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# An Overview of Folding Techniques in Architecture Design

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## Abstract

In recent years, folding techniques are widely used by many architects to make 3D forms from 2D sheets as an inspiration for their design, which enables simpler and more intuitive solutions for architectural realization. This research provides an overview of using folding techniques in architecture design, with an emphasis on their new applications. In this overview, we classify folding techniques as computation geometry folding techniques and manual folding techniques. Finally, we provide recommendations for future development.

## Keywords

Architecture Design, Folding Techniques, Folded Construction, Computation Geometry

## 1. Introduction

Folding techniques, also known as origami, the generic term for paper folding, have been applied to many fields, such as in material research [1], robot structure [2] [3], electric devices [4] and architecture design [5]. Folding techniques are popular in architecture design mainly for two reasons, possessing creative architectural structure with advantageous load-carrying capabilities and generating esthetic and deployable architectural form [6]. The two parts are extremely important in architecture design, especially for innovative design theory. Because of these positive findings, a number studies investigated the specific applications of folding techniques in building design and summarized them in a brief review. For example, Stavric & Wiltsche [5] did investigations on spatial quadrilateral meshes from folding patterns. Furthermore, Lebée [7] presented a review of current challenges regarding folds and structures starting from simple

notions of paper folding. However, these studies are overly specific and practical. On this background, this study aims to present a general review on folding techniques in architecture design and provide recommendations for future development.

## 2. Research Method

To make a comprehensive overview of folding techniques in architecture design, we classify folding techniques as computation geometry folding techniques and manual folding techniques. We searched relevant literature using them as keywords and selectively searched the references from articles and books were searched.

## 3. Contents of Folding Techniques

The concept of fold has many meanings, in nature, it can be found at many different scales from the folding of graphene layers [8] [9] to the unfolding of tree leaves [10] and the mountains building. However, the abstract idea of folding techniques emerged recently [7], which was also called origami in Japan. The association between origami and mathematics is profound and insightful, hence with the rapid development of computer science, computation geometry folding techniques emerged as a new theoretical field in the last decades. This section provides an overview of the key techniques of both manual and computation geometry folding techniques.

### 3.1. Manual Folding Techniques

Jackson [11] is one of the first researchers to try to systematically introduce manual folding techniques for designers. In his works, over 70 techniques explained by clear step by step drawings, crease-pattern drawings, and specially commissioned photography.

#### 3.1.1. Rigid Folding

Rigid folding is when all the deformation is concentrated in the hinges and the faces between the folds remain flat [7]. For architectural considerations, standard plane materials are important and effective. Hence during the procedure of rigid folding, the feature that all single parts stay flat makes it crucial for designers to investigate. **Figure 1** shows a lampshade using rigid folding techniques.

#### 3.1.2. Curved Folding

Curved folding is when the fold line is curved, which is more general and complex than rigid folding. Actually, during the procedure of curved folding, both the fold line and faces between the folds change their curvature, which makes it difficult to use geometric method to describe curved folding [12]. Hence Duncan and Duncan [13] presented a new description of curved folding where local relations between the curvatures of each sides of the fold and the curvature of the fold line itself are provided. **Figure 2** shows an example of curved folding.

**Figure 1.** An example of rigid folding.

**Figure 2.** An Example of curved folding.

### 3.2. Computation Geometry Folding Techniques

Computation geometry problems originated in Albrecht Durer's masterwork on geometry "On Teaching Measurement with a Compass and Straightedge", which opened a new field with a lot of open problem [14]. In 2007, a book about geometric folding algorithms was published by Demaine and O'Rourke [15], which study folding techniques with an emphasis on algorithmic aspects. Inspired by it, many computational geometers became interested in folding problems and computational origami, their works concentrate on piecewise linear structures [15] and curved folding structures [16].

## 4. Applications of Folding Techniques in Architecture Design

As folding is comparatively simple and quick process to achieve three dimensional shapes, it inspired many architects for designing from wide roofing to anomalous architectural structure [17] [18] [19]. In addition, with the combina-

tion of parametric graphical tools, folding techniques accelerate the design cycle significantly. To be more specific, the current applications of folding techniques in architecture design mainly concentrate on architectural structure design and architectural surface design.

### 4.1. Folding Structure in Architectural Design

In architectural terminology, the term folding structure means structures consisting of plane polygonal elements [5] which made of plates and sticks. Some designers also call it origami construction [19].

**Table 1** shows the folded plate structure systems based on geometric shape [19], one of the common advantages of folding structures is improve the static behavior of loads. **Figure 3** shows the bearing capacity of different folding structures increase from **Figure 3(a)** to **Figure 3(e)** with being reinforced by end plates, diaphragms, tie bars or bracings.

### 4.2. Folding Techniques in Architectural Form Design

Folding techniques are often explored by researchers with "learning by doing" methods [5]. Many fantastic forms are generated intuitively in this process. Hence folding techniques usually play an important role of creative stimulation in architectural form design, especially in the early stage of design process [20].

**Figure 4** shows the Chapel at the Air Force Academy in Colorado Springs which is a famous example of buildings constructed as folded form. The basic construction of this building consists of triangular plates—metal panels forming folded construction [19].

The form finding process inspired by folding techniques gives an astonishing formal richness and variability [21], such as Yoshimura pattern, Miura Ori pattern and Diagonal pattern. The three patterns are particularly interesting for architectural form design as these forms allow rapidly complex folded plate structures in space along with unfolded, which is also the core in other applications of folding techniques in architectural form design.

## 5. Discussion and Suggestions for Future Development

The present review reveals that folding techniques have been systematically studied and there are clear indications that folding techniques have positive con-

**Table 1.** Folding structure systems.

| Folding structure systems | Forms of Folding Structures | | |
|---|---|---|---|
| | Folded Plate Surfaces | Folded Plate Frames | Folded Plate Dome |
| | Linear Additions | Continuous | Pyramidal Folded Plate Structure |
| | Combination of Additions | Two/Tree Hinged | Polyhedral Folded Plate Structure |
| | Radial Additions | Cylindrical Folded Structure | Combinations |

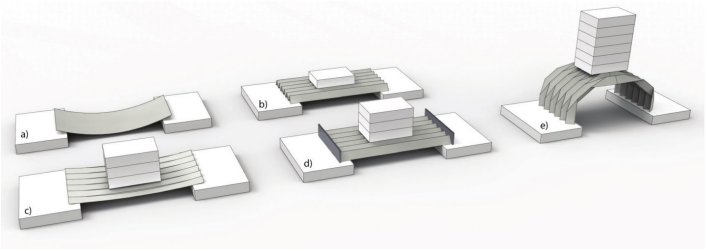


**Figure 3.** Static behavior of different folding structures [5].

**Figure 4.** Air Force Academy Chapel, Colorado Springs, USA [19].

tributions to architecture design. However, there are few previous studies specifically on investigating the folding techniques in architecture design at the level of cognitive science.

In design cognitive process, we describe using folding techniques in architecture design as a design synthesizing process between origami and architecture [22]. Previous study [23] classifies the concept synthesizing process as "concept abstraction", "concept blending" and "concept integration". Current studies about folding techniques in architecture design mainly focus on exploring the similarity and taxonomical relations between folding techniques and architecture design, which are the principles of "concept abstraction" and "concept blending". Nevertheless, the primitive being "concept integration" is proved to led to higher creativity and the principle of "concept integration" is thematic relations, hence future researches are suggested to explore more about the thematic relations between folding techniques and architecture design to achieve higher creativity in architecture design, especially at early stages of architecture innovation [24].

In addition to considering folding techniques at the level of cognitive science, the reverse process of folding is an often overlooked field used in architecture design, the process of unfolding 3D forms also contains lots of information useful for architecture design. For example, answering whether polygon P can be folded into polyhedron Q with polyhedron Q is a kind of unfolding techniques to find common developments from plural cuboids [25]. **Figure 5** shows an

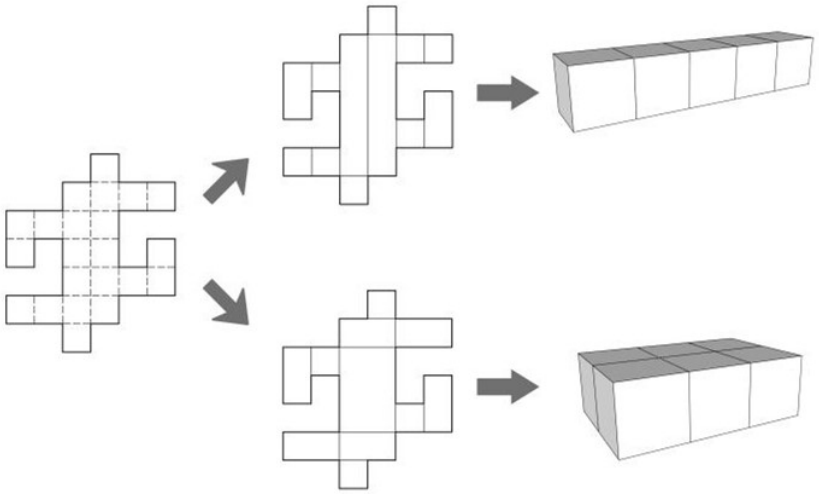

**Figure 5.** A common development folding into two boxes of size 1 × 1 × 5 & 1 × 2 × 3.

example of common development which can fold into two boxes of sizes 1 × 1 × 5 & 1 × 2 × 3.

As the derivative of folding techniques, unfolding techniques is considered as another geometric modelling system applicable in architecture design, which prefer simulating the deconstruction process in architecture design.

## 6. Conclusion

This research presents a general review of folding techniques and their applications in architecture design. Considering the techniques as a form finding process, it is an original mechanism to obtain inspirations both in architectural structure and form design. Furthermore, it plays an important role of design stimulus in the early stage of architecture design process, which generates most ideas in the whole design process.

For future development of folding techniques in architecture design, this research presents two new research fields. The first new field is investigating folding techniques from the perspective of cognitive science, considering folding techniques as a kind of design stimulus and exploring their applications within the framework of a concept synthesizing process may achieve more creativity in architecture design. The second new field is exploring the applications of unfolding techniques for architecture design, as the reverse process of folding. It is more similar to the deconstruction process in architecture design, which opens a wide perspective for developing folding techniques in architecture design.

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