Research on the Application of Origami Structures in Interactive Product Design

Jiayuan Lyu[1(✉)] and Taiwen Zhang[2(✉)]

[1] Royal College of Art, London, England
jiayuan.lyu@outlook.com
[2] Brunel University London, Uxbridge, England
taiwen.zhang@outlook.com

Abstract. Origami plays an important role in both art and science. In the art field, the inherent geometric beauty of origami increases the artistry of many art works. In the scientific field, its powerful and unique structural characteristics solve many physical challenges. However, the geometric artistry and structural function of origami are not regarded as a whole, and usually only one aspect is concerned. In view of this, this paper aims to apply the geometric aesthetics and structural functions of origami structure to interactive product design, so as to bring more space and more interactive forms for the realisation of interactive functions. This study starts from the history of origami, explores its development, and then summarises its current application and the significance of origami structure in contemporary applications. Second, the corresponding relationship between interactive product design and origami structure is explained, and the rationality and advantages of the combination of the two are analysed. Finally, three methods of combining origami structure with interactive product design are proposed, which provides a new idea for interactive product design.

Keywords: interactive product design · origami structures · geometric aesthetics · structural function

1 Introduction

Origami is an activity that most people may participate in in their life. When we think of origami, we may recall paper cranes and paper aeroplanes in our childhood. However, origami is not only an educational handicraft activity, but also a very important research activity in the field of art and science. As an art form, origami converts a two-dimensional plane into a three-dimensional model through physical folding technology, and can be restored to a two-dimensional plane state by disassembling it [1]. The folding principle of origami is simple, but the forms are extremely abundant, with a strong artistic sense. Therefore, origami art is often used as a design technique and is incorporated in various designs, such as the 'in EI' series lamps of Issey Miyake.

In the creation of origami, creases are combined in a myriad of different folds, forming countless origami structures. Origami structures emerged with the development

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of the art of origami. With the development and innovation of modern science and technology, origami structure also shows its brilliance in the scientific field. Different origami structures can bring about different physical functions, which is why they are so versatile and useful in the scientific field, such as the important role of Miura-ori in science. All materials in nature have a positive Poisson's ratio; negative Poisson's ratio materials can only be made artificially. Due to its characteristics, Miura-ori can cleverly achieve a negative Poisson's ratio and solve many structural requirements that need negative Poisson‘s ratio, which also reflects the irreplaceable nature of origami structure [2].

It seems that origami has naturally developed different ways of use in different fields, which distinguishes the two outstanding characteristics of origami. On the one hand, in the field of art and design, origami is often used to establish the basis for the shape of artworks and products with its unique geometric aesthetic. In the field of science, on the other hand, researchers often consider the structural features of origami and choose the correct structural characteristics of origami structure to meet the physical characteristics required for specific research.

Interactive product design is ideally suitable for combining the two outstanding characteristics of origami, using both geometric aesthetics and structural function in the design. As a design discipline, interactive product design requires the product shape to have certain aesthetic quality. The geometric beauty of origami can add artistry and beauty to the product shape. The functions required for interaction can perhaps be realised by using variations in the origami structure, allowing users to participate in changing the origami structure, increasing interactivity and user involvement, and appropriate materials can also assist in the diversification of product interaction.

Therefore, this paper explores the possibility of applying the structural function and geometric aesthetics of origami structures to interactive product design, analyse the correspondence between interactive product design and origami structures, summarises the design method of combining interactive product design and origami structures, delves into the value of applying origami structures to interactive product design, and on this basis, looks into the future development direction of the functionality of origami structures in the design field.

2 Literature Review

2.1 The History of Origami Structures

Origami structures emerged with the development of the art of paper folding, which is a branch of paper art. After 141 B.C., the Chinese made the first piece of paper, and paper art was born. However, due to early technical problems, the paper was not produced in large quantities and was not suitable for folding. Therefore, there are no records of origami in Chinese excavations and related literature, which has led to the origins of origami being untraceable [3].

Origami emerged and flourished soon after the introduction of papermaking into Japan, and was widely used in Buddhist rituals. Around 1200 A.D., origami art developed rapidly in Japan, and more complex origami models appeared, which showed different meanings on various formal occasions. For example, in the ceremony of Japanese samurai at that time, a sword and a paper flower folded by a special folding method were exchanged to prove friendship [4]. After 1557, due to the gradual development of paper-making technology, origami began to spread to all levels of society, which was the heyday of its development. The earliest written record of origami appeared in 1797, when a Japanese monk wrote and published the world's first origami book, Hiden Senbazuru Orikata.

In the following century, the Arabs at the peak of cultural development began to develop origami art independently. In hindsight, their greatest contribution was to apply the principles of European geometric mathematics to origami and use origami to study geometric mathematics, which was the starting point of the combination of origami and mathematics [5]. The year 1800 A.D. was the first year in which origami was integrated into the natural sciences. It began to become an important tool for western teaching and research. Today, the mathematical puzzles found in origami are an important part of modern geometry.

In the late 19th century, the first international origami conference was held in Paris, followed by the second and third conferences in Argentina and New York. At the end of the19th century and the 20th century, modern origami developed rapidly, and many famous masters appeared, such as Yoshizawa and Sam Randlett. They created a worldwide terminology for origami, allowing origami to spread around the world in the form of drawings and avoiding language barriers. Origami has been developed all over the world, of which Japan is the most popular. The Japanese regard origami art as a national treasure, and the word 'origami' originates from Japanese pronunciation [7].

2.2 Application of Origami Structures

In origami, 'mountain fold' and 'valley fold' are the two most basic folding methods [8]. When folding, the paper is folded horizontally, and folded upwards or downwards to form an origami structure, forming 'mountain fold' and 'valley fold'. 'Mountain fold' and 'valley fold' have become decorative representations of origami structure. Although their structure is simple and basic, they still occupy a place in art and design as representative decorative elements with geometric aesthetics, special light and shadow effects and unique language of form.

2.2.1 Origami Structures in Artistic Aesthetics

Geometric patterns have a unique geometric aesthetic. When folds cross each other in the folding process, the paper surface will naturally produce numerous geometric shapes, and finally form the desired origami shape, producing rich and strong geometric visual effects [9]. This unique aesthetic of geometric structures also contributes to the strength of origami structures, is exactly the aesthetics that mankind has been pursuing since ancient times.

The constantly changing external light source, with the origami structure remaining unchanged, produces completely different light and shadow effect, creating a strong contrast between light and dark. For example, some luminaires using origami elements are shaped by folding inside and outside (Fig. 1), pleating and other folding methods. When an internal light source is added, the light is reflected or refracted to form a fuzzy

Fig. 1. Yi-Ting Chen 'Origami Light' (Photo credit: Google Image)

light boundary, creating a unique form of the luminaire. As folds rise, fall, and rotate, light and shadows are shaded in an orderly manner, resulting in a visual effect of light and dark. The addition of light and shadow to the origami structure gives it a unique rhythm and charm, enlivening the monotony and constraint of the silhouette and giving users a sense of emotional rhythm. In addition, the light direction, angle and texture of the material also make the light and shadows more colourful and form different light and shadow effects. Light and shadows create a sense of space in origami, and the perfect fusion of light and shadow with space enhances the aesthetic beauty of the origami structure.

2.2.2 Origami Structures in Scientific Structure

The most remarkable feature of origami is that it is formed by folding a completely flat surface, which gives it a special structural function. A classic example is Miura-ori, which is used as an origami structure in science. Miura-ori is a widely used origami structure composed of stacked grids of parallelograms (Fig. 2), which is an example of origami mosaic. Because each parallelogram remains flat when folded and unfolded, it is also a form of rigid origami [10]. Miura-ori is used by pulling apart the diagonal ends to unfold the item. In addition to saving space, this structure also avoids losses during folding and unfolding. It has been found that this method reduces the volume of the object by a factor of 25 and increases the energy density by a factor of 14. Miura-ori, originally developed for solar panels, found a variety of daily uses, such as map folding [2].

Origami structures can be a new type of material used for stretching and expansion, a material with a negative Poisson's ratio which expands under tension and contracts under pressure. This property makes Miura-ori very useful. Poisson's ratio is the ratio of the absolute value of the transverse positive strain to the axial positive strain when the material is subjected to unidirectional tension or compression. When the expanding material is stretched horizontally, it expands longitudinally, and when it is squeezed horizontally, it contracts longitudinally. Simply put, a piece of Play-Doh, for example, narrows horizontally when stretched vertically - this is the positive Poisson's ratio. A

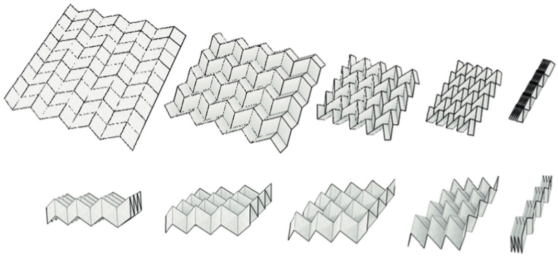

Fig. 2. Miura-ori structure (Photo credit: Google Image)

negative Poisson's ratio, on the other hand, is the opposite: when stretched vertically, it widens laterally.

All materials in nature have positive Poisson's ratio, and materials with negative Poisson's ratio can only be produced manually. The origami structure, can subtly achieve negative Poisson's ratio because of its characteristics. It is found that the negative Poisson's ratio material has strong symmetry, which is fully reflected in the origami structure. This inspired the idea of designing negative Poisson's ratio materials, and solved many structural requirements requiring negative Poisson's ratio, which also reflected the irreplaceable nature of origami structure [11].

2.2.3 Modern Significance of Origami Structure Application

Origami structures provide scientists and artists with new ideas and design inspiration, as they bring together valuable ideas from the fields of science, technology, engineering, art and mathematics.

Origami structure is a new source of scientific creation. To explore the characteristics of origami structures and apply them to science, Robert Lang should be mentioned first. Robert uses various new origami techniques and is known for his work in the 'Glasses' project at Lawrence Livermore National Laboratory. In practical applications, origami structures can be deconstructed and re-applied to engineering fields to solve practical problems in science and life.

Origami structures are widely used in product design because they conform to modern design aesthetics and meet product evaluation standards. The design of the product shape can be based on the more aesthetic value of the origami form, constantly create the origami form, and bring more visual experience to the user. The new direction of modern design has moved closer to the innovation and change of exploration form. When the unique modelling style and design skills of origami structures are reflected in the product design, the formal characteristics of the product are altered, and the structural innovation, functional rationality and visual aesthetics are more subtly integrated into the product.

Origami structure is a new integration of industrial innovation and a new field of intersection of many disciplines. Artists are now exploring and creating more and more abundant origami structures: scientists use the functionality of origami structures in modern scientific products; Mathematicians study the mathematical principles behind the origami structure; Engineers will find suitable applications of the advantages provided by origami structure in real life. However, interdisciplinary research and application is still a new field worth exploring. The functionality of origami structure is used in the structure of interactive products, and its artistic aesthetics is also continued in the appearance of products, providing new ideas for the design of interactive products. Thus, structural innovation, functional rationality and visual aesthetics will be more subtly integrated.

3 Correspondence and Analysis of Interactive Product Design and Origami Structures

3.1 Design Thinking on the Combination of Interactive Product Design and Origami Structures

3.1.1 Interactive Design

Interaction design is a method that reflects the interaction mechanism of any product and service. Through human behaviour, based on user experience, and taking into account the psychological and other relevant factors of users, it can design and improve users' satisfaction with products. Whenever a person uses a product, he or she interacts with it in some way, so it can design how people interact with it [12].

The research of origami structure and interactive product design also needs to combine some ergonomic theories. When people are directly involved in the deformation of origami structures, they need to consider whether some of their gestures conform to ergonomics, and the product needs to be designed so that the user can subconsciously use the correct gestures to control the product. In the case that people do not interact directly with the product, the changes in the product also need to be combined with human common sense, so that users can quickly understand the function of the product in different forms and ways.

3.1.2 The Rationale for Using Origami Structures in Interactive Product Design

At the level of the interactive product structure, product structure requires certain bearing capacity and flexibility. Strength as a form of load-bearing is very important in structures., Origami structures also provide a strong load-bearing capacity for products and save on consumables. Among products with different functions, origami structure also provides better flexibility. Origami structure allows products to alternate between two-dimensional and three-dimensional, and provides a simpler and faster way to convert products when products are changed interactively. This flexibility and variability contribute to the convenience of origami in the use of space, and solves the form and layout conversion of different spaces and different functional requirements.

At the level of interactive product appearance, the origami structure itself is geometrically beautiful, so the origami structure can be directly exposed to the product appearance without creating a product shell covering the internal structure, which also provides more space for product shape-shifting. In the process of product change, different geometric shapes produce different permutations and combinations, which are dynamic and rhythmic, making the interactive products based on origami structure more dynamic.

3.2 Design Approaches Combining Interactive Product Design with Origami Structures

3.2.1 Direct Application

Origami structures have a rich element of points, lines and faces, which can be directly used in interactive product design. Different folding directions create turning points. When folding, the fold will be converted into a straight line. All folds create geometric faces as they intersect with each other. Origami structures can be arranged and combined in countless ways and can be used directly as a basis for enriching the shape and variation of interactive products. The direct use of the origami structure appearance allows for a more dynamic and inherently geometric look to the interactive product, creates the most intuitive artistic aesthetics, and clearly expresses the most basic geometric meaning of design style.

For example, Japanese fashion designer Issey Miyake designed a series of lamps for the Italian lighting manufacturer Artmide, called IN-EI (Fig. 3), which showcases the origami structure look-as-structure approach to design. Origami structure is the core of this product. The shape and structure of the product depend onthe origami structure of the main body. Issey Miyake and his Reality Lab have revolutionised the way products are folded through mathematical algorithms. First, they work with computer experts to conceive three-dimensional shapes, then simplified them into two-dimensional planes, prefabricated the product folds, and finally determined the shape of the product. In terms of appearance, the origami structure gives full play to the geometric aesthetic of the product and has a high decorative quality. The rhythmic combination of geometric shapes demonstrates the sparse relationship and rhythm of the product, and the artistic beauty in its purest form. In terms of the structure of the product, the origami structure provides perfectly for stretching and compression, offering different product forms and functions [13]. In the process of human interaction, the user inevitably gets close to the product. When the user manipulates the origami structure, he/she can feel the beauty of its change at a close distance. Origami art itself is also a craft, which allows people to experience a greater sense of achievement and a deeper sense of intimacy between the user and the product.

Fig. 3. Issey Miyake 'IN-EI' (Photo credit: Google Image)

3.2.2 Material Application

Different materials can supplement the origami structures, bring completely different functions, and broaden its use scenarios and modes. Generally, any material that forms a crease and can be folded can be used as the material of the origami structure. In design, it is often necessary to first consider the scenario of use, the purpose of the product and so on, and then choose the appropriate origami structure before matching it with the right material. When designing interactive furniture, for example, emphasis should be placed on stability and load-bearing capacity, and strong and durable materials such as wood and iron can be chosen. When designing wearable interactive devices, appropriate flexible materials and other materials can be selected to fit the body.

Functional materials can be used to create unique interactions with origami structure. The selection of functional material depends on the matching of origami structure materials in the product. For example, if paper is used as the material for the origami structure, the conductive ink can be used as the interactive material, wherein the ink may adhere to the surface of the paper and make full use of the material. The conductive ink wallpaper design pictured below is a classic example of combining paper materials with conductive ink (Fig. 4). The conductive properties of conductive ink can be used instead of the traditional electrical wiring, and the circuit connections can be completed by drawing the rows of wires required by the electric appliance in the space in the wallpaper. This approach greatly reduces the use of materials and simplifies the decorating process. The use of conductive ink instead of wires also increases the sense of decoration and provides a clean and linear aesthetic feeling for the wallpaper.

If the fabric is used as the material for the origami structure, the selected material should not be conductive ink, but functional material, such as conductive filament suitable for the fabric. For example, in the origami luminaire designed by Yael Akirav in the picture below (Fig. 5), when the structure is unfolded, the conductive filaments form a closed circuit when they contact internally, thereby controlling the lamp to turn on. In this case, the two forms of the product (on and off) are influenced by the connection and disconnection of the electrical circuit, and there is no ordinary light switch. The traditional electrical cables cannot be disconnected or connected at any time, and the change of origami structure can directly control the form of the product.

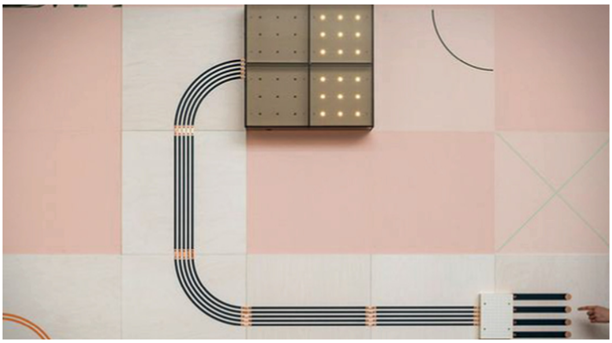

Fig. 4. Conductive ink wallpaper concept (Photo credit: Google Image)

Fig. 5. Yael Akirav '3D-Print Textile light' (Photo credit: Google Image)

Fig. 6. 'Refold' desk (Photo credit: Google Image)

The material mix of origami structures has a broad prospect. Any innovative mix has the potential to generate new modes of interaction and provide new directions for interactive product design.

3.2.3 Structure Application

The structural changes in the origami structure itself allow for different forms of the product to be realised, thus producing different functions. The design of the 'Refold' desk (Fig. 6) is made of corrugated paper and has a flexible form, which can be quickly transformed from a portable cardboard box to a table. When a method of switching functions by changing the shape of the origami structure is used, it is necessary to match the origami structure with the functions required to achieve the design goals. Materials can bring more functional changes to interactive products. Such as a combination of an origami structure and a conductive ink. During the structure change, a unique type of circuit connection can be set so that when the structure is changed to a combination that can be switched on, when all connection points are in contact, the product is activated, and any disconnection in any link controls the power off of the product.

Fig. 7. Kouichi Okamoto 'Bookmark light' (Photo credit: Google Image)

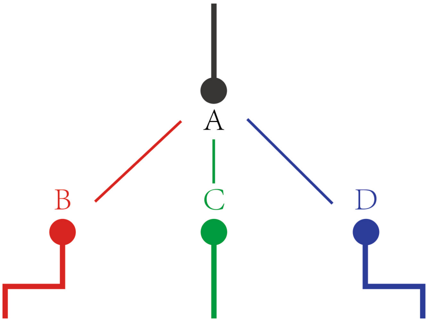

Fig. 8. Demonstration drawing of structural-functional changes (Photo credit: Original)

Structure variations not only control the connection and closure of the product circuit, but also allow different contact connections to be made in different combinations to achieve different functions. In the case of 'bookmark light' (Fig. 7), for example, it can be observed that the function of the product is realised by contacting the contacts and forming a closed circuit. The same principle can be extended to the combination of origami structures with new conductive materials. According to product design requirements, circuit contacts with different functions can be designed in different forms of structural contact. As shown in Fig. 8, in the product structure, the faces of the origami structure are connected, and the revelation position is that AB is connected. After the structure is changed, the surface with the A contact is connected to the surface with the B contact to trigger the new function. When the origami structure is changed again, the surface with the A contact is connected to the surface with the C contact to trigger the new function again. Similarly, when one of these functions is required, the shape of the origami structure can be adapted to the corresponding function, and the corresponding function can be realised after the contact is completed.

4 Conclusion

Based on the study of geometric aesthetics and structural function of origami structure, this paper puts forward a new direction of interactive product design. First of all, starting from an analysis of the history of origami, this paper summarises the current application of origami structures in the fields of art and science, and suggests the relevance of their current applications in various fields. Secondly, based on the in-depth study of origami structure, this paper analyses the combination of origami structure and interactive product design. Starting from the definition of interactive product design, combined with the characteristics of origami structure, the rationality of the combination of origami structure and interactive product design is analysed from the appearance to the structure. Finally, the design methods proposed in this paper for origami structure and interactive products are direct application method, material application method and structure application method.

Although there are examples of the simultaneous use of origami structures in the field of art and design, there are few in interactive product design. In the design approach proposed in this paper, the use of new interactive materials can provide more space for the combination of origami structure and interactive product design. In the future, new origami structures will also emerge as the result of digital technology, which will produce more functions and different physical structures as well as origami shapes that reflect the beauty of mathematical geometry. By matching appropriate product materials and using them in conjunction with structural characteristics, new materials in the future can provide numerous innovative ways for interactive product design.

References

1. M. Joshi, 'Creative Use of Industrial Waste Into Fashion Products Through Fabric Manipulation Using Origami Technique', ECS Trans., vol. 107, no. 1, p. 12019, Apr. 2022, doi: https://doi.org/10.1149/10701.12019ecst.
2. Morris E., McAdams D. A., Malak R., 'The State of the Art of Origami-Inspired Products: A Review', presented at the ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Dec. 2016. doi: https://doi.org/10.1115/DETC2016-59629.
3. N. Budinski, 'Mathematics and Origami: The Art and Science of Folds', in Handbook of the Mathematics of the Arts and Sciences, B. Sriraman, Ed. Cham: Springer International Publishing, 2021, pp. 317–348. doi: https://doi.org/10.1007/978-3-319-57072-3_13.
4. H.-Y. Tseng, 'Analysis of design application on structural model of origami', in 2017 International Conference on Applied System Innovation (ICASI), 2017, pp. 1857–1860. doi: https://doi.org/10.1109/ICASI.2017.7988308.
5. M. Abate, 'Geometric Origami', in Imagine Math 7: Between Culture and Mathematics, M. Emmer and M. Abate, Eds. Cham: Springer International Publishing, 2020, pp. 117–133. doi: https://doi.org/10.1007/978-3-030-42653-8_8.
6. G. Darvas, 'Rationality and impression', in Symmetry: Cultural-historical and ontological aspects of science-arts relations The natural and man-made world in an interdisciplinary approach, Basel: Birkhäuser, 2007, pp. 385–414. doi: https://doi.org/10.1007/978-3-7643-7555-3_15.

7. N. Hook and K. Paul, ‘Beyond the Fold: The Math, History, and Technology behind Origami’, p. 6.
8. P. O. Vaccaro, K. Kubota, T. Fleischmann, S. Saravanan, and T. Aida, ‘Valley-fold and mountain-fold in the micro-origami technique’, Microelectronics Journal, vol. 34, no. 5, pp. 447–449, May 2003, doi: https://doi.org/10.1016/S0026-2692(03)00070-3.
9. Y. Y . Hao, J. X. Zhang, ‘Exploring the use of origami art in lamp design’, Design, no. 23, pp. 114–115, 2016.
10. H. Stachel, ‘Remarks on Miura-ori, a Japanese folding method’, JIDEG: Journal of Industrial Design and Engineering Graphics, vol. 52, Jul. 2009.
11. F. Meng et al., ‘Negative Poisson’s ratio in graphene Miura origami’, Mechanics of Materials, vol. 155, p. 103774, Apr. 2021, doi: https://doi.org/10.1016/j.mechmat.2021.103774.
12. X. Xia and A. R. Ismail, ‘Review on the Application of Interactive Design in the Design of Modern Furniture Products’, in Financial Technology (FinTech), Entrepreneurship, and Business Development, Cham, 2022, pp. 189–201. doi: https://doi.org/10.1007/978-3-031-08087-6_14.
13. J. Wu, ‘Geometric Strategies in Creating Origami Paper Lampshades: Folding Miura-ori, Yoshimura, and Waterbomb Tessellations’, in Handbook of the Mathematics of the Arts and Sciences, B. Sriraman, Ed. Cham: Springer International Publishing, 2021, pp. 349–380. doi: https://doi.org/10.1007/978-3-319-57072-3_102.