Introduction

Modern fashion is renewed with new developments and transformations of color and fabric in a revolved and repeated framework. Textile development can be largely divided into performance and design changes, which are crucial for the evolution of fashion. However, recent advancements in digital technology and computer-aided design (CAD) tools have contributed to new developments in various fields, including fashion and textile design. These advancements have enabled designers to explore new possibilities in the creation of fashion products.

As a result of these developments, the fashion industry is embracing new approaches and methodologies to enhance the design and production processes. One such approach is the use of tessellation, which is the process of covering a plane with a set of shapes in a pattern that fills the plane without gaps or overlaps. Tessellation has been applied in various fields, including clothing, architecture, environment, and products, etc., and its expression principle is also found in various fields such as mathematics and science, etc. However, this pattern is mostly used as a math material with little studies on fashion and culture. In addition, it is thought that Korean traditional culture products need more various and modern design development methods and pattern through preliminary investigation which is simple copy of traditional items, simple copy of Korean Alphabet, Chinese character, and folk paintings. Therefore, it will present the method to make more design cases using Tessellation.

Tessellation that combines mathematics and art will be the infinite form of designing of designers as well as creative training way to understand the composition principles of old culture and to raise sense of modern design. Tessellation of regular triangle, regular square, and regular hexagon was performed on the patterns which have meaning of wealth and prosperity of Korean traditional patterns. As the concrete method, first, each side of the regular triangle is developed symmetrically with patterns of fish, turtle, and cicadas. Second, rotational movement after symmetry movement about middle point of one side × 1 symmetry movement about middle point × 1 using crane and cloud, of the regular triangle was performed. Third, the regular square was tessellated parallel movement × 2 with “Da(multi)” and dragon pattern as the source image. Fourth, the sitting tiger was tessellated with symmetry movement about middle point × 2 and parallel movement × 1. Fifth, three bat patterns are tessellated by again rotational movement of two sides after rotational movement of one side and rotational movement of the other side. In addition, It developed traditional culture product design of the scarf, umbrella, aprons, neckties.

Keywords: tessellation, traditional patterns, cultural product

I. Design Development for Fashion Cultural Product Using Traditional Patterns by Tessellation

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Abstract

Since the development of patterns using tessellation is applied to a wide range of fields such as clothing, architecture, environment, and products, etc. and its expression principle is also found in various fields such as mathematics and science, etc. However, this pattern is mostly used as a math material with little studies on fashion and culture. In addition, it is thought that Korean traditional culture products need more various and modern design development methods and pattern through preliminary investigation which is simple copy of traditional items, simple copy of Korean Alphabet, Chinese character, and folk paintings. Therefore, it will present the method to make more design cases using Tessellation. Tessellation that combines mathematics and art will be the infinite form of designing of designers as well as creative training way to understand the composition principles of old culture and to raise sense of modern design. Tessellation of regular triangle, regular square, and regular hexagon was performed on the patterns which have meaning of wealth and prosperity of Korean traditional patterns. As the concrete method, first, each side of the regular triangle is developed symmetrically with patterns of fish, turtle, and cicadas. Second, rotational movement after symmetry movement about middle point of one side × 1 symmetry movement about middle point × 1 using crane and cloud, of the regular triangle was performed. Third, the regular square was tessellated parallel movement × 2 with “Da(multi)” and dragon pattern as the source image. Fourth, the sitting tiger was tessellated with symmetry movement about middle point × 2 and parallel movement × 1. Fifth, three bat patterns are tessellated by again rotational movement of two sides after rotational movement of one side and rotational movement of the other side. In addition, It developed traditional culture product design of the scarf, umbrella, aprons, neckties.

Keywords: tessellation, traditional patterns, cultural product
and pattern, which can most satisfy human aesthetic sensibility and pleasure. The diversity of pattern in fashion design can be a way to broaden consumer’s choice and enhance design sensitivity.

The pattern has been changed and applied variously in the background and flow of the times. In particular, the traditional pattern has a very high visual value, which inherits the values and traditions of the nation with its national ideals and souls. Most of the traditional cultural products of the museum cultural foundation in Korea are copied and developed in the simple form of letters or patterns. Therefore more various and modern patterns need to be developed. Tessellation is a way to break through the limitation of such patterns and design development. However, Tessellation has been limitedly studied and taught only in mathematics subjects.

Previous studies are mostly done by mathematics textbooks, mathematics curriculum management, and arts and mathematics education.

Lim, H. K. (2002), Bin, J. (2015), Kim, M. (2014), Lim, H. K. (2013), Cha, I. (2015), Son, A. (2005), Lim, H. (1999) carried out the research on the pattern itself by tessellation and the design development in apparel and household goods sector is recently carried out by a few people like Lim, B. (2013), Jeong, R. (2016), who are doing researches on fashion products and 3D chairs.

In the process of design development, we are going to develop pattern and apply product by using tessellation method, which is the basic of molding field and source of mathematical and systematic design development.

Tessellation geometry visualizes various mathematical principles including symmetrical change, vector, periodicity, infinite series, permutation, etc. in a creative way, so it understands the formative principles of art in terms of mathematical aesthetics and uses as an expression tool to express an aesthetic world(Lim, H. (2013). Mathematical concepts in tessellation are taught only in elementary mathematics course. This application of this tessellation is closely related to our everyday life widely in various fields such as wallpaper pattern, sidewalk block, wrapping paper, tile, architecture, etc.

Tessellation of regular triangle, regular square, and regular hexagon was performed for the patterns of which have the meaning of wealth and prosperity from the traditional pattern DB of cultural portal and the traditional patterns. The colors were based on the colors by theme of the Carlin’s 17 Color’s tracks, Cosmopolitan, Breeze and Paradise.

The purpose of this study is to explore the definition and method of tessellation, and to develop a creative pattern based on mathematics by combining it with traditional patterns.

Researching and developing the features of the traditional patterns by the new approach will overcome the limitation of design, develop various designs, modernize the traditional patterns of Korea, and stimulate the international consumption of Korean wave craze for the products accordingly(http://www.culture.go.kr).

II. Research method

Based on the theoretical principles of literature and preliminary research, we extracted patterns by using crane, cloud, tiger, bat, dragon, turtle, fish, cicada and Chinese character “Da (multi)” which means many which have the meaning of
wealth and prosperity from traditional patterns of tradition pattern DB of cultural portal (http://www.culture.go.kr) and Korean traditional pattern (Well design publication, 2015), and used a motif that was properly deformed to the method of tessellation, and tessellated by deforming the triangular, square, and hexagonal shapes that can be tessellated. Motif design and tessellation are developed pattern development design by using the Illustrator CS5 program and applied it to fashion products.

The color was used by theme colors of Tracks, Cosmopolitan, Breeze and Paradise of Carlin’s SS 17 Color.

III. Theoretical Background

1. Tessellation

1) Definition of Tessellation

Tessellation refers to a regular division technique of planes that completely fill the space without overlapping shapes without leaving a gap by using a constant shape (M.C.Escher, 2004). Its pattern can be extended indefinitely in all directions and it is a term derived from the Greek word “tesseres”, which means 4. It is called “JJokmae Machum” in pure Korean words, and was created in the process of putting together a square. Tessellation geometry visualizes various mathematical principles including symmetrical change, vector, periodicity, infinite series, permutation, etc. in a creative way, so it understands the formative principles of art in terms of mathematical aesthetics and uses as an expression tool to express an aesthetic world. (Lim, H. 2013).

The most typical example is Alhambra Palace (Figure 1), the Islamic palace built in Granada, Spain, in the late 13th century, which forms the culmination of Islamic art elaborate and precise such as arch, delicate pillars and wall decorations of the 14th century. The geometric shapes, which are characteristic of Islamic formative arts, consist of circles, squares, polygons, swastika, meandering path, chessboard, and zigzag (Figure 2). In Korea, it can be found in historical sites such as the stone wall of Gyeongbok Palace (Figure 3), the minkkossal pattern (Figure 4), the pattern of Turtle Ship shell (Figure 5), and the Jusangjeolli of Jeju Island (Figure 6).
2) Composition Principle of Tessellation

General conditions of the tessellation are four as follows. First, planes or spaces should be overlapped or filled without gap in unit shape. Second, the sum of the angles gathered around one vertex should be 360°. That is, all regular polygons except regular triangles, regular squares, and regular hexagons can not be tessellated because they may gap or overlap with each other like regular pentagons. Third, it should be arranged to touch side of the same length. Fourth, it should be able to expand infinitely in all directions from the plane (Lee, C., 2001).

The construction principles of tessellation are symmetry theory and the application of basic geometry. Symmetry theory is divided into parallel movement, rotation, and reflection. Parallel movement is to move the same distance in the same direction, and rotation is to rotate the original figure by a certain angle. Reflection is to move one figure upside down on the basis of the axis of symmetry. A typical author of this method is M. C. Escher. (Figure 7) is a Escher’s famous lizard, which is rotated 90° in the regular square to eliminate the distinction between background and figure, and shows the optical illusion that figure and background are reversed.

Tessellation can be classified into two types, depending on the types of figures included in the tessellation: regular polygonal tessellation consisting of the same types of regular polygons and tessellation consisting of different types of regular polygons, and this study will do research according to regular polygonal tessellation.

Computer softwares that can implement tessellation are turtle command program, GSP (Geometers) Sketchpad, Cabri-Geometry II, Tesselmania, Tess, as software only for tessellation, and Paint, PowerPoint etc. as other softwares (Lim, H., 2013).

3) Regular polygon Tessellation

Only regular triangles, regular squares, and regular hexagons can be tessellated, and there is an arrangement method of developing only one type of figure simply and there is a method of transforming each figure. The examples are as follows (Bin, J., 2015).

1) Transformation of regular triangle

There are two types of symmetry movement about the middle point of side and rotation movement about the vertex(Figure 8).

2) Transformation of regular square

If movements that can occur within regular
square are tied, there are, first, the movement of opposite side and the movement within one side, and second, the movement in the neighboring side and the movement within one side (Figure 9).

(3) Transformation of regular hexagon
The methods to transform regular hexagon are symmetry movement about vertex, rotation movement about vertex, symmetric movement about middle line of side, symmetry movement about diagonal, symmetric movement about middle line, rotational movement after symmetric movement about middle line, rotational movement after symmetric movement about middle line, symmetry movement about diagonal, etc. in order (Figure 10). Based on this, tessellation can be performed by transforming all six sides such as regular triangle and regular square.

This tessellation is a creative education method that can realize the artistic creation work in the mathematical approach and it will become a systematic and unlimitedly transformable design work not to rely only on our sense. Examples of tessellation can be found in many places around us, such as the Isao Miyaki baobaobag (Figure 11), Tile of street (Figure 12) http://thearchist.tistory.com/archive/20140719, Japanese architect SHIGERU BAN’s Pompidou Center showed an eight-figure grid with a roof shaped by a Chinese farmer’s hat –http://blog.daum.net/woodgood (Figure 13), and Honeycomb structure made of carbon-fiber-reinforced polymer on a BMW (Figure 14).
2. Traditional Pattern Survey

Patterns in a word, can be said to shape dots or lines, and colors like a figure to invoke an aesthetic sensation (Lim, H., 2013). Patterns are simply beyond decoration and imply symbolic meaning by adding to human inherent origin and desire and religious magic.

In a dictionary sense, patterns generally mean shapes formed by combining various shapes on the outer surface of an object. It is called "Munui" in Korean. Pattern is artistic activity of everyday life, and the source of all formative arts such as craft, painting, sculpture, architecture, etc. It is also a general theory that symbolic patterns are given as means of communication and various symbolic meanings. Traditional patterns of Korea have been developed under the influence of the Neolithic Age, the Bronze Age in which Scythian art spread, and the Unification Silla in which the geometric patterns of Persian art were transmitted (http://www.culture.go.kr).

The symbolic meanings of Korean traditional patterns are as follows.
They are divided into person patterns, animal patterns, vegetation patterns, artifact patterns, natural landscape patterns, letter patterns, geometric patterns, compound patterns, and other patterns. The person patterns are the pattern which express persons, ghosts, murderers, hermits, children, goblins, etc. The goblins have the meaning of wickedness or patronage. The animal patterns are dragons, snakes, deer, carp, mandarin, turtles, cranes, Haitai, lions, tigers, bats, etc. The bat was a symbol of happiness because 'bok' of '蝙蝠 Pyeonbok' which is the Chinese character of bat, is the same pronunciation as 'bok 福 blessing' which means happiness. The dragon meant to mark the virtue of the emperor and the authority of heaven, and the ability to defeat evil and bring blessings. The fish patterns represent the leisure and pleasure of life, the success of the future, filial devotion, the prosperity of the offspring, and the felicity of couples. The cranes mean the heads of all the birds, and longevity along with the clouds. What painted like a cloud and crane was called 'Unhak'. They were used variously in formative arts such as painting, sculpture, craft, etc (Well design publishing department., 2015). The tigers symbolized the king of beasts and meant stopping evil spirits. The cranes symbolized longevity as one of the 10 kinds of longevities.

In letter patterns, '多子' (Many children) and '多男' (Many boys), who wanted to have a lot of children, especially boys, were mainly used.

In vegetation patterns, there are lotus, plum, and vine. The lotus and vine, which have the most used, have been loved because of their strong vitality.

In artifact patterns, Seven Treasures pattern and Yeouidu pattern were loved due to meaning of "multi-blessing".

Natural landscape patterns consist of nature except for animals and plants, which are the Moon, clouds, stars in the sky. The clouds symbolized longevity as one of the 10 kinds of longevities and mainly used with cranes.

Letter patterns symbolize the symbolic meaning of the letter by putting it into the pattern. Geometric patterns are pattern that human beings first started to make, which represented points, lines, circles, etc. There are ghost patterns, Taegueuk patterns, turtle shell patterns, Eight Trigrams patterns, etc. Compound patterns represent new meanings by expressing various patterns together. 10 kinds of longevities, that is, sun, mountain, cloud, stone, water, elixir,
pine tree, turtle, deer, and crane had the meaning of longevity, and all combined to express ten (10) perfection. (KCISA, 2016). For other examples, circles meant heaven, squares meant earth, the universe meant octagon, and spiral shapes meant chaos.

At Cultural Foundation of National Museum in Korea, cultural products that link tradition and modernity were made and sold in major museums. Items designed with mono color or rainbow-striped color for traditional items such as existing Pouch of Korean socks (Figure 15), one-point pattern embroidery magnet (Figure 16.), Hangul or Chinese character pattern (Figure 17, 18), and plant pattern of folktale (Figure 19, 20) were used mostly as patterns.

This pattern is the most important element in modern fashion design because it has the basic and direct connection with the clothes life style. However, since the pattern design using this pattern has limitation, we will suggest the design method for the traditional culture product by using tessellation method which can develop the pattern easily and creatively

IV. Result

Traditional patterns of cultural portal and offline were selected and developed cranes and clouds, tigers, ‘da’ and dragons, cicadas, fishes and turtles, and 2 bats by tessellation method of...
The colors were based on the colors by theme of the CARON-SS 17 COLOR's TRACKS, COSMOPOLITAN, BREEZE and PARADISE.

1) Regular Triangle Tessellation (Table 1)

The first is to use regular triangles as a unit lattice, and it is based on symmetry centered on each side of the triangle. Motive design was made by transforming fish 074113 (Figure 21.), turtle 9947 (Figure 22.), and cicadas 9248 (Figure 23.) to conform to the tessellation.

The second is also to use regular triangle as a unit lattice, and perform as rotational movement after symmetric movement about middle line of side × 1 and symmetry movement about middle point × 1.

Source image is crane pattern 7850 (Figure 24.) and cloud pattern 079847 (Figure 25.).

2) Regular Square Tessellation (Table 2)

The first used "Da (multi)" (Figure 23.) and dragon pattern 2673 (Figure 24.) as source images and tessellated with parallel movement × 2. The regular square was rotated sideways to resemble "da", and the lower part of Chinese character was expressed using the dragon's body.

The two circles represent hole of "Da" and also mean the Yeolju of dragon.

The second regular square was the source image of the tiger sitting with symmetry movement about middle point × 2, parallel movement × 1 tessellation.

3) Regular Hexagon Tessellation (Table 3)

It is a tessellation which is again rotational movement of two sides after rotational movement of one side and rotational movement of the other side. Bat pattern 8786 (Figure 26.), bat pattern 9190 (Figure 27.) and bat pattern 9404 (Figure 28.) were used as source images and color was used. The results of the tessellation according to each figure in Table 1 is the same Table 2. Items presented three designs for Scarf, apron, umbrella, Kitchen gloves, and Necktie respectively.

First, Scarf is regular square tessellation of tiger. The first was designed as a only tessellation. The second applied partly tessellation and tiger fur pattern. The third is regular hexagon tessellation of fish, turtle, and cicadas. The edge is expressed only by the tessellation line, thereby relieving the weight sense (Table 4).

The apron was designed by adjusting the size with regular triangle tessellation of the first crane. The second one also filled the entire area with regular triangle tessellation of crane. The third was the regular hexagonal Tessellation of the two bat patterns, and one-third of the pattern was represented by white lines, adding sophisticated beauty (Table 4).

The umbrella was designed in two colors of the three grid units with regular hexagon tessellation for fish, turtle, and cicada. The third umbrella was represented by the regular triangle Tessellation of crane.

The kitchen gloves were designed with regular square of tiger, regular hexagon of two bats, and regular square tessellation of Da(multi) and dragon. The Necktie was tessellated with regular hexagon of two bats, regular square of Da(multi) and dragon, and regular square of crane (Table 5).
### Table 1. Regular Triangle

| Source image | Regular Triangle Tessellation | Applying colors |
|--------------|-------------------------------|-----------------|
| Figure 21. Fish 074113 -http://www.culture.go.kr | Figure 22. Tortoiseshell 9947 -http://www.culture.go.kr | Figure 23. Cicada 9248 -http://www.culture.go.kr |
| Figure 24. Crane 7850 -http://www.culture.go.kr | Figure 25. Cloud 079847 -http://www.culture.go.kr |

#### Source image

- **Figure 21. Fish 074113**
  - http://www.culture.go.kr
- **Figure 22. Tortoiseshell 9947**
  - http://www.culture.go.kr
- **Figure 23. Cicada 9248**
  - http://www.culture.go.kr
- **Figure 24. Crane 7850**
  - http://www.culture.go.kr
- **Figure 25. Cloud 079847**
  - http://www.culture.go.kr

#### Applying color

| C:28.63 | M:52.55 | Y:46.27 | K:0 |
|---------|---------|---------|-----|
| C:52.94 | M:92.94 | Y:60.78 | K:12.94 |
| C:24.71 | M:44.31 | Y:84.31 | K:0 |
| C:30.98 | M:7.84 | Y:13.33 | K:0 |
| C:32.55 | M:69.02 | Y:49.02 | K:9.8 |
| C:27.06 | M:100 | Y:100 | K:27.45 |
| C:92.94 | M:90.98 | Y:32.55 | K:22.75 |
| C:75.29 | M:53.33 | Y:44.71 | K:20.39 |
| C:34.9 | M:18.04 | Y:6.27 | K:0 |
| C:92.51 | M:87.59 | Y:0 | K:0 |
| C:100 | M:100 | Y:48 | K:5.63 |
| C:5.49 | M:56.47 | Y:24.31 | K:0 |
| C:11 | M:84 | Y:62 | K:0 |
| C:19 | M:92.94 | Y:44 | K:6 |
| C:22.35 | M:12.55 | Y:19.61 | K:0 |
| C:86.29 | M:63.01 | Y:50.85 | K:7.59 |
| C:39.51 | M:100 | Y:100 | K:5.11 |
| C:92.55 | M:69.02 | Y:13.33 | K:0 |
Table 2. Regular Square Tessellation

| Source Image | Regular Square | Result | Applying Color |
|--------------|----------------|--------|----------------|
| Figure 23. Da | Figure 24. Pattern of a Dragon 2673 | Figure 25. Pattern of Tiger sitting - Classical Korean Traditional Patterns p.125 | |
| -http://www.culture.go.kr | -http://www.culture.go.kr | | |
| | | | |
| Tessellation | | | |
| | | | |
| | | | |
| Result | | | |
| | | | |
| | | | |
| Applying Color | | | |
| | | | |
| | | | |
### Table 3. Hexagon Tessellation

| Source image | Regular Hexagon | Hexagon | Hexagon |
|--------------|----------------|---------|---------|
| Figure 26. Bat 8786 | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) |
| Figure 27. Bat 9190 | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) |
| Figure 28. Bat 9404 | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) |

| Tesslation | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) |
|------------|-----------------------------------|-----------------------------------|-----------------------------------|

| Result | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) | ![Image](http://www.culture.go.kr) |
|--------|-----------------------------------|-----------------------------------|-----------------------------------|

| Applying color | C:26.27 | M:28.63 | Y:7.45 | K:0 |
|----------------|---------|---------|--------|-----|
| C:74.12 | M:66.27 | Y:42.75 | K:1.96 |
| C:4.31 | M:56.47 | Y:29.02 | K:0 |
| C:87.06 | M:83.92 | Y:68.63 | K:54.12 |
| C:29.41 | M:22.35 | Y:23.92 | K:0 |
| C:23.53 | M:8.24 | Y:5.49 | K:0 |
| C:49.8 | M:37.65 | Y:18.43 | K:0 |
| C:85.63 | M:83.09 | Y:82.56 | K:71.37 |
Table 4. Results of Scarf, Apron, Umbrella

| Item   | Results |
|--------|---------|
| Scarf  | ![Scarf Image] |
| Apron  | ![Apron Image] |
| Umbrella | ![Umbrella Image] |

V. Conclusions

The application of tessellation is closely related to our everyday life in various fields such as wallpaper pattern, sidewalk block, wrapping paper, tile, and architecture, but the mathematical concept in tessellation is only taught in elementary mathematics course.
Table 5. Results of Kitchen Gloves, Tie

| Item          | Results                          |
|---------------|----------------------------------|
| Kitchen gloves| ![Kitchen gloves](image)         |
| Tie           | ![Tie](image)                    |

In the process of design development, we are going to develop pattern and apply product by using tessellation method which is the basic of formative field and source of mathematical and systematic design development.

In this study, we applied the SS color trend in 2017, using the traditional pattern as the source image, and developed the pattern by the tessellation method and presented the product result.

Based on the theoretical principles of literature and preliminary research, tessellation of regular triangle, regular square, and regular hexagon was performed for the patterns of which have the meaning of wealth and prosperity from the traditional pattern DB of cultural portal and the traditional patterns of the Korean traditional patterns.

As the concrete method, first, each side of the regular triangle is developed symmetrically with patterns of fish, turtle, and cicadas. Second, rotational movement after symmetry movement about middle point of one side × 1 symmetry movement about middle point × 1 using crane and cloud, of the regular triangle was performed. Third, the regular square was tessellated parallel movement × 2 with "Da(multi)" and dragon pattern as the source image. Fourth, the sitting tiger was tessellated with symmetry movement about middle point × 2 and parallel movement × 1. Fifth, three bat patterns are tessellated by again rotational movement of two sides after rotational
movement of one side and rotational movement of the other side.

The pattern results of the developed traditional patterns are designed and presented 3 kinds of each for apron, kitchen gloves, umbrella, scarf, and necktie.

Researching and developing the features of the traditional patterns by a new approach will overcome the limitation of design, develop various designs, modernize the traditional patterns of Korea, and stimulate the international consumption of Korean wave craze for the products accordingly. In addition, tessellation, in which design and mathematics are combined, can become a new breakthrough in the fusion and complex education and design development, which is the most popular.

In this study, only the tessellation of regular polygon limited to plane has been developed. However, it is necessary to proceed study on various application methods by tessellation of semi-regular polygons or arbitrary polygons, three-dimensional tessellation.

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