

# The Use of Simulation for Creating Folding Structures

## *A Teaching Model*

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*In architectural education, the demand for creating forms with a non-Euclidean geometry, which can only be achieved by using the computer-aided design tools, is increasing. The teaching of this subject is a great challenge for both students and instructors, because of the intensive nature of architecture undergraduate programs. Therefore, for the creation of those forms with a non-Euclidean geometry, experimental work was carried out in an elective course based on the learning visual programming language. The creation of folding structures with form-finding by simulation was chosen as the subject of the design production which would be done as part of the content of the course. In this particular course, it was intended that all stages should be experienced, from the modeling in the virtual environment to the digital fabrication. Hence, in their early years of architectural education, the students were able to learn versatile thinking by experiencing, simultaneously, the use of simulation in the environment of visual programming language, the forming space by using folding structures, the material-based thinking and the creation of their designs suitable to the digital fabrication.*

**Keywords:** *Folding Structures, CAAD, Simulation, Form-finding, Architectural Education*

## **INTRODUCTION**

Simulations, which are the virtual models that reveal the behavior of a system according to specific time parameters, and map the behaviors of the system by changing the time parameter. In other words, simulations can be described as an experimental environment which, depending on the time, enable inferences to be drawn on the basis of exact or approximate information. As in the areas of science and engi-

neering, in those cases where it is impossible to carry out the experiments, or where that systems are very complex, the use of simulation to observe the change of time can provide important data for inferences to be made. With the advent of computational design in the field of architecture, the acquisition of the impression related to the life cycle process of architectural products and in the design process, there has



According to Pugnale (2014), the reverse hanging method is likely to be the oldest method for form-finding of shells, vaults and arches.

Figure 3  
A student work on folding structure, which was made with the use of thin cardboard.

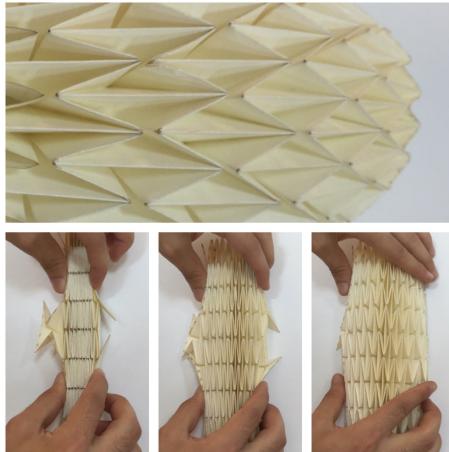


Figure 4  
A student work on folding structure, which was made with the use of acetate material.

This physical model was made using elastic cords or membranes. Thus, the first effective force on the physical model was gravity, and structural pure tension could be identified, following which, the force of mechanical compression could be defined by reversing the model. Robert Hooke expressed this principle for the first time in 1675, and he suggested the reversal of the curve which is formed by a chain, supported only by the tip end points and hanging under its own weight for the definition of the structural optimization of the arch. This curve is called a catenary, and later, in 1697, David Gregory provided a mathematical definition of it (Pugnale 2014). In the present age, mathematical solutions for these systems can be found in the simulation environment.

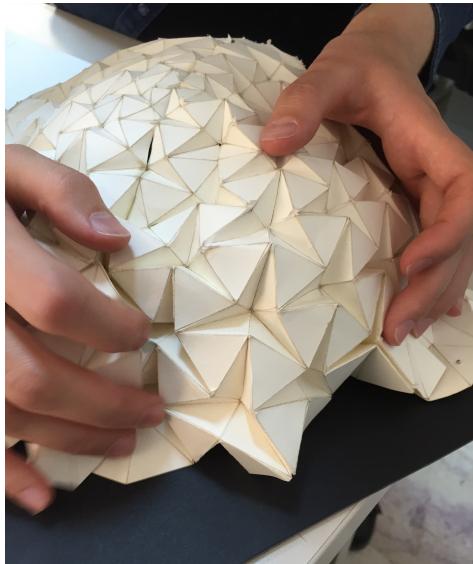
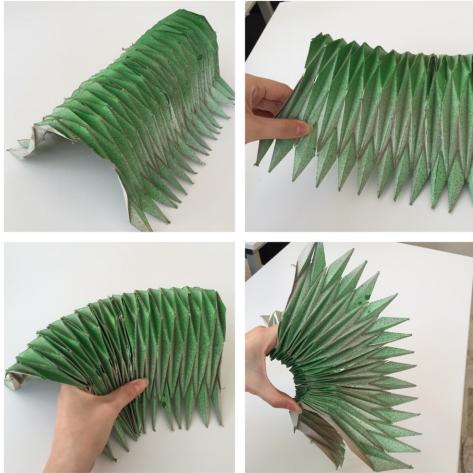
Since architecture has been increasingly moving away from that based on the Euclidean geometry, architects are directed to computer-aided form-finding methods. The development of design environments with non-Euclidean geometries has enabled the creation of variations in the forms of buildings. Building forms in non-Euclidean geometry can be created

with the new computer technology and these have appeared against building forms which came with the industrial revolution and can be produced easily and many in Euclidean geometry. This development of computer-aided architecture has also influenced the architectural education environment.

Today, courses that teach students about various computer programs are included in the curriculum of undergraduate architectural education. In some architectural schools, these are taught about in the form of separate courses, while in some other schools, the use of these programs is integrated in the architectural studio course. No matter which way they learn, students are expected to use these programs, to a greater or lesser degree, in the design process. Moreover, especially in the conceptual design stage, these programs can direct the form of the students' designs. In fact, rediscovery in the sketches of design (Schon, 1983; Schon and Wiggins, 1992; Garner, 1992; Goel, 1995; Suwa and Tversky, 1996; Agirbas, 2015) also arises with the use of these programs.



Especially, since the programs produce complex forms that are not present in Euclidean geometry, their development has increased their involvement in the concept design stage of design.



In the present study, folding structures with the origami concept, which is defined as the content of the elective course “Introduction to parametric design”, which is given to the undergraduate architecture students, are considered.

With the use of simulation, form-finding studies were carried out for the folding structures which were departing from the Euclidean geometry in a holistic sense, and in the end of the course, it was attempted to obtain kinetic structures by digital fabrication.

### METHODOLOGY

In the “Introduction to parametric design” elective course of the architectural undergraduate education, basic 3D modeling is primarily intended to teach students by means of the Rhino program. Following the teaching of basic modeling techniques in Rhino, a focused was made on the basic logic of the Grasshopper visual programming language, which works as a plug-in of the Rhino program. Using Grasshopper, a few scripts were written and forms were produced and altering these forms parametrically was focused on. Next, the students were asked to install Kangaroo (add-on of Grasshopper) onto their laptops.

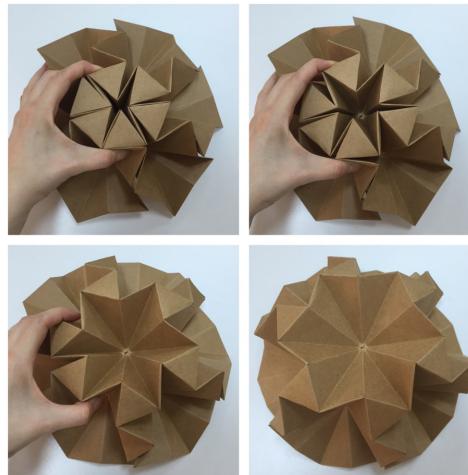


Figure 5  
A student work on folding structure, which was made with the use of thick cardboard.

Figure 6  
A student work with the multi-module.

Figure 7  
A student work with the fewer module.

The Origami component (Vergauwen et. Al., 2014) in Kangaroo, which was written by Daniel Piker (2013) and known as a form-finding physics engine program, was used as a basis for the production of folding structures during the course.

Figure 8  
A student work which was produced by combining the modules.

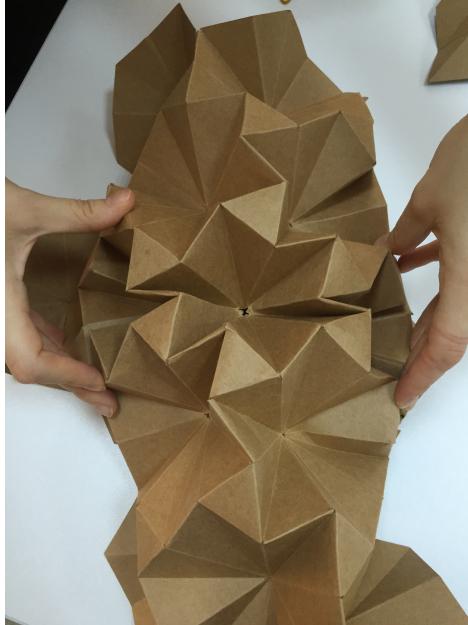


Figure 9  
A student work with the fewer module.

A description was given to the students, simultaneously with the application process, static resistance and the characteristics of less volume spatial occupation of folding structures. Creating a stable form by folding structures was also focused on and examples implemented such as the following; the Folded-Plate Hut in Osaka by Ryuichi Ashizawa Architects, Yokohama International Port Terminal in Tokyo by Foreign Office Architects, United States Air Force Academy - Cadet Chapel by Leo A. Daly, Inc., Henningson and the Chapele St. Loup in Switzerland by Danilo Mondada (Stavric and Wiltsche, 2014) are shown. In addition, experimental examples on a regional scale using Miura-Ori pattern as folding structure were also focused on, as was suggested by Mattoccia and

others (2016). Additionally, some examples of academic articles (Liapi, 2002; Hemmerling, 2010; Lee and Brian, 2011; Abdelmohsen et. al., 2016), which contain different drawings and models on the folding structures, were given to the students for their preliminary work. Subsequently, the students were asked to provide a proposal with the concept of shelter for the refugees or homeless for the folding structure. At this stage, the students had already examined various origami examples from the internet to use in their own folding structures, and were then asked to include their selections of origami tissues to the script (Figure 1) which was prepared by using Kangaroo (Piker, 2013) and to make the simulations of folding. Specifically, the students have to set the curves to the *mountains* and *valleys* components in this script, which are related to folding which they make. After all the students performed their simulations, they were asked to make a digital fabrication of their 2D patterns by using laser cutting.



## RESULTS

Although the students benefited from 2D and 3D examples (found in the internet), they found it difficult



Figure 10  
A student work  
which was  
produced by  
combining the  
modules.

to envisage the folding principles of these examples. At this stage, the use of simulation provided a useful means to help the students understand the principles of folding. Furthermore, if the simulation that they carry out does not work properly or if it fails to give the preferred form of folding, the students are directed to find the correct folding principle. This helps them to imagine the transition of folding from 2D to 3D (or vice versa) and also develops the student's ability to think in three-dimensions. Additionally, during this process, students can gain insight about how they can create a form with a folding type of their choice. Thus, at this stage, as the students were trying to solve the principles of folding, they have simultaneously already started the form-finding studies.

At the digital fabrication stage, the students held the 2-dimensional structure lines as different types (i.e. *mountains* with dashed lines and *valleys* with straight lines). Thus, after the laser cutting process as scoring, students easily understood which line was *valley* and which line was *mountain*.

Before carrying out the laser cutting, students decided upon the materials themselves to be used. Those who used cardboard-like materials, completed the folding process easily, according to the lines (Figure 2, Figure 3). However, the students who selected semi-transparent materials such as acetate (Figure 4), were unable to achieve a satisfactory result as desired in the folding process. Likewise, the students who used very thick cardboard (Figure 5), were un-

able to sufficiently feel the foldability of the material. These outcomes were useful in assisting the students to understand the great importance that the choice of material has on the final design. Thus, the students assimilated the necessity of an integrated consideration of design together with materials during their experience in their early years of architectural education. As Roudavski and Walsh (2011) noted, “early adaptation of material-based consideration by digital fabrication effects on design.”

The number of modules which was used in the folding structures, was left to the student to choose. Some of them preferred to use more modules (Figure 6), while the others preferred to use fewer of them (Figure 7, Figure 9). The students, in fact, noticed that the design is highly influenced by the number of these modules. And some who used fewer modules to produce folding structures, were able to reproduce them with more modules, although this was not specifically stated (Figure 8, Figure 10).

## CONCLUSION

As a result of this study, architecture undergraduate students were able to comprehend the inclusion of simulation as a part of form-finding in the design process. It is important to introduce this new way of thinking to architecture students, since the design representation has been transformed to intelligent modeling and simulation from 2D and static 3D representation. Furthermore, they were able to define the space by using folding structures and in the early years of their architectural education, and had the experience of making complex forms of design with a concept, which was removed from the Euclidean geometry. This provides a basis for students who will make the design studio projects over the coming years.

Also, in the early years of architectural education, students were able to learn that, in practice, design is not an aspect of single thought but it is necessary to use many different tools together in combination. They were able to take advantage of simulation scripts as well as using a 3D modeling program, and

they had contributions from both an analogue from the products of digital fabrication as well as their experience of digital fabrication. By considering the frequency of modules in folding structures, they discussed how these modules can affect the volume of the space that they create in their designs. Therefore, the students were able to experience the necessary versatile thinking in computer-aided design and to use multiple tools.

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