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ORIGAMI DESIGN IN DIGITAL DESIGN METHODS: A PAVILION EXAMPLE

PROJEKTOWANIE ORIGAMI W CYFROWYCH METODACH PROJEKTOWANIA: PRZYKŁAD PAWILONU

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ABSTRACT

In this study, digital design methods are explained and the origami method, one of the most widely used methods, is focused on. In the study, the origami method was created with algorithmic components as an example and the importance of digital design methods was emphasized. As a method, a conceptual infrastructure was created with internet databases, written sources and photographs. Rhinoceros-Grasshopper program was used to implement the origami method. As a result, it was seen how much faster and easier the origami design made by using the digital design method compared to the normal design method.

Key words: Algorithmic design, Digital design methods, Origami.

1. INTRODUCTION

Since the 1960s, the transition from the traditional design process to the digital design process started and became a part of the architectural community. Thus, design thinking has shifted from focusing on the final product of architectural design to focusing on the initial and production methods of design (Dritsas, S. 2012). The most common digital design methods are parametric design method, genetic algorithm method, biomimetic design method and origami method. In this study, these methods are explained, origami method is emphasized and a pavilion is designed with origami method using algorithms in Rhinoceros - Grasshopper program.

2. OBJECTIVE AND METHODS

Digital design methods have been chosen as the subject of the study because they constitute a current area of discussion in terms of today's architecture and their change is constantly emphasized. Because it is seen that the focus on the architectural end product in traditional design shifts more to the design process in digital design. The main purpose of the study is to prove how fast and easy digital design methods are by applying the origami design method digitally with a sample pavilion design. As a method, a conceptual infrastructure was created with internet databases, written sources, analyses and photographs. Rhinoceros-Grasshopper parametric design program was used to implement the origami pavilion design method.

3. DIGITAL DESIGN METHODS

Digital design methods have gained wide popularity in recent times. They are widely used in many industries and adopted by many companies. Digital design methods allow the realization of different design works through computer software. Advances in computer technologies have given architects a freedom in the use of form, space and materials that they never had before.

Computer-aided production has revolutionized architecture, paving the way for new discoveries and innovative designs. Many new techniques have emerged in the field of digital design, and the way these techniques are used determines the quality of the resulting structures. The decision on which of the digital design methods to use according to the desired end product is a problem. In this context, digital design methods can be categorized into 4 groups as parametric design, genetic algorithm, biomimetic and origami design methods.

3.1. Parametric Design Method

Parametric design is a design shaped by variables defined by specific numerical values and algorithms. The integration of art and science in architecture has entered a new era with the rise of parametric design. This advanced way of thinking allows architects to go beyond the conventional and build structures that are not only aesthetically impressive but also functionally perfect. The basis of parametric design entails using algorithms and numerical parameters to create and modify design components.

In the parametric design approach, environmental data or other selected factors are considered as parameters during the concept development process, and the design shape is determined by the effect-response method. By running the design on a flexible system, various options based on variables can be easily tested (Tang, M., 2014).

In Figure 1, it is observed that in the pavilion in Singapore, a parametric design is applied with the principle of action-response as a result of the parametric opening and closing of the roof components depending on the angle of incidence of sunlight (Fig.1) (Wortmann, T., Tunçer, B., 2017. P 173-197).

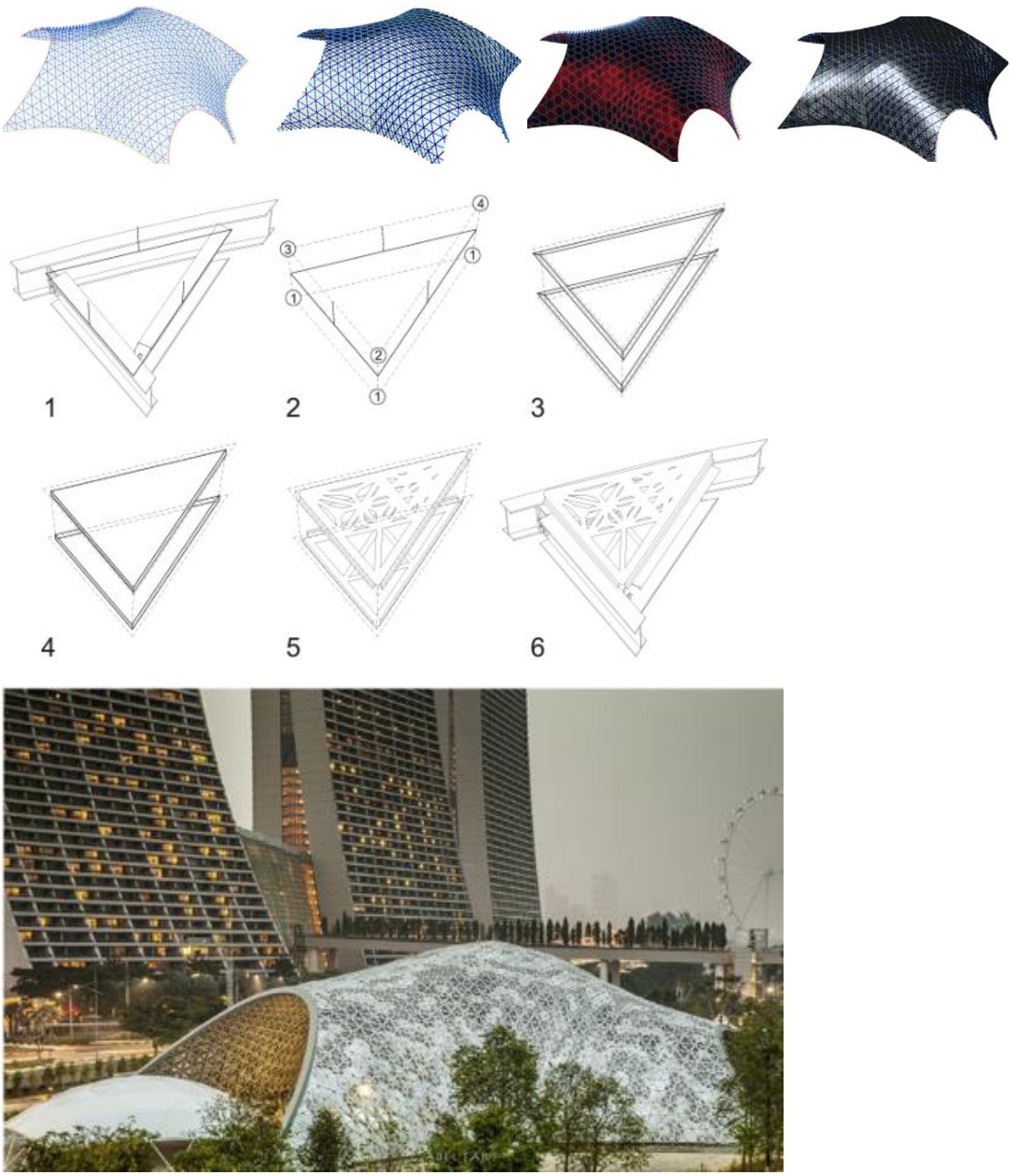

Fig. 1. An example of a pavilion in Singapore. Source: Wortmann, T. and Tunçer, B., 2017. P 173-197

3.2. Genetic Algorithm (Ga) Method

The genetic algorithm (GA) is a heuristic approach that addresses optimization problems based on Darwin's evolutionary theories. This method maps a design space of possible solutions using design variables. Each problem variable is encoded as a unique chromosome segment that constitutes the genetic makeup of an individual, and the variation range of each gene is adjusted to determine the practical solution search space (Rutten, D., 2013.P 132–135.). Following the genetic expression of the design variables, a fitness function needs to be defined. This function evaluates the fitness of a solution in the virtual world of mathematical algorithms, and this evaluation is used to guide the process that transforms the structures within the artificial population. This value indicates the success of the solutions according to the established control parameters and evaluation criteria. Therefore, several algorithm parameters must be defined: the population size, the maximum number of generations to be realized and the rates of use of genetic operators (selection, crossover, mutation, etc.). Once the existence of the best solution and therefore the optimal or sub-optimal performance values are known, a termination criterion is set. Otherwise, the algorithm can be stopped manually until a satisfactory solution is found (Çubukçuoğlu, C., Ekici, B., Taşgetiren, M., F., Sarıyıldız, S., 2019. P141 and Storn, R.; Price, K.,1997. P341–359).

Genetic algorithms for solving (replicating) problems have a flowchart as follows (Fig.2), (Mahdavinejad, M., Latifi, M., 2016).

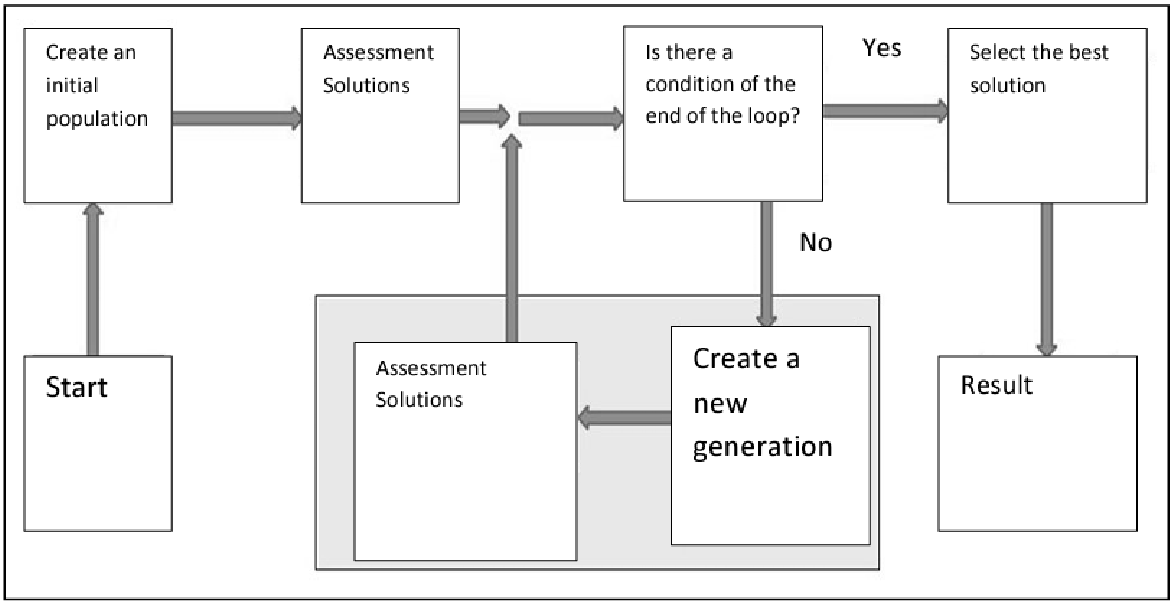

Fig. 2. Algorithmic flow chart. Source: Mahdavinejad, M., Latifi, M., 2016

The shape was optimized through a GA, the solver provided a large number of solutions (Figure 3) and the best performing shape was selected (Fig 4), (Kumar, S., Fantuzzi, N. and Panei, R., 2023. P 142).

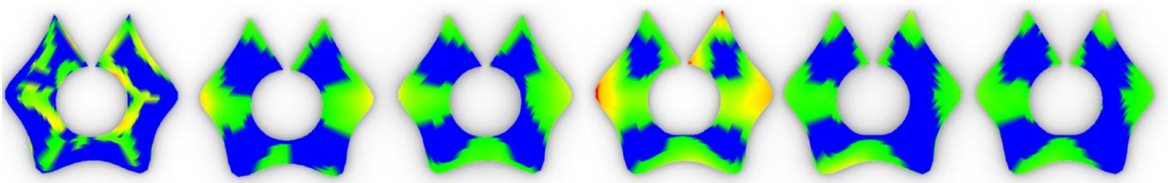

Fig. 3. GA outcome. Source: Kumar, S., Fantuzzi, N. and Panei, R., 2023. P 142

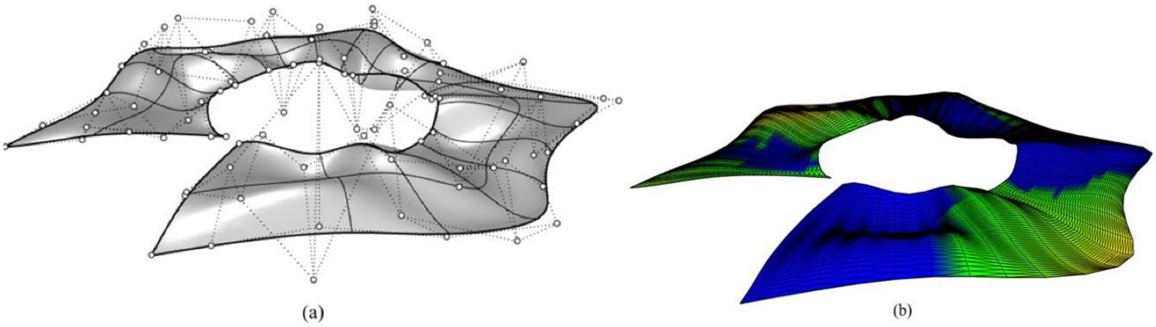

Fig. 4. (a) Optimized NURBS surface with displaced control points. (b) GA's best result for roof cover. Source: Kumar, S., Fantuzzi, N. and Panei, R., 2023. P 142

3.3. Biomimicry Design Method

Biomimicry describes the process of creating more functional, life-enhancing, time-saving and environmentally conscious products inspired by the natural world (Pawlyn, M., 2009). Biomimicry encompasses not only certain methods, but also the cornerstones of innovative and environmentally friendly approaches. The goal of this approach is to strengthen the effectiveness and environmental friendliness of the building by adopting the natural principles found in living things, their functioning and ecosystems as a basic requirement from the very beginning of the design. In this way, the imperatives of design multiply, while at the same time guiding the way to find the most appropriate solutions at various stages (Srinivsan, P., Madhumathi.A, 2020).

Nature's flexible solutions can be considered at three different principles:

a) Organism principle: It is necessary to produce solutions to context-independent problems by imitating the characteristics of certain living species. An important innovation here is the incorporation of technology into structural elements.

b) Process principle: This level encompasses the process of developing alternatives to environmental changes, understanding the environment and identifying patterns of interaction, and integrating this knowledge into building designs.

c) Ecosystem principle: At this point, architecture and the built environment should be considered as part of a larger ecosystem and integrated into its various cycles (Srinivsan, P., Madhumathi.A, 2020).

The Lotus Temple by architect Fariburz Sahba is an example of the biomimicry design method as it is inspired by the lotus flower, the symbolic plant of Vietnam (Fig.2). Every aspect of the building bears the traces of this flower, from interior design to exterior appearance, from landscaping to facade details. The delicate petals of the unopened lotus flower became one of the sources of inspiration for the architectural form. The temple is open to people of all cultures, faiths and languages. It is a symbol of a united India (Sahil, M., Kothari, P., 2020).

The lotus shape is formed by a five-pointed grid arrangement (Fig.6). This geometric shape is used as a metaphor referring to the head, arms and legs of a reclining human figure. It is possible to observe this geometry in many flower forms in nature, including the lotus. This design aims to establish a connection between nature and man. The ceiling of the central transition zone is designed in color and form to give the impression of walking under a lotus leaf. The biological properties of the leaves were analyzed and this information was adapted to biomimetic principles to create a layered architecture on the building facades (Perera, A., Coppens, M., O., 2018).

Fig. 5. Lotus temple inspired by the lotus flower. Source: İnner, S. 2019

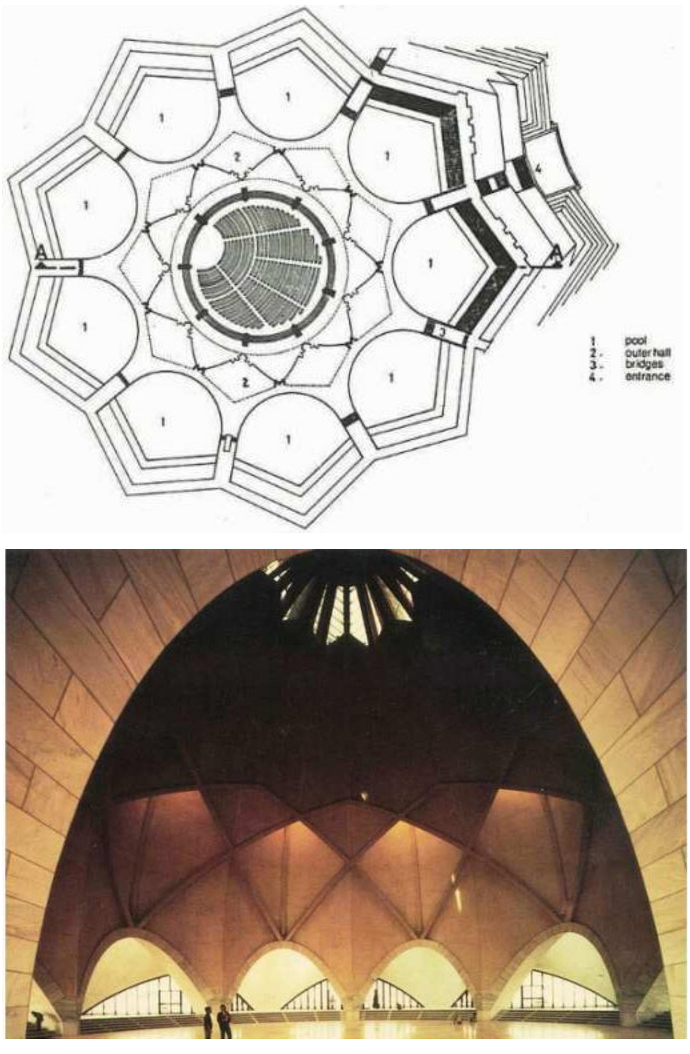

Fig. 6. The geometric shape of the lotus temple. Source: Modern (2021)

3.4. Origami Method

Origami is the traditional name for the ancient Japanese paper folding technique. Although the art is usually known as simple modeling, over the past two decades the art of folding has taken on a new dimension, and more detailed and realistic works are now being created. Much of this progress in origami design is due to the deepening of the mathematical foundations of origami and the newly developed digital design tools.

In modern architecture and engineering, we often see designs inspired by this ancient Japanese art. The basic terminology is a line segment or even a curve on a piece of paper. These lines or curves can be folded in two ways: a mountain fold forming a protruding ridge, or a valley fold forming a valley. A mountain-valley designation is the specification of which folds should be folded as mountains and which as valleys (Schenk, M., 2012).

The traditional art of origami can be divided into three types: classical, modular and mosaic (Buri, H., U., 2010).

a) Classic origami: It is created by transferring simplified, usually two-dimensional images of animals, plants and objects onto a single square of paper without cutting or gluing.

b) Modular origami: Three-dimensional, geometrically solid solids with multiple lateral surfaces, such as spatial lattice structures. These solid objects are brought together and transformed into blocks.

c) Mosaic origami: Only geometric folding patterns are used. The result is usually two-dimensional (Buri, H., U., 2010).

An example of modular origami is the Embedded pavilion structure with a surface of triangles, designed by Beijing studio HHD_FUN for Shanghai in 2018 (Fig 7), (HHD_FUN, 2010).

Fig. 7. Embedded Project origami sample. Source: (HHD_FUN, 2010)

Pavilion surfaces were designed using an iteration algorithm based on a triangular fractal pattern. Each triangle is repeatedly subdivided or folded to create smaller and smaller triangles and a denser pattern. At each stage, two of the three segments are cracked so that one large segment remains intact to create variation in scale across the surface. At each cracking, new triangles are raised vertically by 12 cm to create the three-dimensional surface pattern on the surfaces (Fig.8), (HHD_FUN, 2010).

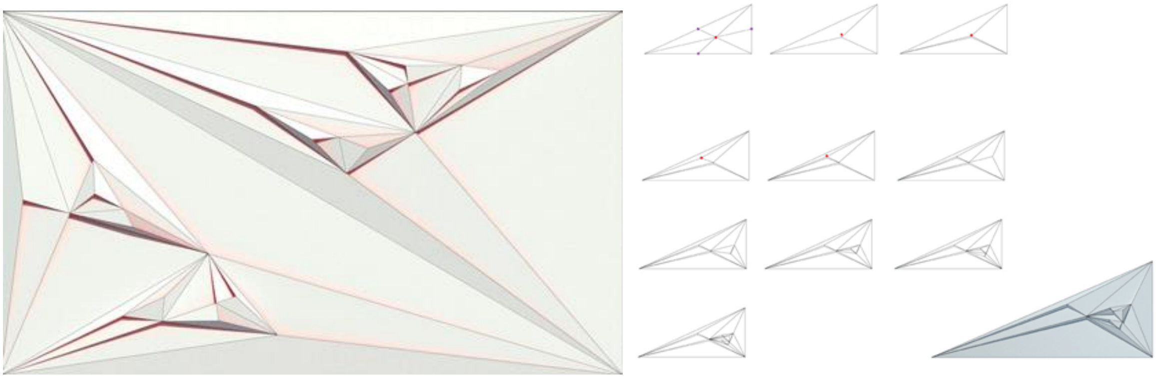

Fig. 8. Formation of triangular surfaces forming the structure. Source: (HHD_FUN, 2010)

In the interior of this pavilion, the distances on the stage are projectively shifted according to the movement and displacement of the visitors. The pavilion offers unusual perspectives for viewers to see the city, open spaces and algorithmic architectures embedded in the Google Earth projection. Thus, the visitors can observe the process of urban change inside the projection (Fig.9), (HHD_FUN, 2010).

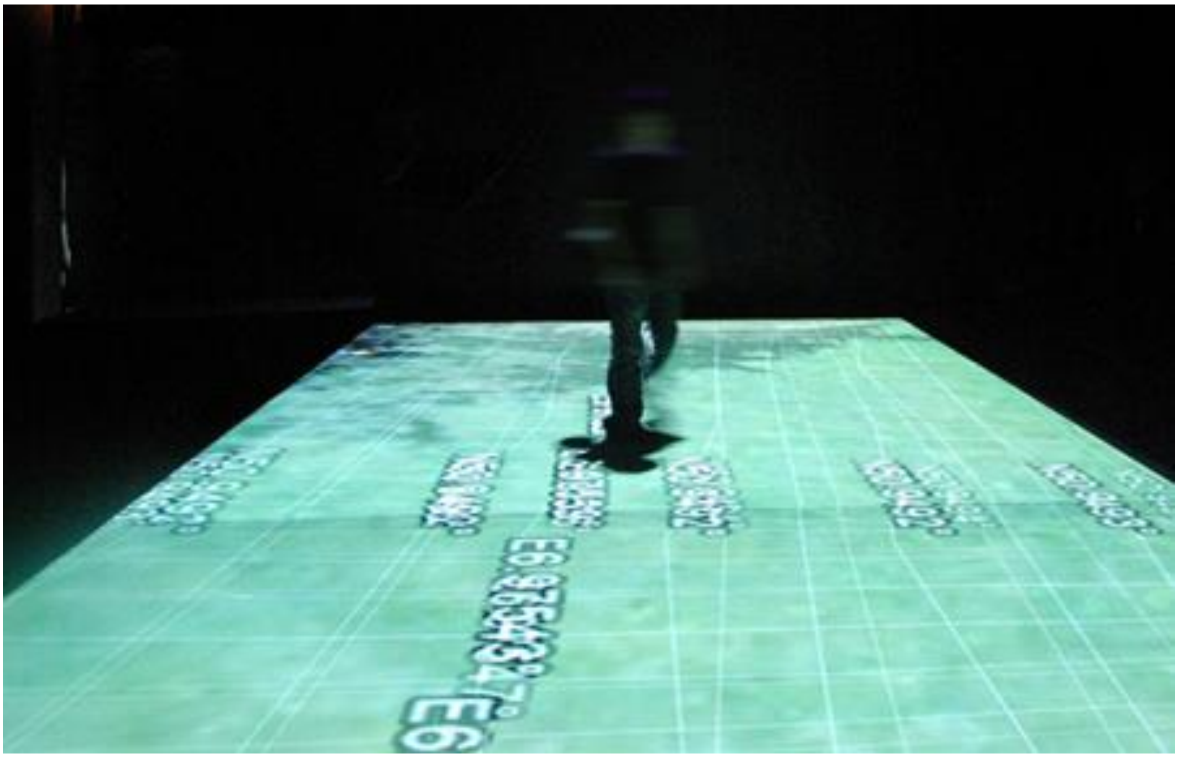

Fig. 9. Visitor interaction with the pavilion interior. Source: (HHD_FUN, 2010)

4. ORIGAMI DESIGN WITH DIGITAL DESIGN METHOD: A PAVILION EXAMPLE

The folding patterns of origami complement the visual appearance of architecture, while at the same time increasing the torsional strength of the material used. Many of the developments in the art of origami have been made possible by the development of the mathematical infrastructure of origami and the emergence of new digital design techniques.
With the Rhino Grasshopper algorithmic program, it is extremely easy and fast to fold or unfold any origami pattern with mountain / valley / border lines. For this design, first of all, using the Rhinoceros interface, the desired design format inputs are applied in two dimensions with the "line" command. However, since the fold lines are in segments within themselves, it is important that each of the lines consists of separate segments (Fig. 10).

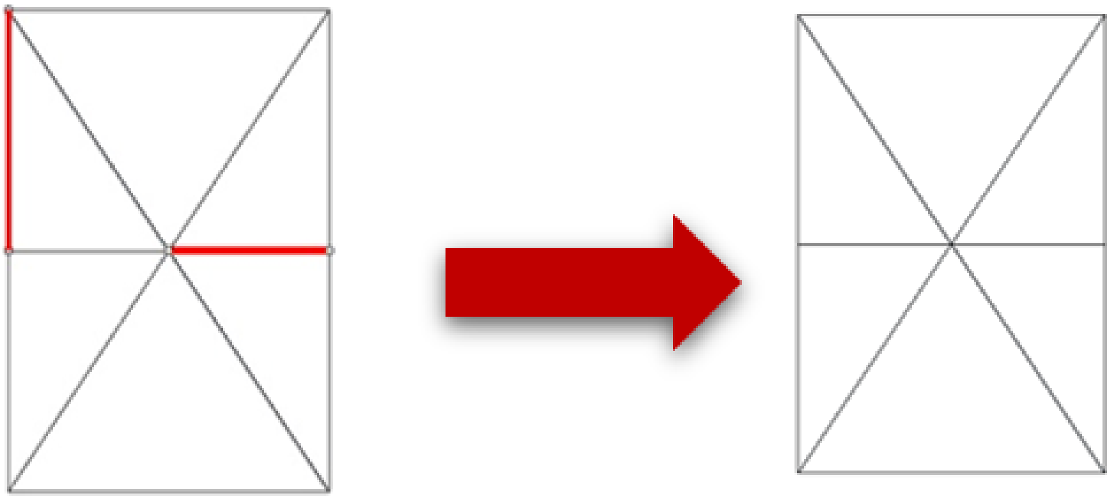

Fig. 10. Formation and segmentation of the module for origami, Source: creating by the author.

Then, in order to bring a created module to the desired skeleton system, the desired number of duplications are made. During the duplication process, the main structure of the parametric origami design is created by taking care not to have more than one line on the same edge.

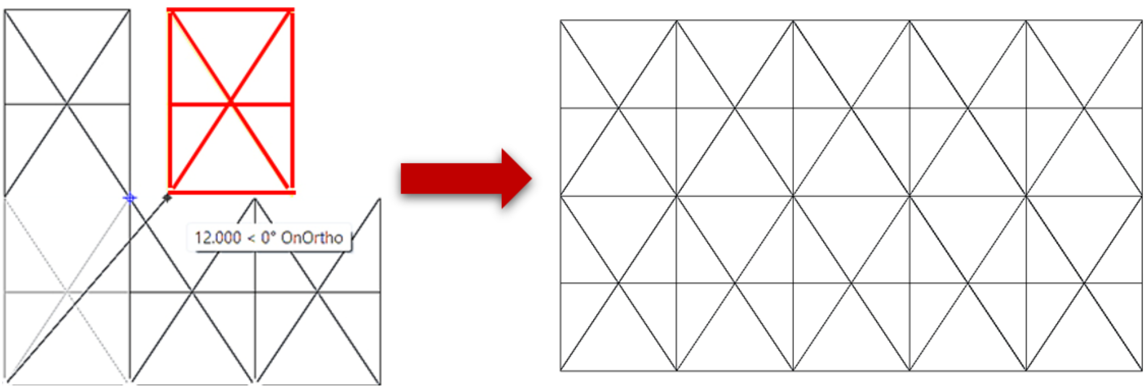

Fig. 11. Formation of the main structure for origami, Source: creating by the author.

Since the pavilion design is structurally in the X-Y direction, the folding edges will be on the Y axis and therefore the line from the X axis in the modules should be deleted (Fig. 12).

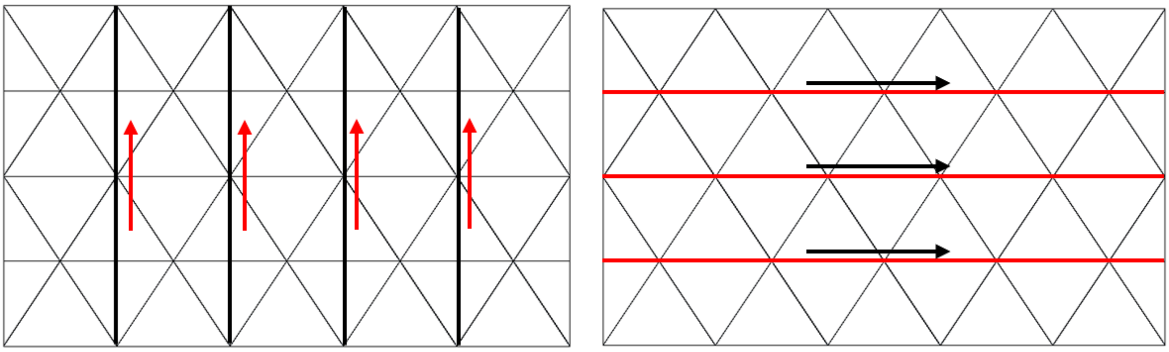

Fig. 12. Deleting modular lines on the Y axis, Source: creating by the author

The structure created in the Rhinoceros interface is transferred to the curve component in the Gras hopper program and transferred to the Grasshopper interface (Fig. 13).

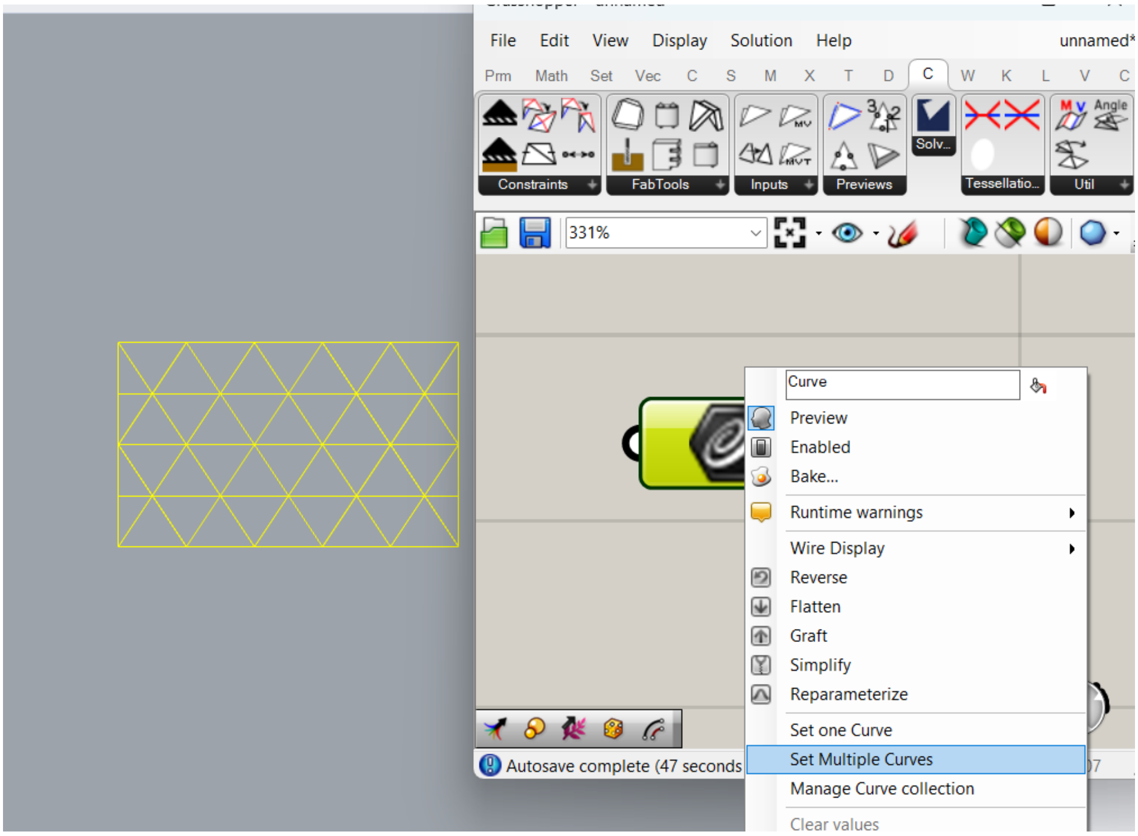

Fig. 13. Transfer to Grasshopper program, Source: creating by the author.

The bounding box component is used to mesh the two-dimensional structure defined in Grasshopper. However, since the bounding box component creates different surfaces for each line, this algorithm is converted to union box. Thus, a single surface is created for all lines in the structure. With the Surface Split component, the surfaces are divided into separate segments considering the lines in the modules (Fig. 14).

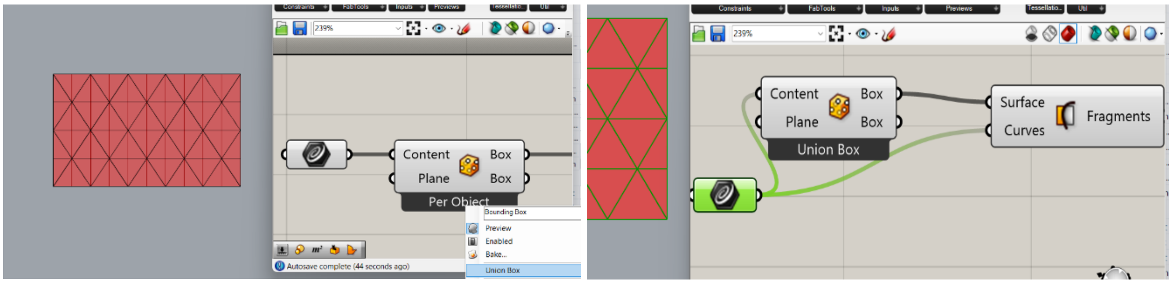

Fig. 14. Separation of segments with algorithmic components in Grasshopper program, Source: creating by the author.

It is possible to transform the pavilion structure into a simple mesh using the Brep join component and at the same time create a complete nurbs surface from the modules. The simple mesh component can also be used to convert a series of triangles or rectangles in the modules into a mesh (Fig. 15).

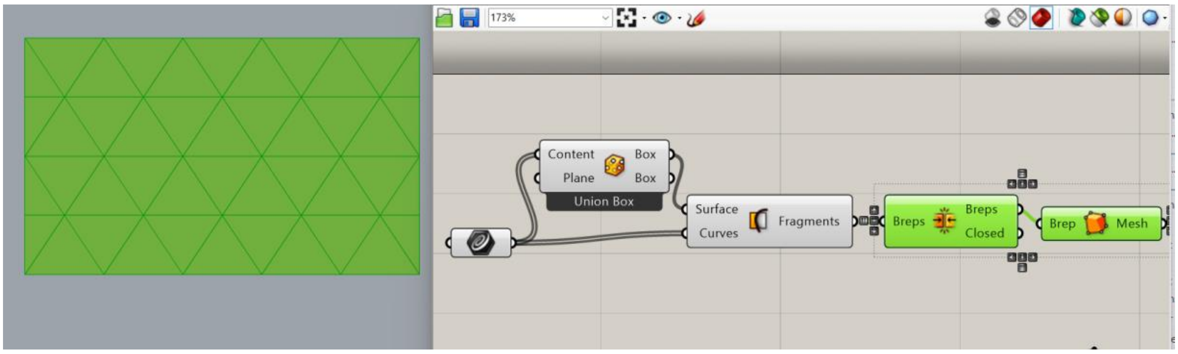

Fig. 15. Converting linear modules to mesh and nurbs surface, Source: creating by the author.

This mesh consists of 132 vertices and 44 faces. To simplify this large number, which affects the number of folds and the shape, the weld mesh component is used. Thus, the optimum dimensions (32 vertices and 44 faces) for origami designed from this selected structure are achieved (Fig. 16).

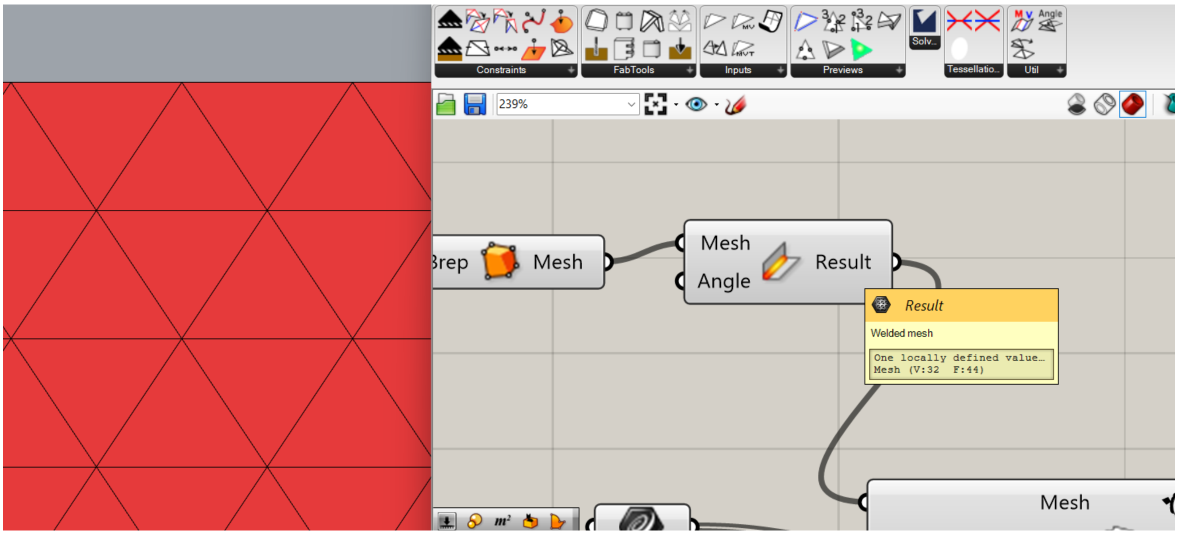

Fig. 16. Reaching the optimum number of folds, Source: creating by the author.

After the basic mesh output in the weld mesh component is input to the CMesh_MVlines component, mountain crease lines (the highest point of the mountain folds) and valley crease lines (the lowest point of the valley folds) are defined. In Figure 17, the segments shown in green in the modular structure are defined in the mountain crease lines input, while the black segments are defined in the valley crease lines and determined as the lowest elevation.

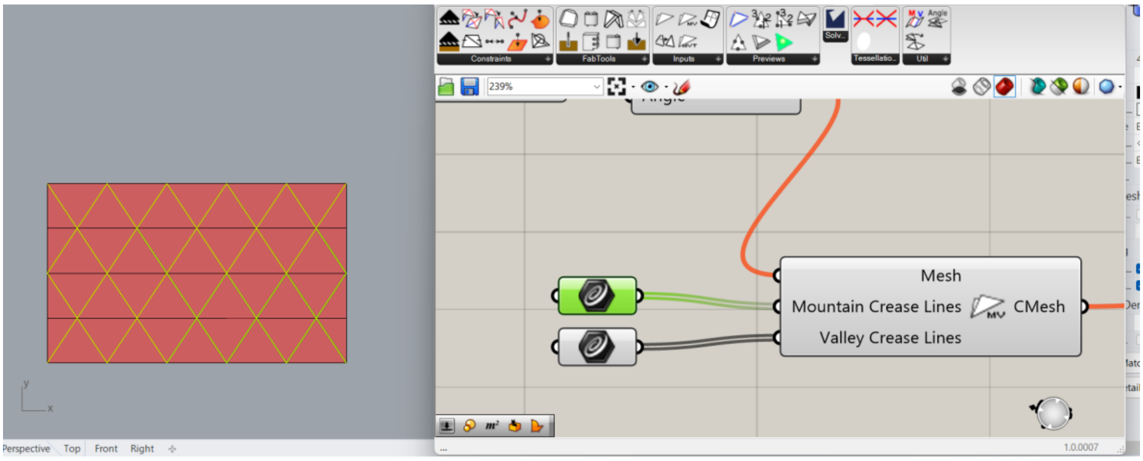

Fig. 17. Mountain crease lines and valley crease lines inputs, Source: creating by the authors.

After all the structure segments of the pavilion are entered into the system, the CraneSolver component is used to fold the pavilion in an origami shape. A value between 0.10 and 0.50 can be entered into the fold speed input as the folding speed (Fig. 18).

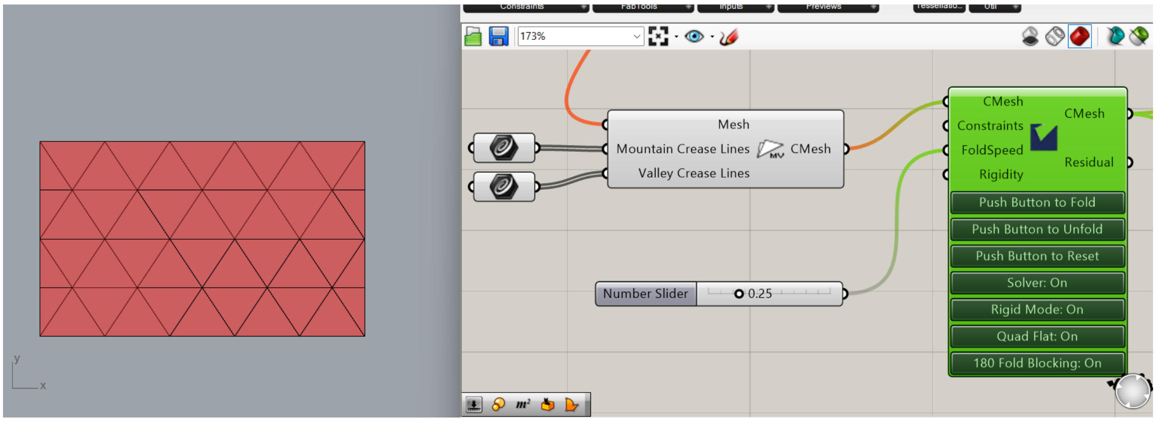

Fig. 18. CraneSolver component inputs, Source: creating by the author.

For origami folding, quad flat, rigid mode and solver buttons in the CraneSolver component are turned on, then push button the fold is pressed and a parametric origami design is made by folding the structure. Deconstruct the Cmesh component is used to deconstruct the resulting shape as a mesh (Fig. 19).

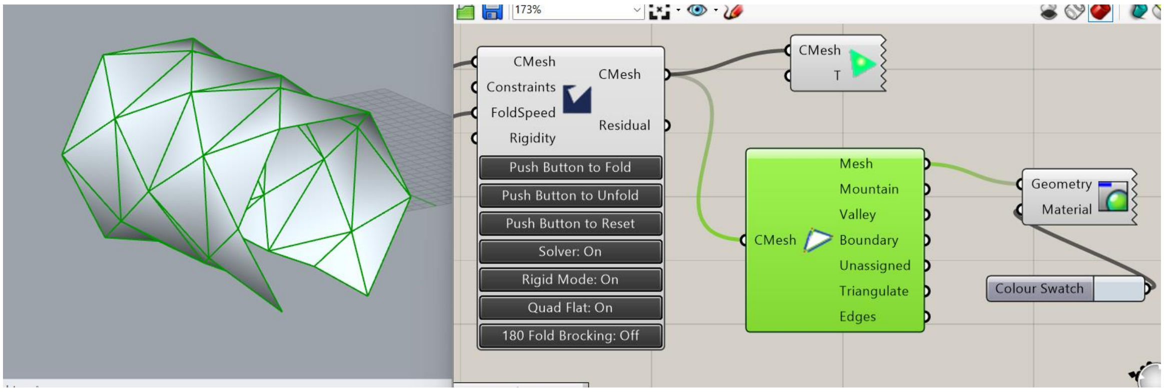

Fig. 19. Creating the origami shape, Source: creating by the author

As a result, when we "bake" the product created in the Grasshopper program, the design created in the Rhinoceros interface is as shown in Figure 20.

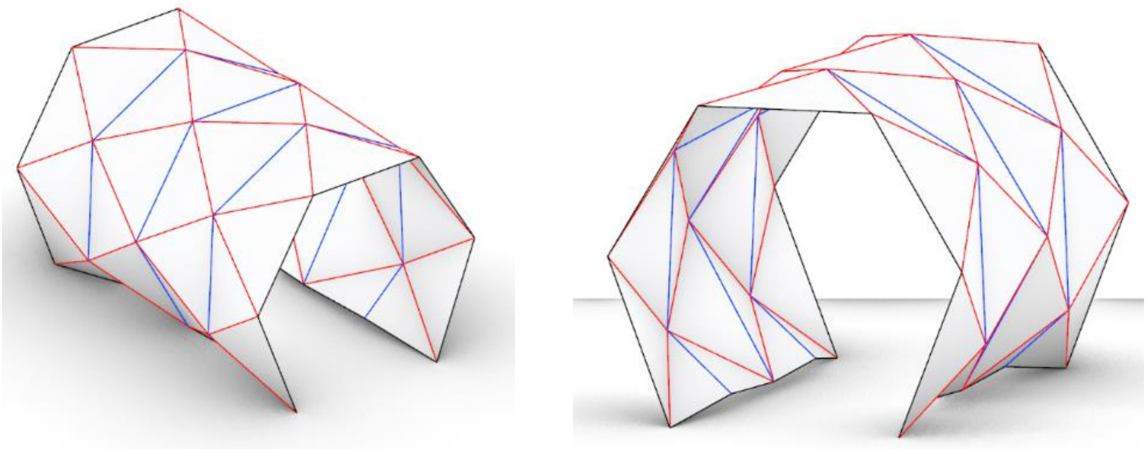

Fig. 20. Result product formed in the Rhinoceros program, Source: creating by the author.

5. CONCLUSIONS

Digital design methods have brought a breath of fresh air to the architectural design process, facilitating and modernizing the design formally and perceptually. With digital design methods, algorithmic programs are utilized with the advancement of technology, unlike the traditional design process, more free, instantly testable and many alternative solutions are brought and the most optimum solution can be selected in a short time. In this study, origami design method was emphasized as an example of the application of digital design methods and a pavilion design was realized. In the design process, the desired result was achieved in a very short and very easy way by using the necessary algorithmic components.

Digital design methods, which started in the 1960s and advanced with the advancement of technology, have been a topic of discussion for today's architecture since that period, as they affect the traditional design process. In response to the discussions in this context, it is a fact that the study will create awareness.

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