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Geometric Structure Analysis Of Islamic Decorative Patterns

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***Abstract*—Decorative patterns are an artistic expression that originated very early in human history. Under the influence of different regions and cultures, each place has developed its own cultural style and will interact with neighboring regions. Therefore, behind the beautiful patterns, there is usually a story of historical development or even national spirit. The decorative style of Islamic patterns has been influenced by Islamic religious ideas since its inception. Its main feature is the beauty of abstract patterns. Although it is complex and varied, it gives people a unified and harmonious visual effect. Therefore, it is based on some basic graphics, which continuously form new decorative forms through regular arrangement, reconstruction, transformation cycle, repeated extension, etc., and combine into all-encompassing, tightly organized, exquisitely complex, and ever-changing Islamic geometric patterns. This article focuses on the style of Islamic graphics and analyzes and summarizes the strategies and steps in constructing Islamic graphics through the characteristics of its geometric shapes, which will enable us to understand and develop Islamic patterns more deeply and systematically.**

***Keywords*—Decorative patterns, Islamic patterns**

I. INTRODUCTION

The development of decorative art is a manifestation of the progress of human civilization. Through historical materials, we can understand that it starts from rock paintings in prehistoric times, to decorative patterns on utensils and even on fabrics and buildings. It is a slow and gradual transformation. It is a record and symbol of human thought and symbols, reflecting people's thoughts and aesthetic concepts at that time. Therefore, even though the emergence and development of many different civilizations have caused changes in the expression of patterns, it has also promoted the diversity of patterns. A pattern is a living shape. From the historical evolution of patterns, we can find that patterns reflect people's depiction of life. Sugiura Kōhei[1] mentioned that under the influence of the “spirit”, the “form” becomes a “shape” with flesh and blood, a shape that is full of spiritual power, golden and dazzling. It is given “life” and begins to move with vitality. From this we can see that the creation of patterns has its background and meaning. Whether it is concrete or abstract, it has a soul.

Regarding the development of decorative art, Ye Liutian Zeng [2] mentioned that from the perspective of the history of human art and cultural development, decorative art can be said to be the earliest artistic activity and aesthetic expression of mankind. The decorative art presented in different periods reflects the thoughts, aesthetic concepts and religious beliefs of the time. From the perspective of historical evolution, human beings have not only created scientific and technological civilization, but also created artistic culture. At the beginning of civilization, people invented and manufactured various tools and utensils to meet their living needs. With the improvement of wisdom and the accumulation of experience, humans became more and more sophisticated in the production of utensils. At first, utensils were made for the need to make a living. With the improvement of production techniques, in addition to practical purposes, aesthetic concepts gradually emerged in the shape. Therefore, the patterns on the utensils also changed from their original practical functions to artistic expressions.

From the evolution of Eastern culture, we know that pattern elements in Western culture entered the Eastern world through activities such as ethnic migration, cultural exchange, war and trade, thus increasing the diversity of pattern expression in the Eastern world. Western patterns also have a history and evolution. Compared with the gods, ghosts, religions, mythical beasts, flowers, plants, people, birds, insects, auspicious patterns, auspicious objects and auspicious words in Eastern culture, the patterns of Western culture are mainly plant patterns and geometric patterns in nature; it changes from simple patterns (squares, circles, diamonds, text shapes and curve shapes, etc.) to complex changes. The composition type has evolved from a two-sided continuous composition to a four-sided continuous composition, and can even expand infinitely outward, and has evolved from simple line expression to complex interwoven pattern presentation. Regarding this evolution process, Riegel[3] divided the patterns into four styles: geometric patterns, heraldic patterns, plant decorative patterns and Arabic decorative patterns.

The so-called Arabic decorative pattern is a complex decoration with repeated geometric shapes. It is an important element of Islamic art and is commonly seen on the wall decorations of mosques.

The way its geometric figures are composed must be based on the Islamic worldview. For Muslims, the combination of countless geometric figures means that there is an infinite existence beyond the visible material world. This geometric style of arabesque did not become widely popular in the Middle East and the Mediterranean basin until the Golden Age of Islam. Therefore, geometric patterns and symmetry are the main themes of Islamic artwork, which naturally give rise to the abstract concept of symmetry. Pattern and symmetry are two of the most profound and pervasive concepts conceivable by the human mind, and no other concept unites science, art, and nature as they do. Patterns and symmetries are equally fascinating and meaningful to kindergarten children and physicists constructing complex theories of the universe [4]. Therefore, this article focuses on the style of Islamic graphics and analyzes and summarizes the strategies and steps in constructing Islamic graphics through the characteristics of its geometric shapes.

II. ISLAMIC GRAPHIC STYLE FEATURES

Geometric patterns appear in large numbers in Islamic culture. They exist on different materials such as tiles, wood, brass, paper, plaster, glass, etc., and they are particularly prominent on the surface of buildings. Leaving aside the patterns on felt, floral motifs and stylized floral designs, Islamic motifs appear in three specific geometric features. One of the most easily recognizable is the rectangular Kufic letter pattern. They used simple rectangles and squares to create calligraphic designs in a stylized form of Arabic letters. This pattern is most commonly used on building surfaces to add majesty and solemnity. The second special Islamic pattern form is the arabesque, which consists of curved elements that resemble leaves and flowers. In this pattern, the spiral shape continuously winds, undulates and connects, and the sense of periodicity and rhythm is very prominent in this pattern.

The largest category of Islamic patterns uses complex polygonal and, less commonly, circular arcs to enclose areas, with designs in a basic grid repeated over and over again to completely fill an enclosed area. The most striking feature of this type of pattern is the symmetrical form of the "stars" and "constellations". Some Islamic designs do not include stars, but they are quite rare and not very elaborate or complex. Stars with six, eight, ten, twelve and sixteen rays occur most frequently, but stars with other numbers of rays (especially multiples of eight, up to ninety-six) may also be seen. The star shape is not just decorative, but has important psychological and historical reasons.

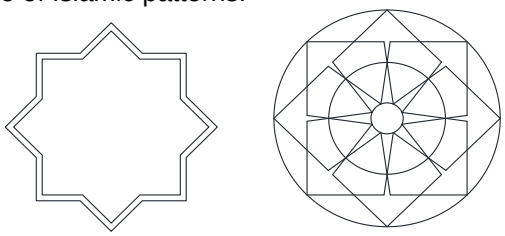
The fusion of straight and curved elements and Arabic calligraphy shows the most obvious characteristics of Islamic architectural decoration. For Muslims, the poetry of the Quran represents the visible reality of God's word, and its calligraphy enhances its sacredness and inspiration. No other civilization has placed such a high value on pattern and symmetry, and no other civilization has so deeply respected the sanctity of words, that it can be said that "calligraphy is the jewel in the crown of Islamic art."

The other two characteristics are related to "fluidity" and "infinity", which may not be obvious from isolated patterns, but as in the Islamic patterns mentioned above, the geometric basis used is the replication of the grid, and the pattern can be repeated infinitely to fill the space as much as possible. A concomitant property is that the viewer's eye has no natural focal point. When people look at an unfolded pattern, their eyes will "flow" continuously along the lines, and they will see many complex structures and relationships. This feature is not evident in the geometric designs of other cultures.

III. GEOMETRIC STRATEGIES AND STRUCTURAL ANALYSIS OF ISLAMIC GRAPHICS

Islam mainly replaces the anthropomorphic image of God with a single abstraction, and this innate feeling is very strong. For Muslims, unlike Christians or Hindus, God has not and cannot be incarnate. The only physical form of God acceptable to Muslims is Nur, which means light. As the Quran declares, "God is the Light of the heavens and of the earth." Because art is primarily concerned with the image of God as we perceive it, and because Islam does not provide such an image, Islamic art embraces geometry.

The most common and basic characteristic shape in Islamic patterns is shown in Figure 1(a). The pattern is also seen in Samar and the Sahara Desert. It contains an eight-pointed star and is known as Khatem Sulemani, which means "Solomon's Seal". This shape is the most common shape in Islamic patterns. If we have to pick out a shape that expresses the characteristics of Islamic patterns, it must be this one. This is not only because of its high frequency of occurrence, but also because there are a large number of Islamic patterns that can be considered as its deformation, as shown in Figure 1(b). And when they fill a certain area of space, anyone familiar with Islamic patterns can immediately recognize what type they are, which is the most characteristic visual feature of Islamic patterns.



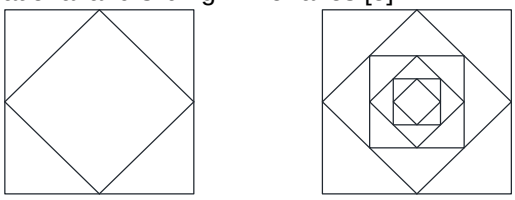
(a) (b)

Figure 1 The most basic Islamic pattern

Since ancient times, people have recognized that beauty lies in a harmonious proportional relationship between the various parts of a structure, and between these parts and the whole. Beautiful patterns must have some inherent logic of proportion. Designers of Islamic patterns used many strategies to achieve harmonious proportions; some were crude methods

discovered through experience. However, there is also a widely adopted systematic strategy, for example Figure 2 is an example of a systematic strategy.

As mentioned above, Islamic civilization attaches great importance to the value of pattern and symmetry, so the Islamic patterns it develops naturally have these characteristics. Here, Islamic patterns that fill a certain area of space are divided into: (a) finite symmetric patterns with a rotation center and a reflection axis. (b) Infinitely symmetrical patterns with translational and sliding mirror axes [5].

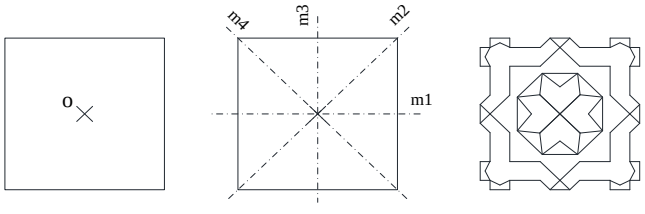


(a) (b)

Figure 2 Square root ratio system

(a) A finite symmetric pattern with a rotation center and a reflection axis: a square as shown in Figure 3(a). It has the quality that if it is rotated 90, 180, or 270 degrees about its center "O", then although its endpoints will be rearranged, the square will still be exactly in the region of space where it was before the rotation. If there are no other distinguishing marks, it will appear as if the location has not changed at all. If you rotate it 360 degrees, of course all the endpoints will return to their original positions.

Similarly, if any line connecting the midpoints of two pairs of sides, or any diagonal line m1, m2, m3 or m4 is used as the axis for reflection, as shown in Figure 3(b). Its appearance also remains unchanged. You only get a congruent copy, that is, a copy that completely overlaps with the original image. Therefore, rotations by multiples of 90 degrees about the center, reflections about a line joining the midpoints of two opposite sides, and reflections about a diagonal are called symmetries of the square. For example, the pattern in Figure 3(c) looks more complex than the undecorated square on the left, but their symmetry is exactly the same. Therefore, for finite symmetric patterns, that is, patterns that occupy a finite region in space, rotation and reflection are the only operations that can produce copies that are congruent to the original.



(a) (b) (c)

Figure 3 Finite symmetric pattern with rotation center and mirror axis

(b) Infinitely symmetrical pattern with translation and sliding mirror axis: as shown in Figure 4. Assume that this pattern extends infinitely in both directions. Here the distance between the first pattern and the next repetition is L. If we pull this pattern horizontally by L or 2L, or any integer multiple of L, the pattern will look exactly the same as before it was pulled. A pattern with this property is called a translationally infinitely symmetric pattern.

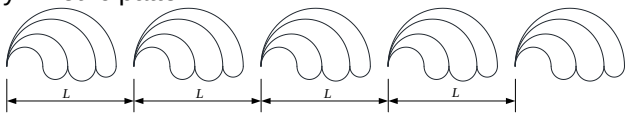


Figure 4 Infinite symmetric pattern with translation

In addition, for the pattern shown in Fig 5, if a horizontal translation of 2L or 4L or any even multiple of L is used, the pattern will move to a position overlapping with the original position without changing the appearance. Alternatively, we can perform another action that leaves the pattern unchanged. This method is to translate the pattern horizontally by L, and then mirror it through the midline of the pattern as the axis. The same result is obtained if the translation is performed by 3L, 5L, or any cardinality multiple of L before the mirroring. This has the property of combining a translation with a mirror operation, called an infinite symmetry pattern of sliding mirroring.

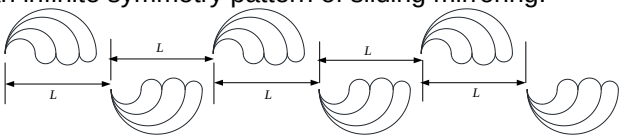


Figure 5 Infinite symmetric pattern with sliding mirror

IV. Classification of Islamic Patterns

This article classifies patterns according to their symmetry groups, and by identifying the symmetry of the patterns, we can clarify the grid system behind them. Here the grid system is divided into five different types, as shown in Figure 6.

(1) An oblique parallelogram with unequal adjacent sides: This type of parallelogram can only be symmetrical if it is rotated 180 degrees, as shown in Figure 6(a).
(2) Rectangular: For this type of pattern, mirroring of one or both sides as well as sliding mirroring are possible symmetries, as shown in Figure 6(b).
(3) Diamonds without 60 degrees: This type is also called "centered rectangular grid system", that is, this type of pattern can be regarded as a rectangle with a center, as shown in Figure 6(c).
(4) Square: This type of pattern is symmetrical regardless of whether the grid sides are 90 degrees or 45 degrees, as shown in Figure 6(d).
(5) 60 degree rhombus: This special rhombus is split into two equilateral triangles. The six equilateral triangles surrounding any node can be gathered into a hexagon. Therefore, this type of pattern is symmetrical whether it is rotated 60 degrees or 120 degrees, or the grid edges are multiples of 60 degrees, as shown in Figure 6(e).

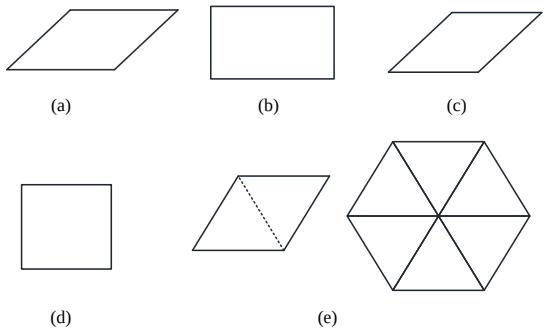


Figure 6 Five types of grid systems

It can also be mathematically proven that if we enumerate all the different symmetry groups of 2D repeating patterns, there are a total of seventeen possibilities. Therefore, if we choose to classify repeating patterns by symmetry group, there are only seventeen different pattern types. These seventeen possible two-dimensional repeating pattern types can be represented by an internationally common notation, as shown in Table 1. The expressions in brackets in Table 1 are abbreviations of the types.

Table 1

Unit grid shape	Pattern Type
Parallelogram	p1, p2
Rectangle	p1m (pm), p1g (pg), p2mm (pmm), p2mg (pmg), p2gg (pgg),
Rhombus	c1m (cm), c2mm (cmm)
Square	p4, p4mm (p4m), p4gm (p4g)
Hexagon	p3, p3m1, p31m, p6, p6mm (p6m)

Generally speaking, the full name (not in abbreviated form) uses the consecutive symbols S1-S2-S3-S4 to express its meaning.

(1) If the grid used is a central rectangle, the first symbol S1 is "c", otherwise it is "p" (the original grid).
(2) The second symbol S2 represents the highest order rotational symmetry in this pattern. For example, the presence of "3" indicates that 120 degrees of rotation is the highest at this position. If "1" appears, it means there is no rotational symmetry.
(3) If there is a mirror axis, the third symbol S3 is an “m” (indicating mirror). If there is no mirroring but there is sliding mirroring, it is "g". If there is neither mirroring nor sliding mirroring, symbol S3 is a "1".
(4) The symbol S4 is used in the same way as the symbol S3 to indicate a mirror image in another direction or a sliding mirror image.

Therefore, according to the above rules, common Islamic patterns can be divided into the following categories:

- No rotational symmetry axis

Such patterns are further divided into different categories depending on whether they have an axis of symmetry, a sliding mirror or a rectangular center, as shown in Figure 7.

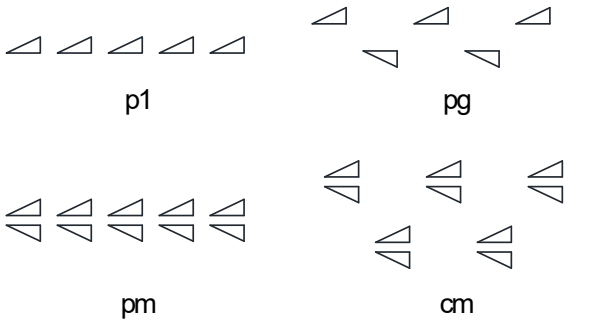


Figure 7 Classification of patterns without rotational symmetry axis

- Double rotational symmetry axis

Such patterns are further divided into different categories according to whether they have an axis of symmetry, a sliding mirror, another axis of symmetry or a rectangular center, as shown in Figure 8.

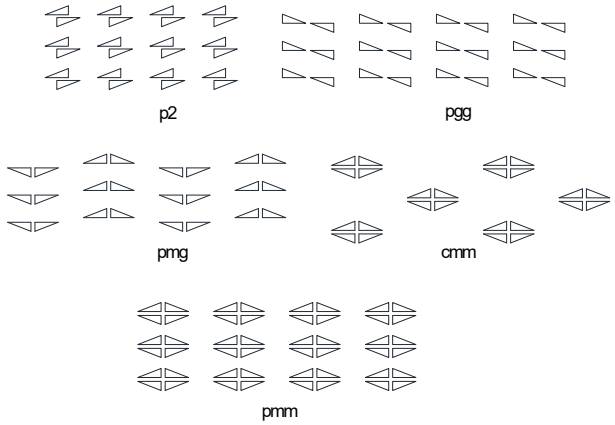


Figure 8 Types of double rotational symmetry axis patterns

- Three-fold rotational symmetry axis

This type of pattern is further divided into different categories according to whether it has an axis of symmetry and whether the center of rotation is on the axis of symmetry, as shown in Figure 9.

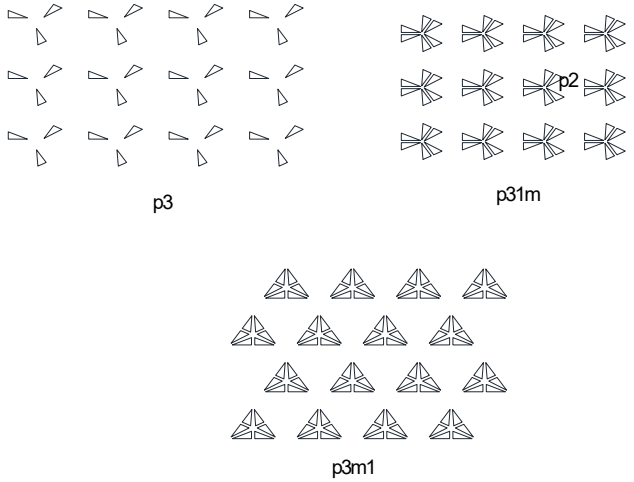


Figure 9. Classification of triple rotational symmetry axis patterns

- Four-fold rotational symmetry axis

This type of pattern is further divided into different categories according to whether it has a mirror axis and whether the mirror axis has four directions, as shown in Figure 10.

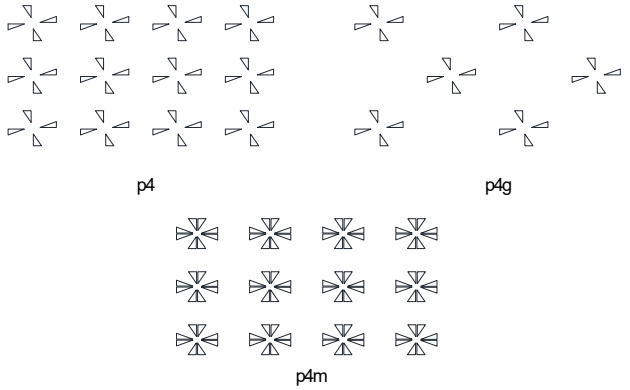


Fig.10 Classification of four-fold rotational symmetry axis patterns

- Six-fold rotational symmetry axis

This type of pattern is further divided into different categories depending on whether it has a mirror axis, as shown in Figure 11.

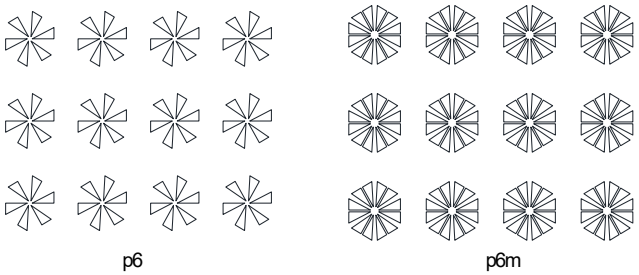


Fig.10 Classification of six-fold rotational symmetry axis patterns

V. CONCLUSION

Islamic patterns appear in three specific geometric features. One of the most easily recognizable is the rectangular Kufic letter pattern. They used simple rectangles and squares to create calligraphic designs in a stylized form of Arabic letters. This pattern is most commonly used on building surfaces to add majesty and solemnity. The second special Islamic pattern form is the arabesque, which consists of curved elements that resemble leaves and flowers. In this pattern, spiral shapes continuously wind, undulate and mesh. The sense of period and rhythm is very evident in this pattern. The largest category of Islamic patterns uses complex polygonal and, less commonly, circular arcs to enclose areas, with designs in a basic grid repeated over and over again to completely fill an enclosed area. The most striking feature of this type of pattern is the symmetrical form of the "stars" and "constellations". This article classifies Islamic patterns into 17 types based on the geometric characteristics of their graphics and the repeated distribution patterns of their composition, using internationally accepted mathematical representation methods. This will enable a deeper and more regular understanding and development of Islamic patterns.

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