

THE APPLICATION OF THE BUDDHIST LOTUS PATTERN ON COSTUME



A Thesis Submitted in Partial Fulfillment of the Requirements for Doctor of Philosophy DESIGN ARTS (INTERNATIONAL PROGRAM) Graduate School, Silpakorn University Academic Year 2020 Copyright of Graduate School, Silpakorn University



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Dunhuang Mogao grottoes is the largest and most abundant Buddhist art place in the world, the caisson lotus pattern decorated in the cave is exquisite and gorgeous. However, due to natural and artificial factors, mural resources are gradually disappearing.

The purpose of this research is to propose an innovative and application method of the caisson lotus pattern in fashion design. And according to the purpose, the research have 4 objectives: 1. To systematic research the caisson lotus pattern; 2. To propose an design method for the caisson lotus pattern; 3. To explore the guideline for the application of lotus pattern on fashion design by combination the origami art; 4. To develop techniques related to simulate three-dimensional structure prototypes by the virtual clothing design technology.

The research methods, first is literature review and field trip in Dunhuang for lotus patterns collection. Second is to analyze the structure of lotus pattern and innovative design of it based on shape grammar. And its design effect is evaluated by the fuzzy comprehensive evaluation method. Third, through the folding method of origami art, the 2D lotus pattern is transformed into 3D garment structure. Fourth, by using virtual fitting technology to statically and dynamically display the design collection. Finally, the effect of applying lotus pattern to costume and virtual clothing design are analyzed through qualitative and quantitative research.

The results of the research show that there are 5 kinds cassion lotus pattern and all have the balanced, symmetry characteristics and deep cultural connotation, this is very useful for perfecting the Dunhuang cultural theory research system. The design effect of the lotus pattern based on the shape grammar not only retains the structural characteristics of the traditional lotus pattern, but also has uniqueness character. It basically meets the aesthetic needs of young people, which provides a feasible solution for the innovative design of traditional patterns. About the application effect of lotus pattern in costume, the folding technique from origami art can convert 2D patterns into 3D clothing structure, which not only breaks the application form of traditional patterns in clothing design, but also creates new clothing styles. Through the CLO 3D software, the virtual design process of the 5 prototypes in this research is obtained, this not only realized the virtual simulation of three-dimensional modeling clothing, broadened the types of virtual clothing, but also from the evaluation results of 10 experts, the virtual clothing can better express the designer's ideas when compared with physical clothing, the garment enterprise can use this technology to optimize the design process and better provide customized services for customers.

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Chapter 1

Introduction

1.1 Background and statement of the problem

Lotus, the most typical decorative pattern, is one of the symbols in Buddhism. It is widely used in Buddhist temples and cave murals. Before the introduction of Buddhism, the lotus was commonly recognized because of its pure and elegant temperament. As a kind of decorative pattern, it appeared in the field of decoration with a long history. Along with the development of Buddhism, lotus pattern combines the Buddhist ideas that symbolizes the social, religious, humanistic, and folk customs of various countries and becomes a pattern being rich in religion, national connotation strong decorative aesthetics.

Locating in Dunhuang, in the western end of the Hexi Corridor, China, Dunhuang Mogao grottoes is commonly known as the thousand Buddha caves with more than 2,000 year history, 735 caves, 45,000 square meter murals, and 2,415 clay sculptures it is regarded as the largest and most abundant Buddhist art place in the world. Dunhuang Mogao grottoes is famous in terms of its gorgeous and colorful decorative pattern art. Among them, the caisson lotus pattern decorated in the cave is exquisite and gorgeous, and it is the focus of the Dunhuang pattern (Chen and Liang, 2004). However, due to natural and artificial factors, mural resources have been gradually disappearing. According to the latest statistics, more than half of the murals and color sculpture in the caves of Mogao grottoes have diseases such as discoloration, shedding, etc (Fu, Ma and Sun, 2019).

On June 27, 2014, the Oriental Morning Post reported that Dunhuang Mogao grottoes were "going to death at a speed 100 times faster than in ancient time." Fan Jinshi, the dean of the Dunhuang Academy and a scholar, once lamented that the trend of the disappearance of Mogao grottoes can only be delayed and cannot be reversed. With the development of the intangible cultural heritage protection in Dunhuang, more and more countries, institutions, artists and scholars have joined the team of excavation, sorting and protection of Dunhuang mural resources. Unfortunately, so far, in the research field of current patterns, few scholars

pay attention to and carry out research on Dunhuang Mogao grottoes caisson lotus patterns some period, such as the Sui Dynasty (Wang, 2017), Tang Dynasty (Luo, 2018), and the research content is limited to the simple introduction of the types of lotus patterns in different periods, lacking the systematic research on lotus pattern also inheritance, and innovation.

In the field of design, traditional Chinese patterns have uniquely unparalleled charm with their beautiful forms, diverse colors, and rich connotations, it is widely used in all aspects of social life, such as clothing, architecture, public art, interior design, product design, packaging design, cultural and creative products, etc. Especially, in the field of fashion design, traditional Chinese patterns have achieved a close integration with modern clothing. Chinese traditional patterns can be seen in many clothing brand designs and clothing exhibitions. This clothing culture is active in front of the public with a fresh attitude. In the actual situation, there are two concerned issues. Firstly, there is a lack of innovative designs for traditional patterns, most of them simply copy the patterns on clothing. Secondly, the main application used is only two-dimensional method, which dyeing, weaving, and embroidery technique are basically used. So far, those has not been meet the aesthetic needs of modern consumers. So far, how to retain the characteristics of traditional patterns while innovative application has always been problems in the design field.

Origami is an ancient art, as an important decorative technique and formal language. The art of origami has become more and more prominent in today's clothing design application. Like injecting fresh blood into the development of clothing design, the overall shape and all details of clothing are marvelously affected. Through the innovation and elegant embellishment of the modeling structure, breaking the traditional clothing modeling structure, showing a broader design space for the design of clothing styles and structures. In the face of the increasing importance of originality, the art of origami undoubtedly provides designers with very good inspiration.

With the advent of the "Internet +" era, a new generation of digital technology represented by virtual fitting injects new elements into the design and development, effect evaluation, and pattern optimization of clothing products.

Compared with traditional garment making, the use of virtual fitting technology can save cost, improves the effect of finished garments, and increases work efficiency. Although the current development of virtual fitting technology changes accelerating with unprecedented speed, the prefect results is still been achieved. At present, virtual fitting is mainly carried out on ordinary clothes which with simple styles. It belongs to the garments that can be fitted according to the positioning points of the garment pieces in the CLO3D system. So far, lack of application to clothing with three-dimensional structures or exaggerated shapes. With the impact of the coronavirus epidemic climate since 2020, discussion of virtual clothing in clothing industry has begun to heat up while it has suffered huge losses of many fashion shows postponements and cancellation. To nowadays situation, it is urgent to conduct indepth discussion and application of key technologies of the virtual fitting system to figure out the new ways to display clothing, under the background such market demand.

The aesthetic quality of caisson lotus patterns, both abstract and concrete, have historical and cultural value that are significant to our country. They shouldn't be faded away. The purpose of this research is to propose an innovative application method of the caisson lotus pattern in fashion design by combining the origami art and virtual clothing design technology. These are not only achieves the inheritance and innovation of Buddhist lotus patterns, but also creates new styles of clothing and improve the feasibility of virtual clothing design, promote continuous innovation of clothing design methods.

1.2 Objectives

To systematic research the Buddhist lotus pattern in the Mogao cave of Dunhuang.

To propose an innovative design method suitable for the caisson lotus pattern, which not only adds pattern innovation, but also retains the characteristics of them.

To explore guideline for the innovative application of lotus pattern on fashion design by combining the origami art.

To develop techniques related to simulating three-dimensional structure prototypes by virtual clothing design technology.

1.3 Scope or delimitation of the research

This research aims to investigate the Buddhist lotus pattern in caisson of Dunhuang Mogao grottoes, in order to design and develop the Buddhist lotus pattern-inspired costume. It only focuses on lotus pattern in center of the caisson.

1.4 Keywords and definition

Keywords: Buddhist lotus pattern, caisson, costume, origami, virtual clothing design.

Definition:

Buddhist lotus pattern refers to the lotus pattern that appears in Buddhist temples, grottoes or other Buddhist-related places.

Caisson is the square part at the top of the Dunhuang grottoes.

Costume is a kind of creative costume that is inspired by lotus pattern and origami art. It is presented as a new style and structure of costume.

Origami is an activity in which flat paper is created into a threedimensional form by folding, flipping and inserting without cutting or pasting.

Virtual clothing design is one of the main applications of virtual fitting technology in the market. It is the production end, "sample room" for designers and clothing companies, the focus of function is to design and modify the pattern to obtain the best ready-to-wear effect.

1.5 Research methodology

1. Collect pictures of the caisson lotus pattern through literature review and field research methods, then summarize and analyze its types and art characteristics.

2. Analyze the structure of the caisson lotus pattern by "making circles, drawing lines, seeking intersection points" method, which is used for drawing Islamic pattern. Then summarize the types of lotus pattern structure and laws of drawing the lotus pattern.

3. Based on the shape grammar rules for the innovative design of the caisson lotus pattern and fuzzy evaluation of design effect.

4. Review the work of famous costume designers and origami artists to get the inspiration form, combine origami techniques and human body structure to design three-dimensional patterned clothing.

5. Experiment on paper to find the folding technique of three-dimensional pattern modeling.

6. Make prototypes by using virtual clothing design technology.

7. Evaluate the virtual effect of clothing by making real clothing.

8. Summarize the results and state the suggestion for the future development.

1.6 Outcomes

1. Systematically research the Buddhist lotus pattern in the Mogao cave of Dunhuang and summary of its types, characteristics and cultural connotation.

2. Showing that the shape grammar rules for the innovative design of the caisson lotus pattern can not only add the innovation, but also retain its characteristics and meet the aesthetic needs of modern consumers.

3. Trying out the new technic of transforming the origami folding from two-dimensional patterns into three-dimensional costume modeling.

4. Completing virtual design process of the 5 prototypes, broaden the types of virtual clothing design adding the feasibility of virtual clothing design technology.

Chapter 2

Literature review

This research aims to innovative application of Buddhist lotus patterns on costume by combining origami art, and using virtual fitting technology for presentation the costume collection. The related literature and studies are divided into five parts. In the first part, readers will get to learn about historical background of Dunhuang Mogao grottoes, caisson structure, development and evolution of caisson lotus pattern, in order to explain Dunhuang secret language. The second part aims to research and examine the theories and methods which could merge and apply into lotus innovative design. Particularly, drawing method of Islamic geometric patterns and shape grammar will be used to experiment on and apply in the artworks. The third part is to investigate the current status of the application of traditional patterns in clothing, then analyze it to find out the existing problems and deficiencies. The fourth part is to research the art of origami, understand its history and development, summarize techniques and application forms in clothing, so that to provide a reference for the clothing design of this research. The fifth part is the introduction of virtual fitting technology, and analysis of the application status and development prospects of virtual clothing design technology.

This research presents the literature review in five parts as follows:

Part 1: Buddhist lotus patterns in the caisson of Dunhuang Mogao grottoes

Part 2: Theories about Islamic geometric patterns and shape grammars

Part 3: The application status of Chinese traditional patterns in modern fashion design

Part 4: Origami Art

Part 5: Virtual fitting technology

Part 1: Buddhist lotus patterns in the caisson of Dunhuang Mogao grottoes 2.1 The historical background of Dunhuang Mogao grottoes

Dunhuang is located in the western part of Gansu Province, where is an important town on the ancient Silk Road, the particularity of its geographical location makes it a place of cultural exchange and convergence between China and foreign countries, as seen in Figure 1. Buddhism was introduced to China in the Eastern Han dynasty (25-220 AD), on the way to the Western countries and the Central Plains, Chinese and foreign eminent monks stayed in Dunhuang for a short time or expound the texts of Buddhism. From the Northern Wei dynasty (386-534 AD), some famous eminent monks came from Dunhuang, and the development of Buddhism was unprecedented, the built of temples and chisel of grottoes were also very popular at the time Dunhuang became a famous Buddhist capital. Although there is still different argument in the academic circles about when to chisel the Dunhuang caves, most of the mainstream opinions agree with the content of the article "Li Kerang rebuilt the Mogao grottoes Buddhist monuments", saying that "it is believed that Yue Zun chiseled cave in 366 AD was the beginning of the Mogao grottoes" (Su,1996, pp.265-266). Though Le Zun cave cannot be verified, it opened the glorious history of the Dunhuang grottoes. Dunhuang grottoes is only one of the precious historical and cultural heritages of China and the world. They include Mogao grottoes, west the thousand Buddha caves, guazhou yulin grottoes, and other 5 caves. Dunhuang grottoes art with Mogao grottoes as the main body, not only integrates architecture, sculpture, murals and other arts, but also combines artistry and practicality.

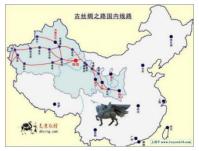


Figure 1: Ancient Silk Road map

(Source:https://image.so.com/?src=tab_www?src=tab_wwwview?src=360pc_normal&z)

Dunhuang Mogao grottoes, the earliest surviving caves, were firstly built in the Qin dynasty. During the continuous creation and transformation for more than 1,600 years, this has formed the largest and richest Buddhist art holy land in the world. There are 735 caves in Mogao grottoes, which is the largest group of grottoes in China. Among them, there are 492 caves with murals, the mural area is about 45,000 square meters (Zhao, 2013, pp. 24). The content of the murals in Mogao grottoes is extensive and profound, with magnificent vision and a wide range of themes, namely the Buddhist history, large-scale meridian, national monster, secular life, landscape, decorative pattern, including paintings about politics, culture, economics, military, geography, religion, humanities, customs and so on. Since most of the paintings of China before the Five Dynasties have been lost, the surviving Dunhuang Mogao grottoes provide us the important physical examples.

2.2 Caisson definition and structure in Dunhuang Mogao grottoes

2.2.1 Caisson definition

(Luo, 2002) It is believed that the caisson refers to the indoor ceiling in traditional Chinese architecture and the upward projection part at the top of palace, as shown in Figure 2. The interpretation in the Dunhuang Studies Dictionary is: "The square part at the top of the Dunhuang grottoes" (Ji, 1998, pp. 32). In modern architecture, the caisson refers to the ceiling that upward projection in a building like dome. According to the study of Dunhuang Architectural Research, there are two kinds of grottoes in Dunhuang, the first is the central stupa-pillar shape grotto as can be seen in Figure 3, and the second is the inverted funnel-shape grotto, as shown in Figure 4. Therefore, the ceiling of the cave has two kinds, one is ping qi and the other is caisson. The ceiling of the cave is decorated with a continuous and neat grid pattern, which is ping qi, as shown the red line area in Figure 5. Ping qi is mainly decorated in the central stupa-pillar shape grottoes, which began in Beiliang (397-460 AD) and completely disappeared in the Northern Zhou dynasty (557-581 AD). Caisson is mainly decorated in the inverted funnel-shape grottoes. The earliest existing caisson is in the cave 272 in Bei Liang dynasty and has been used continuously in the later period, as shown the blue line area in Figure 6. In summary, the caisson in this research is defined as the square part of the ceiling at the top of the Dunhuang inverted funnel-shape caves.



Figure 2: Caisson in architecture (Source: http://image.so.com/view)



Figure 3: The central stupa-pillar shape grotto

(Source: https://www.e-dunhuang.com/cave/10.0001/0001.0001.0254)



Figure 4: The inverted funnel-shape grotto

(Source: https://www.e-dunhuang.com/cave/10.0001/0001.0001.0285)



Figure 5: Ping qi in the cave 251 (Source: https://www.sohu.com/a/332589439_120259260)



Figure 6: Caisson in the cave 272 (Source: https://www.douban.com/note/705407969/?type=rec)

2.2.2 Caisson structure

The caisson before the Sui dynasty were all nested structures, that is, the bottom of the caisson is square, one or two layers of squares are nested in the square, and the center is decorated with a large lotus, as shown in Figure 7. This is to transform the caisson structure on the building into a flat pattern, which is also a difference between the cave caisson and the building caisson, wooden caisson express the profound sense of the whole space through the structure hierarchy, while the hierarchy of grottoes caisson is expressed through the pattern decoration. The nested structure of caisson has been found in many places in Asia. (Zhao, 2008) It is believed that China's nested structure caissons come from Central Asia, accompanied by Buddhism, then introduced to China by India through Central Asia.

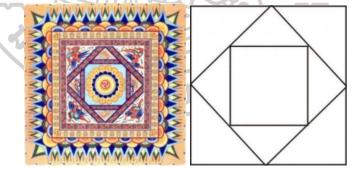


Figure 7: Nested structure caisson

During the prosperous development of the Sui and Tang Dynasties, the structure of the caisson began to change, and the bottom of the caisson was transformed into a central square, as shown in Figure 8. This structure affected the later caisson and became the basic structure of the subsequent caisson.

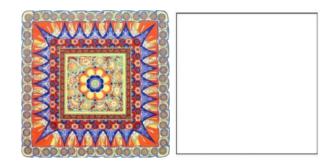


Figure 8: Central square caisson

2.3 Analysis of development and evolution of lotus patterns in Dunhuang Mogao caves

According to the "Contents of Dunhuang Mogao grottoes" published in 1982, the number of caves in Mogao grottoes is 492 (Dunhuang Cultural Relics Research Institute, 1982, pp.1). This research combines this book, relevant research literature, and field investigations of the Dunhuang Mogao grottoes, the number of caisson caves has been sorted out: Among the 492 caves, there are 7 in the period of the Sixteen Kingdoms (Beiliang), including one cave with caisson, 14 caves in the Northern Wei dynasty; with caisson in each, 6 Western Wei caves; with caves with caisson, 17 caves in the Northern Zhou dynasty with 8 caves with caisson, 95 caves in the Sui dynasty; with 53 caves with caisson, 278 caves in the Tang dynasty; with 232 caves with caisson, 27 caves in the Five Dynasties, with 12 caves with caisson, 15 caves in the Song dynasty; with 5 caves with caisson, 16 Xixia caves; with 15 caves with caisson, 9 caves in the Yuan dynasty; with 3 caves of caisson, 2 caves in the Qing dynasty; with 1 cave has caisson, 6 caves of unknown times with 2 caves with caisson as details in the following Table 1.

Era	Total Nur	mber d	of Nu	mber of Caves with Caisson
Eld	Caves	Caves		Inder of Caves with Caisson
Sixteen Kingdoms (Beiliang)	7			1
(397-460 AD)	1			I
Northern Wei Dynasty (386-534 AD)	14			0
Western Wei Dynasty (535-556 AD)	6			2
Northern Zhou Dynasty (557-581 AD)	17			8
Sui Dynasty (582- 617 AD)	95			53
Tang Dynasty (618-907 AD)	278			232
Five Dynasties (908-979 AD)	27			12

Table 1. Statistics on the number of caves with caisson in Mogao grottoes in different

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Era	Total Number of Caves	Number of Caves with Caisson
Song Dynasty (960-1279 AD)	15	5
Xixia Dynasty (1038-1227 AD)	16	15
Yuan Dynasty (1271-1368 AD)	9	3
Qing Dynasty (1636-1911 AD)	2	1
Other (unknown era)	6	2
Total	492	334

2.3.1 Research object

From the field investigation and the artist's imitation works, it can be seen that the lotus pattern in the center of the caisson not only occupies a large area, but also has various forms and rich colors, which is the key part of the decoration of the whole caisson, so this research mainly pay attention to the development and evolution of the lotus in the center of caisson.

As a decorative part at the top of the cave, the caisson is mostly a square frame. However, as the visual center of the whole, the caisson center mainly depicts large circular lotus pattern. As the most beautiful geometric figure, circle gives people the feeling of completeness, symmetry and balance.

2.3.2 Summarize the types, characteristics, development and evolution process of lotus patterns

In this research, according to the petal shape of the lotus pattern in the center of the caisson, the lotus pattern is divided into round-wheel lotus, flat-petal lotus (eight-petal lotus and multi-petal lotus), peach-shaped lotus, curl petal lotus, and Baoxiang flower.

Round-wheel lotus: Firstly appeared in the Northern Dynasties, the pattern refers to the Northern Wei, Western Wei, Beiliang, North Zhou, and other regimes, in the period around 397-581AD. This period is the beginning of the development of Dunhuang decorative pattern art (Zhou, 2005). At the time, northern and southern China was divided for a long time, and gradually formed different cultural characteristics. Dunhuang Buddhism was dominated by the China's north therefore ascetic meditation prevails, and the creation of the Mogao grottoes was presided over by Zen monks. At this time, the art form presents the artistic characteristics of the blending of Western culture and Central Plains culture (Guan, 2015, pp. 6). In the grottoes of the Northern dynasty, there are both "central stupa-

pillar shape" and "Inverted funnel-shape" ceilings. Mainly are central stupa-pillar shape ceiling and was decorated with ping-qi, few caissons appears. The representative round lotus caisson from this period is the cave 272 and 296, as shown in Figure 9 and 10. The earliest existing caves at the Mogao grottoes in Dunhuang were excavated during the Beiliang period. Although there are 7 caves belonging to the Period of the Sixteen Kingdoms (Northern Liang), only the cave 272 is currently preserved, and the rest of the caves are blurred. It can be seen from the caisson in the cave 272 of Mogao grottoes that the caisson is a nested structure, and the center of the caisson is drawn with a circular lotus. Due to the long time, the color corrosion and fallen off, the shape of the petals of this cave has been blurred, and lotus pond is symbolized by green space around lotus. Cave 296 caisson is a relatively representative cave in the Northern Zhou dynasty. The drawing of caisson continues with the nested structure, central green space painting with white lotus, round wheel shape, four corners decorated with vivid flying Apsaras. The color of the caisson is rich and gorgeous. The red and green colors enhance the contrast of the warm and cold colors, making the colors rich and bright. A variety of color and patterns are combined to create a contrasting, unique caisson pattern.



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Figure 9: The cave 272

(Source: Dunhuang Cultural Relics Research Institute, 1984, pp. 21)



Figure 10: The cave 296

(Source: Dunhuang Cultural Relics Research Institute, 1984, pp. 184) With only 37 years of history, the Sui dynasty has carved nearly 100 caves in the Mogao grottoes; more than twice of the total number built from the Sixteen Kingdoms to the Northern Dynasties. This frequency of dig is unprecedented in the construction of the Mogao grottoes. Due to the fact that the political unification of the Sui dynasty and the prosperity of the economy and culture, the two generations of emperors strongly advocated the implementation of Buddhism, as the result the grottoes was vigorously dug in Dunhuang. On the basis of the Northern Dynasties, the caisson pattern of the Sui dynasty furtherly absorbed essence from the Central Plains traditional culture and the Western Region style. The newly created pattern during this period was not only inherited the legacy of the Northern Dynasties, but also created the foundation of the Tang dynasty. There are two main forms of caisson in the Sui dynasty; one is to preserve the ancient, nested structure. The other is central square structure at the center having a large amount of space to facilitate the creativity of painters. The representative cave of the round wheel lotus of this period is 305, 410. The cave 305, overall, also clearly preserves the Northern dynasty style: the center of the caisson is painted in round wheel lotus, but the new pattern appears in the heart of the lotus; drawing of the "three rabbits shared ears" pattern, as shown in Figure 11 (Ou,1981). The three rabbits shared three ears and run in the same direction. The caisson is centered on the circular shape of the three rabbits, and the wheel-shaped big lotus is used as the reel. Three rabbits and winged beasts, flying Apsaras, internal and external echoes, they run and rotational momentum makes the whole caisson swing. The "three rabbits share ears" pattern firstly appeared in the Sui dynasty and disappeared in the late Tang dynasty. In addition to the new patterns in the lotus, the color of the entire caisson contrasts strongly. The color tone of the caisson pattern in the Northern dynasty was mainly based on soil red. Compared with the pattern of the caisson in the Northern dynasty, the proportion of azurite increased significantly in the picture.

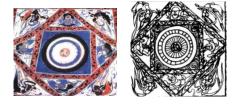
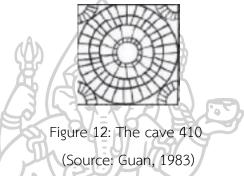


Figure 11: The cave 305 (Left Source: Dunhuang Cultural Relics Research Institute, 1984, pp. 22, Right Source: Guan, 1983)

The top of the cave 410 is a round wheel lotus caisson. It is the old style for the North dynasty, it is also the only round wheel lotus caisson in the middle of the Sui dynasty (589-612 AD). However, the layout of the caisson changed the previous form of the nested structure and became a single square caisson. It was the embodiment of the inheritance and innovation of the caisson pattern in the middle of the Sui dynasty. This change is of great significance in the development of the caisson pattern in the Mogao grottoes. After the middle of the Sui dynasty, the lotus of the caisson, the central round wheel shape did not appear.



In short, the round wheel lotus, popular in the Northern Dynasties and the middle of the Sui dynasty, after the restoration and imitation, it can be seen that there are lotus petals in the round wheel, the number of petals is large, and the shapes are not the same. Due to fading and discoloration, the lines are unclear, leaving a strong round-wheel impression. The round wheel lotus has appeared in the nested and central square caisson, and the lotus heart also has three rabbit share ears with various meanings.

Flat petals lotus: Its shape is simple with petals that are flat, round or square with pointed ends. The overall shape is simple and beautiful witheight or more petals, mainly painted in the Sui and Tang dynasties. The representative caves are 406, 401, 403, 405 in the middle of the Sui dynasty; the cave 390, 398 in the late Sui dynasty; the cave 386, 392 in the early Tang dynasty; and the cave 361, 159 in the middle and late Tang dynasty. After the national reunification (589-612 AD) in the middle of the Sui dynasty, the emperor was committed to the operation of Hexi. At the time, the cultural exchange with the countries of the western regions were strengthened and a series of measures adopted was conducive to the development of culture and art, which will inevitably promote the development of Dunhuang

grottoes. This period of time was coincided with the unification of the North and the South, and the national prosperity; the number of caves in the Mogao grottoes was as many as 34, and the artistic achievements were also hit the highest in the Sui dynasty. During this period, the structure of the caisson changes greatly, mainly by being reduced from the nested structure to the central square structure. Furtherly, the lotus pattern is placed in the heart of the caisson, and the entire lotus is radial. The center square caisson has a multi-layered edge and a richer decorative pattern.

The square caisson of the cave 406 is drawn with a double-layered eightpetal lotus with a frontal view. Eight-petal large lotus with flat petals, square shape and pointed tip giving a fat and plump feeling are the new pattern that appeared in this period. With the disintegration of the nested caisson, the Indian-style round wheel big lotus being popular in the Northern Dynasties and the early Sui dynasties, was gradually replaced by the native eight-petal lotus. The water swirl pattern is arranged in a compact and orderly arrangement around the petals. Inside the flower heart is the three rabbits with shared ears pattern. The image of the three rabbits running cleverly drives the rotation of the lotus visually, making the pattern more vivid and varied. In terms of color, the three rabbits in the center of the lotus are white, with a circle of white and black beads around the center. Inner petals are embellished with red and the outer petals are black with red edges. The square caisson water swirl around the lotus is white. It is a reflection of the innovative attempts, to reflect the tendency of the nested structure caisson to collapse, of the Sui dynasty caisson. The true portrayal of this period can be said as: the old form was broken, and the new form was not fully established.



Figure 13: The cave 406 (Left Source: Dunhuang Cultural Relics Research Institute, 1984, pp. 95, Right Source: Yang et al, 2010, pp. 40)

The cave 401 has a large eight-petal lotus with slender petals and pointed ends. The flying Apsaras and strange beasts surround the lotus. The caisson gradually disappears the original nesting structure and changes into a square structure. To the center square well type caisson, the caisson center is relatively large that is easy for the painters to exert their creativity. In the center of the caisson, an eight-petal lotus flower is painted, and various vivid images of the flying Apsaras are painted around the lotus. Flying Apsaras are the symbol of Dunhuang Mogao grottoes. Flying Apsara in India is the Gandharva, who appears in the Buddha's halo and canopy, and expresses an atmosphere of joy. The eight-petal lotus in the cave 401 is elegant in shape. Surrounded by flying Apsaras playing musical instruments and winged beasts, the whole caisson is mainly turquoise color, earth red as a supplement. The stone green lotus pond in the middle of the caisson is wide and fresh, and the trim around it is delicate and exquisite. The color is gorgeous, forming a contrast between red and green, black and white, as the result this caisson is also one of the representative works of the Sui dynasty.



Figure 14: The cave 401

(Left Source: Dunhuang Cultural Relics Research Institute, 1984, pp.143, Right Source: Yang et al, 2010, pp. 37)

In the middle of the Sui dynasty, there was also honeysuckle wrapped lotus pattern around the eight-petal lotus in the center of the caisson. This new pattern is completely out of the old style to be the only type caisson in the Sui dynasty. In the middle of the Sui dynasty, this pattern was appeared in only the cave 403 and 405, then there were more in the late Sui dynasty. After the Tang dynasty, the patterns were no longer drawn and replaced by other patterns. The cave 403 caisson has a clear structure, and a complete image is gorgeous but not showy, concise, and bright. Its caisson center is painted with eight-petal large lotus that is surrounded by a small lotus with a coil stem and a twined honeysuckle, Mani beads painted in a lotus. At the center of the cave 405, the eight-petal lotus is painted, surrounded by lotus twined branches, honeysuckle-shaped lotus leaves distributed on twined branches. A lotus is painted in each corner of the caisson, with Mani beads in the center. The caisson layout is complicated inside and simple outside.

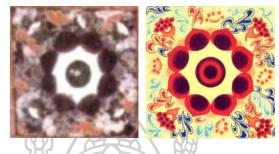


Figure 15: The cave 403

(Left Source: Dunhuang Cultural Relics Research Institute, 1984, pp.102, Right Source:

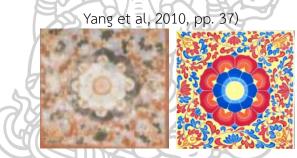


Figure 16: The cave 405

(Left Source: Dunhuang Cultural Relics Research Institute, 1984, pp. 96, Right Source:

Yang et al, 2010, pp. 39)

In the late Sui dynasty, more caves were dug. There are 39 existing caves in the late Sui dynasty. Also, there are a large number of lotus caisson with twining branches and eight petals, which is a continuation of similar caisson from the middle Sui dynasty; namely the cave 311, 314, 390, 397, 383 and 394. The caisson of the cave 390 are all composed of plant patterns, as shown in Figure 17. The eight-petal lotus is surrounded by vines which are composed of lotus, honeysuckle, flame, and beads. The colors are bright, mainly red and blue. The overall square caisson center is set against a green background. Lotus and Mani beads on the twining branches are free, but seek balance and change as a whole. At the end of the Sui dynasty, lotus petals changed a lot. It may indicate the "color wheel" in the lotus, like a shining Mani beads. As example in the cave 398, the caisson is a double square caisson with nested structure. The caisson center is a 16-petal large lotus of which the center is painted with a wave radial color wheel. It can also be regarded as the dharma wheel, with the meaning of "dharma wheel always turns". The dharma wheel is a commonly used instrument in the Buddhism. The eight beams on the wheel symbolize the eight samsara, which are the eight roads that guide all living creatures to achieve summum bonum, as shown in Figure 18. As an unprecedented new pattern, it reflects the characteristics of caisson pattern of the Sui and Tang dynasties.



Figure 17: The cave 390

(Left Source: Dunhuang Cultural Relics Research Institute, 1984, pp. 171, Right Source:

Yang et al, 2010, pp. 30) Figure 18: The cave 398

(Source: Yang et al, 2010, pp. 36)

In the middle Sui dynasty, the twining branches lotus caisson and flying Apsaras lotus caisson were gradually replaced by eight-petal and multi-petal lotus caisson. The eight-petal lotus caisson draws only eight-petal lotus, which tends to be simple in structure and more elegant in style. But the lotus shapes are different, such as the cave 393. Such caisson have been separated from the combination of twining branches lotus, three rabbit lotus, and flying Apsaras lotus, reflecting the more localized and mature characteristics of the lotus pattern in the caisson of the Mogao grottoes.



Figure 19: The cave 393

(Source: Yang et al, 2010, pp. 34)

In the early Tang dynasty (618-704), Dunhuang was generally consistent with the historical background of the Central Plains, and is moving towards an era of prosperity (Zheng and Sha, 2005, pp.153-155). The early Tang dynasty grottoes were magnificent and varied in form. The caisson pattern is rich in content, the flower shape is diverse and the type is varied. From the perspective of decorative art, the Mogao grottoes in the early Tang dynasty continued to have new styles, with both the Central Plains and the Western Regions style, and a new look. There are the grottoes 203, 386, 204, 333 and 392 with flat petal lotus. The central lotus in the caisson has eight or more petals, such as the cave 386 and 392. At the time, the petal shape, aesthetic taste, drawing technique, and color have all undergone new changes, such as the cave 386, the heart of the caisson draws only a flat petal lotus without extra edge. However, the color of the caisson is mainly red and green, as shown in Figure 20. The contrast is clear, giving people a fresh and harmonious feeling.



Figure 20: The cave 386

(Source: Yang et al, 2010, pp. 27)

Dunhuang's multi-petal large lotus caisson is dominated by a large lotus with various lotus petals. There were ten, twelve, and sixteen petals, some with flowers at the four corners, some painted dragons on the left and right sides. These pattern structures were continued in the Tang dynasty. The cave 392 in the early Tang Mogao, grottoes is a multi-petal lotus caisson; the caisson center has a green lotus pond; in the middle is a twelve-petal lotus, on either side of the lotus; two long dragons play with beads. The decorative patterns in the pool are evenly distributed, including lotus leaf patterns, small lotus and water swirl patterns. Light green, dark brown, purple red applied to make the color contrast is clearer and brighter.



Figure 21: The cave 392

(Left Source: Dunhuang Cultural Relics Research Institute, 1984, pp. 161, Right Source: Yang et al, 2010, pp. 32)

In the middle and late Tang dynasty (781 - 906AD), flat lotus caisson was appeared in the grottoes 197, 359, 361, 7, 370, 468, 144, and 18. The lotus pattern in the caisson center is simple, with flat petals and single layer. The end of the petal is square, slightly pointed, multicolor overlay. Visually, although the petals are singlelayered, they still feel rich in content. For example, the flower center of the cave 361 is circular and occupies a larger proportion, decorated with a cross-symmetric Vajra that is originally a weapon of ancient India. Its name "Vajra" derives from the strong texture that can break through all kinds of materials. In Buddhism, the Vajra symbolizes invincible wisdom and the true Buddhahood. The outer layer has 12 petals and the fourth corner is a quarter of the cave decoration of the Tang dynasty. Usually six or eight single camellia patterns, twined branches as the medium, connected in series into a large flower ring. A flat petal lotus is painted at the center of the garland, such as the cave 159.



Figure 22: The cave 361 (Source: Yang et al, 2010, pp. 76)

(Source: Yang et al, 2010, pp. 72) In short, in the Sui and Tang dynasties, the common lotus has eight, twelve, and sixteen petals. The lotus shape is both in long and thin geometric shape, and plump and fat shape. Lotus heart is painted with three rabbit patterns, rotating color wheel, seedpod of the lotus, Vajra and so on. The lotus is decorated around with twining branches lotus pattern, camellia patterns, double dragons, flying Apsaras, winged beast, etc., which makes the caisson heart rich and colorful.

Figure 23: The cave 159

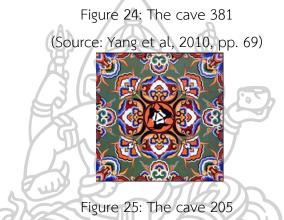
The Tang dynasty was a period of prosperity for Dunhuang art. During 289 years of the Tang dynasty, the Buddha dharma was popular, the Buddhist art flourished, and about 300 caves were dug in the Mogao grottoes (Shi, 2002, pp.162). The grotto art is unprecedentedly prosperous. During this period, the structural development of the caisson was relatively stable, basically the central square structure. The caisson pattern of Tang dynasty is prosperous and rich, the patterns are rich and varied, and the content is diverse. The color is bright and colorful, and the development of the pattern has reached its peak. The lotus caisson was very popular in the Tang dynasty. The lotus in the Dunhuang grottoes took off the original image but retained the characteristics of the lotus. The lotus is full and rich in layers; composed of flower buds, stamens, leaves and flower buds. The density is properly and the proportion is coordinated. At the same time, the honeysuckle pattern and

pomegranate pattern from the Western Region were decorated in the caisson to form a more distinctive Baoxiang flower caisson.

Peach-shaped petal lotus: Some scholars believe that the flat-petal lotus pattern in the late period of the Sui dynasty developed a different style on the basis of the original, before it was replaced by a peach-shaped petal lotus. The lotus petals are in peach-shaped that becomes the main image of the lotus in the early Tang dynasty. Later, influenced by foreign cultures, it absorbed other cultural elements to form a gorgeous Baoxiang flower that often appeared in caisson in the middle and late Tang dynasty. Therefore, it is also known as the embryonic form of the pattern of Baoxiang flower, for example, the early Tang dynasty: the cave caisson 331, 340, 372, the glorious age of Tang dynasty: the cave caisson 323, 216, 217, 215, 103 (Luo, 2018).

Peach-shaped petal lotus caisson is a brand-new caisson structure. The square caisson is painted with radial peach-shaped petal lotus, with wide space, concise and distinct layers, completely abandoned the legacy of the Sui dynasty, such as the 381st and 205th caves of the early Tang dynasty. To the Cave 381, the center of caisson is wide, with red and yellow background, drawn in the shape of eight peach-shaped petal lotus. In the lotus petals, there are honeysuckle patterns, moiré, and ruyi hooks. There is a large gap between the center lotus pattern and the outside lotus petals, also the layout is sparse and the shape is simple and clear. There are lotus at the corners of the square frame. Compared with the lotus pattern of the Sui dynasty caisson; the lotus petals are peach-shaped as a whole. The shape is more complicated and delicate, and the degree of patterning is further improved. At the lotus center of the cave 205 in the early Tang dynasty, three rabbit patterns were painted. The petals are peach-shaped and there are honeysuckle and moire in the lotus petals that show the basic characteristics of the Baoxiang flower. It has some characteristics of caisson patterns of glorious age of the Tang dynasty. The lotus is in the shape of "#", and the central lotus and the four corners of the lotus, head to tip, forming a whole. Like the cave 381, it is the embodiment of the exploration stage of Baoxiang flower. In the early Tang dynasty, it could be said that it was the connecting line between the Sui and Tang dynasties. The old form gradually disappeared with the demise of the old regime, and the new form came with the new dynasty. The lotus pattern in the cave 205 is a new style of the early Tang dynasty, but the three rabbit patterns in the center of the lotus inherit the legacy of the Sui, and the old and the new are integrated into one, run parallel.





(Source: Yang et al, 2010, pp. 74)

China's rich and open period in the glorious age of the Tang dynasty, whether it was for political or cultural aspects, always discard the dross and get the essence and made the country stronger. Foreign exchanges are very frequent and the society is full of confidence. The Dunhuang art of this period is also growing at an unprecedented speed. The combination of multi-culture and rich pattern matching makes the structure of the caisson in Dunhuang Mogao grottoes gradually perfect. The colors are rich and colorful, and the drawing is finer. Baoxiang flower is the most common caisson pattern in the glorious age of the Tang dynasty. Baoxiang flower is not a flower that can be seen in nature. It gathers the character of the lotus pattern of India, the honeysuckle pattern of the Western Region, the peony pattern and the pomegranate pattern. It is an ideal pattern designed by people (Liang and Tang, 2018). It combines peach-shaped lotus petals, hook pattern, moiré, and leaf-shaped pattern to form a pattern. It runs through the development of the entire Tang dynasty's Baoxiang flower, and is also the most popular and not controversial type.

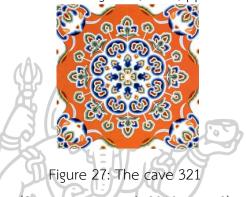
According to the structural relationship of the Baoxiang flower, it can be divided into: petal-type Baoxiang flower, tuan-type Baoxiang flower. According to the relationship between the petals and the flower heart, the tuan-type Baoxiang flower can be divided into two types: the empty-ground Baoxiang flower and the full-ground Baoxiang flower.

Petal-type Baoxiang flower: the petals are arranged around the center of the circle, and the outer petals are not interdependent and connected. The pattern structure is sparse, relatively simple, with obvious characteristics of the large lotus caisson pattern in the early Tang dynasty. At this stage, the representative of the petal-type Baoxiang flower are the cave 211, 321, 323, 32, 33, 46, 215, 216, and 384. From the structural point of view, it is generally three layers, of which the inner central small flower consists of one, four, or eight petals; the outer layer is the unit petal shape which is composed of the hook petal and the leaf shape petal, based on the "cross" shape, four or eight petals radiate up, down, left, and right. For example, the Baoxiang flower of caisson in the 79th cave, grape leaves in the early Tang dynasty patterns appeared. With cyan and green color, together with other leaf shapes to form the Baoxiang flower. Baoxiang flower is made up of four grape leaves and four petals, symmetrically organized. The leaves and petals are connected by eight flower buds, which together form a flower center around the eight petals, and the four corners decorated with flowers. The heart of the caisson is dark brown, which contrasts with the white, cyan, and green of the caisson pattern to form a bright and elegant effect. The structure of pattern in the cave 321, caisson is simple and clear: the center is a small four-petal flower with the second layer is eight small pomegranate leaf patterns; the third layer is eight hook- petals, and the middle of the petals is decorated with leaf patterns; the fourth layer is 16 leaf patterns. The whole lotus is emitted from the center to the outer layer. With the effect of the color change, the rhythmic beauty of the layers bloom is formed.



Figure 26: The cave 79

(Source: Yang et al, 2010, pp. 60)



(Source: Yang et al, 2010, pp. 52)

Tuan-type Baoxiang flower: its organizational characteristics are the fact that the petals of the left and right units are connected and there is no obvious gap between them. The same unit petals repeatedly arranged into a group, rounded and full of charm, like the layers of petals blooming. From the perspective of modeling and composition, it can be divided into two forms: one is the full-ground structure in which the flower heart is connected to the petal layer. The second is the emptyground structure in which the flower heart and the petal layer are separated.

The full-ground Baoxiang flower: the flower heart is connected to the petal layer. Both the external and internal are all blended into one harmonious whole, the representative caves are the 331, 334, 338, 339, 26, and 103. The center of the caisson in the 331th cave is a four-petal flower, which radiates outward in turn. There are small leaf patterns, peach-shaped petals, moiré, lotus petals, etc. To the total seven layers, the outermost is composed of eight peach-shaped petals, and the lotus petals are large and peach-shaped, which are in full bloom. Due to the stability and balance on the composition, it appears to be orderly, fine and delicate, and there is no sense of chaos.



Figure 28: The cave 331 (Source: Yang et al, 2010, pp. 55)

The empty-ground Baoxiang flower: it is divided into two patterns: the empty-ground flower heart without decoration, and the flower heart that is not connected to the flower petals to form empty space. The representative caves about the empty-ground flower heart without decoration are the cave 49, 123, 175 and 320. For example, the five-layer structure of the Baoxiang flower in the cave caisson 49, center is superimposed. Among of both the quiet beauty of the lotus and the wealth of the peony, the modeling is full and luxuriant, extremely rich rhythm (Ou, 2007, pp. 221). The center of the caisson is green, red alternating with green to represents the freshness and elegance.



Figure 29: The cave 49

(Source: Yang et al, 2010, pp. 59)

The representative caves about the flower heart being unconnected to the flower petals to form an empty space are the cave 335, 340, 341, 372, 122, 217, and 319. For example, the center of the caisson 217 becomes smaller, with three layers of eight-petal lotus flowers overlapping. The outer petals are closely combined by leaf patterns, moiré, and peach-shaped petals. Each layer of petals are well-arranged, the shape is exquisite and gorgeous. Four corners are flowers composed of moiré.



Figure 30: The cave 217

(Source: Yang et al, 2010, pp. 66)

Curl petal lotus: The petals of the curl petal lotus is half-opened and half-closed bloom, the inner and outer rolls are all round. There are rare auspicious beast such as lions, three rabbits, dragons or Kalavindotabvka in the inner circle. It was a new type of lotus pattern that appeared in the middle Tang dynasty (782-847 AD) and continued to be used in the late Tang (848-907) and Five dynasties.

During the middle Tang dynasty, Dunhuang was occupied by the Tubo, therefore the communication with the Central Plains appeared problems, and the decoration patterns of the glorious age of Tang dynasty in the Dunhuang Mogao grottoes disappeared silently. In the middle Tang dynasty, the cave 112, 231, 360, 237, 358, and 369 have the curl petal lotus caisson. The curl petal lotus is composed of 8 to 10 petals. From the outside, it looks round shape. The petals are curled inward, and the shape has a three-dimensional sense like a lotus waiting to be released. In the center of the lotus pattern is sometimes painted with Kalavindotabvka pattern, three rabbit pattern, or tuan dragon pattern, of which the shape is very exquisite. For example, in the cave 360, the central square caisson is a lotus decorated with Kalavindotabvka that is the god of heavenly music who can dance and sing in the Buddhism. In the heart of the lotus, the Kalavindotabvka who appears with a human face, a bird body, and a bird claw, holding Pipa playing song and dance, is wrapped in the curl petal lotus of 10 petals. The painters used exaggerated techniques to make full use of their imagination, and arranged the Kalavindotabvka to dance and sing in the lotus heart, which became a unique form of the Dunhuang pattern in the middle Tang dynasty. In color rendering, this period uses more stone yellow. The stone yellow matches the stone green, and the red Pipa with the hands of the Kalavindotabvka presents a contrasting and soft tone. The lotus pattern in the Mogao grottoes of Dunhuang in the middle Tang dynasty also changed in style due to the change of the political environment. The structure starts to go from complicated to simple, the color has also become fresh and elegant from the gorgeous and rich of the glorious age of Tang dynasty.



Figure 31: The cave 360 (Source: Yang et al, 2010, pp. 75)

The lotus caisson in the late Tang dynasty is still the pattern of the middle Tang dynasty, and the caisson heart has a curl petal lotus pattern. There are various patterns like lion, dragon, birds, and beast in the lotus heart. For example, the square caisson in the center of the cave 85 is lion lotus pattern. The lion sits with his head looking back, it has a hairy head, angry eyes, an upturned tail, and lies in the heart of the lotus. This form is contrary to reality. How can a lion lie in the heart of a lotus? Artists use their creative skills to merge the impossible things into a circle lotus heart. The outer layer is a twelve-petal curl petal lotus and twelve moirés, to form a tuan flower. The curl petal lotus is green and the moiré is dark stone blue. The four corners are decorated with flowers, and the colors are quietly elegant and calm. In these caisson patterns, it can be seen that there is a lack of new styles in the late Tang dynasty, and the caisson heart pattern is mostly based on auspicious birds and beasts. The lotus petals are more realistic, and the structure is centripetal, reflecting the introverted social and cultural psychology of the late Tang dynasty. Most of the caves in the late Tang dynasty were rebuilt by the later dynasties, so it is difficult to see the caves in the late Tang dynasty. The lotus pattern of the 369 cave in Dunhuang, as shown in Figure 33, is centered on the tuan dragon pattern. The surrounding lotus petals are multi-layered and inwardly curled, showing a clear tendency to converge inward and the lotus petals are large with simple and compact

shape. The overall pattern occupies the center of the caisson. In color, it is mainly green to give fresh and elegant vibe.



Figure 32: The cave 85 (Source: Yang et al, 2010, pp. 80)

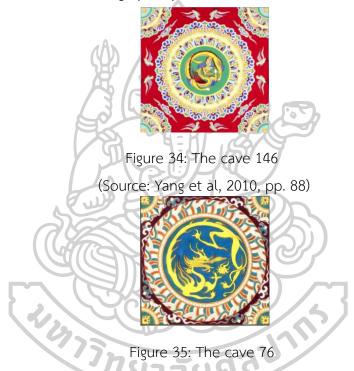


Figure 33: The cave 369

(Source: Yang et al, 2010, pp. 83)

The four eras of the Five Dynasties, Song, Xixia, and Yuan, for about four hundred years, known as the late art of Dunhuang Mogao grottoes. At the time, it has experienced the political power of three different nationalities, social thoughts and religious beliefs have undergone the great changes. The whole structure of the caisson pattern in this period inherits the previous generation, but presents a new content in the pattern, creating a unique tuan dragons caisson which belong to that era. The tuan dragon symbolizes the existence of the imperial power, expresses the auspicious meaning, and is placed in the center of the caisson. Later, it gradually replaced the lotus and became the representative of the late caisson pattern in Dunhuang. At this period, the representative lotus cave with dragon curl petals are the cave 55,146, 61, 76. The cave 146 of the Mogao grottoes of the Five Dynasties is a lotus caisson of tuan dragon and parrots. Caisson center painting tuan dragon curl petals lotus, the dragon is in the green pool, with vivid expression. Outer ring is with cirrus moire large garland that is surrounded by green-body and blue-wings parrots, and the colorful clouds set off. The cyan and green lotuses are blended with the

golden dragons. The combination of movement and static makes the picture beautiful and harmonious. Mogao grottoes in the 76th cave of the Song dynasty is dragon curl petal lotus, it is located in the center of the cave. The dragon is curled up and its thin body is golden with mouth open and play with flame beads. Dragon's legs are strong and powerful. It is swimming in the green pool; and surrounded by white beads and thirty-two curl lotus petals wrapped tightly around the tuan dragon. It is a neat and exquisite lotus pattern, and also one of the masterpieces of Dunhuang patterns in the Song dynasty.



(Source: Yang et al, 2010, pp. 91)

In general, the characteristics of the artistic style of the Dunhuang caisson heart lotus pattern have changed in different periods. In the early Dunhuang period (from the Sixteen Kingdoms to the Northern Zhou dynasty), the patterns of the caisson center were mainly the round wheel lotus with simple shapes. In terms of color, the settings are not rich due to the limitation of color materials. However, the artists cleverly contrasted the stone cyan, stone green, and earth red, and through the contrast of brightness, contrast between cold and warm, make the picture colorful and simple, forming a solemnly simple style, and a harmoniously, unified color aesthetic feeling. In this period, the development of caisson patterns is very inheriting and new patterns are constantly developed that became the beginning of the development of the whole Dunhuang caisson lotus patterns.

The middle period of Dunhuang (the Sui and Tang dynasties) is a key period for the art of the Mogao grottoes. In addition to inheriting and developing the style of the Northern Dynasties, the lotus of the Sui dynasty has extended a new pattern belonging to the style of this era also. In the history of the development of Mogao grottoes, the Sui dynasty was in the transitional period from the early to the maturity stage of the art of grottoes, and it has the role of "a connecting link between the preceding and the following" (Li, 1986, pp. 5). The lotus pattern evolved from a round wheel to a large-sized lotus with eight petals, sixteen petals and so on. The lotus heart has new patterns, such as the three rabbit, the rotating color wheel, and so on. The twining branches lotus caisson, developed on the basis of the round wheel lotus caisson, is also a unique new pattern formed in the Sui dynasty. The image of the eight-petal lotus has a certain realistic meaning. The petals are round and plump, and the shape is full. Moreover, it appears in the pattern of the caisson center in the form of multiple petals, which is more close to the reality. It is completely different from the image of the slender geometric pattern in the Northern Dynasties and the early Sui dynasty. The realistic style has promoted the emergence of realistic patterns in the Tang dynasty. In terms of color of the caisson pattern during the early days of the Sui dynasty, the soil red was background, and the dark brown, white, cyan, and stone green were secondary color. The tone of the caisson pattern was simple. In the middle of the Sui dynasty, the tone of the pattern is increasingly diversified. In addition to the stone green and earth red, the middle tones are greatly increased. There have been many colors that have never been used before, such as blush, orange, green lotus, orange red, emerald green, golden color, etc. The overall color tone tends to be gorgeous and warm, and the contrast is strong. In the late period of the Sui dynasty, the variety of colors used in the pattern continued to increase, and the painter became bolder in his use of color. In the complex color matching, the hue; brightness; purity and area contrast of the color are carefully designed to make the colors complement each other. The Dunhuang caisson pattern in the Tang dynasty is dominated by lotus patterns, borrowing and

incorporating exotic cultural elements in the center shape, combining several different floral elements through imagination, creating a pattern of Baoxiang flowers that is full of imagination and aesthetic taste. The overall shape of the lotus pattern in the center of the caisson in the Tang dynasty is a tuan flower type, and the petals are composed of hooks, curls, moiré, and peach-shape petals. Compared with the lotus pattern of the caisson in the early Tang dynasty, it is more complicated in modeling, and pays attention to the symmetrical relationship between the upper, lower, left, and right sides. Seeking change in unity, seeking harmony in the prosperous, prominent theme, and distinct levels, constitutes a well-formed and rhythmic change of caisson pattern. In addition, most of the caisson pattern is colorful and dazzling. However, it seems that there are not many types of colors used, but five or six colors are used repeatedly. The color features mainly use contrasting colors, complementary colors, and the colors are interspersed with each other. This is the charm of the caisson pattern in Dunhuang Mogao. After the Five dynasties, it was the final stage of the development of Dunhuang art. Due to the lack of influence of foreign culture, Dunhuang art is become stylization. The tuan dragon lotus are the most representative, and the dragon pattern is a symbol of the imperial power. After transformation and utilization, it presents a brand new image. Although the caisson coloring is not as brilliant as the Tang dynasty, it is fresh and bright, natural and rich. าลัยศิลป์

2.4 Dunhuang secret language

2.4.1 The meaning of the caisson

As an important part of Dunhuang Grotto art, Dunhuang's caisson combines the characteristics of Chinese civilization, Indian culture and Western style, with rich decorative patterns and harmonious color composition. This presents a localized, diverse and intertwined artistic style and decorative features.

The Buddhist caves create the world of Buddhism, but the structure of the world of Buddhism still comes from the imagination and beautification of human life. Regardless of the architecture in the murals or the top of the cave, the craftsmen and painters of the time were constructed with reference to the form of ancient architecture. The caisson is the highest and most central part of the Buddhist cave. The overall shape follows the structure of the traditional Chinese architecture that is "round above and square below", as shown in Figure 36, responding to the ideological concept of China's "the Earth was square, and Heaven was round." Like the dome in the western church, this symbolizes the epitome of celestial bodies and the high of heaven. The Buddhist philosophy believes that above the earth is the heaven, and outside the heaven is the void. There were men in the earth, gods in the heavens, and no master in the void. The purpose of drawing beautiful caisson in the Buddhist caves is to let the monks create meditations that are "beyond the caisson, nothing else". In this way, the pure land desired by human beings and gods will be perfectly reflected in the caves.



Figure 36: Caisson structure in Buddhist cave

(Left Source: https://www.e-dunhuang.com/cave/10.0001/0001.0001.0012)

In the Han dynasty, the palace building has many caissons. Zhang Heng's "Xijing Fu" has two sentences describing the decoration of the caisson in the palace of the Han dynasty. The ceiling of the palace is like a well, and the well is painted with lotus. The petals are facing downwards, and the lotus leaves hanging down are rolled up. The reason why the roof of the palace was built into a well was because one of the twenty-eight mansions was called "well mansion". The ancients believed that the well mansion was in charge of water. The ancient palaces are mostly wooden buildings, which are prone to fire in a long time. In the Qin and Han dynasties, the yin-yang and five elements of the doctrine were popular. In terms of the five elements, water can restricts fire, and the well mansion is in charge of the water, so the roof of the palace should be shaped like a well. The caisson is decorated with lotus, meaning that the lotus is born in water, water can restrict fire. Wu Rengxiang's article on the lotus caisson in the murals of the Hexi Jin Tomb said

that M39 lotus caisson pattern in Foye temple of Dunhuang, between the tip of the lotus petal, wild duck, swim fish, andwater waves, is the evidence that the yin-yang and five elements are water restricting fire. In the article, he pointed out that the lotus caisson pattern is a symbol of counteract fire. It was decorated in the palace as early as the Western Han dynasty (Wu, 2004). The caisson in the Dunhuang period imitated the structure of the Han and Jin dynasty wood caissons and simplified them. The caisson lotus pattern decoration tends to be complex and gorgeous, and its cultural connotation still has the aftertaste of the Hanjin yin-yang and five elements culture.

2.4.2 Balanced and symmetrical composition

The caisson pattern in Dunhuang reflects not only the development of Chinese traditional culture, but also the influence of traditional Chinese thoughts. Chinese traditional thoughts emphasizes the beauty of stability and harmony. The ancients applied the beauty of harmonious spirit to the art of decoration, which is the beauty of balanced symmetry in pattern modeling. Balanced symmetry is the most common form of aesthetic law. The balance in graphic design is the balance formed by the visual judgment based on the size, weight, color, and structure of the pattern. Symmetry is a special case of balance, which is equiform and equivalent balance. Symmetrical balance can achieve a better visual balance, bringing people a sense of natural harmony, order stability, elegance and dignity. In the Dunhuang caisson lotus pattern, most of the balance symmetry is used to reflect the form beauty of the pattern. Some lotus patterns are axisymmetric figure, such as the flat petal lotus and the round wheel lotus, as shown in Figure 37. Baoxiang flower adopts the traditional "cross" four-petal mode to maintain a stable and quiet sense of simplicity. There are also some lotuses that turn 45 degrees on the basis of the four petals to form the "米" eight-petal structure. In addition, each unit space of the word "米" is decorated with the same figure, or two separate patterns are alternately distributed to form a decorative picture in which repetition and symmetry coexist. The petals of each layer are big and small sets, the pattern tends to be gorgeous, as shown in Figure 38. The outer contour shape varies with the shape of the petals or has a diamond or round shape. The balanced symmetry of the Dunhuang caisson lotus pattern on the composition gives us a sense of natural harmony and a stable sense of order, which is consistent with the aesthetic culture concept of harmony and order advocated by Chinese tradition.

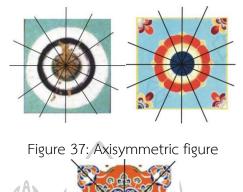


Figure 38: 米 structure

2.4.3 The three rabbit lotus caisson, reflecting the fusion of multiculturalism

The three rabbit patterns drawn in the caisson lotus in the middle of the Sui dynasty are a new pattern, which firstly appeared in the Sui dynasty and disappeared in the late Tang dynasty. As an independent pattern, the three rabbit patterns are different from the strange beasts. They are designed by ancient artists to fit the central circle of the lotus. The central triangle is made up of ears of three rabbit that looks like an inseparable circular pattern that is chasing each other. Using patterns that are constrained by equilateral triangles, the circular sidelines do not have an end point, and it looks like the three rabbits still have two ears. With the dynamics of the three rabbits, the center circle seems to be moving, creating a never-ending sense of movement, as shown in Figure 39.



Figure 39: The cave 407 (Source: Yang et al, 2010, pp. 41)

At present, there are different views on the connotation of three rabbit patterns. In the Chinese translation of the Buddhist scriptures, stories of rabbits sacrificing their lives often appear, and the image of the rabbit is sanctified more than once in many of Buddhist classics. According to Buddhistbelief, the rabbit is one of the Buddha's own life, so the status of the rabbit is very sacred in the Buddhism. Mr. Xu Junxiong believes that the three rabbits represent the three Buddhas, namely Past, Present, and Future Buddha. Just like the three rabbit ears are in contact with each other, meaning that the previous, present, and after life are related to each other. This corresponds to the idea of "karma", "karma cycle" and "cycle of life and death". In addition, with the prosperity of the social economy and the stability of politics in the Sui dynasty, people's willingness to live longer and have more children is more intense. At this time, people need an idealized schema sustentation, meaning longevity, multiple children and reincarnation so the three-rabbit pattern will become the only choice. In the Sui dynasty, which was prevalent in Taoism, Lao Zi's theory of "the three begets all things of the world" made people worship the number three more, and recognized that "three" means unlimited, then the image of three reciprocating white rabbits came into being. Thus, the symbolic image of the three rabbit lotus caisson that merged with various cultural elements appeared in the Mogao grottoes (Zhao, 2017).

2.4.4 Baoxiang flower modeling analysis

The word "Baoxiang" comes from Buddhism and refers to the solemn appearance of the Buddha. In the Mogao grottoes of the Tang dynasty, some popular patterns, such as Baoxiang flower, are the solemn appearance that symbolizes the three treasures of the Buddhism, the Buddha, dharma and monk. For the accurate definition of the Baoxiang flower, a large number of references to the traditional patterns have their own interpretation. Although the arguments are not completely consistent, through inductive and comparison, it can be seen that Baoxiang flower is not a real flower, but an ideal flower produced by deforming natural flowers, reflecting people's artistic creativity (Chen and Fan, 2019).

The essence of the Baoxiang flower pattern is the typical tuan type pattern in the Middle Ages, especially in the Tang dynasty. Its flower pattern is a combination of various flowers: mainly composed of lotus, peony pattern, pomegranate pattern, etc.. The petals are in the form of hook, peach-shape petal, and moire. Its main features are presented in the form of a combination of a floral monomer variety then recombined with the "米" or "cross" structure according to the law of symmetrical radiation to form a complicated and disorderly shape structure (Tang, 2014).

The overall shape of the Baoxiang flower. The popular Baoxiang flower of the Tang dynasty is the tuan style. Starting from the heart of the flower: the petals of the whole flower have their own shapes, the outlines are clear, the layers are stacked, the front and back are interlaced, the inside is tight, and the outside is loose, and all of them give people a fullness feeling, as shown in Figure 40. The pattern is apparently round in shape, but the reason why the word "tuan" is used to describe its shape instead of "round" is, and first of all, from the perspective of semantics, the word "round" is biased towards the round appearance of the object. The word "tuan" means to knead non-round objects into round, to gather scattered people and objects into a whole. In this sense, the round flower simply indicates that the outline of the pattern is round. The tuan flower means that all kinds of irregular scattered plants and animal patterns are condensed together, making it a rich and diverse harmonious whole. This is also the spirit of "harmony" and "combination" advocated by Chinese traditional culture. Secondly, Baoxiang flower pattern of this tuan style has a relatively large area in the caisson. If it is not large, it cannot show the meaning of "tuan", nor can it be called "tuan flower". It can only be called "small round flower". It can be said that the round flower only speaks its shape, and the tuan flower can highlight its "big", so the tuan word has the extended meaning of "big", and this is a reflection of the prosperity of the Tang dynasty economy and culture.



Figure 40: Tuan style

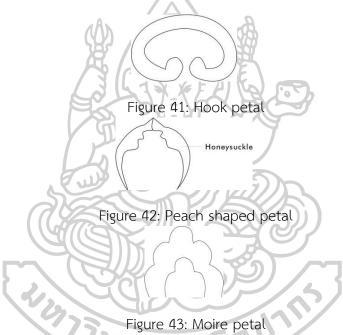
(Source: Yang et al, 2010, pp. 55)

In addition, the pattern of Baoxiang flower, which is based on the shape of tuan, presents a"round" shape on the whole. Even the caisson lotus pattern that is not a tuan shape, also, because the various flowers, fruits, and branches are clustered together, the composition is full and gives a sense of completeness. The Tang dynasty's national strength was strong, the economy and culture were prosperous, and the social morality was open. The Tang people have strong self-confidence and pride, and in the aesthetic concept, they advocate the beauty of health, plump and round. Especially, since the Tang dynasty, with the integration of peony, the fat rounded petals increased. Peony is a rich flower, which makes the caisson lotus pattern more rich and gorgeous visual experience. The rich and round shape of the caisson lotus, the rich and gorgeous atmosphere reflects the magnificent and vigorous Tang dynasty artistic conception, and caters to magnificent aesthetic pursuit of the Tang dynasty.

The basic shape of Baoxiang flower petals. Tian Zibing's "History of Chinese Patterns" believes that the Baoxiang flower pattern "petal is the same" has stylized features. At present, most scholars believe that there are three basic petal shapes of the Tang dynasty Baoxiang flower, which are the hook, peach-shaped, and moire petal respectively. The hook petal, according to the current research results of the academic circle, is mainly influenced by the Chinese traditional curl moire, and also absorbed some factors from the Indian Buddhism, so it is also called "ru yi hook petal", as shown in Figure 41. The word "ru yi" derived from the free translation of Sanskrit "Aniruddha". The Buddhist believers often hold a "ru yi" in hands when they are teaching the scriptures, therefore "ru yi" is marked with scriptures to prevent

moments of forgetting. The hook petal in the Baoxiang flower pattern of the Tang dynasty also combines the abstract "ru yi" pattern with the traditional "hooked moiré". The shape is oval, and the two ends are rolled back like a flower pedicle, holding a peach shape petal. In the early Tang dynasty, it is one of the most basic patterns of Baoxiang pattern, having the auspicious meaning of "looking back, everything being as you wish." It is not only like a lucid ganoderma, but it also has the meaning of longevity and praying for safety (Xu, 2009). The peach shaped petal consists of two honeysuckle leaves in a floral pattern, shaped like a peach, as shown in Figure 42. The honeysuckle pattern originates in Greece. Due toits staying alive through wintertime so it is later used extensively in the Buddhism, compared with the soul of the human being, samsara, and eternal life. The honeysuckle patterns became popular in the Southern and Northern dynasties and were combined with lotus patterns to form a twing lotus branch pattern. In the early Tang dynasty, the peach shape lotus of Dunhuang caisson was mostly lotus pattern, decorated with honeysuckle pattern. On the combination basis of lotus and honeysuckle, it also incorporates grape and pomegranate. The lotus symbolizes pure land of the Buddhism, and the moral of honeysuckle is the everlasting soul, while the grapes and pomegranates symbolize the plentiful descendants. It can be seen that the peach-shaped petal in the lotus pattern of the Dunhuang caisson in the Tang dynasty is to express the longing for the good life of local people with the popular foreign ornament. Moire petal is greatly influenced by the peony pattern, as shown in Figure 43. The colorful, rich, and dignified peony flower is a symbol of wealth, auspicious, and prosperity. It is also in harmony with the Tang dynasty's magnificent, dignified, and graceful style. According to historical records, during the Tang dynasty, the world was peaceful, and its social is stable, flower viewing became a great renowned event in the capital city of Chang'an. The economic prosperity has led to the social atmosphere of flower viewing. People in the flower viewing especially prefer peony, so the peony pattern has become a very popular decorative pattern at that time, and the Baoxiang flower pattern has also been greatly affected. The main feature of the peony pattern is the layered petals, short-and-fat head, and cloud-like curved edges. The outer layer of the Baoxiang flower pattern is mostly composed of moire

petals. Looking down, like a large peony with petal layers, this petal shape gradually disappeared until the late Tang dynasty. From the above analysis, we can see that the Baoxiang flower pattern of the Tang dynasty are borrowed from the shape of the petals and incorporated the exotic cultural elements. Combining several different floral elements through imagination can creates a pattern that is full of imagination and aesthetic taste. It not only has a completeness and satisfactory religious implication, it also reflects people's secular psychology of advocating rich and gorgeous, embodies the eclectic cultural mentality of the Tang people to the exotic customs.



2.5 Conclusion

Dunhuang grottoes is a treasure house of the ancient Chinese decorative art. The Dunhuang caisson lotus pattern is an outstanding representative of the national traditional culture. Its exquisite shape, rich patterns, and beautiful colors are the pearls of the Dunhuang pattern. Applying the classical decorative art of Dunhuang caisson lotus pattern to modern design can not only protect and promote the national traditional culture but also broaden the new ideas of modern design. Applying the decorative art in Dunhuang caisson lotus pattern to modern fashion design can not only designs costumes that meet the psychological needs of the public but also highlights the decorative art characteristics of caisson lotus patterns, which is the key to the success of modern applications of traditional patterns.

Part 2: Analysis of Islamic geometric patterns and shape grammars

2.6 Analysis of Islamic geometric patterns

Islamic pattern art decoration is a dazzling star in the history of human art. It absorbs and integrates the different characteristics of Eastern and Western art, plus the unique religious characteristics of Islam, forming a unique and distinctive decorative style. The Arab pattern system pattern that has been produced and developed gradually since the mid-seventh century has formed a typical Islamic decorative pattern with the rise of Islam and the prosperity of culture. Its unique artistic style mainly decorates various buildings represented by mosques, carvings, arts and crafts, fabric decoration, etc, and has an important decorative role.

The pattern art painted by geometric figures is called "geometric patterns". The Islamic nation is the first nation in the world to use geometric patterns. Their love for geometric figures stems from the influence of mathematical and astronomical abstract geometric concepts (Teng, 2004). As the main decoration of Islamic pattern art, geometric pattern is also the highest achievement of pattern art in Islamic pattern art. They expressed simpleness and unity, solemnity and infinity in a repeated geometric form, which is not found in other cultures. In Islamic-style buildings, most of them use lines inlay to form geometric figures for decoration. Lacking of the precise drawing instruments in the Islamic era, the mathematical calculations are applied for arrangement of pattern shapes. The method for drawing graphics with ruler and compass and mosaic principle are used to construct the zigzag line and connect to form a single crystal, and connect the decorative edge through the edge of the tile to form a complete pattern of continuous tiling. In Islamic architectural decoration, line decoration figures are often used as the unit center, and its repeated and rotating transformations form continuous and precise patterns to improve the visual impact.

2.6.1 Traditional Islamic pattern design method

The traditional Islamic pattern design mainly uses the construction with ruler and compasses and mosaic method, the resulting patterns are not only coherent, but can also be freely expanded and changed at any time to suit the needs of the overall layout (Qiu, 2011). The construction with ruler and compasses uses only a ruler with no scale and a compass to draw. This rule was proposed by the first ancient Greek mathematician, Inopides, who discovered the obliquity of the ecliptic. This requires a ruler and compass without scales for drawing: ruler to connect two points to make a straight line or extend a line segment and compass to draw an arc or make a circle. Using of ruler and compasses for a limited number of times can be the simplest way to make graphics. Among them, "make a circle, draw a line, and find the intersection point" are the most commonly used method in the construction with ruler and compass. The Islamic pattern is made by a finite combination of these three methods. In this process, many unexpected patterns produced, among them, the quasi-crystal pattern attracted wide attention. The quasi-crystals discovered only in the 1920s appeared in the mosque buildings 500 years ago. And these complex quasi-crystal patterns are the result of the continuous "making circles, drawing lines, and finding intersections".

The mosaic method is to put different materials together according to different pattern requirements and make a sense of hierarchy. The main consideration is the continuity and free extension of the pattern layout, the principle is to form a circle when the pattern is arranged clockwise or counterclockwise. The earliest method of mosaic art is to engrave patterns on the asphalt wood by incised carving and fill them with shells. The mosaic of Arabic geometric patterns is related to mosaics in ancient Rome, it is no longer to fill one material into another, but to lay out different materials such as shells, stones, glass, etc. on the floor or wall by color classification.

Take the ten-pointed star pattern as example, to elaborate on the process of drawing Islamic patterns, as shown below.

Step1: Divide a circle into ten equal parts. Ten intersections are created along the circle's edge.

Step 2: Use a ruler to connect the intersections created in step 1, as shown above, to make a ten-pointed star.

Step 3: Draw a pentagon, as highlighted, connecting five of the ten intersections created in step 1.

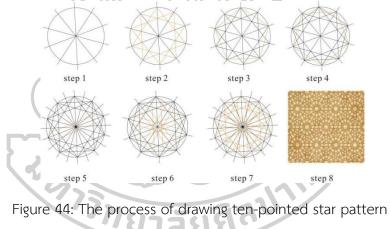
Step 4: Draw a second pentagon, connecting the remaining five intersections.

Step 5: Draw parallel lines between four of the intersections created in step 4.

Step 6: Work clockwise around the circle, drawing four more sets of parallel lines between the intersections created in step 4. The construction lines are now complete.

Step 7: Trace the segments of the construction lines that are needed to create the star pattern.

Then use the mosaic principle to get a continuous pattern, as shown in the Figure 44 (Eric, 2016, pp. 6-9).

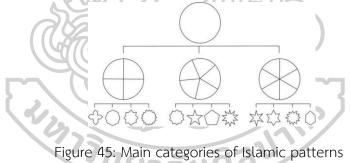


(Source: Eric, 2016, pp. 6-9)

2.6.2 The structure of Islamic geometric pattern

Through the research of the construction of Islamic geometric patterns, it is not difficult to find out why the Islamic geometric patterns have different appearances. Their starting points are all a circle, and their changes start from the division of the circle to form several polygons or other graphics, and these different graphics are the same in many steps, only the last step is different.

Most patterns fall into three main categories in Islamic geometric design: fourfold, fivefold, and sixfold that are determined by the number of equal parts into which the circle that forms the basis of the composition is divided. When a circle is divided into four equal parts, the resulting pattern is known as fourfold. A design based on a circle of eight, sixteen, or thirty-two equal parts -i.e. multiples of four - is also fourfold. Similarly, a pattern based on a circle of six equal parts is called sixfold, while fivefold is used to describe a pattern based on a circle of five or ten equal parts. Around 90 percent of all patterns and compositions in Islamic art and architecture fall into one of these three categories, the other 10 percent includes, for example, sevenfold and elevenfold designs. Among these three main branches of the Islamic geometric design family tree, there is an immense variety and wealth of patterns. Each branch has its own unique characteristics. Sixfold is the biggest branch of the family and offers the most variation, with a huge number of different patterns. Fivefold is the cleverest and most chaltenging branch of the family, providing the most surprising, and creative patterns and compositions. In contrast, the fourfold branch of the family is typically the most straightforward and accessible - the least problematic to read and understand. The main categories of Islamic patterns are shown as below, as shown in Figure 45 (Eric, 2016, pp. 6-9).



(Source: Eric, 2016, pp. 6-9)

2.6.3 Artistic characteristics of Islamic patterns

Islamic patterns are not only decorative arts, but also have a symbolic meaning. Although the three patterns of geometry, plants and text have their own characteristics, no matter in the layout or in the rhythm and other artistic elements, it has the characteristics of abstraction, coherence and unified rhythmic beauty. The biggest feature of Islamic patterns is always dense and complicated because of the unique religious Islamic thoughts that like "heavy and complicated art" and "do not like empty space". The artistic characteristics of Islamic patterns are outstanding, which can be summarized as follows:

(1) Abstract

Because of the fact that Islam prohibits idolatry, Islamic artists use abstract geometric patterns to express the thoughts of the Islamic world, therefore, the stylized tendril pattern, vine pattern and other abstract outlines of the plant matrix contain highly abstract meanings. In addition, there were many mathematicians in the Islamic world in the middle Ages. They have made outstanding achievements in the research of numbers, the formulation of trigonometric functions, and the research of astronomy. The Arabs applied the in-depth research of mathematics and astronomy to the art decoration, and created many abstract geometric patterns.

(2) Dense and delicate

The biggest feature of Islamic patterns is that they are dense and complicated, and without blanks. Under the guidance and restriction of Islamic culture, the "infinite connection" as its unique form of artistic expression to express the freedom of Muslims also constitutes the artistic style of Islamic patterns. Such artistic features can be seen everywhere in the wall decoration of mosques (Wang, Luo and Liu, 2016).

(3) Balance and unity

Islamic decorative art mainly adopts spiral lines and parabola to interweave the lines, so even though the pattern is complicated, it can still keep the thread clear and not messy. In the law of art form, it pays attention to the unity of the whole and the part, the conciseness and the overelaborate, the text and the image (Nan, 2014).

2.6.4 Conclusion

Islamic geometric pattern art, its regular arrangement and rhythm, symmetry, and balanced expression are rich in decoration. When Islamic patterns are all over mosques and crafts, it is enough to show its influence, especially the traditional drawing method of Islamic geometric patterns, more than 1,000 years ago, craftsmen and designer used a compass and ruler to create the dense and delicate geometric patterns, which fully reflected their ingenuity. The caisson lotus pattern is also round, and the size of the petals on each layer is also relatively equal. There is a slight difference due to hand drawing. And after thousands of years of development and change, it still maintained this kind of structure, this point that made me wonder whether the Chinese artisans, at the time also used the compass and rulers to draw the caisson lotus pattern. With this question, in the next chapter will describe the method of making circles, drawing lines, and finding intersection points to analyze the lotus pattern structure.

2.7 Shape grammars

2.7.1 Introduction to shape grammar

Shape Grammars (SG) is a design inference method that uses label shapes as basic elements and uses shape rules to generate new shapes. In 1972, George Stiny, a professor of architecture at the Massachusetts Institute of Technology, proposed the concept of shape grammar (George and Jame, 1972). In 1980, he published the article "Introduction to Shape and Shape Grammars" in "Environment and Planning B: Planning and Design". The definition of shape and shape grammar is described in details, and the concept of parametric shape grammar is initially proposed, that consequently lays a theoretical foundation for the development of shape grammar.

The shape elements contained in the shape grammar are "vocabulary", the reasoning rules are "logic", and the process that words form a sentence into language according to a certain logic is the process that shape elements generate shapes according to the reasoning rules. So the advantage of shape grammar is that the procedure is clear and easy to understand, even people without design background can easily use. According to a series of shape rules, it is possible to generate shapes that did not exist from several sets of known shapes, and through repeated application of limited rules and modeling elements, the shapes that can be obtained are difficult to count.

In 1982, Stiny put forward the concept of Set Grammar on the basis of the original shape grammar, and summarized the "shape" and "rule" in the original shape grammar into labeled shape sets, and all operations are operations on a set of known shapes, further improving the theory of shape grammar.

Under this premise, the design activity will no longer depend entirely on the designer's intuition and experience. Shape grammar can be used as a design method in the early stage of design, not limited by the designer's experience and inspiration, providing designers with a lot of preliminary program. What the designer needs to do is to screen the generated plan according to the design needs and personal experience, and then refine and improve on the basis of the selected plan. The advantage of this is that the designer can greatly reduce the time spent in the design conception stage and the workload of searching for various possible solutions, so as to focus on improving the design plan and improving the design quality.

According to George Stiny's definition of shape grammar, it can be expressed as:

SG= (T, L, R, I)

Where: T is the set of shapes, L is the set of marks, R is the set of inference rules, and I is the set of initial shapes. In the inference process of the actual pattern, the initial shape is the typical feature extracted from the pattern. Its basic operation is to carry out the morphological evolution of the initial shape through certain rules (Yang et al, 2013).

2.7.2 Evolution rules of shape grammar

Shape grammar is a design method that evolves according to rules. Its basic operation is to perform a morphological evolution process on the initial form combined with the reference product family form through certain rules.

Commonly used shape grammar inference rules include: replacement, scale, add and delete, mirror, copy, rotate and so on (Wang et al, 2014). Replacement refers to the replacement of part of the morphological curve of other products with the existing morphological curve, scale means reducing or enlarging part or all of the curve of the original shape, addition and deletion refers to adding or deleting part or all of the initial shape curve, mirror means that part or all of the initial shape curve, more the initial shape curve, rotation is an angle transformation of the initial shape (Lu, Tang and Xue, 2010).

Take a simple figure as an example to illustrate the process of obtaining the pattern from the initial shape through different shape rules, as shown in Figure 46. The left side is the initial shape, and the right side is the shape generated after applying the transformation rule. Figure 46 is a simple generative rule, R1 is copy, R2 is rotation, R3 is scale, and R4 is delete. Then several kinds of rules are superimposed and used to obtain derivative rules and generate new patterns. Continue to use the derivative rules for the new patterns multiple times to generate more new patterns, as shown in Figure 47. First use the derivative rule of copy + rotation for the capital A to get a new pattern shape, then continue to use the copy + rotation rule for another new pattern, so continue, you will get more new pattern.

Among the existing design methods, shape grammar as a shape deduction method, is not only able to extract the shape features, but also able to carry out the shape deduction design on this basis, to generate a continuous style of product design. Shape grammar was first proposed to be used in architectural design, and now has been successfully applied to architectural (Neeta and Alpana, 2019), product design (Hsiao and Watada, 2018), computational creativity (Tching, Reis and Paiodue, 2017), and urban design (Duarte and Beirão, 2011). Shape grammar also addresses different design tasks, such as, the generation of original designs, the generation of new designs within a style or a brand (Ondra, Škaroupka and Rajlich, 2017), the generation of product families (Castro e Costa and Duarte, 2014), and the transformation of existing designs (Eloy and Duarte, 2012). They are also useful for evaluation and optimization tasks (Barros, Duarte and Chaparro, 2015).

Here is an example of ceramic product innovation using shape grammar.

Feng et al (2019) analyzed the models of Song dynasty porcelain, extracted the model as the initial shape, and combined the evolution rules such as r1 is the moving, r2 is the replacement, r3 is the scaling, r4 is the addition and deletion, r6 is the coping, and r8 is the switching to get new porcelain models. For example, taking the Song dynasty porcelain bowl as an example, first extract its shape, and then execute the rules r1 and r2 in the first step to replace the mouth edge. The second step is to execute the rules r2 and r3, scale the abdomen, and at the same time replace the foot. The third step is to execute rules r3 and r4, first add or delete the edge of the mouth, then scale and change the shape of the edge. The fourth step is to execute rules r3 and r4, add and delete the abdomen, and then scale the foot, the fifth step is to execute rules r4 and r8, switch the abdomen, add and delete the feet. Then finally complete the evolution, get a new porcelain model, as shown in Figure 48.

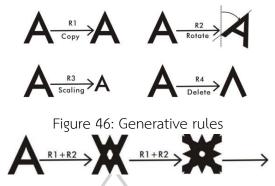


Figure 47: The process of pattern evolution 2.7.3 Application status of shape grammar

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Figure 48: The evolution process of porcelain modeling based on shape grammar Some scholars applied shape grammar to the innovative design of traditional patterns. For example, Lee et al (2013) studied Bosanghwamun, a traditional Korean pattern, and decomposed its pattern structure step by step to obtain a series of pattern templates. Sayed det al (2016) proposed a novel approach in generating 3D Islamic geometric patterns using the shape grammar method. Cui and Tang (2013) studied the Zhuang nationality embroidery patterns, realized the automatic generation of new patterns through the shape grammar computer system. Wang and Wei (2018) studied the composition rule of the Banpo colored pottery triangle pattern, extracted it as a design factor, combined with the shape grammar to redesign the pattern, so that the newly generated pattern inherited the simple and repetitive design style of the Banpo colored pottery pattern. At the same time, it has a simple and stylish modern design to meet the aesthetic needs of modern people, the specific design process is shown in the Figure 49.

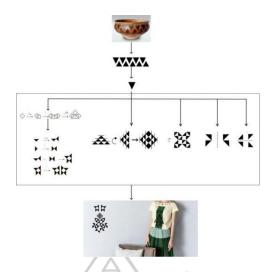


Figure 49: Banpo T-shirt design process based on shape grammar 2.7.4 Conclusion

From the above research, we can find that the use of shape grammar rules for product design or pattern design can better retain the characteristics of the original object. At present, how to maintain the characteristics of traditional patterns while improving its innovation has always been a problem in the design field. Therefore, this research will combine the shape grammar to explore how to innovate the caisson lotus pattern, so that it can be survived in the modern society.

Part 3: Analysis of the application status of Chinese traditional patterns in modern fashion design

2.8 The application status of Chinese traditional patterns in modern clothing design

Chinese traditional patterns have a long history of five thousand years. With the change of dynasties and the integration of different nationalities, they have gradually formed a broad, profound, unique and charming form and connotation with Chinese characteristics. Traditional patterns are loved by the public with their unique visual performance, distinctive traditional cultural characteristics, and auspicious cultural meaning. After thousands of years, it is still widely used in all aspects of social life, such as clothing, architecture, public art, home textile design, product design, packaging design, etc., fully embodying the unparalleled charm of traditional Chinese patterns, as shown in Figure 50 (Fan, 2014).



Figure 50: Modern application of traditional patterns

(Source: https://)

With the continuous development of contemporary clothing culture, clothing has evolved from basic needs and practical functions such as shame and warmth into a social and cultural phenomenon with deeper meaning. As Marilyn Horn said: "Clothing has the function of conveying personal social status, occupation, role, self-confidence, and other personality characteristics to others." Modern consumers pay more attention to the cultural function and aesthetic factors of the product itself. That is far-exceeded beyond the practical function of the product itself, and people are more seeking difference and uniqueness. People like to add their favorite cultural elements, totem patterns, and even photos of their relatives into their clothing to show their unique individual needs.

Among the various application elements in fashion design, the traditional Chinese pattern elements represented by blue-and-white are one of the most favored elements by contemporary designers. As early as 1952, French fashion master Mr. Dior has used blue-and-white porcelain elements to make a beautiful fashion interpretation.



Figure 51: Dior (1952)

(Source: https://www.sohu.com/a/335768714_272374) In 1984, Chanel took the blue-and-white elements as his design inspiration and designed a blue-and-white porcelain dress, called Porcelain Doll.



Figure 52: CHANEL (1984)

(Source: https://image.so.com/?src=tab_www?src=tab_www/?src=tab_image) Also in 1986, a blue-and-white porcelain dress by Valentino was equally amazing. This is a beautiful and unusual design even today. However, because blueand-white printing or embroidery requires complicated and meticulous craftsmanship to show its magnificence, it is destined to be a glimpse of haute couture dresses in the early years, and cannot cause international trends.



(Source: https://www.sohu.com/a/335768714_272374)

In 2005, Italian designer Roberto Cavalli launched a blue and white porcelain fishtail skirt evening dress and a short skirt at the press conference. At this time, the Western media did not realize the flow of this long skirt that was about to detonate. Until sometime later, Victoria Beckham wore this blue-and-white dress to attend Elton John's birthday party, and this perfect blue-and-white porcelain dress finally entered the public eye of the world.



Figure 54: Roberto Cavalli (2005)

(Source: https://www.sohu.com/a/335768714 272374)

Since Roberto Cavalli created the blue-and-white evening dress, various blue-and-white porcelain fashion products have been coming, from clothing to various lifestyle products. The "blue-and-white porcelain" fashion at the Spanish luxury Loewe 2008 spring and summer fashion conference, and even the 2008 Beijing Olympics Miss Etiquette costume also adopted blue-and-white porcelain elements as the dress design.



Figure 55: 2008 Beijing Olympic Games award dress (Source: https://petssky.com/life-29735/3) In spring/summer 2009, blue-and-white pattern of French fashion Dior appeared inside the white skirt.



Figure 56: Dior (2009)

(Source: https://www.sohu.com/a/335768714_272374) Chinese designer Guo Pei also used this element in the 2010 autumn and

winter high-end design. The pattern is a traditional Chinese element, and the silhouette is a complete Western dress silhouette.



Figure 57: Guo pei (2010)

(Source: https://www.sohu.com/a/335768714_272374)

With the maturity of printing and embroidery technology, blue-and-white porcelain elements gradually showed their youthful and people-friendly side on the T stage. Such as Rodarte 2011 spring and summer series: blue-and-white porcelain printed long skirt, with a waterproof platform wooden shoes, there is a kind of novelty. There is no blue pattern that is full of inlays, but the outline of the pattern

is drawn from the neckline to the waist, or the elegant feeling of flowing water swaying in the skirt and lining, which reminds people of the blue-and-white porcelain.



Figure 58: Rodarte (2011)

(Source: https://m.sohu.com/a/130214205_464365)

In addition to the blue-and-white patterns, the Chinese fashion brand "Legend of Gaia" 2019 Spring/Summer collection, incorporates Dunhuang mural painting elements into high-end dresses, and combines Chinese clothing skills to surprise the world in Paris. Xiong Ying, the designer of Gaia legend, integrates the extreme presentation of gorgeous clothes with the color elements, content materials and creative design of Dunhuang mural painting, forming a natural infiltration and interweaving. This has also attracted great attention from representatives of the international and Chinese Dunhuang academic circles, and praised that "The Legend of Gaia has led the way with color and built a bridge between the world's fashion capital and China's millennium civilization."



Figure 59: "Heaven Gaia" 2019 Spring/Summer Fashion Show (Source: https://k.sina.cn/article_1817587403_p6c562ecb02700map6.html) 2.9 Conclusion

Through the above research, it can be found that, at the current stage, traditional Chinese patterns have achieved a close integration with modern clothing. Chinese traditional patterns can be seen in many clothing brand designs and clothing exhibitions. This clothing culture is active in front of the public with a fresh attitude. Considering the actual situation, on the one hand, many domestic and foreign clothing brands are a little bit blunt in the use of traditional patterns in clothing, therefore the pattern lacks rhythm, and the form performance is not prominent. And this is a common problem in design now. Many of the extracted pattern elements are just copied to clothing, or some patterns are deleted or colors are changed, and there is a lack of innovative use of traditional patterns. Although some brands associate traditional patterns with modern urban sports and leisure style clothes and pop-style clothing designs, they still lack of creativity of patterns. On the other hand, the application of traditional patterns in modern clothing generally presents a two-dimensional planar decorative effect, basically with dyeing (tie-dyeing, batik), weaving, and embroidery (single-sided embroidery, double-sided embroidery, appliqué, etc.) This relatively flat method is mainly used.

In the field of fashion design, while the new technologies, machines, fabrics, and the aesthetic needs of people continuously emerge and change. The challenging question is why traditional patterns are still inherited and applied in traditional way. Why do embroidery, printing and dyeing, tie-dyeing, batik, weaving, etc., with huge handwork and relatively flat form need to continue and inherit in the same way? in the actual situation, although traditional Chinese patterns have been widely used in modern clothing design, the people who choose or favor these clothing are still a small group or older people who are regarded as culturally favorite consumer groups. The modern clothing with traditional Chinese patterns has not yet entered the mainstream people's vision, which also shows that this clothing design element is out of touch with the public's aesthetic values and requires more profound thinking.

Nowadays, the inheritance and promotion of my country's traditional culture has become a hot topic in the society, which has promoted more and more designers to devote themselves to exploring how to develop and apply traditional patterns in modern design (Liu, 2019). Traditional patterns need innovation, but innovation is not simply copying, but should meet the aesthetic requirements of the public living in a modern society for visual communication. And relying on the aesthetic taste of the public in modern society, absorbing advanced design concepts

and science and technology, keeping up with the trend of the times, so that the traditional patterns can show certain characteristics of the times while maintaining the original characteristics. It can be seen that exploring and researching the innovative application of traditional patterns in modern clothing design has very important practical significance.

Part 4: Origami Art

2.10 Definition of Origami

Definition: Origami is an activity in which flat paper is created into a threedimensional form by folding, flipping and inserting without cutting or pasting (Bolitho, 2017, PP. 6). Origami art is based on this idea to add creative artistic activities.

Normally, a flat paper has a front side and a back side. After repeated folding, the original front side will be hidden in the inside or back side of the folded three-dimensional shape, and then some new surfaces will be formed. Through the combination of front and back folding and lamination, the original surface will be replaced by the new surface, and so on, repeated this way, such folding, rearrangement and combination can often get unexpected surprises. The art of origami can allow people to use both hands and brains when performing origami activities, and obtain a sense of creative achievement and fun. The folk origami art has a long history and has a very broad group of fans. With the progress of the times and the development of science and technology, origami is not only a folk art activity, but also a subject with scientific research value (Meredith et al, 2017; Wu, Chen and Tsai, 2019).

2.11 Origin and development of origami art

Since the documents and unearthed cultural relics still have no exact records about origami, so far its origin has not been verified. Therefore, there are various opinions on the origin of origami, mainly including the three main schools of Chinese origin theory, Japanese origin theory and Spanish origin theory (Budinski, Sriraman and Lee, 2018). After that, origami has been developed in countries all over the world, combined with mathematics, natural sciences, and teaching theories to promote each other's development and research. In this process, many origami artists have been born, and they have made great contributions to the development of origami art.

2.11.1 Chinese origami art

The paper manufacturing technology originated in China. From the kindergarten, teachers teach their students that paper making is one of the country's four great inventions. Ancient paper is mostly used for calligraphy and painting art, and the output is not much, paper quality is not suitable for folding, so the paper used for folding is not recorded. On the other hand, other three-dimensional sculptures in China are very sophisticated. The craftsmanship, shape, and materials are extremely sophisticated, while the material of paper folding is difficult to be loved and valued by high-ranking officials. Therefore, the three-dimensional art of origami has always been a marginal art. And not get the attention it deserves (Xiu, 2019).

Historically, the art of origami did appear very early in China and spread far and wide. In some areas, every Ghost Festival, people make the custom of lighting river lanterns. The river lantern is folded from paper, often made into the image of a lotus. A lighted candle is placed in the heart of the flower. At night, the lantern is set by the river to express the thoughts of the dead relatives and friends. In some areas, during the Dragon Boat Festival, origami fish will be made and hung on the door with a red thread, expressing a kind of auspicious meaning of praying for a good harvest, and wealth. For many generations born in the 1980s, the paper airplanes, paper cranes, origami frogs, origami boats, origami windmills, and so on that they used to play when they were young are all contemporary manifestations of origami art.

However, these are just folk origami arts, and they have not formed a unique origami system. In the contemporary era, with the progress of the times and the development of technology, the most cutting-edge origami art in the world has entered China through the Internet, which has brought a strong impact on the art of origami to China. This art of perfect combination of heart, mind, and fingers has made young people in China realize that the art of Chinese origami must be revitalized and carried forward. Some first-tier cities have even set up professional paper art studios. In the period when paper art was at its most sluggish, they relied on their thin power to support the contemporary Chinese origami art. Now, the art of origami has begun to enter people's lives as a kind of interest-based art. Some cities have also opened origami art interest classes and established professional forums for origami art.

2.11.2 Japanese origami art

In 583 AD, ancient Japan did not invent or learn Chinese paper-making technology, and there was no way to produce high-quality paper. Buddhism was prevalent at that time. Because of missionary needs, Buddhist monks crossed the sea to travel to Japan to preach. Among the accompanying items were scriptures written on Chinese paper and a large number of high-quality papers that were cleanly used for writing travels. For the first time, Chinese paper traveled across the ocean to reach the island country of Japan. Because of its scarcity, these "imported" highquality papers are very expensive, so people take very good care of using them. For decades, Buddhist monks have used North Korea as a transit point for missionary work between Japan and mainland China. When the Korean monk Tan Zheng crossed to Japan in 610 AD, he not only brought with him various scriptures and Buddha's relics, but also advanced paper-making techniques. However, paper is still an expensive rare item that can only be used by the upper class. At that time, people folded these precious papers and used them to wrap gifts between each other as a way of ceremonial communication. This was the early origami. A mainstream view in the Japanese Origami School believes that the true sense of Japanese origami appeared in the Heian period (around 794 to 1185 AD). However, due to the age, there are no leftover works or documents.

Japan's Bushido culture is world-famous. In the Heian period, the custom of exchanging tokens was popular among samurai to prove their loyal friendship. The exchange was usually their own samurai sword and with an origami flower bundled with dried meat. Therefore, flower origami, a more complex origami technique, became a social communication skill during this period.

During the Muromachi shogunate era, the phenomenon of social hierarchy under the rule of the nobility was very obvious. In such a general environment, different types of origami were artificially identified as corresponding to different social classes, which gave origami art more political flavor (Zhu and Wei, 2015).

The earliest known written record of the art of origami appeared in the haiku of the poet Ihara Nishizuru in the Edo period (Xu, 2014). He wrote the words "male and female butterfly" in the haiku. The male and female paper butterflies are a kind of celebration utensils. Japanese Shinto nobles would decorate the mouth of the hip flask with male and female paper butterflies when celebrating their wedding. It is used to represent the bride and groom, praying that they can stay and fly like butterflies. This should be the earliest bionic origami art. The origami art of the Japanese tea ceremony, to some extent, endow fragile paper with a special purpose of safety insurance. They usually use specially folded paper to pack the tea ceremony master diploma. This kind of packaging is similar to the current one-time packaging principle. If you want to open the package, you can only destroy the original crease. Once you find that the paper package is damaged or the crease changes after opening, it means that it has been touched by someone. It has a very good safety insurance function.

During the Tokugawa shogunate era, the development of the paper industry made paper a cheap product "flying into the homes of ordinary people." The populace art of origami has emerged, and the art of origami has developed rapidly as a characteristic art culture in Japan.

In modern times, Japan's origami art level has made a breakthrough, and the biggest contribution is undoubtedly the world-recognized father of modern origami- Akira Yoshizawa. Since 1930, Akira Yoshizawa has continued to create origami, and has elevated the art of origami to an unprecedented level. Around 1950, Akira Yoshizawa created many breathtaking works. After the works were exhibited in some countries in Western Europe, they brought a full shock to the European origami art, inspired the passion and motivation of a group of people who love origami, and promoted the development and progress of European origami art. 1954 was a special year for the art of origami. In this year, Akira Yoshizawa published the first origami book "Origami Reader". It was also the year that the international origami society was established. Origami is no longer just popular in Japanese art culture, the derivative English word "origami" with Japanese "folding paper" as the pronunciation standard has become the international common vocabulary of origami art. Akira Yoshizawa's important contribution to the art of origami lies not only in the tens of thousands of origami patterns designed by him in his lifetime, but also in the establishment of a very complete set of graphic terms to regulate the art of origami. It has gradually become the international universal language of origami art. This universal language has broken the text and communication barriers of origami enthusiasts all over the world, greatly increasing the circulation of origami art, and it is still used all over the world.



Figure 60: Akira Yoshizawa

(Source: https://www.jianshu.com/p/8516507ede71)

The art of origami has become the quintessence of Japanese culture. It not only offers special origami courses in schools, but also holds an open origami contest every year to select outstanding origami artists and promote the development of origami art. A group of world-class origami masters have emerged. For example, the "post-80s" origami master Kamiya Satoshi, this genius origami player who has shown amazing talent since the age of 2 is well known in the world of origami art. Masterpieces such as "Dragon God", "Bumblebee", and "Horberis" have caused a huge sensation in the world.



Figure 61: Dragon God (Source: https://www.360kuai.com/pc/95e44eeaa3488bfc4?cota=4&tj_url=so_rec&sign=360_57

c3bbd1&refer_scene=so_1)

2.11.3 Western origami art

While the art of origami is booming in East Asia, the art of origami is also self-contained in the European continent on the other side of the earth, forming a European origami art with regional characteristics. Regarding the development of European origami art, the academic circles have different opinions, and the author agrees with one point: In 751 AD, the Anxi army of the Tang dynasty encountered an allied force of Arab and Central Asian states in a battle known as the Tantra Battle. The war ended with the tragic victory of the Arab Empire. The captive soldiers of the Tang dynasty were taken back to the Arab region to spread the paper art technology of the Tang dynasty in China, learned by the craftsmen in the Arab region, and then spread to the Moors (Muslims in North Africa).

In the 8th century, the Moorish invasion allowed origami to reach Spain at the southern tip of the European continent through the Strait of Gibraltar. Later, it gradually developed into a characteristic art of Spain and spread widely in Spain's vast colonies.

Since the beginning of the 19th century, the rise of natural science has injected new life into the art of origami. The art of origami has not only become a branch of the current geometric disciplines, it has also been applied to educational curriculum. Curriculum designers at the Bauhaus Institute use the art of origami and architectural design to teach students to understand the characteristics and character of materials: different fibers and different paper qualities form subtle or strong contrasts and changes, which are exercises, homework, and a fresh art form. Among the student homework during the Bauhaus period, there are many excellent paper art works that focus on the beauty and spiritual expression of the material itself. In addition, the German education master Froebel even proposed the use of origami for educational enlightenment. These have produced great impetus to the development of origami art.

In the middle of the 20th century, the application of origami art also appeared in magic performances. A very representative figure is the famous South African magician Robert Habin. His book "Magic of Paper" introduced the word "origami" to the West for the first time, and it had a great influence on both magic and origami (Li, 2006, pp. 166-168). He also naturally became the first president of the British Origami Association.

2.11.4 The rise of modern origami

Traditional origami art is relatively demanding on paper, and the effect of the finished product is very dependent on the accumulation of decades of experience by origami artists. Some traditional origami methods have been preserved from generation to generation. For some of the newly emerging object shapes, if you want to fold successfully, it often requires origami artists to accumulate experience from hundreds of failures to achieve success. Compared with traditional origami, modern origami art no longer adheres to traditional origami methods. It not only uses advanced computer technology, but also innovates in folding methods. With the development of material science, we are still trying to change the physical properties of paper and use other auxiliary materials to meet the ever-increasing requirements of origami.

In the 1990s, Robert J. Lang, an American laser physicist who worked at NASA, developed and designed a computer software for making complex origami designs - Tree Make. Robert is a veteran origami enthusiast. After having worked at NASA for 13 years, he resolutely resigned from this enviable high-end career in order to pursue the art of origami he loves without distraction. The Tree Make designed by Robert J. Lang can be said to fundamentally subvert the traditional origami art design method. It can use high-speed computing computers instead of manual work, and use mathematical models to calculate all the creases that you want to fold. At the same time, it can also simulate the correct folding sequence based on the matching physical model designed, as the result the art of origami has entered a new era.



Figure 62: Robert Lang works (Source: https://www.shouyihuo.com/view/9558.html)

2.12 Types of origami techniques

The folding technique is one of the most commonly used techniques in origami. There are other auxiliary techniques such as turning, rolling, and bending during the folding process. Due to the wide variety of origami techniques, this topic mainly focuses on the most commonly used folding techniques for origami. This research is based on the summary of the literature review. The classification of origami techniques is mainly divided according to the folding method, the folding content, and the folding geometric form.

2.12.1 Classified by folding method

(1) Straight-line folding

Straight-line folding method refers to the regular folding, from one direction in order to fold back and forth into a rectangle, the crease is in a straight state, and the width of the rectangle is determined according to needs. Straight-line folding is the most common and basic method of origami.



Curve folding technique is a processing method that uses the elasticity

and plasticity of paper to express the beauty of curved surfaces. The threedimensional shape expressed by the curve has a sharp contrast between light and dark. Its shape is characterized by a certain degree of curvature, rhythm, threedimensionality and modeling.



Figure 64: Curve folding (Source: Jackson, 2017, pp. 205)

(3) Broken line folding technique

The broken line folding technique refers to the straight lines and arcs repeatedly bending in accordance with a certain law. Draw regular, continuous parallel crease lines on the reverse side of the paper before folding, then fold in the positive and negative directions, fold the fabric into a corrugated shape. On this basis, repeated horizontal bending is performed to form an origami model with a strong three-dimensional effect.

Snake belly folding is a typical folding technique, named from the shape of the snake's belly. The basic method of snake belly folding is to draw regular, continuous parallel creases on the front and back of the paper, and then fold it in the front and back directions to form a valley. The advantage of snake belly folding is that the design is relatively simple, the folding method is strong, the horizontal and vertical, the design unit is easy to find on the paper, so it is relatively simple to change the position and length of the branch.

> Figure 65: Snake belly folding (Source: Jackson, 2017, pp. 245)

(4) Irregular line folding technique

Irregular line folding can produce two forms, namely creases and wrinkle. Crease refers to folding a new three-dimensional origami work with a twodimensional paper. If you spread the origami work, you will find that there will be various creases on the paper. Another form is to crumple the paper. After unfolding, there will be many irregular creases on the paper. Along a specific line or area, selectively open this wrinkled surface to expand it. Wrinkle refers to the process of compacting and kneading the paper into an uneven texture effect, forming random and natural lines.



Figure 66: Irregular line folding (Source: Jackson, 2017, pp. 204) 2.12.2 Classified by folded content

According to the folded content, it is mainly divided into imitation plants, imitation animals, and imitation items.

(1) Imitation plants

According to the image of plants in nature, using origami techniques can fold out the shapes of all plants, such as roses, sunflowers, lilies, tulips, poppies, dogwood, jasmine, lotus, morning glory and so on. When choosing plants as origami objects, direct imitation is often used to fold the shapes of plants.



(Source: https://image.so.com/?src=tab_www?src=tab_www) (2) Imitation animals

There are many origami shapes that imitate animals, mainly divided into animals in the sky, in the sea, on land, and ancient animals. The sample of animals in the sky are: eagles, bats, vultures, and sparrows, also including poultry animals like geese, ducks, chickens, etc.; the animals in the ocean are dolphins, lionfish, humpback whales, and octopuses; Animals on land include giraffes, elephants, stars, zebras; and ancient animals include brontosaurus, triceratops, stegosaurus, ankylosaurus, and tyrannosaurus. These animals can all be shaped by using origami techniques. Some imitating origami animals seem to be like real animals, and their fidelity is simply unbelievable, as shown in Figure 68.





(Source: Hoang Tiến Quyế works, https://www.sohu.com/a/295159123_534792) (3) Imitation items

Origami works of everyday items can be seen everywhere as the most common daily necessities. They are all both decorative and have practical functions, for example, envelopes , card brochures, snack boxes, wastepaper boxes, business card holders, tablecloths, paper fans, bowls, photo frames, etc. The imitated costume origami works are a common type of objects, such as shirts, hats, socks, ties, pants, necklaces, bracelets, etc. There are many kinds of toys, such as paper sailboats, paper airplanes, darts, paper windmills, paper slingshots, and paper masks, like American origami artist Joel Cooper works as shown in Figure 69. There are countless types of decorations, such as paper vases, paper chains, circular garlands, and flower-shaped bowls, and so on. These origami works of daily necessities can be seen everywhere in our lives, bringing more convenience to our lives.



Figure 69: Item origami

(Source: Joel Cooper works, https://image.so.com/?src=tab_www?src=tab_www) 2.12.3 Classified by geometric spatial form

Origami is essentially based on geometry, each crease is a line, and each folding step will form a geometric figure. Geometric folding is mainly divided into two folding methods: single geometric folding and sandwich geometric folding. Each step in the folding process will present a single geometric shape. The resulting geometric shape is the first step for the basic shape of the paper to enter the biochemical movement. According to the classification of geometrical space, geometric folding modeling can be divided into flat, semi-three-dimensional, and three-dimensional.

(1) Plane geometry

The plane geometric shape of origami only develops horizontally, without changes in depth, such as paper flying discs, paper leaves, envelopes, etc.



Figure 70: Plane geometric form (Source: Yosuke Hasegawa works, https://image.so.com/?src=tab_www?src=tab_www) (2) Semi three-dimensional geometry

A semi three-dimensional geometry is a form between a plane and threedimensional. During the folding process, it not only extends horizontally but also extends longitudinally. Semi-three-dimensional geometry is similar to plane geometry, and has a certain sense of three-dimensionality and volume due to volume fluctuations.



Figure 71: Semi three-dimensional geometry form

(Source: Yuko Nishimura works,

http://www.360doc.com/content/17/0403/12/38449423_642512669.shtml)

(3) Three-dimensional geometry

Three-dimensional geometric modeling has three-dimensional space: height, width, and length. It is multi-angled, and is also completely three-dimensional and independently shaped. In the folding process, the hardness of the material directly affects the effect of geometric folding modeling and the visual sense of appearance.



Figure 72: Three-dimensional geometric form (Source: Robby Kraft works, http://k.sina.com.cn/article_3175909014_pbd4c86960270093s3.html) 2.13 The application of origami art in fashion design Origami art is widely used in various fields of the design industry l

Origami art is widely used in various fields of the design industry because it has outstanding geometric characteristics, and irreplaceable position in both two and three-dimensional design fields. Particularly, in clothing design, the art of origami has been adopted and has an impact. Some designers use traditional origami techniques such as folding, pleats and fabrics with paper characteristics to explore the structural creativity and morphological changes of fashion. Abandoning the previous combination of various styles or components, breaking the inherent symbolic relationship between the overall structure and material of the previous clothing, and returning the old elements in a new way to form "origami clothing", these emphasize the overall sense and visual impact of clothing, inject extraordinary new ideas into the development of clothing, and bring an opportunity for industry development (Li and Wang, 2010).

The biggest feature of "origami clothing" is its sense of volume and sculpture. It is influenced by the minimalism that emphasizes the concept of rational, cold, and simple artistic style and the oriental style that emphasizes linear cutting. It also blends with the western narrow clothing culture, which makes the structure of the clothing creative. The fabrics are folded, stacked in an orderly manner, so that the two-dimensional fabric has a certain three-dimensional effect. Whether it is a thin, straight accordion-like folding, a folding in the same direction, or a staggered folding inside and outside, origami technique can make the original flat and simple clothing appear three-dimensional. The repeated details in the cascade give people a sense

of simplicity and elegance. In summary, the application form of origami techniques in clothing can be classified into two points: inventive clothing structure and decorative details.

2.13.1 Inventive clothing structure

Clothing structure mainly refers to the combination of the shape and structure of the style and the geometry of the various parts of the clothing. It is an important link in the transformation of clothing from flat to three-dimensional. Clothing design is like the structural design of buildings and bridges. It is not only closely related to modeling design, but also a creative design of a structural system based on modeling. It is based on the understanding and mastery of the regularity of human structure, especially for decorative garment structure design, if there is no basic understanding of human structure. It is impossible to have a reasonable and unique structural design. Relying on this basic understanding of the structure of the human body, the art of origami is introduced into the clothing, so that the fabric breaks the inherent structure of the clothing in the irregular folding, and overlapping. This original design has become the finishing touch of origami clothing (Zhao, 2019).

In fact, this type of clothing appeared as early as in ancient Greece. At that time, its wrinkles were still in the natural form, and they were very harmonious with the human body. The beauty of the clothing itself and the beauty of the human body are completely one with a natural feeling, the two-dimensional structure of the original flat cloth has also formed various three-dimensional structures along with people's wear. Later, layers were formed, so the western narrow clothing culture was effectively integrated to create the different styles and structures of clothing. The oil crisis in the last century caused an economic downturn in some foreign regions so that the public has a mentality of resistance to overly luxurious clothing. Even woman's clothing emphasizes no longer the beauty of lines but pays more attention to the convenience of production and life; after a while this concept became the main feature. At the time, a trend of "unstructured design" appeared in the fashion industry, focusing on the integrity and natural properties of fabrics. Traditional origami techniques such as folding, binding, winding, and draping were adopted to make the integrity of the fabric fit the curves of the human body. The structural features and expression methods in traditional origami art are exactly the inspiration and wisdom of such unstructured clothing such as "origami clothing". Some designers use this to pursue free creative space to create more personalized, tasteful and stylized design works. For example, the famous Japanese fashion designer Issey Miyake can be said to be a representative of the application of origami art to clothing design. In his work: 132.5 collection, the four numbers in the name of the series represent: 1 represents a whole piece of fabric; 3 represents three-dimensional body; 2 represents the folded two-dimensional shape; and 5 represents a new three-dimensional experience. This series includes a geometric pattern that can be stretched into shirts, pants, skirts and dresses. These flat patterns can be turned into a set of fashions at a glance, which is quite shocking. The entire series was completed by a team led by designer Issey Miyake, and the complex folding process was completed in collaboration with computer engineers. The three-dimensional shape formed by folding can be a single three-dimensional shape, and multiple separate three-dimensional shapes are interspersed and combined to form a new clothing shape structure. The effect of the gathering and combination of this group of three-dimensional folding forms has completely changed the basic structure of clothing, and the overall sense and threedimensional sense of clothing have been greatly improved. Through the repeated folding of a large area, a multi-level visual effect is formed. The unstructured design breaks the traditional fixed structure mode, abandons the simple combination of various styles or parts in the past, and combines the creative techniques of twodimensional plane and three-dimensional structure. Origami inspiration in fashion stresses a will-to-form rather than mere bodily proportion and structure, which explores a trans-extensity that goes beyond the boundary of the body (Yim, 2009). Create new shapes with brand-new structures, laying the foundation for the development of origami clothing art (Cai, 2009).



Figure 73: 132 5. Clothing collection

(Source: http://image.so.com/)

The designer Mauricio Velasquez Posada brought us a series of unique origami-style clothing, with bold outlines and tough lines that wrap the human body in it like an architectural structure. By stacking, diagonally, folding in half, folding again, pulling, and flipping the fabric, the original fixed structure mode of clothing is completely broken. Without waistline fitting and dart contraction, there are only architectural block surface structure and bright and tough lines, the designer's ingenious conception and bold innovative structure are jaw-dropping. The use of origami art in clothing design has made the structural design more diverse that not only breaks the traditional clothing structure, but also makes the clothing's functionality and visual aesthetics a perfect combination.



Figure 74: Mauricio Velasquez Posada works (Source: http://blog.sina.com.cn/s/blog_6981eb500100ka9v.html) 2.13.2 Decorative details

Applying the art of origami to clothing is not a simple imitation, but to abstract and generalize by absorbing the techniques and forms of origami. By folding and overlapping fabric, it replaces darts and cracks to carry out residual treatment and construction, which not only supports the structure, but also becomes the carrier of details and a special ornament in clothing. Tough and distinct lines, crisp and unique shapes combined with fabrics that can reflect the texture of paper and toughness, using the same direction, different directions, or interlaced inside and outside folding techniques, the clothing has an orderly or disorderly structure in the body, and gives people a meticulous, elegant, and lively impression. This origami effect has become an indispensable highlight in clothing.

Among the works displayed in Milan, Paris, London and other fashion weeks, some master-class design works obviously incorporate in the essence of oriental origami art. For example, the use of origami techniques such as valley folds, mountain folds, stretching, inward folds, and creases on the sleeves, collar, and other parts make the details of the work change endlessly.



Figure 75: Junya Watanabe works use origami technique (Source: https://www.sohu.com/a/413460142_500120/)

Lily seems to be the favorite of many fashion masters, Chapman is also great minds think alike. The origami lilies dotted on the chest complement each other with the wide folded skirt that resembles flowing water, combined with light purple stiff gauze fabric, embodying women, noble and elegant without losing the sense of beauty and playfulness.



Figure 76: Chapman origami lilies

(Source: https://huaban.com/pins/81171735/)

In 2007 Dior brand designer John Galliano (John Galliano) in the "Madame Butterfly" as the theme of the advanced customization conference, the creativity of the costumes embellished with oriental sentiment and origami details attracted our attention. Gray dress with two three-dimensional lilies inlaid on the waist, radiating from the waist down, which not only reflects the graceful and slender waist, but also creates an elegant dynamic feeling. The full skirt shape and the embellishment of lilies seem to remind us of the beauty, laziness and luxury of the Baroque period costumes.



Figure 77: Dior origami lilies (Source: http://shows.vogue.com.cn/dior/2007-ss-ctr/runway/)

2.14 Conclusion

As an important decorative technique and formal language, the art of origami has become more and more prominent in today's clothing design applications. After the designer broke through the conventional reference, using ingenious wisdom to inject this ancient oriental art into the fashion design. Through the innovation and elegant embellishment of the modeling structure, breaking the traditional clothing modeling structure, showing a broader design space for the design of clothing styles and structures. Origami inspiration in fashion stresses a willto-form rather than mere bodily proportion and structure, which explores a transextensity that goes beyond the boundary of the body. In the face of the increasing importance of originality, the art of origami undoubtedly provides designers with very good inspiration. This research will use the art of origami to explore how to transform the flat lotus pattern into three-dimensional costume structure.

Part 5: Virtual fitting technology

2.15 Overview of virtual fitting technology

With the advent of the "Internet +" era, a new generation of digital technology represented by virtual fitting has injected new elements into the design and development, effect evaluation, and pattern optimization of clothing products.

2.15.1 Definition

Virtual fitting technology is the product of the development of Internet human-computer interaction technology. Using the knowledge of computer science, materials science, art and other disciplines to construct the virtual human body model similar to the real user, by simulating the appearance and movement characteristics of the fabric, the effect of the movement between the fabric and the human body is rendered in real time, so that users can remotely observe the effect of their own clothing and realize the three-dimensional display of the clothing.

2.15.2 Application type of virtual fitting technology in the market

There are two main applications of virtual fitting technology in the market. One is the retail end, a "fitting room" for ordinary consumers to wear online and offline clothing.

With the rapid development of the Internet and the continuous improvement of living standards, in the field of clothing consumption, people have begun to pursue personalized clothing that meets their needs, and shopping channels have gradually favored intelligent and convenient online purchases. However, the new online shopping model also brings about a series of problems. For example, consumers cannot accurately judge whether the clothing fits comfortably on themselves, and purchases are blind and inaccurate. In order to enable consumers to have a more realistic fitting experience online, three-dimensional virtual fitting technology has emerged, Such as Canada's My Virtual Model, Britain's Fit-me.com, Metail and the United States' Fitiquette, and other mature fitting websites (An, 2014). Through the fitting simulation, consumers can intuitively see the wearing effect of clothing, thereby saving shopping time and energy, optimizing the shopping experience, and reducing the risk of return and exchange, that also meets the shopping needs of modern consumers (Lee and Xu, 2019). With the improvement of fitting functions, these fitting systems can create personalized human models, and some can also modify data such as skin color, hairstyle, body shape, etc., which enhances the authenticity and interest of interaction.

At the same time, in order to meet the upgrade of people's daily offline consumption experience services, the smart dressing mirrors placed in offline clothing stores provide consumers with a new experience service for offline "choosing, buying, and matching clothes". At present, many department store retail companies around the world have designed, produced and used this dressing mirror. It can measure body parameters in real time, feedback facial and other body dynamic characteristics in real time, and finally achieve a 3D simulated try-on effect. Through the data obtained from the test, customers can change from one style to another in a short period of time, freeing up the inconvenience of changing clothes in the fitting room.



Figure 78: Smart fitting glasses

(Source: https://image.so.com/?src=tab www?src=tab www)

The other is the production end. "sample room" for designers and clothing companies, the focus of function is to design and modify the pattern to obtain the best ready-to-wear effect also known as virtual clothing design. Virtual clothing design is to facilitate clothing designers to accurately and quickly realize the ideas in their minds on the computer through virtual technology, without having to make samples to see the three-dimensional effect (Porterfield and Lamar, 2016). According to a report by Salmon (2014), 3D virtual fitting technology lets apparel manufacturers produce far fewer physical samples for each garment beforehand, decreasing to two samples from the average of three to five that were needed formerly. Further, this technology can cut the total amount of time needed for designing and prototyping by an estimated 50%. Currently, several retailers, including Target, Kohl's, and Levi's, are successfully piloting the use of 3D virtual fitting technology to produce their garment samples (Salmon, 2014; Yoon, 2013). The clear benefits are that 3D technology offers both retailers and manufacturers "speed" and "lower overall costs." Therefore, 3D virtual fitting technology can not only shorten the production cycle and save production cost, but also enable products to enter the market as soon as possible to form a good rapid response, better highlight the fashion characteristics of clothing, take into account the protection of design patents, and reduce enterprise risks. With the development and promotion of virtual reality technology, a variety of virtual clothing design software has been launched. The most common software used to design virtual clothing on the market mainly includes V-Stitcher developed by Gerber, Runway 3D developed by PGM, Moders developed by Lectra, and CLO3D developed by CLO (Yuan and Bae, 2017; Shin and lee, 2020). Different virtual clothing design software has different advantages and disadvantages. Designers can choose the most suitable design software according to the specific requirements of virtual clothing design to assist in completing the corresponding virtual clothing design tasks in order to achieve the best design effect. **2.16 Introduction of CLO3D virtual fitting software**

The research of this thesis is based on the CLO 3D software of South Korea's CLO Company, which is a relatively excellent 3D virtual clothing design and development software. The software's operating interface includes a pattern window and a 3D virtual display window to display 2D clothing patterns and Three-dimensional clothing virtual effects, as shown in Figure 79. It can well realize the mutual transformation of three-dimensional modeling and two-dimensional plane pattern. The garment structure, which is difficult to be displayed by two-dimensional plane, is presented through virtual sewing technology. It can effectively check the accuracy of the two-dimensional clothing structure. The clothing pattern can be adjusted in two windows to achieve the effect of dressing.



Figure 79: CLO 3D operating interface

The virtual clothing design process works based on CLO3D as: First, create a human body model and parameterize the human body model. The initial human body model can be based on the actual size of the human body, and subsequent changes can be made according to the change of the human body size. Second, make a pattern. CLO software has its own pattern drawing function to create patterns on a two-dimensional window or on human body model. At the same time, patterns drawn by other pattern drawing software can be imported and applied. Third, sew the virtual clothing. In the two-dimensional pattern window, drag the piece to the part corresponding to the three-dimensional model, and select the free sewing tool to sew the plate in turn. After carefully checking the sewing thread, click the simulation tool to try on the three-dimensional clothing. You can drag the garment with your hand to adjust. Then use the gripper to adjust the clothing effect. Fourth, the choice of fabrics for virtual clothing. Add the required fabric to the object window, adjust the basic properties such as texture, color, transparency, and then adjust its strength, tension, density, drape and other physical properties, then test, and simulate the reality of the fabric to achieve a realistic three-dimensional effect. Fifth, the final dynamic or static display of virtual clothing design effects. The clothing 3D virtual technology can carry out 360° multi-view static display and dynamic catwalk display of clothing. Static display can make preliminary judgments on clothing, designers, technicians, customers, etc. can observe from different angles, evaluate the advantages and disadvantages of the design more comprehensively, and make timely corrections. Dynamic display can more comprehensively present the texture and overall dressing effect of clothing. Different from the real fashion show, the virtual dynamic display does not need to consider the constraints of the space environment and material conditions, which not only saves the high cost of hiring professional models, but also saves a lot of manpower and material resources required to plan the fashion show.

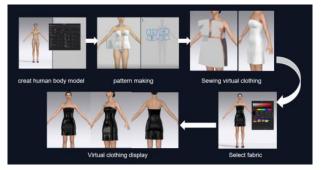


Figure 80: Clothing design process based on CLO 3D platform

2.17 Application status of virtual clothing design technology

In recent years, with the rapid development of computer technology, its application in the clothing design industry has continued to deepen, and due to the impact of the coronavirus epidemic, the discussion of virtual clothing in the clothing industry has also begun to heat up. The clothing industry has suffered huge losses and many fashion shows have been canceled. They urgently need new ways to present their clothing.

On April 7, 2019, Wenzhou University held a virtual simulation fashion show. This is an online and offline exclusive industry and customer technical service product created by team members to replace real-world fashion shows. This has practical significance and application value for the transformation and upgrading of the clothing industry.



Figure 81: Wenzhou University virtual fashion show (Source: http://xyw.wzu.edu.cn/info/1010/4173.htm) Fashion brand Hanifa broadcasts a virtual fashion show on Instagram Live on May 22. Each piece of clothing appears in 3D against a black background, as if invisible models are wearing them while walking on the fashion show runway. When social distancing made traditional fashion shows impossible, this high-tech approach allowed it to cause a sensation in the fashion industry.



Figure 82: Hanifa fashion show (Source: http://sohu.com/a/412207569 184351)



Figure 83: Current virtual clothing type

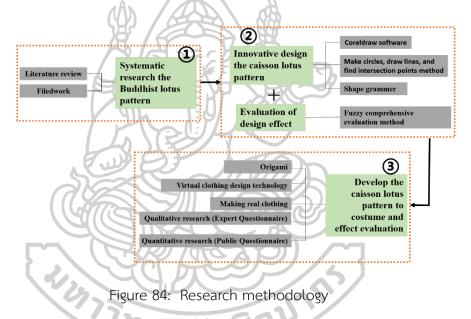
2.18 Conclusion

Although the current development of virtual clothing design technology is very fast, very good results have also been achieved. However, at present, virtual clothing design are mainly carried out on flat and simple ready-to-wear garments such as skirt, dress, pants, shirt and so on (Wan, Tie and Shi, 2017; Sabina, et al, 2014; Song and Ashdown, 2015; Yan and Kuzmichev, 2018). These garments are relatively close-fitting, with a more common style, symmetrical structure, and conform to the human body. It belongs to the garments that can be fitted according to the arrangement points of the garment pieces in the CLO3D system. So far, lack of application to some clothing with three-dimensional structures and exaggerated shapes. Therefore, this research will combine virtual clothing design technology to display the effect of this research costume collection. So as to explore the key technologies and methods to realize the virtual expression of three-dimensional modeling clothing, improve the feasibility of virtual clothing design, and promote continuous innovation of clothing design methods.

Chapter 3

Methodology and process

The research is a practice-based, in chapter 2 have systematically researched the Buddhist lotus pattern through literature review and field trip method. For this chapter will focus on the research methodology and processes too. It is consists of two parts, the first part include innovative design process of the caisson lotus pattern base on shape grammar and the method for evaluation the design effect, the second part is develop new lotus pattern to costume by origami art and virtual fitting technology, and the method for evaluation the development effect.



Part 1 Innovative design process of the caisson lotus pattern and the method for evaluation lotus pattern innovative design effect

3.1 Design analysis.

This part serves as an analysis of the information about the lotus pattern available from Chapter 2. The process started from conducting further research on the 86 pictures of the caisson lotus pattern related to this research, and this includes the use of making circles, drawing lines, and finding intersection points method to analysis the structure of the lotus pattern, and then summarize the types of lotus pattern structure and laws of drawing the lotus pattern. The existing research on the caisson lotus pattern is mainly to analyze and summarize the origin, classification, characteristics, and cultural connotation of the lotus pattern. Even some well-known researchers who did a lot of imitation work on the content of Dunhuang frescoes did not provide information about the lotus pattern structure. Through the collection and collation of the well-known artists such as Chang Shana, Duan Wenjie, Yang Dongmiao and other imitation pictures of the caissons in Mogao grottoes, 86 pictures of caisson lotus patterns were collected. It includes 56 flat-petal lotus, 5 curly-petal lotus, 1 peach-shaped petal, and 23 Baoxiang flowers. The image of the round lotus is blurred because of its old age as the result details of its pattern cannot be identified. Therefore, the structure of the round lotus is not explored in this research.

3.1.1 Structural analysis of flat-petal lotus

Take the 401 caisson lotus as an example, using CorelDraw software to make circles, draw lines, and find intersection points to elaborate the lotus pattern structure analysis process, as shown in Figure 85.

Step 1: Connect the petal point AB and point CD with a ruler, and the two lines intersect at point O. Draw a circle with O as the center and OA as the radius. At the time, you can see that almost all the points of the petals are on the circumference.

Step 2: Draw three concentric circles in the flower center with O as the center.

Step 3: First copy the line segment AB, then rotate the line segment AB by 45 degrees and 90 degrees respectively to get the line segments EF, GH. The ends of these two line segments just fell on the points of the petals. As can be seen from the Figure 85, the points of the petals are located on the eight equilateral points of the outermost circle.

Step 4: Combine the line segments AB, CD, EF, GH, and copy, and then rotate 22.5 degrees, you can see that the copied line segments fall on the junction of petals and petals. It can be seen from the figure that each petal is located at one eighth of the circle formed by the outermost circle and the adjacent circle.

Step 5: Copy the outermost circle and zoom to point J. As you can see from the Figure 85, the red line segment and the red circle produce intersection points. And these intersection points are the key points of petal modeling, from which the two petals are separated, and the ends of the petals are modeled with arcs.

Step 6: Connect the key points formed by the red line segment and the red circle to points A, C, H, F, B, D, G, and E to form the petal structure line.

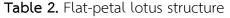
Step 7: Copy the outermost circle and scale to the intersection point K of blue petals and white petals. It can be seen that the intersection points of blue layer petals and white layer petals are on the blue circle. By using the protractor to measure the angle MOK is 10 degrees, it can be seen that the point K is the intersection point of the line segment OM rotated 10 degrees counterclockwise and the blue circle. Point N is the intersection point of the line segment OM rotated clockwise 10 degrees and the blue circle. Similarly, the intersection point of the blue petals and the white petals are all obtained by rotating the red line 10 degrees. Then connect these intersection points with the intersection points of the red line segment and the outermost circle, respectively, to form a blue petal structure. As shown in the blue petal structure diagram.

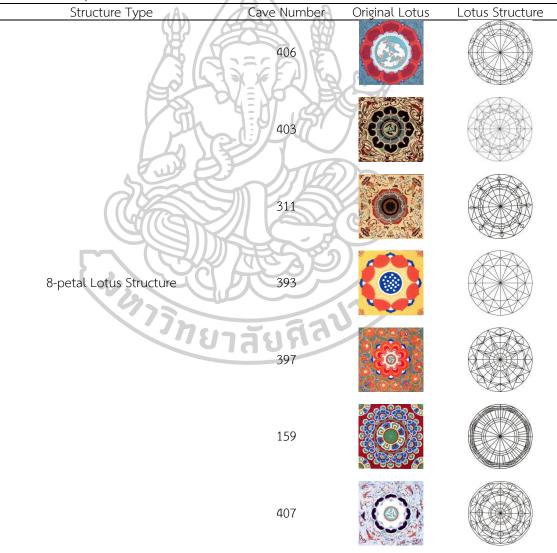
Step 8: Remove the auxiliary lines in the picture to get the structure diagram of the cave 401.

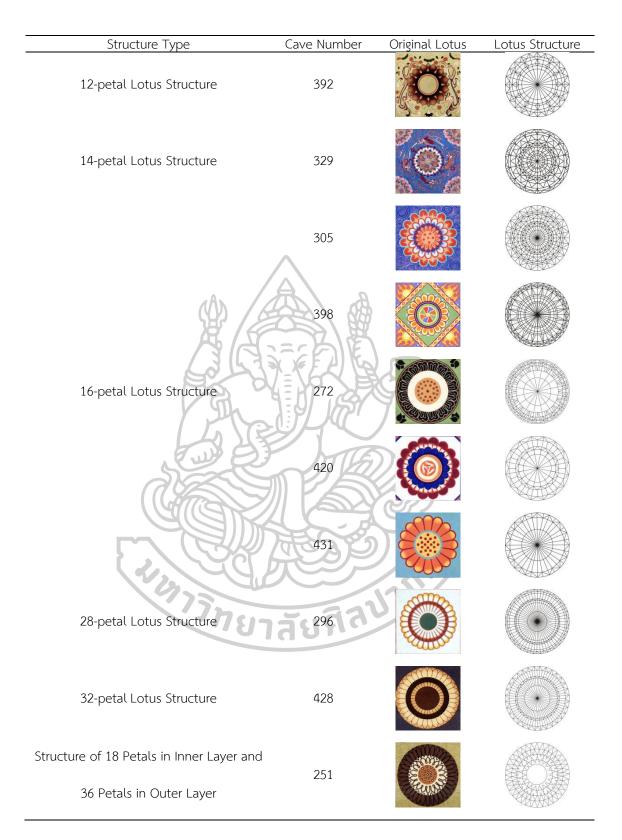


Figure 85: Analysis process of flat-petal lotus structure in cave 401

According to the above method, the structure analysis of other 55 flatpetal lotus was carried out. After summarizing the structure of these 56 flat-petaled lotus, it can be concluded that the flat-petaled lotus are divided into two types: the number of inner and outer petals are equal and unequal. The lotus structure with the same number of inner and outer petals has 8 petals. In the 8-petal lotus, there are different structures because of the different petal layers, such as the cave 406, 403, 311, 393, 159, 407, 397, etc. 12 petals like the cave 392, 14 petals like the cave 329, 16 petals like the cave 305, 398, 272, 431, 420, etc. 28 petals are like the cave 296, 32 petals are like the cave 428, the lotus structure with unequal number of inner and outer petals is the cave 251 (outer layer 36 petals, inner layer 18 petals), 462 (outer layer 16 petals inner layer 32 petals), and 249 (outer layer 32 petals inner layer 16 petals), as shown in Table 2.







Structure Type	Cave Number	Original Lotus	Lotus Structure
Structure of 32 Petals in Inner Layer and	462		
16 Petals in Outer Layer	102		
Structure of 16 Petals in Inner Layer and	249		•
32 Petals in Outer Layer			

From the analysis of the flat-petal lotus structure, it can be concluded that for the lotus structure with the same number of inner and outer petals, the main structure of the petal is to obtain equal petals by dividing all the circles in the structure equally. Commonly there are 8 equal parts, 12 equal parts, 14 equal parts, 16 equal parts, 28 equal parts and 32 equal parts. For the petal shape, it is formed by connecting the intersection points of the structure line that bisects the circle and the circumference. For lotus structures with different numbers of petals in the inner and outer layers, the method is the same as above, except that the number of aliquots on different layers varies. Then, each petal is distributed in an equal area, and the petal shape is drawn with bisector as the axis of symmetry. It is also in this way to draw the petal shape, which makes every petal the same, finally, each layer of petals is divided with a circular line, so the flat petal lotus pattern, whether simple or complex, gives a balanced and symmetrical character in the overall shape.

3.1.2 Structural analysis of curl petal lotus

First, take the cave 85 caisson lotus as an example, using CorelDraw software to draw, to elaborate the structure analysis process of curl petal lotus. The cave 85 lotus has 3 layers, the layer near the heart of the flower is 12 curl petals, as shown in Figure 86.

Step 1: Connect the gap points between the petals with a ruler, as shown in the AB and CD line segments, and then draw a circle with the intersection point O of these two line segments as the center and OA as the radius. At the time, the petal ends are all on the circumference.

Step 2: Then copy the line segment AB and rotate 30 degrees, 60 degrees, 90 degrees, 120 degrees, and 150 degrees respectively. It can be seen from the

Figure 86 that the rotated line segments just fall at the junction between petals and petals, which also shows that this volume petal lotus also divides the circle by 12 and each petal falls in this division.

Step 3: The circle is then copied and scaled at the point of the petal and the central white area, the points of the petals are on the circumference.

Step 4: Then the line segments in the figure are combined, copied, and rotated by 10 degree. The 12 points of the petals almost all fall on the line segment after rotation, that is, the points of the petals are on the 12 equilateral points of the second layer circle. The intersection point between the green line segment in the sector AOC region and the second layer circle is set as E.

Step 5: Connect the points A, E and C in a straight line, then the broken line AEC formed is the structure of curl-petal lotus.

Step 6: Connect the key points of other petals according to the method of step 5 to form the petal structure of the lotus petal.

Step 7: Copy the outermost circle, scale to the position where the petal color changes, and then copy and rotate the black line segment by 15 degrees to get the blue line segment, finally, connect the point where the color changes and the intersection of the blue line segment and the circle to form the internal structure. According to the above method, the internal structure of other petals is obtained.

Step 8: Remove the auxiliary lines and circles to get the curl petal lotus

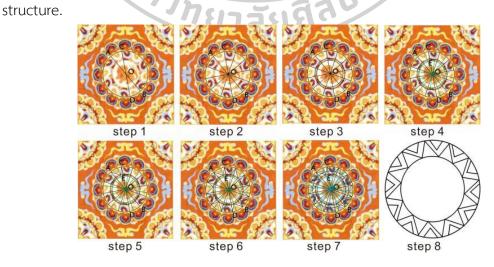
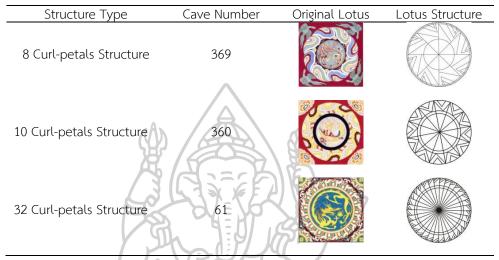


Figure 86: Analysis process of curl petal lotus structure in the cave 85

According to the above method, the structure analysis of the other three curl lotus petals is carried out. After summarizing the structure of these 5 lotus petals, we can see that the lotus petals are divided into 8 petals such as the cave 369, 10 petals such as the cave 360, and 32 petals such as the cave 61.

Table 3. Curl petal lotus structure



From the analysis of the structure of the lotus petals, it can be seen that the lotus petals also obtain the modeling area of each petal by equally dividing the circle, common petals are divided into 8, 10, and 32 equal parts. Because the number of equal parts of the circle is different, the width of the petals is different. At the same time, the smaller the number of equal parts, the more the lotus petals curled toward the heart of the flower, showing a bud shape, as the number of petals increases, the petals move away from the heart of the flower and appear in full bloom. In addition, all the points of the petals of the curled petals are biased to a certain angle in a clockwise or counterclockwise direction, which causes the optical illusion of petal rotation.

3.1.3 Structure analysis of peach-shaped petal lotus

The peach-shaped petals are the early form of Baoxiang flower. In the collected lotus images, only the cave 205 is named peach-shaped petal. This article takes this as an example and uses CorelDraw software to elaborate the structure analysis process of peach-shaped petal lotus, as shown in Figure 87.

Step 1: Connect the points of the symmetrical petals with straight lines, and the line segments AB and CD intersect at point O, then draw a circle with O as

the center of the circle and OA as the radius to get the structure. It can be seen from the Figure 87 that all the petal points are on the circumference.

Step 2: Copy the circle, then scale to the center of the flower, copy the line AB and rotate 45 degrees and 135 degrees to get the structure. The rotated line segment just fell on the position of the other four petals, from which we can see that the four curled petals are located in the quarter of the outermost circle.

Step 3: Copy the outermost circle and scale to the point of the outer decorative petal, then stretch the two line segments at the decorative petals to the points of the petals to obtain the structure. It can be seen from the figure that the other four decorative petals are located at 4 equal parts of the circle.

Step 4: Observe the petal structure and scale the circle at the critical turning point of the petal shape, then connect the points where the petals and the circle intersect in a straight line to obtain the outer contour structure of the petals, for the details of the interior decoration, the general modeling structure frame is also obtained by this method.

Step 5: Draw the other three petal structures according to this method.

Step 6: In the same way, the outer contour structure of 4 decorative petals is obtained.

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Step 7: Remove the extra lines and circles to get the lotus petal structure.

Figure 87: Analysis process of peach-shaped petal lotus structure in the cave 205 From the structure of the 4-petal lotus in the cave 205, it can be seen that its structure is to divide the circle into four quarters, and the cusps of the petals fall on the four quarter points. The petal shape area is located in the four quarters of the circle, and the overall structure is cross-shaped. Then rotate the cross structure by 45 degrees and extend it to obtain the outer decorative petal area. Using this structure line as the axis of symmetry, draw 4 axisymmetric petals of the same shape, thus forming % structure.

3.1.4 Structural analysis of Baoxiang flower

Drafting with CorelDraw, caisson lotus of the cave 321 as an example, using CorelDraw software, to elaborate on the analysis process of Baoxiang pattern structure, as shown in Figure 88.

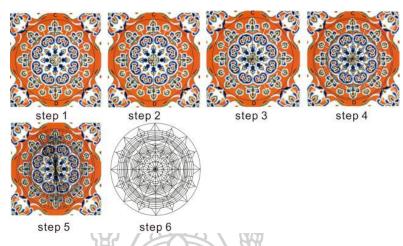
Step 1: First, the sharp points A, B, and C, D of the outermost large petals are connected in a straight line, the two straight lines intersect at point O, and draw a circle with OA as the radius. It can be seen from the figure that the sharp points of the outermost large petals are all on the circumference.

Step 2: Duplicate the line segment AB and rotate it by 45 degrees and 90 degrees respectively. The rotated line segments fall on other petals, and the petals are symmetrical structures with this line segment as the axis of symmetry. At the same time, the second layer of petals closer to the center also takes this line segment as the axis of symmetry, and the four petals in the center take two of the perpendicular line segments as the axis of symmetry.

Step 3: Combine these 4 line segments, copy and rotate 22.5 degrees to get the effect shown in Figure 88. It can be seen from the figure that the eight small petals in the outermost layer are all on the line segment, and the petal has a symmetric structure with the line segment as the axis of symmetry. The 8 petals adjacent to the outer petals are also symmetrical structures with these four lines as the axis of symmetry.

Step 4: Duplicate the outer circle and scale it at the highest and lowest points of each petal. The petals are in the area of these two rings.

Step 5: Duplicate a line segment and place it at the critical turning point of the petal shape, and then connect the point where the circle and the line intersect to obtain the outer contour of the petal.



Step 6: In the above way, get the shape of other petals and remove the extra lines.

Figure 88 : Analysis process of Baoxiang flower structure in the cave 321

According to the above method, the structure analysis of other Baoxiang flower patterns is carried out. The structure of the Baoxiang flower pattern has a lphastructure such as the cave 373. The center is a cross structure formed by four quarters, and then the outer two layers are also four quarters. But one of the cross structures rotates by 22.5 degrees, and the diameter of the circle is smaller than the outer layer, so it forms a 米 structure. There is also a center of 8 equal parts, the outer layer is the 米 structure, such as the cave 79. 6 equal parts structure like the cave 197, center is 6 equal parts structure, the outer layer is to replicate and rotate the six equal parts structure by 15 degrees to form a 12 equal parts structure. The center is divided into 8 equal parts, and the outer layer is divided into 16 equal parts, such as the cave 123, 31, 381. 8 equal parts such as the cave 171, each layer of petals is an 8 equal parts structure, which is emitted from the center to the outer layer. The center is divided into 4 equal parts, the internal 8 equal parts, and the outermost 16 equal parts, such as the cave 319 and 331. The center is divided into 4 equal parts and the outer layer is divided into 8 equal parts such as the cave 321. The cave 335 with 8 petals in the center and 7 petals in the outer layer.

Table 4. Baoxiang flower structure

Structure Type	Cave Number	Original Lotus	Lotus Structure
米 Structure	373		
Center is 8 Equal Parts, Outer Layer is the 米 Structure	79		
6 Equal Parts Structure	197		
	123		
	31		
8 Equal Parts Structure	381		
	171 ยาลัยที่		
Center 4 Equal Parts, the Internal 8 Equal Parts, and the Outermost 16 Equal Parts	319		
	331		
8 Petals in the Center and 7 Petals in the Outer	335		

From the above analysis of the structure of the Baoxiang flower, it can be seen that the structure of the Baoxiang flower pattern is complex and diverse. The center has a cross structure formed by four quarters, there are also 6 equal parts structure, 8 equal parts structure, from the center to the outside, the number of petals in each layer is rotated on the basis of the center structure and formed by superposition, the number of equal parts becomes 2 times or 3 times of the center. Finally, a radiating structure from the center to the outside is formed. Under the circular radiation, the petals of each layer are interlocked, and the inner and outer petals are shifted left and right. The shape of the petals is on a central axis, and the pattern tends to be gorgeous. The shape of the outer contour changes with the shape of the petals or is rhombic or circular.

3.1.5 Summarize structure types of caisson lotus pattern and laws of drawing the lotus pattern

From the above analysis of the structure of the lotus pattern in the Mogao grottoes, it can be seen that the lotus pattern structure has a cross type, four equal parts pattern, this model maintains a stable and quiet sense of simplicity. Then, turn it by 45 degrees on the basis of four equal parts to form an eight equal parts radial structure. When the radius of the rotating cross structure is reduced, the 米 structure is formed. Rotating 22.5 degrees on the basis of 8 equal parts structure can form 16 equal parts structure, and so on to form 32 equal parts structure. The structure of 8 equal parts, 16 equal parts, and 32 equal parts are all based on the cross structure of 4 equal parts, so they are unified into 4 equal parts. In addition to the 4 equal parts structure, there are also the 6 equal parts structure, as well as the 12 equal parts structure and the 24 equal parts structure formed on the basis of the 6 equal parts structure, which are uniformly classified as the 6 equal parts structure. There are also 7 equal parts structure and 14 equal parts structure obtained by rotating once, and 28 equal parts structure obtained by rotating 14 equal parts again, unified into 7 equal parts structure. There are10 equal parts structure, as shown in Figure 89. The 18 equal parts and the resulting 36 equal parts are unified into 18 equal parts. Therefore, the caisson lotus pattern structure can be summarized into 4 equal parts, 6 equal parts, 7 equal parts, 10 equal parts and 18 equal parts, as shown in Figure 89.

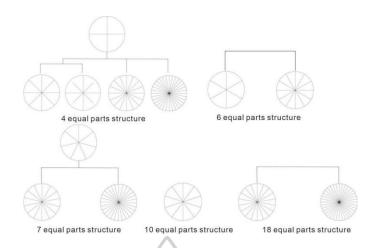


Figure 89 : Structure types of caisson lotus pattern

Through the above process of obtaining the lotus pattern structure by "making circles, drawing lines, seeking intersection points", it can be seen that the drawing of the lotus pattern is firstly obtained by equally dividing the circle to obtain the number of petals, and the bisector is the axis of symmetry of the petals. Then by using copy and scale command the outermost circle, draw multiple concentric circles, the non-overlapping part of adjacent concentric circles is the modeling area of each layer of petals. And when finish one petal then just use the copy and rotate command can get others petals. So, can summarize that the laws of drawing the lotus pattern are copy, scale, and rotate when use CorelDraw software for drawing lotus pattern.

The structure of flat petals, curl petals and peach-shaped petals is simple, the number of petal layers is 1-3, and the number of petals of Baoxiang pattern is up to 10 layers, the overall shape is layered, complex and rich. At the same time, in the process of analyzing the lotus pattern structure by "making circles, drawing lines, seeking intersection points" methods, the lotus pattern was geometrized and a large number of geometric lotus patterns were obtained, providing materials for the subsequent application of lotus pattern.

3.2 Lotus pattern innovative design based on shape grammar.

This part is based on the shape grammar for the innovative design of the caisson lotus pattern which were selected 50 out of 86 lotus pictures. First, the lotus pattern structure is used as the initial shape, and use the drawing laws of lotus

pattern obtained in the previous part and add delete commands as evolution rules to innovate design the lotus patterns.

With the development of the traditional cultural revival movement, more young people began to pay attention to the return of traditional culture, and more and more traditional patterns appeared in the design of modern cultural creative products (Ma and Yu, 2018). A large number of cultural and creative products related to the caisson lotus pattern have appeared on the market today. And the impact of "fashion culture" and the changes in the aesthetic needs of modern people have made it impossible to meet the changes in people's aesthetic needs by simply copying, mechanically replicating, and rigidly designing lotus patterns. How to balance the relationship between the two, we need to start with the characteristics of the lotus pattern, combined with modern innovative design methods, evolved a large number of new features that meet the needs of the times; not only retaining the characteristics of traditional lotus patterns, but also have distinctive features of the times. For the design of traditional patterns, how to retain the characteristics of traditional patterns while improving their innovation has also been a problem in the design field. In the existing design methods, shape grammar is a form deduction method, which not only can extract the modeling features, but also can carry out the modeling form deduction design on this basis, and is famous for generating a product design plan with a continuous style.

According to the theoretical study on shape grammar in Chapter 2, in order to retain the structure characteristics of traditional lotus pattern, this research uses the lotus pattern structure as the initial shape, and selects the drawing laws of lotus pattern and add delete rule as the evolution rules to evolve the lotus pattern, as shown in Figure 90.

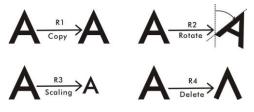


Figure 90: Evolution rules

According to the above shape grammar evolution rules, the structure of the lotus pattern of 50 caves is evolved by using them individually or in combination with several rules. Take the lotus pattern of the cave 401, 407 and 249 as an example to show the evolution process in detail, as shown in Figure 91. The effect of the lotus pattern of other 47 caves after evolution is shown in Appendix A.

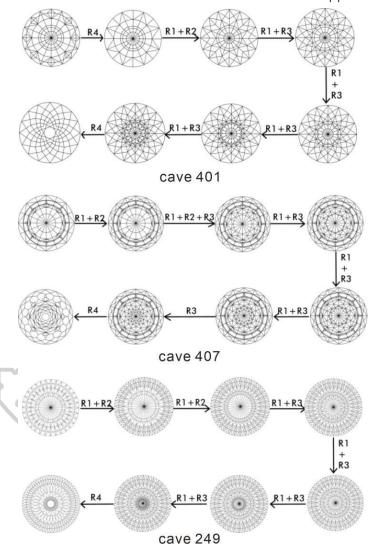


Figure 91: Evolution of lotus pattern based on shape grammar

It can be seen from the evolution results of the lotus pattern structure, using the traditional lotus structure as the initial shape, applying shape grammar, and repeatedly using evolution rules such as copying, rotating, scaling, deleting, and any combination of these rules to obtain innovative patterns. Under the evolution of shape grammar rules, the lotus structure becomes interesting and unique. Although the overall structure has changed, it evolved on the basis of the initial structure, so the evolved pattern not only gives people a fresh feeling, but also has a familiar feeling because of the characteristics of the initial structure.

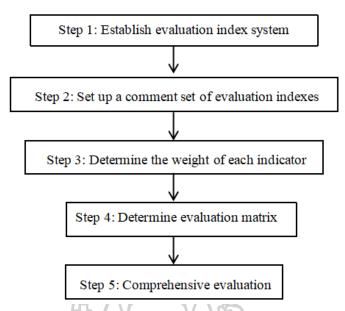
3.3 The method for evaluation lotus pattern innovative design effect.

In this part, in order to evaluate the innovative design effect of lotus pattern more objectively and reasonably, combined with the questionnaire survey of experts and college students, the fuzzy comprehensive evaluation method is adopted to verify the feasibility of the innovative design method of lotus pattern proposed in this research.

In order to verify whether the lotus pattern designed by shape grammar can meet the needs of modern consumers, at the same time, qualitative and quantitative analysis of design effects, this research combines the characteristics of lotus pattern and selects a fuzzy comprehensive evaluation method to evaluate the new lotus pattern.

Fuzzy comprehensive evaluation (FCE) method is a comprehensive evaluation method based on fuzzy mathematics which aims to comprehensively evaluate the membership of the objective to different grades. Fuzzy refers to these concepts that their boundaries are not clear, for instance, good, bad, high and low (Yu et al, 2020). The fuzzy comprehensive evaluation method is derived from Fuzzy sets theory proposed by Zadeh in 1965 (Zadeh, 1965). In this theory, everything is a matter of grade. In other words, the truth value is not either completely true or completely false. Instead, the truth value varies between completely true, and completely false, both inclusive. In fuzzy mathematics, the degree to which an element belongs to a specific set is known as membership. Fuzzy comprehensive evaluation method has the characteristics of clear results and strong systematicness, fuzzy and qualitative problems can be converted to quantitative problems and quantifies some factors with unclear boundaries which are difficult to be quantified from qualitative research (Tang, 2019). There are mainly five steps to use the FCE method:

The evaluation process of lotus pattern using fuzzy comprehensive evaluation method is as follows:



First, in the form of face-to-face interviews and questionnaires, 5 experts with design background were asked to evaluate 50 new lotus patterns. The specific questionnaire design is in the Appendix B. Then, according to the expert's scoring situation, the 10 highest-scoring lotus patterns are selected as evaluation samples, as shown in Figure 92.

Combined with the design features of the lotus pattern, the evaluation index is set as: $E = \{E1, E2, E3... En\}$, (n = 4). According to the five preference scales, the review set is V = {V1 = very good, V2 = good, V3 = generally, V4 = bad, V5 = very bad}. Then using experts scoring method to determine the evaluation weight of each evaluation index of lotus pattern design, W = {0.3, 0.2, 0.3, 0.2}, the details are shown in Table 5.

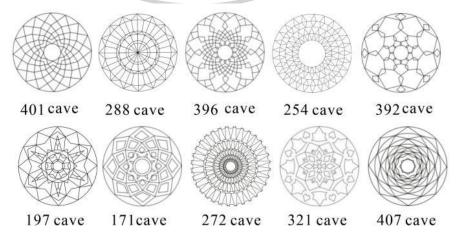


Figure 92: Evaluation samples

	· · ·		
Evaluation	Evaluation Index Description	Evaluation Weight	
Index	Evaluation index Description		
E1	Innovative, unique, in line with the modern	odern 0.3	
	aesthetic		
E2	Shape neat, harmonious, with melody	0.2	
E3	Both traditional characteristics and innovation	0.3	
E4	Suitable for use in modern products	0.2	

Table 5. Evaluation index description and evaluation weight of lotus pattern

According to the evaluation indicators in Table 5, an online questionnaire was prepared and distributed to 116 college students, the questionnaire design is in the Appendix C.

3.4 Summary

By using the method of making circles, drawing lines, and finding intersections, which used for drawing Islamic geometric patterns, to analyze the caisson lotus pattern structure, and obtain the types of caisson lotus pattern structure are five, in the process of analyzing the lotus structure; the lotus pattern is also geometric. Then apply the shape grammar to the innovative design of the lotus pattern, for the selection of the initial shape. This research changes the traditional method of directly using the typical features or elements of the pattern as the initial shape, and instead use the geometric lotus structure as the initial shape and combine the copy, rotation, scaling, and deletion rules to evolve the lotus pattern to obtain a series of new lotus patterns.

Part 2: Develop new lotus pattern to costume by origami art and virtual fitting technology, and the method for evaluation the design development effect.

Following the design and development was a process to apply caisson lotus pattern and the folding techniques of origami to create costumes and use virtual clothing design technology to display the overall effect of clothing. Finally, the design effect is evaluated by making real clothing, so as to verify the feasibility of the method of applying the lotus pattern to clothing, and the key technology and method of virtual expression of three-dimensional clothing in this research. The procedure were consist of inspiration and sketch, the design and implementation process of virtual clothing, which include create a virtual model, pattern making, virtual sewing, set fabric properties, virtual clothing static and dynamic display. Finally, the design effect is evaluated, and the effect of lotus pattern applied to the clothing and the virtual clothing design effect are evaluated respectively by making the real clothing. The design development process is shown in Figure 93.

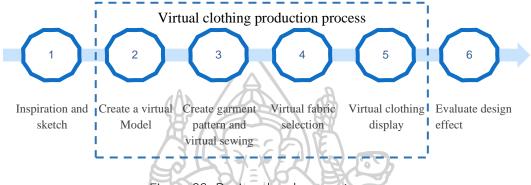


Figure 93: Design development process

3.5 Inspiration and sketch

Select pattern, color, inspiration forms, and sketch

3.5.1 Select pattern

In this research, lotus patterns ranked top 5 in fuzzy comprehensive evaluation in chapter 3 were selected and developed to woman's clothing. These 5 patterns are respectively the patterns after the innovative design of the cave 272, 288, 197, 254, and 407, as shown in the Figure 93 below.

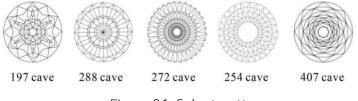


Figure 94: Select pattern

3.5.2 Color

White color is used in this costume collection. The first reason is the symbolic meaning of lotus. Lotus has always been respected as the holy and pure flower of Buddhism. Chinese also like the purity of lotus. For example, in the very famous poem "The love lotus say", the author strongly praised the lotus growing out of silt, but it still maintains its own purity. In china, the lotus is known called qing lian

(青莲), which has the same pronunciation with Chinese character "清廉". The term " 清廉" is used to warn people to be like a lotus, in the official career, you must be a pure and upright officer, don't associate with evil person. Among the colors, white represents holiness and purity.

The second reason is Japanese graphic designer Kenya Hara explained that white denotes "emptiness." Emptiness doesn't mean "nothingness" or "energy-less", rather, it indicates a condition, or kizen, which will likely be filled with content in the future. On the basis of this assumption, the application of white is able to create a forceful energy for communication (Hara, 2010, pp.36). And in Thailand artist Sone Simatrang paper, he also proposed that white color can give out the dreamy, imaginative feelings, thoughts, understandings and beliefs more effectively than true color (Pattanapitoon, 2012, pp.9)

Therefore, white will be mainly used in clothing collection. Of course, when people see white clothing works, they can easily understand the origami technique used.

3.5.3 Inspiration form

The design inspiration for the form of this series of works is mainly from origami works and the works of costume designers, and part of it comes from sculpture works and architectural forms.

The word "origami" plays an indispensable role in our childhood memories. Starting from our knowledge of paper, parents will tirelessly teach us origami, such as fans, five-pointed stars, and paper cranes, boats, airplanes, etc. After repeated manual folding, a piece of seemingly ordinary paper can be "transformed" into a three-dimensional object through different methods, which left a very deep impression on me as a child.



Figure 95: Children origami

(Source: https://image.so.com/?src=tab_www?src=tab_www) Secondly, the works of some origami artists, such as those of Matthew Shlian, are full of geometric charm. Behind their beautiful origami patterns, there are mysterious mathematical logic. Through precise mathematical calculations, the flat white paper is folded into an incredible rich dimensions.



Figure 96: Matthew Shlian works

(Source: http://www.333cn.com/shejizixun/201852/43495_146978.html)

The works of some well-known fashion designers have inspired me, such as the fashion designers Rei Kawakubo and Issey Miyake, who are known for their flexible application of deconstruction. Their costume modeling breaks the traditional design mode and designs unprecedented new concept clothing, which is worth learning.



Figure 97: Issey Miyake works

(Source: https://image.so.com/?src=tab_www?src=tab_www)



Figure 98: Rei Kawakubo works

(Source: https://image.so.com/?src=tab_www?src=tab_www) 3.5.4 Sketch

With the continuous progress and development of today's society, too much material is around people's lives, giving people the feeling of overwhelming and dazzling, causing people in this period to return to the simple and concise surrounding environment as their pursuit and love. Many people advocate "minimalist life" and pursue "minimalist style". They pursue simplicity in many aspects, such as material, social, speech, etc. "Minimalist style" has been applied to many fields of beauty and design. It is a lifestyle that many people love and a design concept that many corporate brands are keen on. In today's fashion world, the minimalist style has always been loved by fashion designers and consumers. They express their pursuit of beautiful things with their own characteristics, focusing on the unity of minimalist style and inner application. Therefore, minimalist style clothing still plays an extremely important role in many clothing styles in the 21st century. In view of this background and the design of this collection, first use decomposes, simplifies and reorganizes methods to get a new simple lotus shape, and then combines the origami technique to apply to modern woman's clothing to achieve different spatial forms of clothing, and then form new clothing modeling and styles.

(1) Sketch no.1

The front modeling of this set of works mainly draws on the skeletal structure form of the innovative pattern of the cave 272. First, simplify the design of the middle part of the pattern, and only retain the shape characteristics of the edge of the pattern. Then the diamond structure extracted from the geometric pattern of the cave 254 is regularly arranged in the middle of the pattern to form a new and relatively simple pattern. Then combined with the sculptures and the shape of the folding fan, the circular pattern is split into two semicircular shapes, and the linear folding technique is used to form a semi-dimensional shape, which is decorated on the waist of the human body shape. The overall body adopts a tube top-style tight skirt shape, and is decorated with regular organ pleats above the chest.

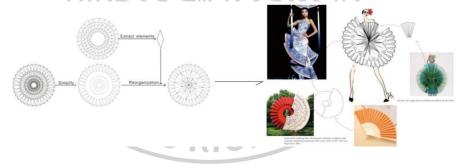


Figure 99: Sketch no.1 design process

(2) Sketch no.2

The upper body of this set is a tube top composed of 3 layers of regular pleats. The lower body is inspired by the innovative pattern for the cave 197. First extract the diamond-shaped elements from the pattern, and then reorganize the diamond-shaped elements to form a new pattern. Combining some threedimensional origami works and the shape of clothing, the pattern is made into a three-dimensional diamond shape by folding, and the left side of the skirt is decorated with regular pleats.

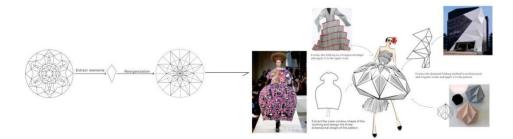


Figure 100 : Sketch no.2 design process

(3) Sketch no.3

The inspiration comes from the lotus pattern of the cave 254, which is already very simple, so applied it directly. Combining the folding and stretching features of the origami organ lantern and the shape of other origami works and clothing, the pattern is divided into two layers of different sizes. The upper layer fits the human body more and highlights the feminine shoulders. The lower layer adopts a wide structure to cover the feminine characteristics, and the lower hem is decorated with fishtail-like regular pleats, thereby adding fun to the overall clothing.

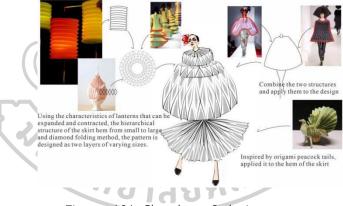


Figure 101: Sketch no.3 design process

(4) Sketch no.4

This set is applied from the geometric lotus in the cave 288, mainly uses the method of decomposition and disintegration for application. First, extract a triangle with a positive direction and an inverted direction from the pattern, and then combine them into irregular figure. Combining with the shape and design ideas of other clothing, the irregular figure is designed as three-dimensional shapes and decorated on the models' shoulders. Finally, 4 layers of organ pleats are designed to decorate the skirt. When the model walks, it produces a beautiful sense of moving and static.

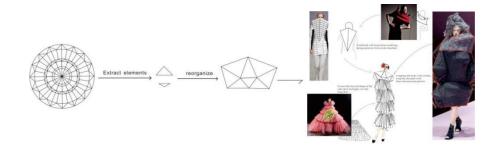


Figure 102: Sketch no.4 design process

(5) Sketch no.5

This set mainly applies the pattern after the innovation and evolution of the lotus pattern in the cave 407. First delete the shape in the center of the pattern, and use folding technique to make the remaining part of the pattern into a cloak-like three-dimensional shape. The neck and hem are decorated with regular pleats. The expansion of the pattern part and the compression produced by the regular pleats make the whole set of clothes have harmonious and unified aesthetic characteristics.



Figure 104: The overall effect of costume collection

3.6 Virtual clothing making process

3.6.1 Experiment with paper for finding out the folding technique

In order to the better show of clothing design effect, before making clothing, the proper paper must be chosen firstly to experiment to find the folding method used in some parts of the clothing.

Choose a thicker sketch paper to experiment. The tools used are scissors, compasses, rulers, etc., as shown in the Figure 105.



Figure 105: Tools used in the experiment

Sketch no.1 was experimented with paper, and the pattern folding process obtained was shown in the Figure 106. First draw the pattern, use different colors to distinguish different lines, then fold the black lines first, as shown in the second step. After the folding is completed, the effect is as shown in the third step, and then the blue line is folded as shown in the fourth step, the folding effect is the fifth step in the figure, and the red line is finally folded as shown in the sixth step, the folding effect is as shown in step 7.



Figure 106: Pattern folding process of sketch no.1

In sketch no.1, the folding process of the pleat of the fan-shaped edge is as follows in 107. First draw a rectangle and divide it into small rectangles of equal size, as in step 1, and then fold rectangle 1 to rectangle 2 according to the line between rectangles 1 and 2 as the fold line, as shown in step 2. Similarly, use the line between rectangles 3 and 4 as fold lines, and fold rectangle 4 to rectangle 3, as shown in step 3, and so on, fold rectangle 7 to rectangle 8, as shown in step 4, fold the rectangle 10 to rectangle 9, as shown in step 5. Follow this method to continue to fold to the desired length, and the final folding effect is shown in step 6.

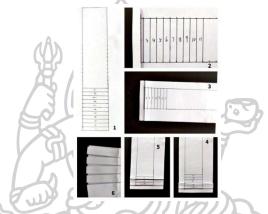


Figure 107: Pleat folding process of fan-shaped edges

The experiment process of sketch no.2 three-dimensional modeling with paper is shown in the Figure 108. First draw the pattern of the upper part of the sphere, and mark the fold lines with different colored pens, as shown in the first step. Then first fold the black line, as shown in the second step, after the folding is completed, the effect is as shown in the third step, and then cut off the circle at the center, as shown in the fourth step. Fold the red line as shown in step 5, the effect after folding is step 6, and then fold the green line as shown in step 7, the effect after folding is step 8, and finally fold the blue line in the figure step 9, the folded effect is the 10th step. Draw the lower part of the spherical pattern, as shown in step 11, follow the folding method of the upper part of the pattern, and get the folding effect as shown in step 12. Finally, the upper and lower parts of the sphere are spliced, as in step 13, the effect after splicing is shown in step 14.

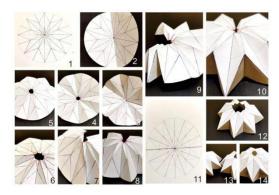


Figure 108: Three-dimensional modeling part of the paper experiment process of

sketch no.2

Sketch no.3 three-dimensional modeling part of the experiment process with paper as shown in Figure 109 below. First draw the pattern as shown in Figure step 1, and then use the diameter of the circle as the fold line as shown in step 2 to fold. After all, the inner diameters of the circle are folded, the effect is shown in step 3. Then, fold a circle of black lines close to the center of the circle. The folding method is shown in step 4, and the effect after folding is shown in step 5. Then, fold the adjacent red lines as shown in step 6, and the folded effect is shown in step 7. Fold the blue line and the red line according to the method of folding the black line, and the effect after folding is shown in step 8, 9. Fold the blue straight line again, the effect after folding is shown in step 10. The same method is used to fold the green line, black line, the effect after folding is shown in step 11, 12, 13 and the final three-dimensional pattern effect is shown in step 14.

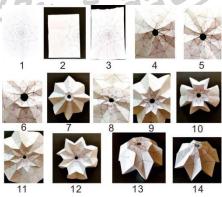


Figure 109: Three-dimensional modeling part of the paper experiment process of sketch no.3

Sketch no.4 uses paper for the experiment process as shown in Figure 110 below: First draw an irregular figure as shown in step 1, fold the zigzag line 1, and the effect after folding is shown in step 2. Then fold line 2 inward, the effect is as shown in step 3, the same as the folding method of line 1, fold line 3, the effect is as shown in step 4, fold line 4 outward, the effect after folding is shown in step 5. Fold another irregular figure in the same way, and then stitch the sides of the two figures as shown in step 6. After the two sides are spliced, the effect is shown in step 7.



Figure 110 : Three-dimensional modeling part of the paper experiment process of sketch no.4

Sketch no.5 mainly adopts the method of curve folding. The specific experiment process with paper is as follows in Figure 111. First draw a rectangle, then select a point on the upper side of the rectangle and connect it with a point on the lower side, and then connect this point on the lower side with another point on the upper side, and so on, and finally form a jagged line, as shown in step 1, first fold line 1, as shown in step 2, then fold line 2, as shown in step 3, and finally fold line 3 to line 2, as shown in step 4. According to this method, continue to fold, and finally get the folding effect as shown in step 5.

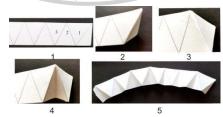


Figure 111: Curve folding process of sketch no.5

3.6.2 Virtual clothing production process

(1) Create a human model

The human body model is the main body of virtual clothing. The corresponding human body model should be established according to the needs of

clothing styles, materials and other elements. Its size and posture are particularly important in the virtual display of clothing (Liang and Zhang, 2015). Choose a female virtual model that comes with the system, select the model's body shape according to the needs in the virtual model editor, adjust the model's shoulder width, bust, waist, hip and other size data to obtain a female model that meets the requirements. A standard body model with a height of 175 cm and a bust circumference of 84 cm was chosen for this research.

In order to present the best clothing effect, the model is adjusted to the action of opening the arms to show the front part of the clothing. Finally, select the appropriate skin, hair type and shoes for the model according to the desired effect, and complete the steps of establishing the human model.



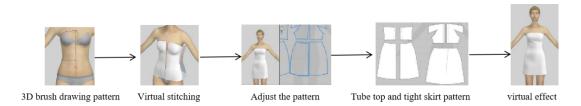
(2) The virtual clothing production process

This article directly uses the CLO3D software's pattern making function and virtual stitching technology to obtain the pattern and stitched effect of each part in the garment.

Sketch no.1 virtual clothing production process

A.The production of tube top and tight skirt

For tight-fitting tube top skirts, use the 3D brush tool to directly draw the pattern on the virtual model, then choose Fabric_matte as this sketch fabric, set its color as white, then perform virtual stitching, according to the effect of virtual stitching, and at the same time combine the two-dimensional pattern window to continuously adjust the pattern, until the 3D display effect meets the requirements, select the fabric properties, set the thickness of the fabric to 0.5cm, the roughness to 50, and the reflection intensity to 15. Finally get the tube top and tight skirt pattern and virtual effect, as shown in the Figure 113.





B. Pleat production

The pleated pattern is made in the 2D pattern making window. First draw the rectangle, divide it into 15 small rectangles of equal size, and select the same fabric as tube top, then sew it at the waist line according to the pleated stitching method. Because the fabric is soft, part of the fabric collapses on the body, and then adjusts the properties of the pleated fabric to increase the diagonal bending strength of the yarn to 99 and the deformation strength to 0, thereby improving the stiffness of the fabric. Then adjust the pattern width and pleat shape according to the sketch no.1, and finally get the pleat pattern and the virtual effect of pleats, as shown in Figure 114.

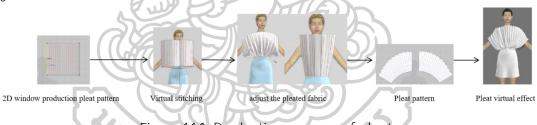
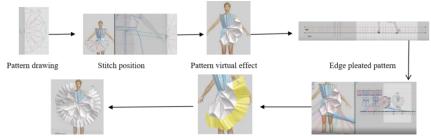


Figure 114: Production process of pleat

C. Fan-shaped production

First draw the pattern at the center of the fan in the 2D window, then set different folding strengths and folding angles for the structure lines of the pattern according to the folding method obtained in the paper experiment, and take a section of the fan-shaped center point and stitch it on the center line of the skirt, the stitching position and virtual effect after stitching are shown in the Figure 115. To make fan-shaped edge pleats, first draw rectangles and divide them equally, follow the pleat sewing method and stitch them on the edge of the center semicircle. Then adjust the fan-shaped, copy and paste to get the other half of the fan-shaped, the final effect is shown in the Figure 115.



Fan-shaped virtual effect after adjustment Fan-shaped virtual effect before adjustment Pleated and semi-circular edge stitching

Figure 115: Production process of fan-shaped D. Adjustment and display of the final virtual effect

Finally, according to the clothing display effect and aesthetic needs, adjust the fan-shaped center pattern again. Redesign the shape of each petal from the original wide to slender shape, the effect is shown in the Figure 116. Reset the folding strength, and simply adjust the overall shape, and finally get the pattern and virtual static effect of the whole set of clothing as shown in the Figure 117, 118.

In order to fully express the effect of clothing fitting, dynamic display can not only show the function of clothing more comprehensively, but also enable the wearer to fully experience the effect of fitting. In CLO3D, the software has a catwalk video recording function. You can select the catwalk action that comes with the software for video recording according to your needs, or you can set the catwalk action by yourself in combination with other animation software. Because of the particularity of the costume modeling in this research, it is combined with other animation software to make the catwalk action. The specific process is to first export the virtual model from CLO3D, then bind the human model bones in mixamo, then perform action synthesis in cinema 4D, and finally import the human model with catwalk actions into CLO3D to record the catwalk video. Figure 119 show the clothing effect when model walking.



Figure 116: Pattern shape after adjustment

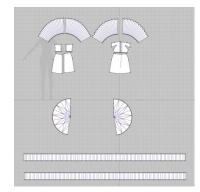


Figure 117: Sketch no.1 clothing pattern



First use the 3D brush tool to draw a tight-fitting tube top on the model, then choose the same fabric as sketch no.1, and perform virtual stitching, according to the effect of virtual stitching, the pattern is continuously adjusted in combination with the two-dimensional pattern window to obtain the final effect of the tube top. Then draw two lines parallel to the waist line on the tube top, these two lines and the waist line are used as the position of the pleated stitches, select the pleating method to sew, and fold it inward by 270 degrees. Follow the same method to make three layers of pleats, and then according to the design effect, readjust the pleats, the final virtual effect and pattern of the pleats are shown in the Figure 120.

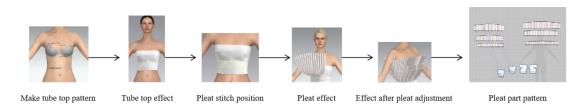
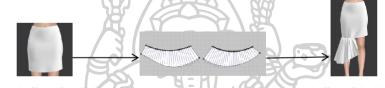


Figure 120: Production process of pleats

B. Make lining skirt and hem

The lining skirt is made according to the hip skirt pattern in Sketch no.1, directly imported into the pattern, and virtual stitching. Draw the hem pleated pattern in 2D pattern window, and stitch with the hem of the skirt, finally get the virtual effect of the skirt and hem, as shown in the Figure 121.



The virtual effect of the lining skirt Hem pleats pattern The virtual effect of the lining skirt and hem

Figure 121: Production process of lining skirt and hem

C. Make three-dimensional pattern

First, perform virtual stitching according to the sketch and clothing style drawings, and the effect after stitching is shown in the Figure 122.

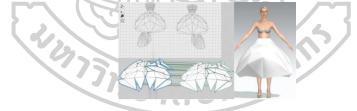
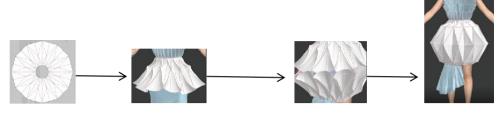


Figure 122: First virtual effect of the three-dimensional pattern

However, from the perspective of the aesthetic requirements of virtual clothing, the aesthetics of the three-dimensional pattern is insufficient. Therefore, the virtual design of the three-dimensional pattern is re-designed. The detailed process is as follows:

Draw the pattern in the 2D window to get the upper half of the threedimensional pattern, then adjust the folding strength of the pattern structure line to get the folded effect. Copy the upper half of the pattern as the lower half of the pattern, and virtual stitch with the upper half part, after stitching, continue to adjust the pattern and folding strength to get the virtual effect as shown in the Figure 123.



Upper part pattern The virtual effect of the upper part Pattern virtual stitch Virtual effect

Figure 123: Production process of three-dimensional pattern

D. Adjustment and display of the final virtual effect

According to the clothing display effect and aesthetic requirements, the overall shape and folding strength are adjusted again, and finally the pattern and virtual static effect of the whole set of clothing are obtained as shown in the Figure 124, 125. And created a catwalk video, the Figure 126 shows the clothing change effect when the model walking.

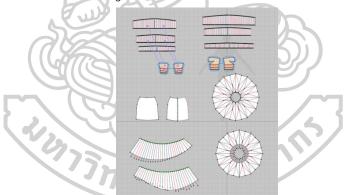


Figure 124: Sketch no.2 pattern

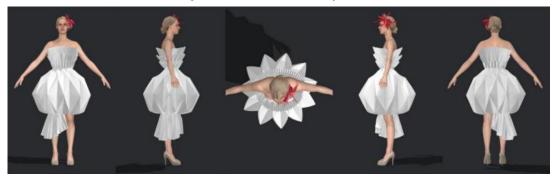


Figure 125: Sketch no.2 static effect



Figure 126: Sketch no.2 dynamic effect

Sketch no.3 virtual clothing production process

A. Make upper wear with three-dimensional pattern shape

The three-dimensional pattern modeling part is divided into three layers. First draw 1/4 part of the first layer pattern, then copy and paste to get the first layer pattern, and perform virtual stitching, use the pattern structure line as the folding line, set the folding strength to 5 and the folding angle between 120 and 320. Draw 1/4 part of the second layer pattern, copy and paste to get the second layer pattern, perform virtual stitching and adjust the folding attributes same as the first layer pattern. Draw 1/4 part of the third layer pattern, copy and paste to obtain the third layer pattern, perform virtual stitching and adjust the folding attributes, set the folding attributes, set the folding strength to 5, and the folding angle between 90 and 320. In order to prevent the three-dimensional shape from collapsing, a pressure of 1N is applied to the entire three-dimensional pattern shape and the strength of the fabric yarn is increased, the final virtual effect is shown in the Figure 127.

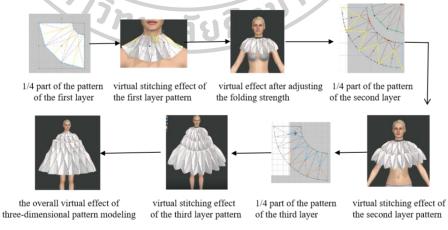


Figure 127: Production process of upper wear with three-dimensional pattern shape

B. Make hip skirt and pleat

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Use the 3D brush tool to draw the hip skirt pattern directly on the model, then constantly adjust the pattern according to the sketch. Draw the pleat pattern at the hem in the 2D window, and according to the pleat stitching method, stitch it on the hem of the hip skirt. The virtual stitching effect is shown in the Figure 128.

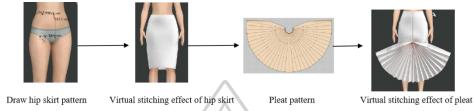


Figure 128: Production process of hip skirt and pleat C. Adjustment and display of the final virtual effect

According to the aesthetic requirements of the sketch and virtual clothing, adjust the first layer of the three-dimensional pattern modeling, and the modified pattern is shown in the Figure 129. Then re-virtual stitching and adjusting the overall costume model, the final virtual static effect and clothing pattern are shown in the Figure 130 and Figure 131. And combined with other 3D software to make catwalk videos, dynamically display the overall effect of clothing, and intercept some of the dynamic pictures, as shown in the Figure 132.

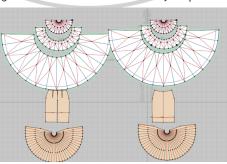


Figure 129: Modified first layer pattern

Figure 130: Sketch no.3 pattern

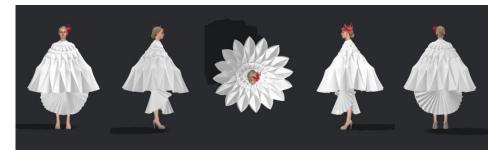


Figure 131: Virtual static effect of sketch no.3



Figure 132: Virtual dynamic effect of sketch no.3 Sketch no.4 virtual clothing production process

A. Make three-dimensional modeling on the shoulder

In the 2D pattern window draw pattern, and choose the fabric Fabric_matte for virtual stitching, and then set the inner line of the pattern to different folding angles and strengths to get the virtual effect. Combined with the sketch, continue to adjust the pattern and set the folding strength of the structural line to 5, and the folding angle to be between 120-270, and finally get the virtual effect as shown in the Figure 133.

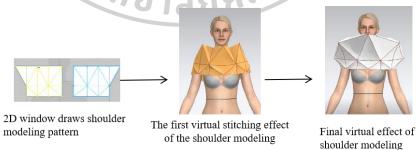
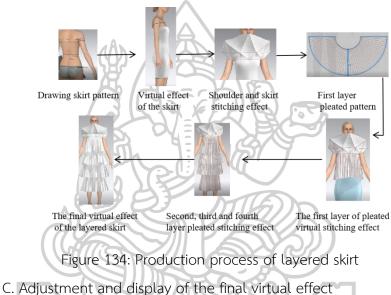


Figure 133: Production process of three-dimensional modeling on the shoulder

B. Make layered skirt

First use a 3D brush to draw the pattern of the skirt on the model, according to the fit degree, constantly adjust the pattern. Then stitch the skirt and

shoulder modeling together, in the 2D window, draw the first layer of organ pleats, and then stitch it with the skirt according to the pleat stitching method. Copy the first layer of pleated pattern as the second, third, and fourth layer pattern. The method is the same as that of the first layer of pleated. Sewing it on the skirt, finally, adjust the distance between the pleated layers and the folding angle of the pleated layers, set the inward turning angle to 300 and the fold angle to the outside is set to 60, and the virtual effect of the final layered skirt is obtained as shown in the Figure 134.



According to the aesthetic requirements of the sketch and virtual clothing, make simple adjustments to the overall model of the clothing to get the final virtual static effect and clothing pattern as shown in the Figure 135,136. And combined with other 3D software to make catwalk videos, dynamically display the overall effect of clothing, and intercept some of the dynamic pictures, as shown in the Figure 137.

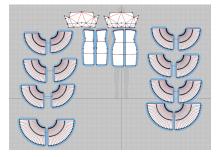


Figure 135: Sketch no.4 pattern



Figure 136: Sketch no.4 virtual static effect



Figure 137: Sketch no.4 virtual dynamic effect Sketch no.5 virtual clothing production process A. Making hip skirt and pleat hem

The pattern of this set is made with ET garment pattern making software, and then imported into CLO 3D software. First drag the pattern to the model's hip according to the displayed arrangement points, then select Fabric-Matte fabric as the hip skirt fabric, perform virtual stitching. Place the pleat under the hem of the hip skirt, and select the pleat stitching method to stitch it on the hem, adjust the strength of the pleat fabric yarn to improve the stiffness of the fabric. The final virtual effect is shown in the Figure 138.

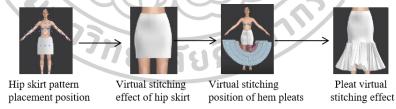


Figure 138: Production process of hip skirt and pleat hem

B. Making upper wear with three-dimensional patterns

According to the imported upper wear pattern, place it in the corresponding position of the model, choose the same fabric as the hip skirt for virtual stitching, then adjust the pattern of the collar according to the sketch, follow the pleat method to stitch, and adjust the folding angle according to the effect. Then adjust the pattern of other parts of the upper wear and the folding strength of the folding line. Finally, the virtual effect of the upper wear are shown in the Figure 139.



The placement of the upper wear pattern

Upper wear virtual effect

Collar pattern

Collar virtual effect Upper wear virtual effect

Figure 139: Production process of upper wear C. Adjustment and display of the final virtual effect

According to the aesthetic requirements of the sketch and virtual clothing, make simple adjustments to the overall model of the clothing to get the final virtual static effect and clothing pattern as shown in the Figure 140,141. And combined with other 3D software to make catwalk videos, dynamically display the overall effect of clothing, and intercept some of the dynamic pictures, as shown in the Figure 142.

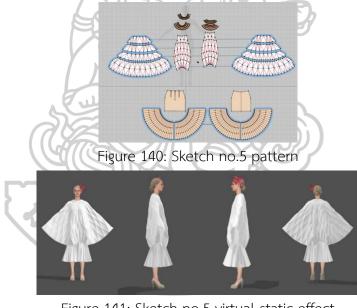


Figure 141: Sketch no.5 virtual static effect



Figure 142: Sketch no.5 virtual dynamic effect

3.7 The method for evaluation the design development effect

This part Including the effect evaluation of applying lotus pattern to clothing and virtual clothing design effect evaluation, this research evaluates the effect of applying lotus pattern to clothing by making real clothing, and evaluates the effect of virtual clothing design by contrasting virtual and real clothing.

3.7.1 Real clothing production process

Mainly include the preparation of materials, pattern making, clothing making process and model try on.

(1) Material preparation

Clothing materials mainly include fabrics and accessories. In the origami modeling part of the clothing collection of this research, polyester/cotton fabric is adopted, which can meet the modeling design of hot pressing to a certain extent. Adding hard adhesive lining in the garment production can increase the stiffness of the fabric and facilitate the three-dimensional modeling design. The other parts of the garment are made of polyester/cotton fabric with elasticity. The accessories used are mainly invisible zipper, adhesive lining, iron wire, pannier and so on.



This research uses ET clothing pattern-making software to make patterns for 5 sketches, as shown in Figure 144.



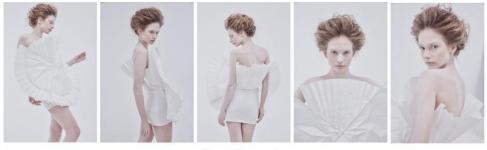
(3) Clothing making process

This research uses ironing, folding and other methods to create origami part. For the origami effect of the pattern part, first draw a pattern on the fabric, then iron the pattern structure line to produce creases, and use different folding methods to obtain different origami effects. The regular pleats are also stacked one after another. Such small pleats have a certain decorative effect, and the outer edges are wavy, which can better reflect the feminine psychological state of women.



Figure 145: Clothing making process

(1) Real clothing effect display



sketch no.1

























sketch no.4



sketch no.5 Figure 146: Real clothing effect of model try on

3.7.2 Design development effect evaluation by qualitative and quantitative research

Design development effect evaluation include the effect evaluation of applying lotus pattern to clothing and virtual clothing design effect evaluation.

(1) Evaluation of the effect of lotus pattern applied to clothing---Quantitative research: Public questionnaire

Target group: Young people who love fashion aged 18-35.

Sample size: 100 copies

Question design: The objective of this questionnaire is to investigate the satisfaction of the public toward the prototype clothing in terms of design effect, fabric selection, color application and value. The Appendix D is the detailed questionnaire design, and 100 questionnaires were issued to the target group.

(2) Evaluation of the effect of virtual clothing

At present, the related research on clothing digitization in the fields of computer and clothing is gradually deepening, but the evaluation standard of clothing virtual simulation effect has not been established. The evaluation of the virtual clothing effect in this research is mainly subjective evaluation of the appearance of the clothing and objective evaluation of the comfort of the clothing.

A. Subjective evaluation of virtual clothing appearance effect--- Qualitative research: Experts questionnaire

Target group: Professor and designer who are design background and have a certain understanding and mastery of fashion design and virtual fitting technology.

Sample size: 10 copies.

Question design: The objective of subjective evaluation of clothing appearance effect is to retrieve the experts' opinions toward the effect of this research's virtual clothing based on the experts' experience and vision. Mainly use virtual clothing and physical clothing to compare the static appearance of clothing from the front, side and back to observe the origami effect, the three-dimensional modeling effect of the pattern, the pleating effect, and the static overall effect. By comparing the virtual clothing and physical clothing with the sketch respectively, the index content of the designer's design ideas is evaluated. The dynamic effect is mainly evaluated from the three indicators of the clothing swinging effect with the human body, the fabric drape effect, and the dynamic overall effect. The detailed questionnaire design is shown in the Appendix E.

B. Objective evaluation method of the comfort of virtual clothing

When the designer completes the entire virtual clothing design work, the designer needs to test the comfort of the clothing design work. The traditional clothing design needs to experience the comfort of the clothing through the try-on of the model, while the virtual clothing design work needs to pass special test to check its true comfort level. From a technical perspective, the principle of comfort testing is to indirectly reflect the comfort of virtual clothing through the distance and force between the virtual clothing and the human body. The comfort of virtual clothing is mainly reflected by the distribution of pressure and contact points. Designers usually use color to mark the degree of pressure on the model by clothing: the larger the red area in the virtual clothing design works, the higher the tensile strength of the fabric, and the larger the green area, the weaker the tensile strength of the fabric. If the contact points of the virtual clothing design are very evenly distributed and the distribution range is relatively small, it means that the fabric has a weaker sense of restraint on the model and higher comfort (Li, 2019).

Therefore, this research use CLO3D virtual fitting software to objectively evaluate the comfort of virtual clothing from the two indicators of clothing pressure and contact point.

Clothing pressure

Clothing pressure refers to the pressure caused by the shape, size, weight and other factors of clothing on the human body after the body is dressed. In the CLO3D software, the clothing pressure can be distinguished by the color of the clothing displayed on the model.

Contact points

The distribution of clothing contact points uses points to indicate the contact between the virtual model and the clothing. If the contact points of the virtual clothing are very evenly distributed and the distribution range is relatively small, it means that the fabric has a weaker sense of restraint on the model and higher comfort.

3.8 The exhibition

In order to more accurately gain how people think about this research's results and collect feedback, the exhibition was set up at Silpakorn University Gallery (Wang Tha Phra Campus) which open for public to participate in the exhibition. In the exhibition space, each area provide various information about research background, design processes, methodology and research result, so that the audience can easily understand my research. This research also created four questions, so that when communicate with the audiences can get their opinions. The questions which contain as following:

(1) How do you think of these fashion design works?

(2) Can you imagine that the crease on the costume is a pattern?

(3) Do you like the pattern of this 3D clothing structure form?

(4) This 3D pattern can let you easily understand the Dunhuang caisson lotus pattern?



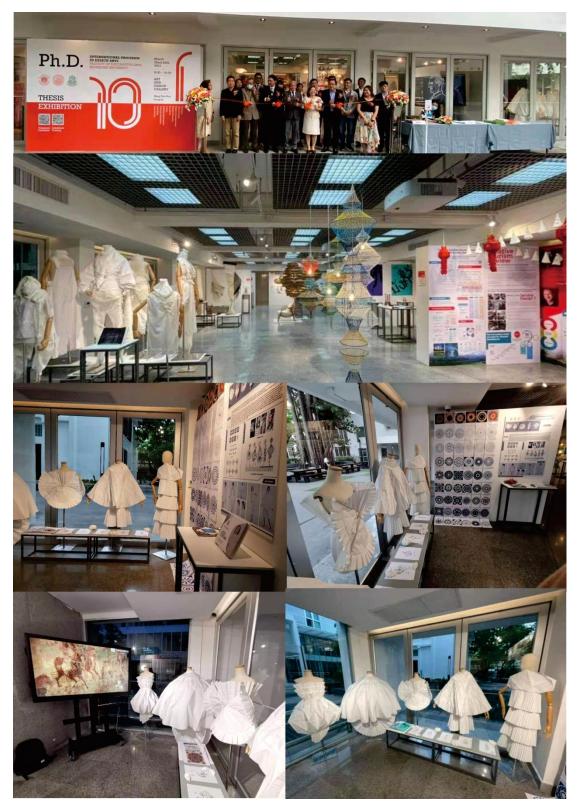


Figure 147: The exhibition space



Figure 148: viewers who visited the exhibition

3.9 Summary

In the process of sketch, methods such as simplification, deconstruction and reorganization are mainly used. First, the lotus is redesigned, and then combined with three-dimensional origami techniques to apply it to modern woman's clothing. Part of the pattern is designed as a three-dimensional clothing structure, and the other is designed as a three-dimensional decoration, thus forming new clothing shapes and styles. In order to observe the design effect more intuitively, virtual clothing design technology is used to statically and dynamically display the design effect. Before the virtual design, first experiment with paper and summarize the folding methods required for the origami model in the sketch. Then the virtual clothing design was performed in the CLO3D software, and the virtual design process of each sketch was recorded separately, and the pattern and static virtual effect of each sketch were obtained. Combined with related animation production software, a catwalk video was made, which fully demonstrated the effect of human body try on. In order to evaluate the results of this research, the methods of comparison of physical clothing and virtual clothing, qualitative research, quantitative research and exhibition were selected respectively to obtain the opinions of the audience.



Chapter 4

Research result

4.1 The result of lotus pattern innovative design effect

In chapter 3, an online questionnaire was distributed to 116 college students, at last 100 valid questionnaires were received. Taking the new lotus pattern in the cave 401 as an example, the scoring statistical results are shown in Table 6.

		1		-
V1	V2	V3	V4	V5
46	24	10	13	7
52	21	14	10	3
49	32	12	5	2
57	28	12	3	0
	V1 46 52 49	V1 V2 46 24 52 21 49 32	V1 V2 V3 46 24 10 52 21 14 49 32 12	46 24 10 13 52 21 14 10 49 32 12 5

 Table 6. Evaluation score for the new lotus pattern in the cave 401

The fuzzy judgment matrix D of the design optimization solution is obtained from Table 6, namely:

 $\mathbf{D} = \begin{bmatrix} 0.46 & 0.24 & 0.10 & 0.13 & 0.07 \\ 0.52 & 0.21 & 0.14 & 0.10 & 0.03 \\ 0.49 & 0.32 & 0.12 & 0.05 & 0.02 \\ 0.57 & 0.28 & 0.12 & 0.03 & 0 \end{bmatrix}$

Then, the comprehensive evaluation model B can be obtained as follows:

$$B = W \times D = \begin{bmatrix} 0.3 & 0.2 & 0.3 & 0.2 \end{bmatrix} \begin{bmatrix} 0.46 & 0.24 & 0.10 & 0.13 & 0.07 \\ 0.52 & 0.21 & 0.14 & 0.10 & 0.03 \\ 0.49 & 0.32 & 0.12 & 0.05 & 0.02 \\ 0.57 & 0.28 & 0.12 & 0.03 & 0 \end{bmatrix} = \{0.503, 0.266, 0.118, 0.08, 0.033\}$$

The evaluation results of the new lotus pattern in the cave 401 are as follows: 50.3% think it is very good, 26.6% think it is good, 11.8% think it is generally, 8% think it is bad and 3.3% think it is very bad. The evaluation scores of 10 samples were calculated, as shown in Table 7.

Cave Number of New Pattern	Very Good	Good	Moderate	Bad	Very Bad
401	50.3	26.6	11.8	8	3.3
288	62.3	35.4	1.8	0.3	0.2
396	52.9	32.3	8.3	4.3	2.2
254	63.6	35.2	0.7	0.4	0.1
392	59.5	28.5	5.4	4	2.6
197	64.1	30.9	3.9	0.8	0.3
171	61.8	31.4	3.6	2.7	0.5
272	64.7	29.3	3.9	1.8	0.3
321	49.7	29.8	9.3	6.4	4.8
407	65.4	27.7	3.4	2.4	1.1

 Table 7. Comprehensive evaluation results of 10 new lotus patterns

It can be seen from Table 7 that 59.43% of college students think that the design of the ten new lotus patterns is very good, and the design of the cave 407 is the best. Followed by the cave 272 and 197, 64.7% and 64.1%, respectively. The proportion of those who think that the design is poor is below 5%. Among them, the design of the cave 321 is low, but nearly 50% of college students think that the design is very good. In short, the new patterns evolved through shape grammar basically meet the aesthetic needs of college students.

In short, through the fuzzy evaluation of the new lotus pattern by college students, the results show that the new lotus pattern obtained by combining the shape grammar not only retains the structural characteristics of the traditional lotus pattern, but also has innovation and uniqueness characteristics, which are basically in line with college students favorite. The result of the innovative design of the lotus pattern is satisfactory.

4. 2 The results of design development effect evaluation

Including the effect evaluation results of applying lotus pattern to clothing and virtual clothing design effect evaluation result.

4.2.1 The effect evaluation results of lotus pattern applied to clothing

In chapter 3, 100 questionnaires were issued to the target group and 92 valid questionnaires were returned. By averaging the scoring results of each evaluation content as the final result of this item, the effect evaluation results of the lotus pattern applied to clothing are as follows:

Evaluation Index	Evaluation Content	Evaluation Score	Satisfaction Level
	The fabric is appropriate with the clothing design.	2.75	Slightly Satisfied
Selection	The folding crease on the fabric is an appropriate decoration.	3	Satisfied
	The folding pattern increases the values of the cloth.	3.13	Satisfied
Color Application	The choice of color is appropriate with the design of the prototype clothing.	3	Satisfied
	The choice of color highlights the folding crease on the fabric.	2.88	Slightly Satisfied
	The choice of white color makes it easy for you to understand the design methods used by designer.	3.13	Satisfied
	The cloth has a unique style.	3.25	Satisfied
Design Effect	The cloth has an interesting structure.	3.38	Satisfied
	The clothes in the collection are related to each other.	3	Satisfied
	The overall look of the prototype clothing.	3.13	Satisfied
Value	By using the folding technique change the 2D lotus pattern into 3D cloth structure. It is the innovation in the field of apply patterns on clothing.	3.5	Satisfied
	Innovative application methods of the lotus pattern can inspire you.	3	Satisfied
	By applying the lotus pattern in the designing of cloth help raising awareness of you in terms of traditional art value.	3.13	Satisfied
	The apply of tradition lotus pattern on cloth helps you to easily understand the Dunhuang culture and art.	3.25	Satisfied

Table 8. Evaluation results of the lotus pattern applied to clothing

Table 8 shows that about fabric selection, the public highest satisfaction on the cloth values that increased by the folding pattern, with evaluation score 3.13. The second highest satisfaction is relate to the folding crease can be a decoration texture on the fabric. Last, the least satisfaction is related to the appropriate choice of cloth for this design, with the lowest evaluation score 2.75. About the color application, the public satisfaction on the choose of white color, it is not only appropriate for the prototype clothing, but also can let people understand the methodology the designer use. And public has a slightly satisfy the color can highlights the folding crease on the fabric, with evaluation score 2.88. Relate to design effect, the public are all satisfied with the evaluation content of 4 aspects. The public is most satisfied with the structure and style of the clothing, which gives them an interesting and unique feeling, and with evaluation score 3.38 and 3.25 respectively. The public is also quite satisfied with the overall effect of the clothing and the connection between the cloth collection, with evaluation score 3.13 and 3 respectively. From the overall evaluation score situation, the public's evaluation scores for value are generally higher, especially the public highest satisfaction on use the folding technique change the 2D lotus pattern into 3D cloth structure, it is the innovation in the field clothing design and with the highest evaluation score 3.5. Followed by the value of letting people easily understand the Dunhuang culture and art, with the evaluation score 3.25. And public also satisfy the method this research use can inspire them and let them pay more attention on traditional art value, with evaluation score 3.13 and 3 respectively.

In short, the public is satisfied with the effect of applying the lotus pattern to clothing. Among them, the satisfaction of design value and design effect is slightly higher than that of fabric selection and color application. Regarding the fabric appropriate with the clothing design and the white color highlights the crease effect, it needs to be improved.

4.2.2 The effect evaluation results of virtual clothing --- Subjective evaluation

The scoring results of 10 expert questionnaires were sorted out, and the scoring results of each index were averaged as the final result. The specific evaluation results are as follows: hina

		100,	Evaluation Score
Evaluation Index	Evaluation Content		1 = "Very bad", 2 = "Bad", 3 = "General", 4 = "Good", 5 = "Very Good"
	Origami Effect	Virtual Clothing	4.5
		Real Clothing	3.3
Static Effect Evaluation	Pattern Three-	Virtual Clothing	4.6
	Dimensional Modeling Effect	Real Clothing	3.1
	Pleat Effect	Virtual Clothing	4.2
		Real Clothing	3.7
	Static Overall Effect	Virtual Clothing	4.3
		Real Clothing	3.3
	Expression of	Virtual Clothing	4.4
	Designer's Design Ideas	Real Clothing	2.7
Dynamic	Clothing Swinging Effect with the Human		4.3

Table 9. Subjective	evaluation	results of	clothing	appearance	effects

Effect	Body	
Evaluation	Fabric Drape Effect	4.3
	Dynamic Overall Effect	4.5

It can be seen from Table 9 that, whether it is the origami effect, the three-dimensional modeling effect of the pattern, the pleating effect, the static overall effect, or the expression of design ideas, the experts' ratings of virtual clothing are higher than real clothing. Especially in the expression of the designer's design ideas, the difference between the virtual clothing effect score and the real effect score is 1.7, which shows that the virtual clothing and the clothing design sketch are relatively close and can better present the designer's ideas. Secondly, in terms of the three-dimensional modeling effect of patterns and pleating effect, there is also a big difference between the virtual costume effect score and the real costume effect score, which is 1.5. Experts scored virtual clothing and physical clothing in terms of origami effect and static overall effect, with a small difference of 1.2 and 1 respectively. Compared with other virtual effects, virtual clothing technology can well present the three-dimensional modeling effect of patterns, and the experts gave a high score of 4.6. Experts believe that physical clothing is also more effective in showing pleated effects.

In short, the effect of virtual clothing is better than physical clothing. The powerful virtual function can better present the three-dimensional shape, origami effect and pleating effect. Real clothing may not be able to accurately represent the designer's idea due to limitations in fabric performance, production skills and other aspects.

4.2.3 The effect evaluation results of virtual clothing --- Objective evaluation

Clothing pressure

Figure 149 shows the state of clothing pressure on the sketch no.1 model. It can be seen from the figure that the pressure on the waist, chest and back of the human body is relatively large, the color is red. This may be related to the style of the clothing. These parts have a large area of decorative objects, which results in greater pressure on these parts. While the clothing pays attention to the style, the comfort will inevitably decrease. Other areas are green, blue, and yellow, which shows that other parts of the clothing are basically free of restriction to the human body and meet the requirements of human comfort.



Figure 149: Sketch no.1 clothing pressure

Figure 150 shows the state of clothing pressure on the sketch no.2 model. It can be seen from the figure that the pressure at the waistline is too high and it appears red. This may be because the three-dimensional pattern and the lower pleated part are sewn at the waistline. The body needs to bear the weight of the two parts of the fabric, so the pressure generated is too much big. The position of the bp point on the chest also appears red, which may be the pleated part exerts a feeling of pressure on the chest, and the other parts of the garment appear bluegreen, which indicates that there is almost no pressure in other parts.



Figure 150: Sketch no.2 clothing pressure

Figure 151 shows the state of clothing pressure on the sketch no.3 model. As can be seen from the figure, the pressure on the collar and hem is relatively high, showing red. This is because the neckline bears the weight of the entire threedimensional shape of the pattern, and the hem of the skirt needs to bear the weight of the pleated fabric, which leads to greater pressure on these parts.

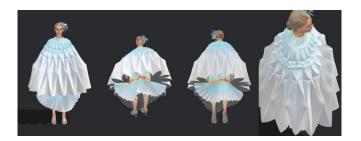


Figure 151: Sketch no.3 clothing pressure

It can be seen from the Figure 152 that because this style of clothing is relatively simple, the overall pressure color is blue-green, and only the underarms on the back show a little red. This may be because the weight of the shoulder shape and the first layer of pleated fabric are all accumulated here, which puts pressure on the arm. However, the pressure is not particularly large, and the red area is small, which does not affect the overall comfort of the clothing.



Figure 152: Sketch no.4 clothing pressure

As can be seen from the Figure 153, because this clothing is looser and the shape is not particularly exaggerated, the pressure color of this clothing is bluegreen as a whole, and only the neck and skirt are red. The pressure on the neck is higher because the support point of the whole coat is at the neck, and the red at the hem is because the hem shape causes more fabric here, and the weight of the fabric exerts pressure on the human body.



Figure 153: Sketch no.5 clothing pressure

Contact points

It can be seen from Figure 154 that the body surface contact between the clothing and the human body is mainly reflected in the hips and chest, and the contact points of these two parts are also relatively evenly distributed. There are few contact points in other parts, so there is no unnecessary contact, which shows that this clothing is very comfortable.



Figure 154: Sketch no.1 clothing contact points

It can be seen from the Figure 155 that the tube tops and lining skirts are mainly in contact with the body, and the contact points are evenly distributed, which meets the needs of clothing styles. The pleated at the leg has a little contact with body, but this has little effect on the comfort of the garment.



Figure 155: Sketch no.2 clothing contact points

It can be seen from the Figure 156 that the collar, shoulders, skirt waist, buttocks, and side seams are mainly in contact with the body. The contact of these parts is necessary contact and the contact points are evenly distributed, indicating that the fit of the clothing is very high and satisfying the human body's demand for clothing comfort.



Figure 156: Sketch no.3 clothing contact points

It can be seen from the Figure 157 that the bottom edge of the shoulder shape is in contact with the human body and the contact points are more evenly distributed. The pleats are sewn on the outside of the skirt inside, so there is basically no contact with the human body. Because the skirt inside fits better, the contact area with the human body is relatively large, mainly the hips, waist and chest, but the distribution of contact points is relatively even. This shows that the skirt inside fits well and meets the human body comfort needs.



Figure 157: Sketch no.4 clothing contact points

It can be seen from the Figure 158 that the contact parts of the top are mainly on the shoulders, arms and chest, and the contact points are evenly distributed. The buttocks, waist and lower abdomen of the hip skirt are evenly distributed. There are no contact points in other parts, which shows that the overall comfort of the garment is relatively high.



Figure 158: Sketch no.5 clothing contact points

From an objective evaluation point of view, the comfort of the virtual clothing is very high, the contact points are evenly distributed, and there is no unnecessary contact. The pressure on certain parts of the body due to styling reasons is relatively high, but this cannot be avoided.

4.3 The result of exhibition

During these 3 days exhibition, there are many audiences came to see my exhibition, some are artist, fashion designer, professors, business man, students and so on. Through communication with them, I get their opinions about the questions which I created in chapter 3 that are relate to my design works in the exhibition. (1) How do you think of these fashion design works?

Most of the audience said that my design works were very interesting and unique, some viewers said that they saw the promotional video and they felt very interesting, so they came to visit my exhibition specially, there are also some businessmen and fashion designers who say that my work is of great commercial value.

(2) Can you imagine that the crease on the costume is a pattern?

For this question, many audience said that they can imagine that the crease on the costume is a pattern and they were attracted by the shapes and creases of these costume when they first saw them. Only a few viewers said that they didn't know that is a pattern, but after they read the design process at the exhibition, they all can imagine that the crease on the costume is a pattern.

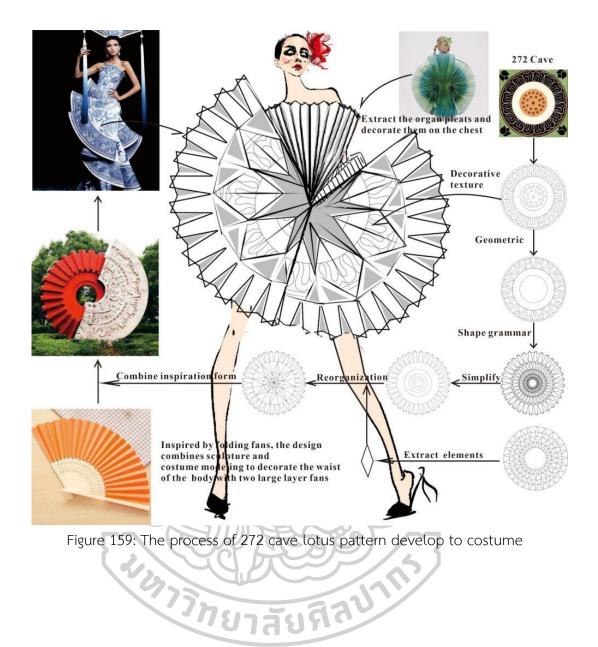
(3) Do you like the pattern of this 3D clothing structure form?

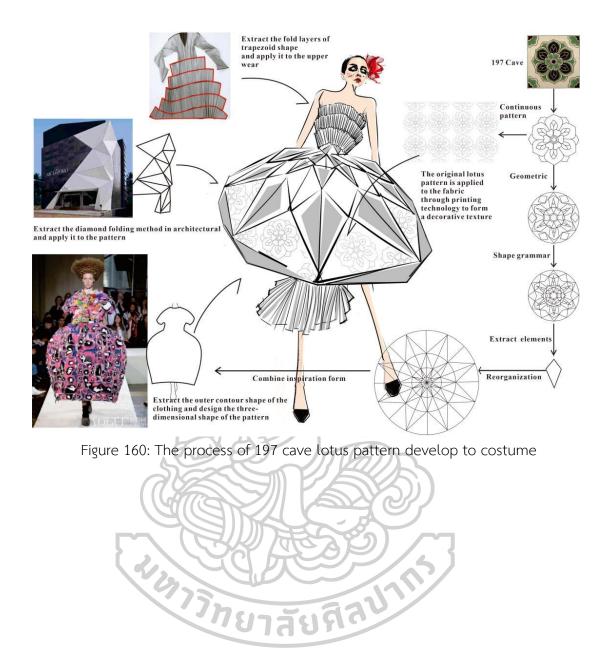
All viewers expressed their preference to present patterns in this 3D format, which is very novel and unique. Some viewers expressed that they were inspired by these design works.

(4) This 3D pattern can let you easily understand the Dunhuang caisson lotus pattern?

Most viewers said that presenting the patterns in 3D form makes them easier to understand, but they don't know what patterns these are and where they come from. Because most people have never heard of Dunhuang, let alone know the caisson lotus pattern of Dunhuang. But when put the lotus pattern in the cave with the costume design works together, they are easy to understand and said that the design works are very creative.

Through the above feedback from the audience, it can be found that the methods and results of this research have been recognized by the audience. However, because most viewers do not know Dunhuang, it is difficult for them to associate the costume design works with the Dunhuang caisson lotus pattern. Therefore, in order to solve this problem, this research modified the sketch by using the original lotus pattern as the decorative texture on fabric, the sketch effect is shown in below Figures.





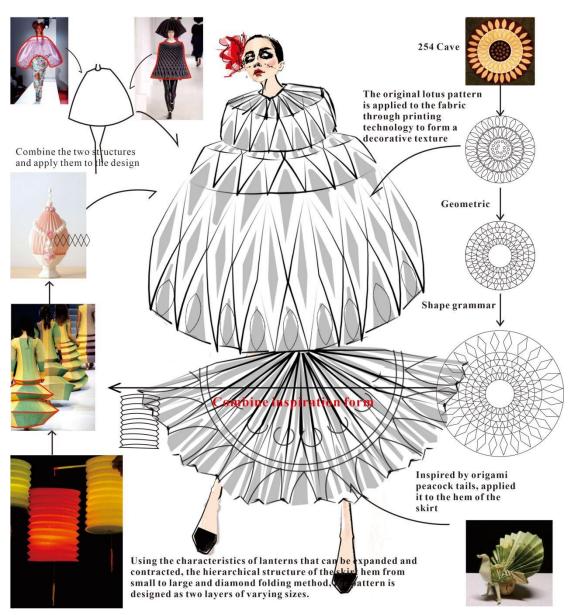


Figure 161: The process of 254 cave lotus pattern develop to costume



Figure 162: The process of 288 cave lotus pattern develop to costume

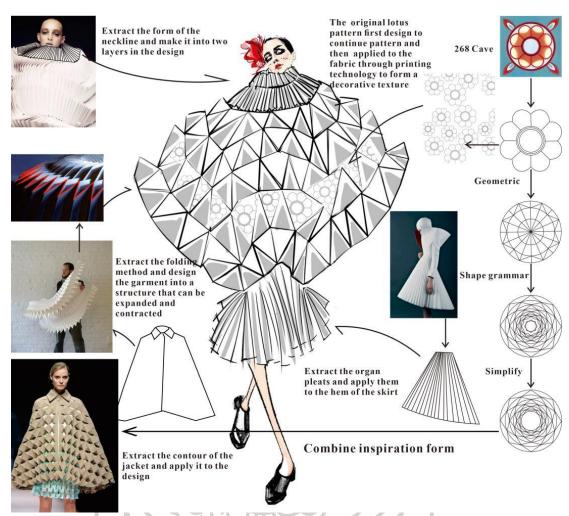


Figure 163: The process of 268 cave lotus pattern develop to costume

4.4 Summary

From the evaluation results of applying lotus pattern to clothing, by using the folding technique of origami to change the 2D lotus pattern into 3D cloth structure. It is not only the innovation in the field of apply patterns on clothing, but also makes clothing interesting and unique, and it is deeply loved by young consumers.

Through the virtual and real clothes comparison research, the evaluation results of the virtual clothing in this research are obtained. From the results, experts believe that the virtual effect is better than the physical effect, especially for the simulation of three-dimensional structure and origami effects in clothing, giving high scores of 4.6 and 4.5. Comparing virtual clothing, real clothing and sketches, experts

believe that virtual clothing can better present the designer's design points, while real clothing is due to limitations in fabrics and production skills, resulting in a large gap between real clothing and sketches. In addition, virtual catwalks can better show the overall effect of clothing, so virtual clothing design technology can fully simulate clothing effects and improve design efficiency, which has great advantages compared with traditional design method.

Through the way of exhibition, viewers' feedback on the research results were obtained. Generally speaking, the results of this research were very unique and interesting, and the audience liked it very much and had inspiration and reference value for them. And through a detailed introduction of the process of applying lotus pattern to costume, so that viewers can more clearly connect the lotus pattern and costume shape together.



Chapter 5

Conclusion and contribution

The purpose of this research is to propose an innovative application method of the caisson lotus pattern in fashion design by combination the origami art and virtual clothing design technology, so as to preserve the artistic characteristics of the caisson lotus pattern and create new styles of clothing from the roots of Dunhuang art and origami art, and improve the feasibility of virtual clothing design technology, promote continuous innovation of clothing design methods.

Caisson lotus pattern, as an important decorative pattern in the Dunhuang Buddhist grottoes murals, is an important symbol of Dunhuang culture. Due to natural and artificial factors, Dunhuang mural resources are gradually disappearing. Therefore, it is urgently needed to carry out research and innovative application for it, so that it can be inherited and developed in modern society. This research objectives can conclude the results below.

5.1 Conclusion

5.1.1 Response to research objective 1---To systematic research the Buddhist lotus pattern in the Mogao cave of Dunhuang.

In order to better protect and inherit Dunhuang culture, this research conducted a systematic research of caisson lotus patterns in Mogao grottoes, and summarized the types, characteristics, evolution process and profound cultural connotations of caisson lotus patterns, which are as follows:

Types and evolution process of caisson lotus patterns. According to the relevant research literature and field investigations of the Dunhuang Mogao grottoes, there are 334 caves have caisson lotus patterns. In this research, according to the petal shape of the lotus pattern in the center of the caisson, the lotus pattern is divided into round-wheel lotus, flat-petal lotus, peach-shaped lotus, curl petal lotus, and Baoxiang flower. And in different periods, the caisson lotus pattern has different development paths and evolution processes, as shown in Figure 164. With the development and changes of social economy and communication with other countries, people's aesthetic tastes have also changed. In the early period of Dunhuang (397-581AD), the popular shape was simple round-shaped lotus, in the middle period of Dunhuang (582-906AD), the popular shape before the Tang dynasty was flat-petal lotus and peach-shaped lotus at the beginning of Tang dynasty, later were replaced by the complex and colorful Baoxiang flowers after entering the Tang dynasty. Afterwards, with the economic downturn and social unrest, people started to pursue simple, dynamic curling petal lotus.

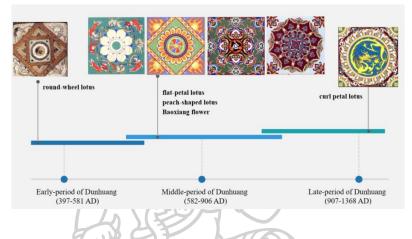


Figure 164: The evolution of the lotus pattern

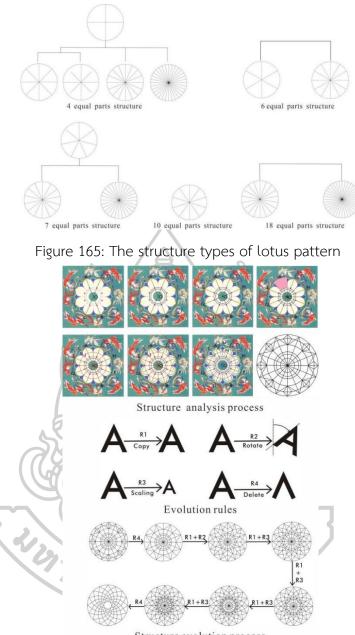
Characteristic 1: Balanced and symmetrical composition. In the Dunhuang caisson lotus pattern, some lotus patterns are axisymmetric figure, such as the flat petal lotus and the round wheel lotus. Baoxiang flower adopts the traditional "cross" four-petal mode to maintain a stable and quiet sense of simplicity. There are also some lotuses that turn 45 degrees on the basis of the four petals to form the "米" eight-petal structure. The balanced symmetry of the Dunhuang caisson lotus pattern on the composition gives us a sense of natural harmony and a stable sense of order, which is consistent with the aesthetic culture concept of harmony and order advocated by Chinese tradition.

Characteristic 2: The three rabbit lotus caisson, reflecting the fusion of multiculturalism. In the Sui dynasty, there was a lotus pattern with three rabbits. In the center of the lotus, three rabbits share three ears and chase each other in a circle. With the dynamics of the three rabbits, the center circle seems to be moving, creating a never-ending sense of movement. At present, there are different views on the connotation of three rabbit patterns. According to the Buddhist theory, three rabbits represent past, present and future Buddha. Just like the three rabbit ears are in contact with each other, the previous life, this life and after life are related to each other, it corresponds to the theory of "karma", "karma cycle" and "cycle of life and death". For the folk, with the prosperity of the social economy and the stability of politics in the Sui dynasty, people's willingness to live longer and have more children. In the folk, rabbit can give birth many children one time, so people choose rabbits to decorate the heart of the lotus to express their desire for more children. Under the influence of the Taoist theory of "the three begets all things of the world", people also worship the number three, thus, the symbolic image of the three rabbit lotus caisson that merged with various cultural elements appeared in the Mogao grottoes.

Cultural connotation 1: The multiple meanings of caisson. Through the analysis of caisson structure found that "round above and square below" structure the ideological concept of China's "the responding to Earth was square and Heaven was round." Like the dome in the western church, it symbolizes the epitome of celestial bodies and the high of heaven. The purpose of drawing beautiful caisson in the Buddhist caves is to let the monks create meditations that are "beyond the caisson, nothing else". In this way, the pure land desired by human beings and gods will be perfectly reflected in the caves. In the center of the caisson is decorated with lotus, meaning that the lotus is born in water, affected by the yin and yang thoughts of the five elements, water can restrict fire, continuing the meaning of caisson in traditional architecture to protect the caves from fire.

Cultural connotation 2: The meaning of "tuan" style of baoxiang flower. Baoxiang flower is the typical "tuan" type pattern in the Tang dynasty. In appearance, this pattern is round in shape, but why not use the word "round" to describe its shape, the reason is to highlight its "big", this "tuan" style has a relatively large area in the caisson when compare with other caisson, so the "tuan" word has the extended meaning of "big", and this is a reflection of the prosperity of the Tang dynasty economy and culture. Secondly, the word "tuan", means that all kinds of irregular scattered plants and animal patterns are condensed together, making it a rich and diverse harmonious whole. This is also the spirit of "harmony" and "combination" advocated by Chinese traditional culture. 5.1.2 Response to research objective 2---To propose an innovative design method suitable for the caisson lotus pattern, which not only adds the innovation of the pattern, but also retains the characteristics of the pattern.

For the innovative design of traditional patterns, currently, there are a large number of innovative design methods to be used for reference. In order to better retain the characteristics of lotus patterns, this research first to analysis the structure of the lotus pattern in the Mogao grottoes by "making circles, drawing lines, seeking intersection points" method which is used for drawing Islamic pattern. In this structure analysis process, not only geometric lotus pattern, but also summary that the lotus pattern structure has 4, 6, 7, 10 and 18 equal parts structure, as shown in Figure 165. Applying the shape grammar to the innovative design of the lotus pattern, for the selection of the initial shape, this research changes the traditional method of directly using the typical features or elements of the pattern as the initial shape, but takes geometric lotus pattern structure as the initial shape, and uses copy, rotate, scaling and delete as the evolution rules, through multiple use of evolution rules alone or in combination, the lotus pattern structure of the 50 caves are evolved to obtain new lotus patterns, Figure 166 is the design process of lotus pattern. Finally, through the fuzzy evaluation of the new lotus pattern by college students, the results show that the new lotus pattern obtained by combining the shape grammar, not only retains the structural characteristics of the traditional lotus pattern, but also has innovation and uniqueness characteristic, which are basically in line with college students favorite. This proves the feasibility and effectiveness of the method in this research, and provides new design ideas for the inheritance and innovative design of traditional pattern.



Structure evolution process

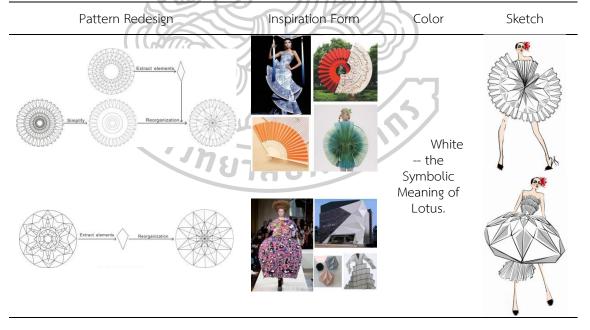
Figure 166: The design process of the cave 401 lotus pattern based on shape grammar

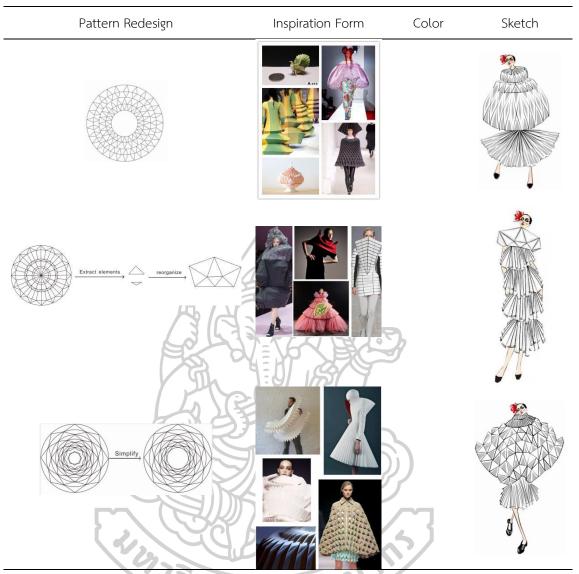
5.1.3 Response to research objective 3---To explore the guideline for the innovative application of lotus pattern on fashion design by combination the origami art.

In order to break the form of 2 dimensional application of traditional patterns on clothing, this research combines the art of origami to convert the flat patterns into three-dimensional clothing structure, summarized the design process and evaluated the effect of applying lotus patterns to clothing. Firstly, according to the current consumer's preference for simple style clothing, the lotus pattern designed in Chapter 3 is redesigned to make its structure more concise, thus more in line with the aesthetic needs of modern people. The main methods are simplification, deconstruction and reorganization. Secondly, the pattern is combined with the forms of some origami works, clothing works, sculptures, architectural works, etc., and the white color representing purity is used for sketch design. In the design process, the structure line of the pattern is used as the folding line, the imagination is expanded, and the inspiration form is combined to design the pattern into a threedimensional form, part of the pattern is designed as the decorative part of the clothing, and the other part is designed as the clothing structure. Finally, through a questionnaire survey, the effect of applying the lotus pattern to clothing is evaluated.

For the lotus patterns of 5 caves, the design processes of transforming from 2D patterns to 3D clothing models are summarized as follows:

 Table 10. Summary the process of 2D pattern conversion to 3D clothing modeling





Evaluation of the effect of applying lotus pattern to clothing

After sorting out and analyzing 92 questionnaires about the public's satisfaction with the effect of applying the lotus pattern to clothing, it was found that the public is satisfied with the effect of applying the lotus pattern to clothing, especially the public highest satisfaction on use the folding technique change the 2D lotus pattern into 3D cloth model with the highest evaluation score 3.5. This proves that the method proposed in this research is highly innovative and unique. Applying patterns to clothing through this method, not only letting people easily understand the Dunhuang culture and art, but also inspire them and let them pay more attention on traditional art value. However, the selection of fabrics and the use of colors need to be further improved to better meet the needs of the public.

In short, the folding method is used to transform the two-dimensional pattern into the three-dimensional clothing model, and the space brought by the folding is perfectly combined with the human body structure, and the creativity and functionality brought by the integration of the origami design method and the clothing design are completed, and make the clothing's functionality and visual aesthetics a perfect combination.

5.1.4 Response to research objective 4---To develop relating techniques to simulate three-dimensional modeling prototypes by the virtual clothing design technology.

In order to better show the effect of clothing design and broaden the types of virtual clothing design, this research combines virtual clothing design technology to statically and dynamically present the clothing collection. And through the production of real clothing, the feasibility of the virtual clothing design technology in this research is verified, and the related folding methods, virtual technology for making three-dimensional modeling clothing and clothing virtual effect evaluation results are summarized, as follows.

Through experiments with paper, the crease diagram and the folding method of the clothing origami modeling part are obtained, as shown in the following Table 11:

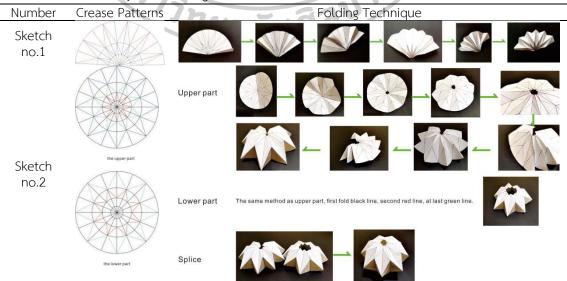
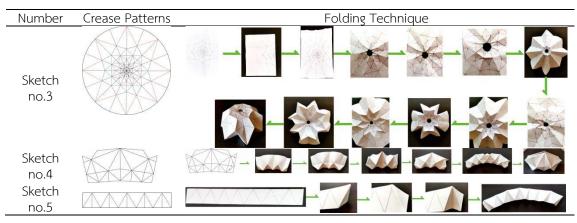


Table 11. Summary the folding methods



Based on the CLO3D system, this research realized the virtual design and dynamic display of three-dimensional origami clothing. In summary of the specific production process and methods of three-dimensional origami clothing, this research has achieved some beneficial results in theory, method and practice. The main research work is summarized as follows:

(1) Clothing pattern making technology: This research uses two methods to obtain the clothing pattern. The first one uses the 3D brush tool and the twodimensional pattern-making window in the CLO3D software to quickly make the clothing pattern, and through the linkage of the two-dimensional window and the three-dimensional window, modify the pattern in time to save the time of making samples and improve the overall design efficiency. The second method is to use clothing pattern-making software such as ET software for pattern-making, and then import it into CLO3D software, modify the pattern according to the virtual wearing effect, and obtain the final clothing pattern.

(2) Virtual production technology of pleated effect: First, convert the lines in the pleated pattern to inner lines, then set the folding angle of the outward fold line to 0° , and set the fold angle of the inward fold line to 360° , and finally select the pleated method to stitch, then get the pleated effect after virtual stitching. Finally, the stiffness of the fabric can be improved by adjusting the physical properties of the fabric, such as the strength of the yarn and the bending stiffness properties, so that the virtual pleats effect is more realistic.

(3) Three-dimensional pattern origami effect production technology. First draw the lotus pattern and use it as the clothing pattern, and then set each structural line in the pattern as a fold line. Second, according to the sketch, different folding strengths and folding angles are set for the fold lines, so that the fold lines become creases, and the two-dimensional fabric has a three-dimensional effect. Sometimes in order to prevent the three-dimensional modeling from collapsing, pressure can be applied to the entire fabric to make it more three-dimensional.

(4) Dynamic display technology. First export the virtual model from CLO3D, then bind the bones of the model in mixamo, then perform the action synthesis in cinema4D, and finally import the model with catwalk action into the CLO3D system. The virtual model demonstrates the dynamic effects of wrinkles, friction, collision, and draping of clothes with the movement of the human body through real human movements, and realizes the dynamic display of the clothing collection in this research.

Evaluate the virtual effect of clothing

In view of the current problem that there is no unified standard for the evaluation of virtual clothing design effects, the evaluation of virtual clothing effects in this research is mainly divided into subjective evaluation of clothing appearance effects and objective evaluation of clothing comfort. Among them, the evaluation of the appearance effect of virtual clothing is divided into static appearance effect evaluation and dynamic appearance effect evaluation. The virtual and real clothing are compared and evaluated in the form of questionnaires. The dynamic evaluation is mainly based on the way experts watch the catwalk video, from the three indexes of dynamic swinging effect, dynamic fabric draping effect and dynamic overall effect. The evaluation of clothing comfort is mainly based on the pressure distribution in CLO3D software and the distribution of contact points to judge.

Judging from the evaluation results of 10 experts, virtual clothing technology can better present the origami effect, the three-dimensional modeling effect of the pattern, and the pleating effect. By freely setting fabric attributes, folding strength and other indicators, virtual clothing can more accurately express the designer's ideas. Real clothing cannot achieve the same effect as virtual technology due to factors such as fabrics, production techniques, skills and other reasons. The dynamic display more realistically simulates the effect of clothing on the human body. You can clearly see the changes in the clothing during the walking process of the human body. The drape effect of the fabric is also relatively natural, clearly showing the designer's design ideas and design level. The fit of the virtual clothing is very high, the contact points are evenly distributed, and there is no unnecessary contact. The pressure on certain parts of the body due to the shape of the clothing is greater, but this is unavoidable. While paying attention to the beautiful appearance of clothing, it will inevitably reduce the comfort of clothing.

5.2 Contribution

(1) This research systematically studied the caisson lotus pattern in Dunhuang Mogao cave, summarized the types, characteristics and cultural connotation of it, which is very useful for perfecting the research system of Dunhuang culture theory.

(2) Based on shape grammar, this research innovates design of caisson lotus pattern, and the research results show that this method not only preserves the traditional characteristics of lotus pattern, but also increases its innovation and uniqueness, which provides an effective method for the innovative design of traditional pattern.

(3) This research uses folding method of origami art to convert 2D patterns into 3D costume structure. This not only breaks the application form of patterns in clothing, but also innovates the structure of clothing.

(4) This research by using the CLO 3D software, realize the virtual simulation of three-dimensional structure clothing, it is a breakthrough in the types of virtual clothing, improved the feasibility of virtual fitting technology.

5.3 Limitation and recommendation

(1) This research only explored the innovative application of lotus structure in modern clothing design, this should be seen as the beginning point for designers who are interested in the art of caisson lotus pattern, and they could develop further from this research in their own field. Combining modern new technology, new materials, etc., the traditional caisson lotus pattern is applied to modern design, and the past serves the present. This not only enables the inheritance and development of traditional Chinese aesthetic elements, but also enriches modern design themes.

(2) This research propose an innovation and application method for caisson lotus pattern base on shape grammar and folding method of origami, it is hoped that it can provide meaningful reference value for designers to innovative application of other traditional patterns, so that traditional patterns can be better passed down and developed in modern society.

(3) The virtual fitting technology has a strong development space. This research only conducts in-depth research on the virtual simulate of clothing with three-dimensional origami effect. However, there are many types of clothing and different production methods. Therefore, it is hoped that fashion designers and clothing-related enthusiasts will continue to expand the types of virtual clothing, further enhance the feasibility of virtual fitting technology, and lay a solid foundation for the digital development of the clothing industry.



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APPENDIX

Cave Number	Original	Structure	Structural Evolution
197			
217			
251			
268			
272			
288			

Appendix A: Evolution Effect of Lotus Pattern Structure of 47 Caves

Cave Number	Original	Structure	Structural Evolution
312			
373			
391			
394			
420		רי	
427			

Cave Number	Original	Structure	Structural Evolution
431			
126			
254			
386			
392			
395			

Cave Number	Original	Structure	Structural Evolution
403			
405			
406			
408			
428		מ	
79			

Cave Number	Original	Structure	Structural Evolution
381			
462			
296			
305			
311			
331			

Cave Number	Original	Structure	Structural Evolution
335			
360			
397			
394			
393			
49			

Cave Number	Original	Structure	Structural Evolution
123			
159			
321			
334			
409			
31			

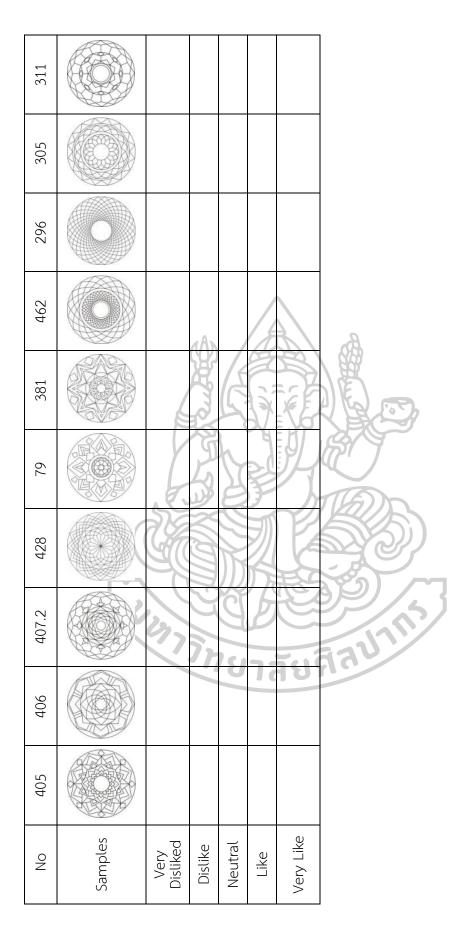
Cave Number	Original	Structure	Structural Evolution
166			
171			
250			
319			
329			
398			

Qualitative Research)
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Form
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Appendix

Your name ______ your occupation: Professor (), Designer ()

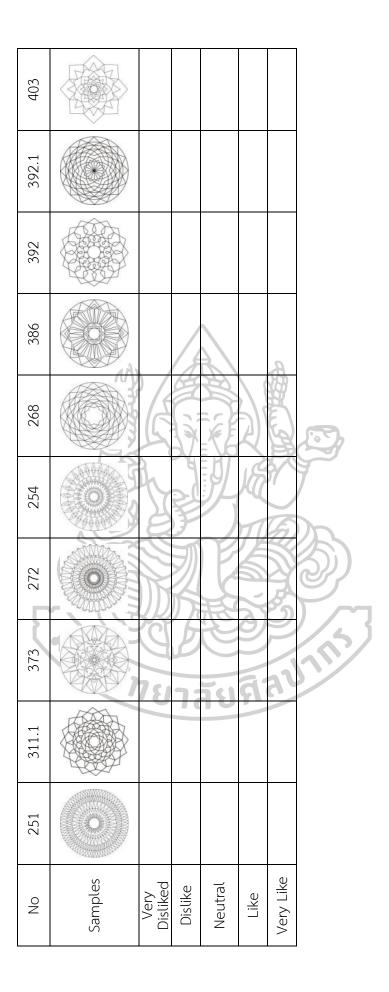
Please evaluate the following lotus pattern according to your preferences, put (v) in the corresponding box.

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401							
64							
12							-
407					A		
334					Ban Jin		2
321		S	Л Л		5		
159			K			5	
123		15				11	55
49							
398							
No	Samples	Very Disliked (1 point)	Dislike (2 points)	Neutral (3 points)	Like (4 points)	Very Like (5 points)	



329							
319							
249							
171		(A)				A	
166		50000			and the second		S
31		ALL ALL	ß				
335			P				Ð
397				次「う		2/2	7175
360							
331							
No	Samples	Very Disliked	Dislike	Neutral	Like	Very Like	

217							
431							
428.1							
420						Ą	
392.2					AR	BRAN STI	J.
288					NA N		
390.1			デ	ľ.	Na K		2)
249.1		0/2			<u>ຈ)) /ເຮ</u>	2/2	1115
197							
126							
No	Samples	Very Disliked	Dislike	Neutral	Like	Very Like	





Please evaluate the following lotus pattern according to your preferences, put (v) in the corresponding box.

											_
	Level	V1 = Very Good, V2 = Good, V3 = Moderate, V4 = Bad, V5 = Very Bad	□			□	□	□		□	
	Preference Level	ery Good, V2 = Gooc Moderate, V4 = Bad, V5 = Very Bad	2 🗌 V3	2 🗌 V3	2 🗌 V3	2 🗌 V3	2 🗌 v3	2	2 🗌 V3	2 🗌 V3	
	д	V1 = Very Mc			□v1 □v2	□v1 □v2	□v1 □v2		□v1 □v2	□v1 □v2	
]						-
ricase evaluate the horiowing rotus partent according to your preferences, put (V) in the corresponding pow		Evaluation Index Description	Innovative, unique, in line with the modern aesthetic	Shape neat, harmonious, with melody	Both traditional characteristics and innovation	Suitable for use in modern products	Innovative, unique, in line with the modern aesthetic	Shape neat, harmonious, with melody	Both traditional characteristics and innovation	Suitable for use in modern products	3
שאוווצ וחומ אוווא		Evaluation Index	E1	E2	E3	TA PE	E1	E2	E3	ÞЭ	
		Cave Number				401				288	

Preference Level	V1 = Very Good, V2 = Good, V3 = Moderate, V4 = Bad, V5 = Very Bad								
	Evaluation Index Description	Innovative, unique, in line with the modern aesthetic	Shape neat, harmonious, with melody	Both traditional characteristics and innovation	Suitable for use in modern products	Innovative, unique, in line with the modern aesthetic	Shape neat, harmonious, with melody	Both traditional characteristics and innovation	Suitable for use in modern products
	Evaluation Index	E1	E2 / 64	E3	Ed Ed	E1	E2	E3	E4
	Cave Number			A	396				254

Preference Level	V1 = Very Good, V2 = Good, V3 = Moderate, V4 = Bad, V5 = Very Bad								
ξ	Evaluation Index Description	Innovative, unique, in line with the modern aesthetic	Shape neat, harmonious, with melody	Both traditional characteristics and innovation	Suitable for use in modern products	Innovative, unique, in line with the modern aesthetic	Shape neat, harmonious, with melody	Both traditional characteristics and innovation	Suitable for use in modern products
	Evaluation Index	E1	E2	E3	Ed B	E1	E2	E3	E4
	Cave Number				171	- 11-11-12			272

			Preference Level
Cave Number	Evaluation Index	Evaluation Index Description	V1 = Very Good, V2 = Good, V3 = Moderate, V4 = Bad, V5 = Very Bad
A A A A A A A A A A A A A A A A A A A	E1 /	Innovative, unique, in line with the modern aesthetic	
	E2	Shape neat, harmonious, with melody	
	E3 DI	Both traditional characteristics and innovation	
321	Ed G	Suitable for use in modern products	
	E1	Innovative, unique, in line with the modern aesthetic	
	E2	Shape neat, harmonious, with melody	
	E3	Both traditional characteristics and innovation	
407	E4	Suitable for use in modern products	

Appendix D: Evaluation of the Effect of Applying Lotus Pattern to Clothing

Occupation: Teacher 🛛 Student 🗍 Worker 🖓 Others 🗍

Please evaluate the effect of applying the lotus pattern to clothing. And according to your evaluation, put (\checkmark) in the corresponding box.

		Satisfaction Level
No	Evaluation Content	1 = Least Satisfied, 2 = Slightly Satisfied, 3 = Satisfied, 4 = Most Satisfied.
1	The design is interesting.	
2	The fabric is appropriate with the clothing design.	□1 □2 □3 □4
3	The folding crease on the fabric is an appropriate decoration.	
4	The folding pattern increases the values of the cloth.	□1 □2 □3 □4
5	The cloth has a unique style.	\Box_1 \Box_2 \Box_3 \Box_4
6	The cloth has an interesting structure.	1 2 3 4
7	The choice of color is appropriate with the design of the prototype clothing.	□1 □2 □3 □4
8	The choice of color highlights the folding crease on the fabric.	
9	The choice of white color makes it easy for you to understand the design methods used by designer.	□1 □2 □3 □4
10	By using the folding technique change the 2D lotus pattern into 3D cloth structure. It is the innovation in the field of apply patterns on clothing.	
11	The clothes in the collection are related to each other.	□1 □2 □3 □4
12	The overall look of the prototype clothing.	□1 □2 □3 □4
13	Innovative application methods of the lotus pattern can inspire you.	□1 □2 □3 □4
14	By applying the lotus pattern in the designing of cloth help raising awareness of you in terms of traditional art value.	□1 □2 □3 □4
15	The apply of tradition lotus pattern on cloth helps you to easily understand the Dunhuang culture and art.	

Original Lotus Pattern	Redesign Pattern		Real Clothing	
				A A
			<pre>Control</pre>	
		A.		N N N N N N N N N N N N N N N N N N N

The Effect of Applying the Lotus Pattern to Clothing

Appendix E: Evaluate the Effect of Virtual Clothing

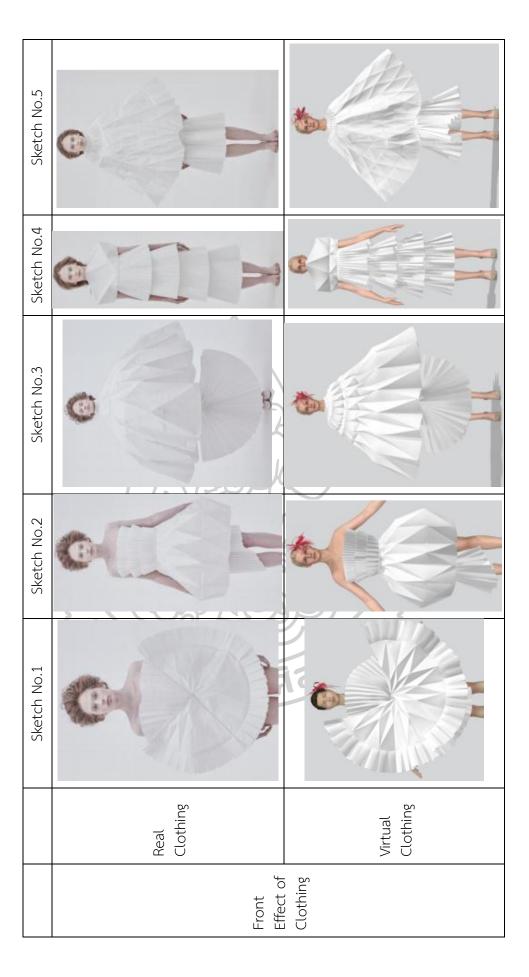
Name _____

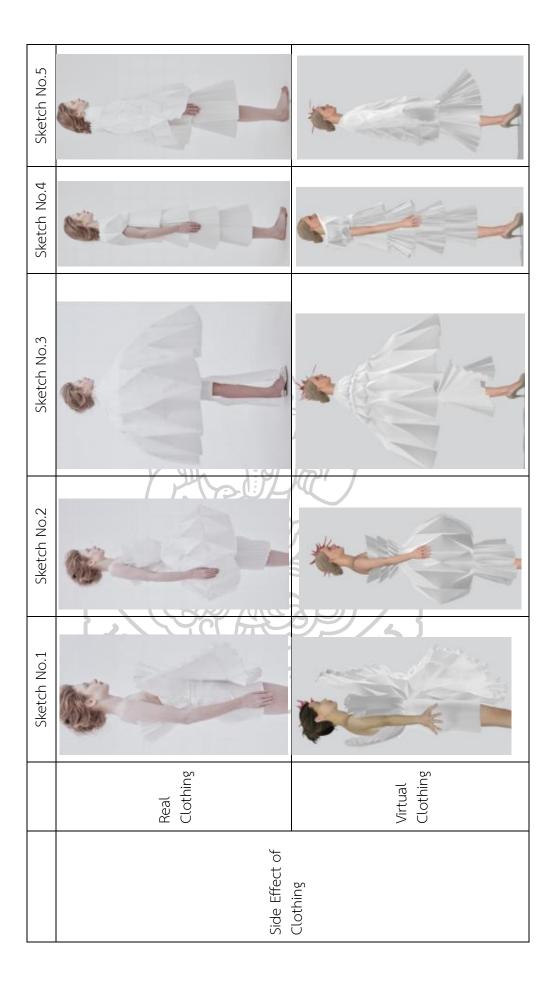
Occupation: Professor \Box Designer \Box

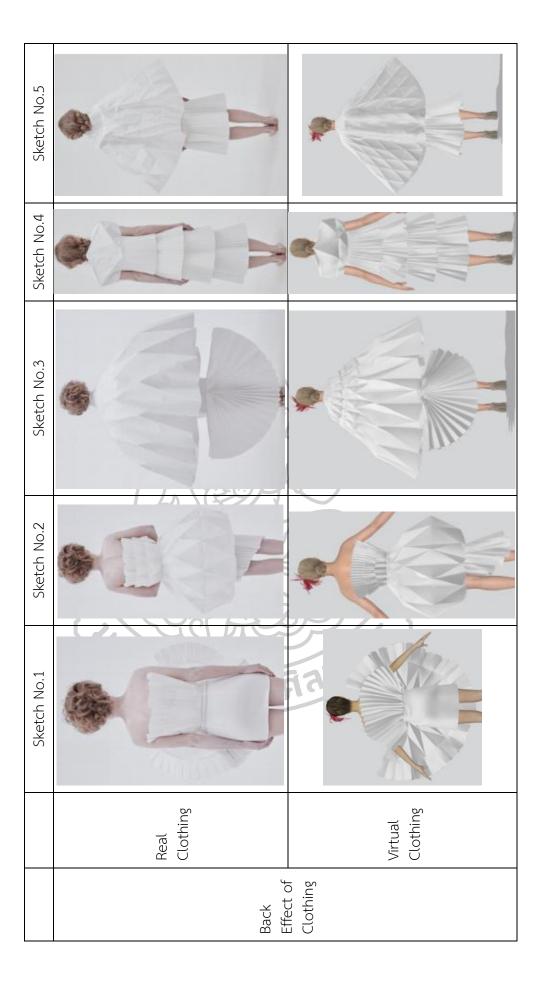
Please evaluate the effect between the virtual and the real clothing, according to your evaluation, put (\checkmark) in the corresponding box.

1 = Very Bad, 2 = Bad, 3= Moderate, 4=Good, 5=Very Good.							
		real clothing	Π1	2	3	4 5	
	Origami effect	virtual clothing	1	2	3	4 5	
	Lotus pattern	real clothing	Π1	□ 2	3	4 5	
	three- dimensional modeling effect	virtual clothing		2	3	□4 □5	
Static		real clothing	1	2	3	4 5	
effect evaluation	Pleated effect	virtual clothing	E A		3	4 5	
	Static overall	real clothing	\Box_1	□2	3	4 5	
	effect	virtual clothing		2	□3	4 5	
	Expression of design ideas	real clothing	\Box_1	U 2	□3	4 5	
		virtual clothing		□2	3	4 5	
Dynamic Effect		The effect of clothing swinging with the human body		2	□3	□4 □5	
Evaluation		Fabric drape effect	1	2	3	4 5	
		Dynamic overall effect	1	2	3	4 5	









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	Simatrang, Eakachat Joneurairatana. (2019). "Kansei Engineering as a Tool for the Design of Traditional Pattern." Autex Research Journal,
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	caisson lotus pattern in Mogao grottoes based on shape
	grammar." 2020 Sustainability Innovation & Fashion
	Technology International Conference. (EI/SCOPUS index)
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	Eakachat Joneurairatana, Veerawat Sirivesmas.
	(2020)."Innovative design of caisson lotus pattern in
	Dunhuang." Humanities, Arts and Social Sciences Studies
	(HASSS). (SCOPUS index)