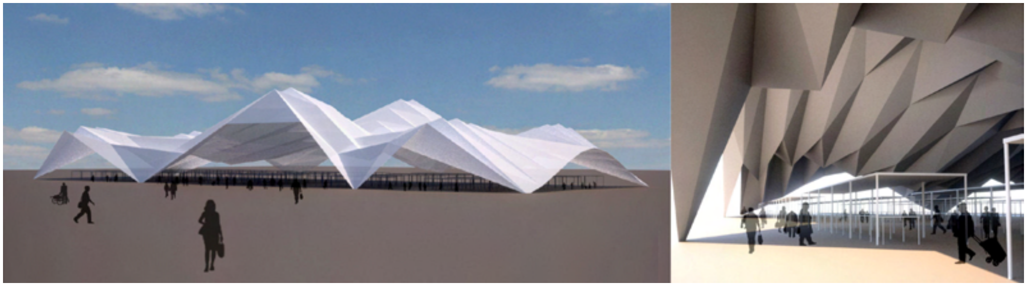


Figure 4
Building example using Yoshimura folding: market hall.

Figure 5
Building example using Yoshimura folding: shelter housing.

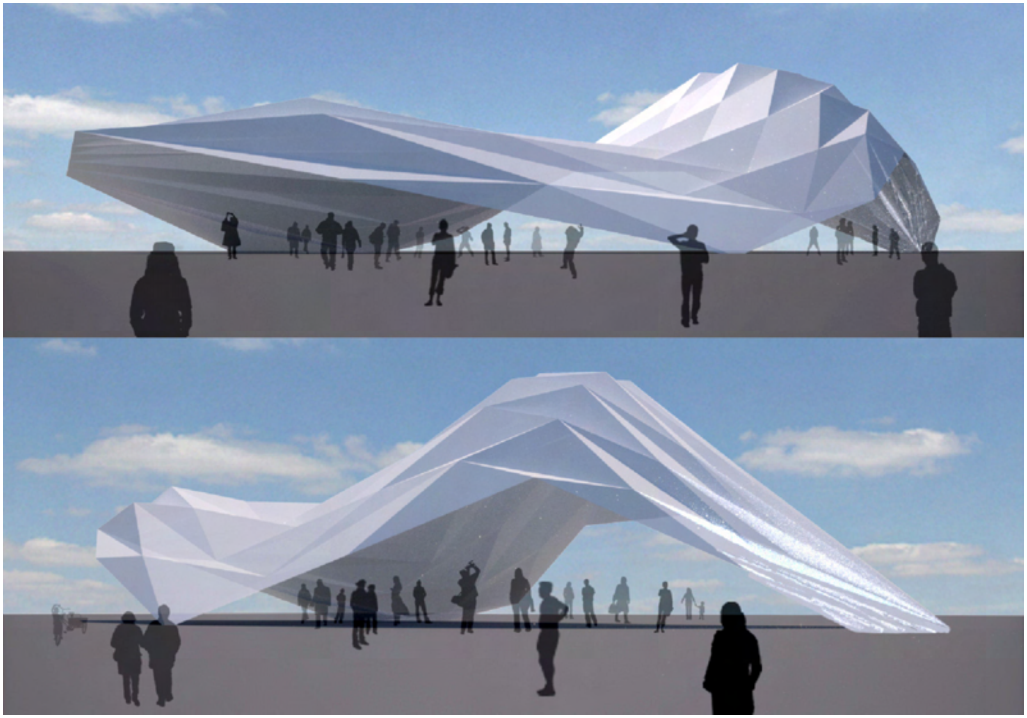


Figure 6
Building example using Yoshimura folding: assembly hall.

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

Figure 7
Variations of Yoshimura foldings.

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 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

Figure 8
Building process of the prototype.

Figure 9
Building process of the prototype.

Figure 10
Prototype as trade fair stand representing the Department of Architecture, TU Darmstadt

Figure 11
Prototype as trade fair stand representing the Department of Architecture, TU Darmstadt

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 prefabricated 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.

Acknowledgements

The project was conducted in cooperation with Rüdiger Karzel, Institute of Design & Industrial Construction Methods, Professor Moritz Hauschild. Thanks to Martin Manegold for the Grasshopper course and all the help and input during the process. And of course many thanks to all the students who participated in the project. Special thanks our partners from the building industry for their support, especially the cardboard company Kunert, and to our department for funding our research project.

References

Buri, Hans and Weinand, Yves 2008, 'Origami - Folded Plate Structure, Architecture', *Proceedings of the 10th World Conference on Timber Engineering,* Miyazaki,

Japan.
Iwamoto, Lisa 2009, *Digital Fabrications - Architectural And Material Techniques,* Princeton Architectural Press, New York.
Engel, Heino 1997, *Tragsysteme I Structure Systems,* Verlag Gerd Hatje, Ostfildern.
[1] www.grasshopper3d.com