Foldable Structures In Architecture: A Temporary Exhibition Unit Design

FOLDABLE STRUCTURES IN ARCHITECTURE: A TEMPORARY EXHIBITION UNIT DESIGN

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ABSTRACT

Foldable structures get the origin from origami and the limitless design possibilities it offers. The foldable structures are used in the architecture due to their contribution to function, aesthetics, and ecological concerns supported by advanced technological developments. Foldable structures allow the design and production of complex structures, which provide advantages in material and labor usage and construction practices. The foldable construction techniques minimize material usage, decreasing the labor requirement and construction costs. It also has advantages in transportation, assembly, and disassembly processes. It prevents damages to the environment during the construction process by providing the production of temporary spaces.

This study focuses on folding techniques used in architecture for designing temporary spaces using foldable and deployable structures. The primary aim of the study is to understand the techniques used for the transition of two-dimensional surfaces to three-dimensional spaces formed by the folding technique. First, the contribution of the folding technique to architecture in terms of design and function is discussed. Then, the folding techniques used in architecture are analyzed through built examples. In the context of the study, a temporary exhibition unit is designed following folding techniques. The design principles, mathematical calculation of geometrical patterns, and techniques used for the design are explained in detail. The software “Freeform Origami, " developed by Tomohiro Tachi, is used to design and fabrication processes. Finally, the advantages of using foldable techniques and the possibilities and limits of the materials to be used in foldable structures in architecture are discussed to set forth future projections.

Keywords: Foldable structure, foldıng technıque, orıgamı archıtecture, freeform orıgamı, deployable structure

1. INTRODUCTION

The folding technique has been used for a variety of purposes, such as designing robot parts and producing thin conductors in electrical devices by folding them into three dimensions (Lee et al., 2013; Miyashita et al., 2014). Architecture is also among the fields where folding technique can be seen as part of architectural design (Shen and Nagai, 2017). The basis of this technique originates from origami, namely the art of paper folding.

In origami, three-dimensional objects are obtained by folding two-dimensional thin materials (Andreozzi et al., 2016). Thus, the thin, less durable, and weak material becomes three-dimensional, stable, and load bearing due to the advantages of the folding technique (Wierzbicki and Neagu, 2005).

In origami, geometric shapes are created by folding paper, which is defined as a mapping from the Euclidean plane to three-dimensional space with specific properties (Hull, 2011). The lengths of the folded lines used in the calculation and the angle between the two folding lines constitute the parameters of this calculation. Changes in parameters create the transformation range, which provides the control of three-dimensional shape (Zuk and Clark, 1970; Tachi, 2010). When the folding method is used as part of architectural design, meeting the design requirements depends on this control (Tachi, 2010).

Although the folding techniques used in origami have been adapted to architectural design, more appropriate materials than paper have been required to build the designed product (O'Neil et al., 2018). In origami, the thickness of the paper affects the extent to which it can be folded (Yasuda et al., 2013). Therefore, experiments were done with materials such as carbon fiber and glass fiber. New methods, as vacuum bag only (VBO), were used in the folding technique to increase origami usage in different areas such as architecture and engineering (O'Neil et al., 2018). Moreover, the folding technique was tested with concrete in order to make the concrete foldable, and folding curves were created by adding a foldable thin material between two concrete slabs (Woerd, Chudoba, and Hegger, 2013).

In this study, folding techniques in the design of temporary spaces are discussed through a design experience. The origami architecture is explained with examples to put forward the use of folding techniques in architecture. A temporary exhibition unit is then designed to demonstrate the folding technique in architectural design using Freeform Origami software that provides using alternative folding techniques based on defined shapes and functions. Finally, the potentials, advantages, and limitations of folding techniques for designing temporary spaces and deployable structures are discussed.

2. ORIGAMI ARCHITECTURE

Origami is a paper-folding art that means "folded paper" in Japanese with visual and functional features. It is used in architecture due to its load-bearing feature and potential to provide deployable aesthetic design alternatives (Andreozzi et al., 2016). Traditional origami patterns such as Miura-ori are commonly used in architecture. Filipov, Tachi, and Paulino (2015) used this pattern in their work and designed a bridge using origami's load-bearing feature. Tachi (2010) also worked on the same pattern and explained the advantages of origami architecture in four stages. First, he claimed that the use of rigid-foldable and flat-foldable surfaces in architecture is applicable; hence the frame structures can be packed compactly. The second advantage is that the folding motion can control the rotation of the hinges. Third, because the flexibility of the material is not used in the folding technique, thick materials can also be used with hinges. Fourth and lastly, it is stated that the pattern is suitable for the facade to protect the building from external factors such as water (Tachi, 2010). While these advantages are listed, it is emphasized that the folded material is two-dimensional, and the structures designed in this size must meet the architectural requirements when they become three-dimensional. It is argued that the origami pattern should be controllable (Tachi, 2010). Freeform Origami is software that can be used to control whether drawings drawn on a two-dimensional plane are foldable or not (Figure 1).

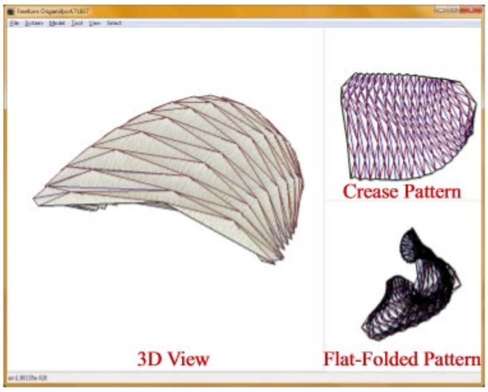

Figure 1. General view of Freeform Origami software (Tachi, n.d.).

In architecture, folding techniques can be seen in the components, elements, or building itself both for the permanent and temporary spaces.

Sulfur Extraction Facility, designed as a factory building, is one of the first examples where the folding technique was used in architectural design at the component level (Image 1). In this building, an origami pattern was used on the ceiling as the finishing material. The ceiling panels were made of fiberglass with a weight of fourteen kilograms for each panel, and these panels were also capable of transmitting light. The connection details were not visible to provide the finished look as a single piece. Aesthetic concerns were not the only reason to prefer an origami pattern for the design of this ceiling component. On the other hand, this form increased the durability of the system statically.

Image 1. Sulfur Extraction Facility (Glancey, 2018).

Pulkovo International Airport is an example of the folding technique used in building element level (Image 2). In the roof design of the airport, a design based on the folding technique was used not only to have an iconic design but also to design a roof that is adaptive to the climatic conditions of the region. The roof is designed to bear the heavy snow load during the winter months (Pulkovo International Airport, n.d.).

Image 2. Pulkovo International Airport (Pulkovo International Airport, n.d.).

Origami Pavilion is an example of the temporary designs built by using folding techniques (Image 3). The pavilion can remain standing without the need for any additional support due to the surface rigidity. The basic logic in designing this pavilion, created by folding composite aluminum sheets, comes from origami. The use of thin hard aluminum also increases the durability of the structure (Tal Friedman Architecture and Design, n.d.).

Image 3. Origami Pavilion (Tal Friedman Architecture and Design, n.d.).

Bamboo Forest and Corinth Hut is another foldable structure example designed as a temporary structure (Image 4). It creates a semi-open space for visitors to watch nature. This foldable structure is designed to be folded and dismantled without harming the environment when it is no longer needed (Cilento, 2009).

Image 4. Bamboo Forest and Corinth Hut (Cilento, 2009).

3. TEMPORARY EXHIBITION UNIT DESIGN

In this study, a temporary exhibition unit was designed to demonstrate the use of the folding technique in architectural design. The temporary exhibition unit was designed to be located in the main corridor of the Great Storehouse Building of the Abdullah Gul University, where the Architectural Design Studios are located, and the students' projects are usually exhibited. The design requirements focused on creating clean spaces for exhibitions in a corridor with heavy human traffic by highlighting the exhibitions and presenting the models and posters in a protected environment. Therefore, the design aimed to provide an exhibition space for the temporary exhibitions, both for the poster and model productions, that can be folded, deployed, and stored when it is not in use.

The design process was started with experiments to understand the use of Freeform Origami software by preparing digital folding designs and making models using paper folding techniques (Image 5). This process aimed to understand how the lengths and angles used in the two-dimensional design would result in three dimensions. Through these experimental studies, it was observed that changes in the angle affect the design. Besides, the suitable angles and for the folding technique were ascertained. It was seen that the use of narrow angles and short lengths makes it difficult to fold the paper and pushes the durability limits of the material. Short fold lines, which create mountain and valley folds, drawn at a narrow-angle in the two-dimension plane, were likely to deform during folding.

The exhibition unit's design was made through trials on the folding technique using various angles (Figure 2 and Figure 3). Within the scope of this design trials, 45-35, 45-55, 45-25, and 45-65 degree angles were used. The most critical factor determining these angles during the design phase was the functions that the temporary structures should meet, such as structurally durable to stand without any support by creating ribs for the structure.

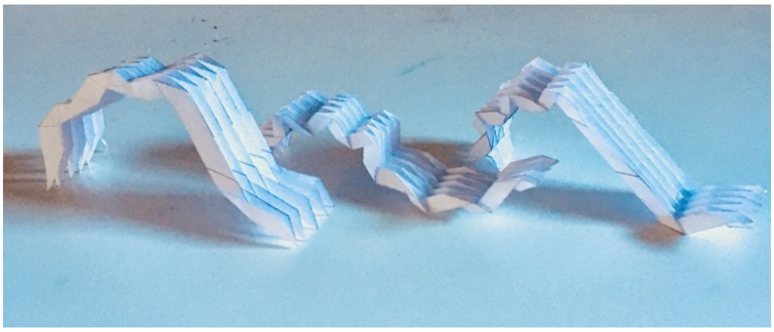

Image 5. Experimental models (Produced by Deniz Demir, 2020).

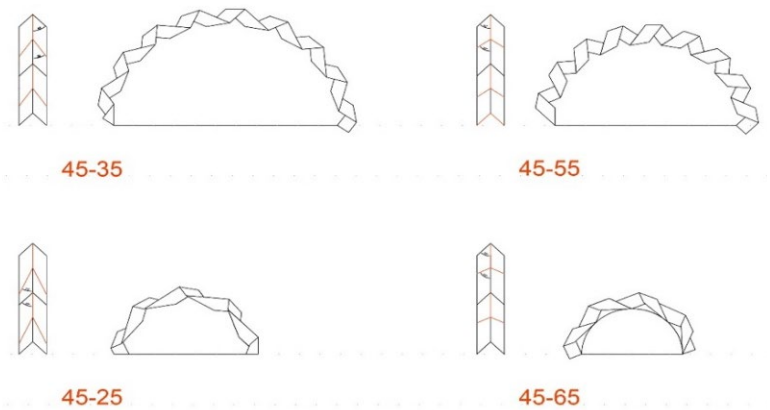

Figure 2. Plan and section drawings of designs created with different angles (Designed by Deniz Demir, 2020).

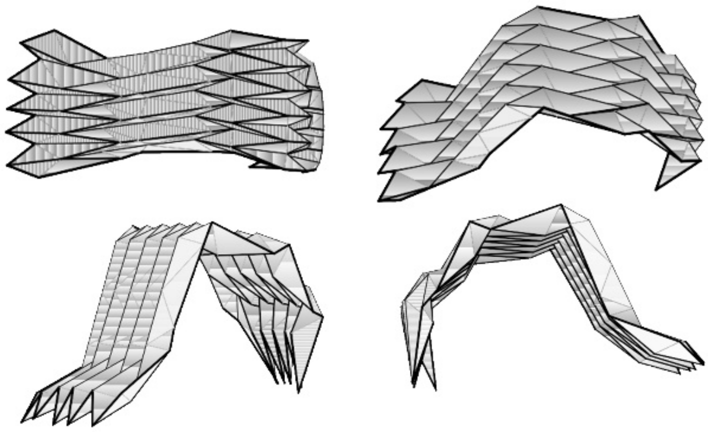

Figure 3. Three-dimensional models (produced by Deniz Demir using Freeform Origami, 2020).

The calculations required for the design of the temporary exhibition unit design were made using the mathematical and geometric formulas developed by Hull and Tachi (2017) as described below:

$$z = 45° \quad q = 25° \quad w = (180° - q) \quad v = (180° - z) \quad a = 4\text{ cm} \quad b = 4\text{cm}$$

$$A = v - z = (180° - z) - z = 180° - 2z = 180° - 2.45° = 90°$$
$$A = 90° \text{ (Rotation angle first)}$$

$$B = w - q = (180° - q) - q = 180° - 2q = 180° - 2.25° = 130°$$
$$B = 130° \text{ (Rotation angle second)}$$

$$z > q;\ x = 90° - z + q;\ x = 90° - 45° + 25° = 70°$$
$$x = 70° \text{ (External angle)}$$

$$2x + y = 180°;\ y = 180° - 2x;\ y = 180° - 2.70° = 40°$$
$$y = 40° \text{ (Unit angle)}$$

$$k^2 = a^2 + b^2 - 2ab\cos A = 4^2 + 4^2 - 2.4.4.\cos 90° = 32$$
$$k = 5{,}6568 \text{ (Length of one unit)}$$

$$r / \sin x = k / \sin y;\ r = k.\sin x / \sin y = k.\sin x / \sin(180° - 2x)$$
$$r = 5{,}6568.\sin x / \sin y;\ r = 5{,}6568.\sin 60° / \sin 40°$$
$$r = 7{,}62 \text{ (Radius of the pattern)}$$

A: First rotation angle; B: Second rotation angle; x: External angle; y: Unit angle; k: Length of one unit; r: Radius of the pattern; z: The first angle chosen for the design; q: The second angle chosen for the design; a and b: The selected lengths between angled horizontal lines in the pattern.

Finally, the design of the foldable structure for the exhibition unit was gathered as shown in Figure 4 to be located in the Great Storehouse Building of the Abdullah Gul University, in front of the architecture design studios, as represented in Image 6.

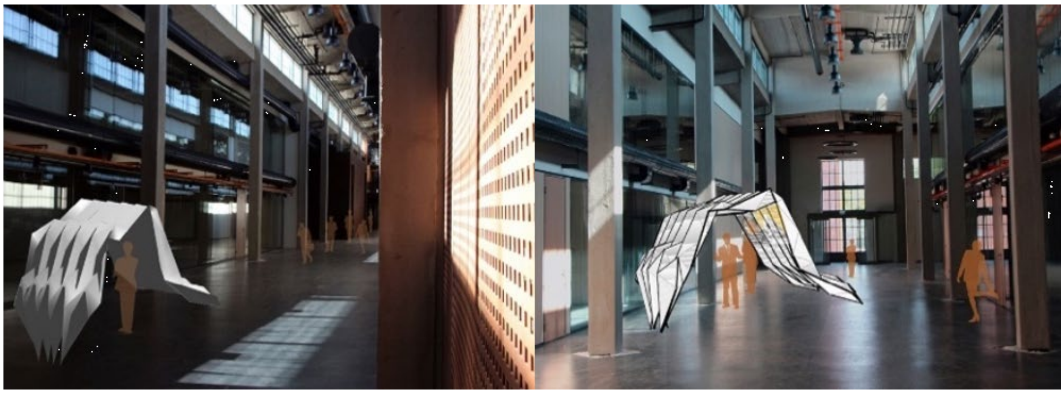

Image 6. General view of the temporary exhibition unit located in Great Storehouse corridor (Photo taken by Burak Asiliskender, collage produced by Deniz Demir, 2020).

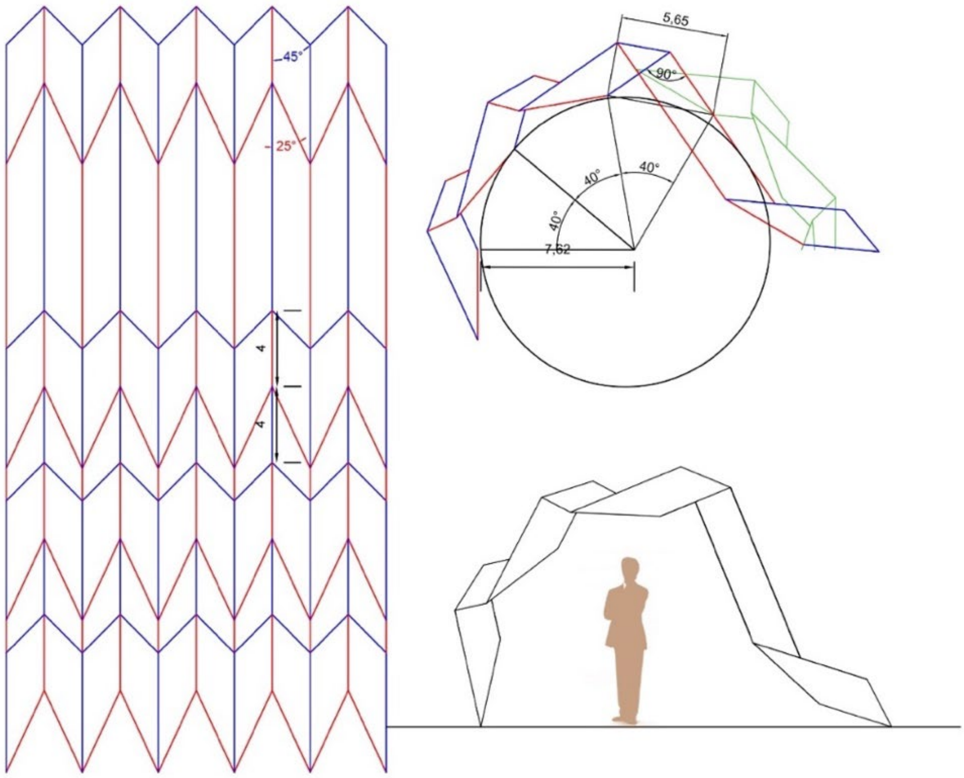

Figure 4. Plan and section drawings of the Exhibition Unit Design (Designed by Deniz Demir, 2020).

4. CONCLUSION AND DISCUSSION

The folding technique, which originates from origami and provides limitless design possibilities, is used in the architecture not only for aesthetics concerns but also due to its contribution to functional requirements such as having foldable and deployable temporary spaces. Within the context of this study, the use of folding techniques and structures in architecture were analyzed through built examples for providing basic knowledge to design temporary spaces. A temporary exhibition unit was then designed as a foldable and deployable structure for AGU School of Architecture exhibitions. The “Freeform Origami” software was used for the mathematical calculations of geometrical patterns to design a foldable and deployable exhibition unit. The design process showed that the traditional technique could be predictable with various calculations to design the correct pattern required for design with all its details. It systematizes and simplifies the design process of complex structures by providing advantages and optimization in terms of material and labor usage and construction practices. The foldable techniques can be used in architecture at different levels, such as designing and constructing components, building elements, and the building itself. The advantages of foldable techniques, especially for the temporary and deployable structures, should also be considered within the possibilities and limits of building materials. Since the service life of temporary structures can be limited, it is also possible to consider using reclaimed or natural building materials to produce environmentally friendly structures.

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YÜZEN EVLER ve TEKNOLOJİSİ

FLOATING HOUSES AND THEIR TECHNOLOGY

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ÖZET

İnsan yaşamının devamlılığının sağlanması açısından ‘su’ ve ‘barınma’ ihtiyacının karşılanması hayati bir öneme sahiptir. Bu nedenledir ki insanlar ya suya yakın yerleşim yerlerinde yaşamayı tercih etmiş ya da yaşadıkları yerlere suyu ulaştırmak için çaba göstermiştir. İnsanların ‘su’ya ulaşma çabası fiziksel olarak ona ihtiyaç duymalarının dışında, ‘su’ öğesinin huzur, sakinlik, dinginlik vb. pozitif duygularla bağdaştırılmasıdır.

İlk başlarda zorunluluklardan doğan ‘su ve barınma’ birlikteliği daha sonraları teknolojinin katkısıyla şehrin kargaşasından uzaklaşıp göl veya deniz üzerinde keyifli vakit geçirmek amacıyla oluşturulan ‘tekne–ev’ konseptli yaşam alanları ile su ve yaşam kültürünün oluşmasına olanak sağlamıştır.

Zamanla gelişen teknoloji ile birlikte ilkel niteliklere sahip diyebileceğimiz botlar pek çok imkana sahip hızlı yer değiştirmeye olanak sağlayan yatlara dönüşmüştür. Ancak sahip olduğu tüm özelliklere rağmen yatlar daha çok su üzerinde keyifli zaman geçirmek için kısa süreli bir konaklama gereksinimi karşılamak için kullanılmıştır.

Oysaki su ve yaşam kültürünü daha geniş bir çerçevede ele almak mümkündür. Bu çerçevede karada bulunan normal bir evden tek farkı su üzerinde yüzen bir temele sahip olması olan ‘Yüzen Evler’ karşımıza çıkmaktadır. Günümüzde yüzen evler yalnızca turistik bir amaca hizmet etmek için değil küresel ısınma gibi insan hayatını olumsuz yönde etkileyebilecek muhtemel sorunlara bir çözüm üretebilmek amacıyla da teknolojik imkanlar doğrultusunda geliştirilmektedir. Tüm dünyada yeni bir konut tipi ve esnek yaşam tarzı olarak ‘yüzen ev’ popüler hale gelmektedir.

Bu doğrultuda çalışmada özellikle suyla büyüyen kentlerde yer alan yerleşkelerden yola çıkılarak yüzen ev teknolojisi; farklı bölgelerde yer alan çeşitli fonksiyonlara sahip örnekler üzerinden incelenmektedir. Yüzen evlerin sahip olduğu modüler yapım, kendi kendine yetebilen dönüşümlü enerji sistemleri ve sürdürülebilir özellikleri araştırılmaktadır.

Anahtar Kelimeler: Su ve yaşam kültürü, barınma, yüzen evler, yüzen ev teknolojisi, sürdürülebilir evler

ABSTRACT

In order to ensure the continuity of human life, meeting the need for 'water' and 'shelter' is vital. For this reason, people either preferred to live in settlements close to water or they make an effort to