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Algorithmic Comparison of "Shamsah" in Iranian Architecture, Carpet and Pottery

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Abstract

During various art periods of Iran, three art fields of pottery, architectural decorations and carpet weaving have had a significant contribution to the artistic trends of the Islamic period. The purpose of the present research was to explain and analyze the geometric patterns used in the Islamic artworks of pottery, architecture and carpet weaving and the influence of these three fields of art on each other. Other research objectives were also to examine the common features of above-mentioned fields of art in order to provide a schematic model based on their artistic nature. The main question of the present research were as follows: 1.What are the common features of Shamsah, in terms of geometric shape, in the three above-mentioned fields of art, given their different historical intervals and art periods? 2. How is it possible to achieve similar shapes through changing the geometrical parameters in the mathematical algorithm of these Shamsah? This research was conducted using a comparative-analytical approach. Data were collected using desk studies – due to the research literature – and field studies – because of observing and taking pictures of some decorations in three above-mentioned fields of art. Finally, computer simulation was used to do data analysis. The results of this study indicated that the principles of composition of geometric patterns in the three studied fields of art were based on the order, arrangement and organization of motifs to achieve a coherent format.

Keywords: Shamsah; Pottery; Architectural Decoration; Carpet Weaving; Smart Algorithm; Shape Grammar

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1. Introduction

Decorative art in Iran comes from the cultural ideas governing the minds of artists, and sometimes their creative minds. In the early Islamic centuries, Iranian artists achieved valuable concepts in the process of forming their artistic structure through combining ideas and thoughts arising from Islam and the historical periods, especially the Islamic period. On the other hand, the knowledge of mathematics and geometry was invented by human beings to discover the relationships between different phenomena and organize their surroundings. The use of geometric patterns is one of the most ancient methods of decoration in the Iranian art industry. Geometric patterns appear in the composition of geometric shapes based on the concepts and regular creativity (Zaero-Polo and Moussavi, 2013). Three art fields of pottery, architectural decoration and carpet weaving during various art periods of Iran have had a significant contribution to the artistic trends of the Islamic period. Due to the impact of religious beliefs, as well as economic and social issues, these three areas underwent dramatic changes in terms of the form and criticism. In the meantime, geometric patterns played a significant role in the division of other patterns as a coherent method.

Geometric and mathematical calculations of patterns, their location, type, number and geometric sizes, as well as the calculations taken place with regard to the application and positioning of the patterns, indicate that traditional geometric patterns are complicated and follow specific rules, despite their simplicity or their superficial ease in comparison with other decorations (Soltanzadeh, 2009). When complexity increases in geometric rules, it takes more time and effort to draw, understand, and analyze the mathematical relationships used in them. Today, with the development of technology, especially computer science, it is possible to draw complicated geometries using computer tools. In the past, the outdated Code software accelerated the drawing time of geometries; but in this type of software, if one of the geometric components were removed or modified, the modeling relationship might have been eliminated. Another aspect of the matter is that the geometric grammar of shapes can be transmitted to a computer by an algorithmic grammar. "The algorithm is a computational process that involves a few parameters or a group of parameters as inputs" (Barrios, 2006: 10). Algorithms provide variables as outputs after the completion of the process. Therefore, an algorithm expresses a set of computational steps that converts inputs into desired outputs. In algorithmic methods, one can use the "shape grammar" method and achieve a geometric instruction based on its constructive parameters through applying a series of commands or rules executed on an initial shape. Hence, the parametric shape grammar allows the lengths of the lines, the angle between the lines and other geometric parameters to be varied in different shapes (Stiny, 1985: 32).

Therefore, parametric design strategies are used to help solve this complexity. Parametric design makes geometry more relevant and dependent. As a result, geometry is introduced as a smart geometry in a new complexity.

Given the description provided, the purpose of the present research is to explain and analyze the geometric patterns used in the Islamic artworks of pottery, architecture and carpet weaving and the influence of these three arts on each other during various historical periods of Islamic art in Iran. Other research objectives include the examination of their common features in order to provide a graphic design based on their artistic nature. The main questions of the present research are as follows:

1. What are the common features of Shamsah, in terms of geometric shape, in the three above-mentioned fields of art, given their different historical intervals and art periods?
2. How is it possible to achieve similar shapes through changing the geometrical parameters in the mathematical algorithm of these Shamsah?

Awareness of how these art fields influence each other in different Islamic periods, as well as discovering common geometric patterns and analyzing their mathematical relationships are of great importance.

2. Methodology

The present research intends to introduce various types of geometric patterns used in the design and decorations of three art fields of pottery, architecture and carpet weaving as well as discover their influences and commonalities in different periods of Islamic art while examining the executive aspects and techniques of these three areas of art. This research was conducted using a comparative-analytical approach. Data were collected using desk studies – due to the research literature – and field studies – because of observing and taking pictures of some decorations in three above-mentioned art fields. Initially, the images of the Seljuk and Ilkhanid pottery were collected from the archives of Daphneh Museum, as well as Reza Abbasi and National Museums and their geometric patterns were examined. In the next step, the authors photographed the patterns of decorations of the specific buildings of the Ilkhanid and Seljuk eras. Finally, the geometric patterns used in the Safavid carpet patterns were analyzed using the same analysis method used in the two previous fields.

In this paper, the quantitative research method was employed along with computer simulation. First, data were collected and selected as the statistical population, through desk studies. Then the authors classified the typological categories based on the geometry of their fields. In the next step, the authors employed computer simulation to analyze the form development of the Shamsah. For this purpose, initially AutoCAD was used as a non-algorithmic application. Then Rhino, Plugin, and Grasshopper were used as graphical scripting languages to run the tests.

3. Literature Review

About the studies on shape grammar, several authors have provided sound reasons for the usefulness of grammars in design research (e.g., Stiny, 1994; Knight, 1998; Flemming, 1987; Gips, 1975; Stiny and Mitchell, 1978). In an article titled “palladium grammar” Stiny, G., and W.J. Mitchel, attempt to make a recast parts of Palladio's architectural grammar in a modern, generative form. The rules of a parametric shape grammar that generates villa ground plans are specified. In many cases these rules are direct translations of Palladio's explicit canons of design (Stiny and Mitchell, 1978).

In the paper “Shape Grammars and the Generative Specification of Painting and Sculpture" by James Gips and Stiny, formalism for the complete specification of families of non-representational, geometric paintings and sculptures has been presented (Stiny and Gips, 1972).

Ramesh Krishnamurti in “The maximal representation of a shape” investigates the rules and grammar of geometric shapes, this paper starts by giving a motivation for studying grammars in design and is based on considerations of style, discovery, and constructive techniques. This paper goes on to survey a variety of spatial grammar formalisms from an implementation standpoint. For each formalism, the salient computational issues pertaining to rule application are discussed. Two aspects of shape grammars are considered in detail: (a) the conditions for reversibility of shape rules, and (b) the recognition of planar shapes (Krishnamurti, 1992).

Researchers such as Kaplan (2004), Hankin (1925), and Al-Jalali (2003) conducted some studies on the mathematical and computational relations of Islamic geometry and the way in which the knots, geometric drawings and Islamic patterns were drawn. In the book of “Geometric Patterns in the Islamic Art", Al-Sa'id (1984) studied the geometric patterns and motifs in different Islamic buildings using basic geometric shapes, especially circles.

4. Theoretical Foundation

Grammar formalisms come in a large variety, requiring different representations of the objects being generated, and different interpretative mechanisms for this generation. Altering the representation may necessitate a rewrite of the interpretative mechanism, resulting in a redevelopment of the entire system (Stouffs and Krishnamurti, 2001).

In the other hand, shape grammars that generate languages of designs have been used widely over the past several years to describe and understand a diversity of architectural and other styles of designs. These grammars have been developed to address two fundamental concerns in design: 1) the analysis or description of contemporary or historic styles of designs, and 2) the synthesis or creation of completely new and original styles of designs. A vocabulary of shapes by itself does not determine designs; it merely determines the pieces from which designs may be made. To actually construct designs, the ways that shapes in a vocabulary can be combined with one another must also be specified. These particular ways of combining shapes are given with spatial relations.

Each architectural style has its own special grammar of shape. There are two main types of shape grammar: standard grammar and parametric grammar. In the standard grammars, most properties of the shapes are constant; but in parametric grammars, the shapes tend to be more flexible and variable (Stiny, 1985: 39). In fact, parametric design allows the use of a system in which a set of relationships between several variables that make up the parameters of a larger entity interact with each other. This system connects geometric grammars and mathematical relations of the shapes in such a way that if the quantitative parameters of a certain shape changes; then, this change is reflected on other variables of the related shapes and changes the initial characteristics and properties of the shape (Woodbury, 2010: 34). The direct entry of graphic programming languages into architecture in recent years has led to the emergence of a "parametric design" approach in the field of controlling those parameters that are effective on design. The parametric design, or grammar of geometry shapes is a new branch of computer science the purpose of which is to discover and apply mathematical and logical relationships between numbers and figures, on the one hand, and between numbers and shapes, on the other hand (Oxman, 2017: 45). Another important issue that has a significant impact on parametric architecture is algorithmic thinking, which is defined for the architecture design process. "Algorithm is a computational process that involves a few parameters or a group of parameters as inputs" (Barrios, 2006: 10). After the completion of the process, algorithms provide variables as outputs. Therefore, an algorithm is the expression of a set of computational steps that converts inputs into the desired outputs (Khabbazi, 2013: 58). In algorithmic methods, a "geometric grammar" can be achieved by applying a series of grammars or rules executed on an initial shape by a "shape grammar". By changing the existing parameters, one also can find a similar set of shapes, the formation of which follows certain principles (Hemberg et al., 2007: 32). According to Terzidis, the purpose of using algorithm in the formation of smart and computational geometry is not to invent a new geometry, but rather to consider its speed and generalizability (Terzidis, 2005: 34). Definitely, smart geometry provides a rule-based geometry in which geometry can be defined with a set of variables and mathematical relations as an algorithmic environment; an environment in which straight and curved lines, points, surfaces, and volumes can be converted to each other (Day, 2005: 12). Hence, using fixed and variable parameters in the algorithm, a generative geometry is formed which is smart to the changes in the variables. In this way, the possibility of controlling and manipulating geometric relationships increases, and as a result, new and unpredictable controlled forms of buildings also increase.

5. Geometric Patterns Related to the Art of Pottery

Geometric patterns are one of the most popular decorative designs of prehistoric, historic and Islamic periods implicated on pottery. Due to its unique unity and despite the formation of various decorative techniques in the cities of Islamic lands, pottery art is displayed under a general framework. The evolution of the art styles after Islam is a combination of Sassanid and Eastern Byzantine artistic sources and patterns used in the great deal of Islamic eras. "With the advent of Islam in Iran, the pottery industry was changed, until a large part of the Sassanid style was abandoned, so that these products found another shape that was a combination of the elements of Islamic pottery and Iranian styles (Mohammad Hassan, 1987: 148). Motifs with plain, geometric, and arabesque lines were drawn on glaze-less ceramics (terracotta) in the first Islamic era and also in the late 3rd century AH, when the technique of glaze was invented. In the 3rd century AH, Iranian governments became independent from the Iraqi Caliphate. Governments such as Taherian, Safari and Samanids developed a special style of Sassanid period in different cities (Abbasian, 1991: 89). With this trend, ancient Iranian culture was gradually revived, and this process was manifested in the artworks of that period. Simultaneously with the political and social trends, the art of pottery was also flourished (Kayani and Karimi, 1984: 46). It seems that the decoration of pottery with the geometric shapes reached to its peak in Iran in the fifth century AH. The middle ages of the Islamic period are politically and culturally important among different periods of the Islamic civilization in Iran; and some researchers have named the period between the fifth to the eighth centuries AH as the Golden Age of the pottery industry. "In this period, pottery enjoyed a special position among other Islamic industries, so that it was considered in close connection with other art fields such as metalworking, painting and book designing (bibliopegy)" (Illenbran, 1994: 142,). In Table 1, there are a number of geometric patterns on ceramics (terracotta) carried on by two conventional techniques of under-glaze and in-glaze paintings.

6. Geometric Patterns of Architectural Decoration

In the Iranian architecture, the interest in decorating the surfaces was of the same importance of constructing unique buildings, and decorative designs were constructed in the immediate vicinity of all components of construction, so that this connection was even less visible among the real elements of the building. Decoration of building during the Islamic period of Iran is usually composed of three kinds of brick, plaster, tile or a combination of them (Wilber, 1967: 33-35). Geometric patterns in the building decorations are often in the form of knots, as well as the combination of regular polygons, sometimes simple polygons and sometimes multi-point stars or Shamsah (Rouhani, 2014).

The Seljuk and Ilkhanid periods can be considered a milestone in the history of Iranian architecture. New forms of architecture and decorative techniques have led Iranian architecture to gradually develop a final shape and ultimately achieve complete coherence and sophistication. Application of two elements of plaster (stucco) and brick, as the materials and a part of decorations, is one of the most important architectural features of this era. The main features of the Seljuk and Ilkhanid architecture have been the use of bricks and stucco, respectively. The history of the use of bricks dates back to ancient times, and the bricks were the oldest building materials used by human beings after the stone. Plaster has also long been used in Iranian architecture both as a binding agent and an ornamental material (Baykusoglu, 2009). The architecture of the Seljuk era was the continuation of the earlier architecture, i.e. the Sassanid era and Buyid dynasty. Although there were changes in the art of stucco during the Seljuk period, but this art reached its ideal perfection during the Ilkhanid period. The widespread use of stucco decorations, along with a variety of geometric patterns and knots, has led to the creation of tremendous works. The use of bricks was also widespread in the Seljuk architecture; so that a variety of geometric patterns were used in bricks during that time. The art of bricklaying and beautiful brick decorations, especially the creation of geometric patterns using gauged bricks, is one of the features of the Seljuk architecture (Bosworth, 2001). (Table2).

7. Carpet-Weaving Geometric Patterns

In various historical occasions, textiles have always been considered by governments as one of the fields of art. In the Islamic world, precious textiles have a symbolic role in expressing political power and religious backgrounds and have been a good tool for displaying and defining different criteria of beauty (Mackie, 2015: 12). In the meantime, the art of carpet weaving can be considered as the most significant element in the art of textiles. Carpet weaving is one of the most original and valuable arts with a long history in Iran. This original art has an unbreakable link with the ancient culture of this territory and has been an important achievement of Iranians for centuries. It is currently a part of the life and culture of the Islamic society of Iran. The presence of geometric motifs in the carpet designs has put this art in the category of decorative arts. Unfortunately few high-quality textiles of the Seljuk and Ilkhanid periods, especially carpets, have been remained.

But after this period, i.e. during the Safavid era, especially in the tenth and eleventh centuries AH, a new paradigm in the history of Persian carpet was formed (both quantitatively and technically and in terms of quality and design). In the Safavid period, due to the quality of raw materials consumed, the use of standard tools and quality carpet weaving materials, paying attention to providing favorable conditions for workshops, as well as paying special attention to the stability, variety of colors and coloring of carpets, the art of carpet weaving was developed (Bosworth, 2001: 19).

The geometric patterns used in the carpets of this period can be classified into urban (curved), rural and nomadic (broken) patterns based on the movement of the lines of patterns. However, according to the structure of their design, they can be divided into major groups of bergamot and lachak, bergamot-bergamot, afshan, altar, etc. In this regard, the structure of bergamots (Shamsah) has more geometric features than other motifs (Baker, 2006). In the Safavid carpets, bergamots in the middle are often embroidered with around them, and thus makes the concept of the Shamsah more vivid. Another factor influencing the geometry of motifs can be the type of knots used in them. Wrapping by turning the silk (pile) around a pair of warps (up and down) in such a way that the two ends of the warping thread come out from the carpet after wrapping around the warps and provide double pile on the surface of the carpet is called a knot (Bier, 2014). The carpet is in fact a knotted carpet composed of hundreds of thousands of knots in parallel rows. In general, the carpet weaving technique during Safavid period was based on two types of knots, i.e. symmetrical (Turkish) and asymmetrical knots (Persian) (Table3).

Table 1 Pictures of pottery (ceramics) from the fifth to the eighth centuries AH and the technique of the execution of motifs on them (Archives of National Museums, Daphneh and Reza Abbasi)

Under-glaze painting technique	Fig 1 Pottery with Wheel Technique, Kashan, 6th Century AH	Fig 2 Sultan Abad Pottery, 8th century AH	Fig 3 Lacquered pottery, Kashan, Ilkhanid era
			
In-glaze painting technique	Fig 4 Ceramic lustrous plate, Kashan - Isfahan, 8th Century AH	Fig 5 ceramic, enameled and gilt pot, Gorgan, 7th century AH	Fig 6 Enameled standing plate, Ray, late 6th century AH
			

Table 2 Pictures of geometric patterns used in the brick and stucco decorations of prominent Ilkhanid and Seljuk monuments

Methods of performing geometric patterns using bricks	Fig 7 Decorations of Male Zuzan Mosque	Fig 8 Decorations of Jameh Mosque of Varamin	Fig 9 Decorations of Male Zuzan Mosque
			
	The use of pre-cut and molded bricks	The use of pre-cut and molded bricks	Knot making through the use of brick cutter and paint
Methods of performing geometric patterns using plaster (stucco)	Fig 10 Decorations of the Dome of Soltaniyeh	Fig 11 Decorations of Jameh Mosque of Forumad	Fig 12 Decorations of the Dome of Soltaniyeh
			
	The technique of low stucco relief (hollow and filled)	The technique of high stucco relief	Painting on stucco

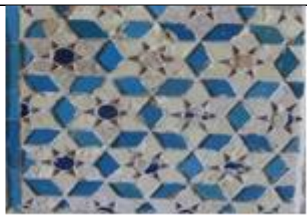
Methods of performing geometric patterns using bricks, plaster (stucco) and tile	Fig 13 Jameh Mosque of Zavareh	Fig 14 Pir Bakran mausoleum	Fig 15 Jameh Mosque of Varamin
			
	Knots with bricks and honeycomb stucco	Combination of stucco and tile decorations	Combination of Brick and tile decorations

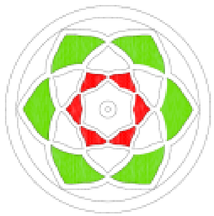
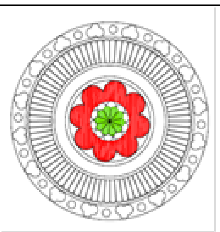
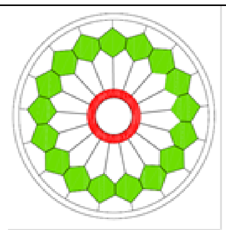
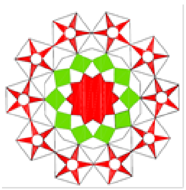
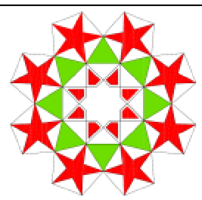
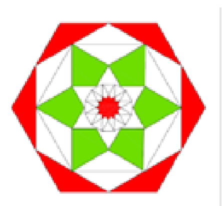
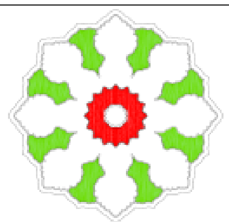
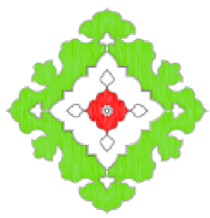
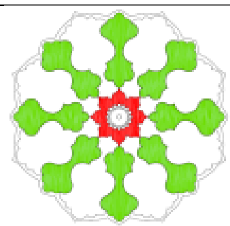
Table 3 Pictures of Safavid period carpets and their categorization based on the symmetric and asymmetric knotting methods (National Carpet Museum)

The technique of carpet weaving with symmetric knots	Fig 16	Fig 17	Fig 18
			
The technique of carpet weaving with asymmetric knots	Fig 19	Fig 20	Fig 21
			

8. Analysis and Evaluation

The most prominent feature of geometric patterns in decorations of three art fields is the presence of regular polygons and multi-point stars. Multi-point geometric shapes, sometimes in the form of Shamsah on potteries or bergamot decorations in textiles, are systematically displayed with a central point. Most of the stars have regular 5, 6, 8, 10, 12, or 16 points or are drawn in the form of a part of a circle beside another similar circle. In decorations related to the architectural design, there are a large star in the middle together with other stars and geometric shapes around it that are drawn on different scales. The center of the star, the center of the circle and its other points are tangent to the circle's circumference (perimeter). These geometric patterns are based on the rotation, multiplication and combination of a number of regular polygons in the horizontal and vertical direction. Regular tetragonal, pentagonal, hexagonal, octagonal, decagonal, and dodecagonal shapes are most used compared to other forms. In fact, these forms are in some way similar and can be generalized to each other; so that the three shapes of regular octagon, decagon and dodecagon are respectively formed through the rotation of the regular tetragonal, pentagonal and hexagonal shapes under a certain angle. As a result, three regular tetragonal (square), pentagonal, and hexagonal shapes can be considered as three basic geometric shapes in decorations, the other shapes are formed on the basis of alterations to them.

Table 4 Examination and analysis of geometric patterns used in the samples of ceramics (potteries), architectural decorations and carpets

<table>
<tr><td rowspan="2">Geometric patterns on ceramics</td><td>Drawing of geometric details of Fig 2</td><td>Drawing of geometric details of Fig 4</td><td>Drawing of geometric details of Fig 6</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Geometric patterns in architectural decorations</td><td>Drawing of geometric details of Fig 10</td><td>Drawing of geometric details of Fig 12</td><td>Drawing of geometric details of Fig 14</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Geometric patterns of bergamot in carpets</td><td>Drawing of geometric details of Fig 20</td><td>Drawing of geometric details of Fig 21</td><td>Drawing of geometric details of Fig 17</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Common features of patterns (motifs)</td><td colspan="3">Symmetry: One of the most important features of traditional arts is to create symmetry in shapes, because it brings balance. Symmetry has a complementary and perfectionism aspect.
Geometric Centeredness: The most important feature of centeredness is the issue of timelessness. With a number of centres, the main centre gets the critical importance, to which the identity of the rests depends.
Fitness: Scale or fitness, with the mathematical concept of implementing geometric points, is of great importance and application. The level segmentation is used to determine the balanced ratios in order to find the relationship between the components of the patterns or motifs.</td></tr>
</table>

The study of the structure of geometric designs and patterns in various artworks during the Middle Islamic historical periods has shown their common features indicating that the arts schools used in different art fields affect each other. In general, the execution of motifs that differs in three art fields has common features. Different types of Shamsah in each of the three art fields are also redefined based on three parameters of the length of regular polygon sides, the number of regular polygon sides and the angle between the sides of the Shamsah.

For example, in each of the three art fields, the use of octagonal Shamsah is quite evident. With equal number of sides and their inclusion in a regular octagon, these three Shamsah are geometrically distinct in terms of their geometric forms due to differences in angles between the sides. Shamsah are drawn based on a bottom-up approach. Thus, by drawing one of the corners of the regular polygon and multiplying it around the center of polygon, the desired roundel will be formed based on the number of polygon sides. As a result, the authors found a common modular structure containing one of the corners of the roundel to draw different types of Shamsah through redefining the way in which it was drawn in algorithmic language. As shown in Fig 3, the ABCD tetragon is a shape containing one of the angles of roundel, but since this shape is symmetrical in relation to the AC axis, the ABC triangle can be assumed to be a common base modulus of the shape. Among different geometric shapes of Shamsah, the ABC triangle is drawn based on a distinct and fixed method; so that it is carried out based on drawing a triangular with three sides. These three sides include the half of the base shape (AB), the line drawn from the vertex to the center of the shape (AC), and the line drawn from the middle to the center of the shape (BC). Given that the ABC triangle is of the right-angled type, the ABC angle is always 90 degrees. But two other inner angles (Θ and β) are functionally dependent on the number of polygon sides. For example, in a regular octagon, the angles created in the ABC triangle are derived based on relations 1 and 2, whereby the values of Θ and β are 22.5 and 67.5, respectively. But the factor that causes the changes in the geometry of the Shamsah is a line that begins from the regular polygon vertex (A) and cross the BC line (from the center of the side to the center of the shape) at M point. The AM line can be considered as a factor of changes in the three Shamsah formed based on the parameter of the angle α (the angle between the AM line and the AB side). On the other hand, it should be noted that the angle α, as a variable parameter, can only include values between the open interval 0 and β. Then, by mirroring the AM line relative to the AC line, the other side of the roundel (AN) will be formed. AMN can be considered as one of the corners of the roundel and part of a whole unit. Now, the desired roundel in formed through rotary multiplication of AMN based on the number of polygon sides around its center,

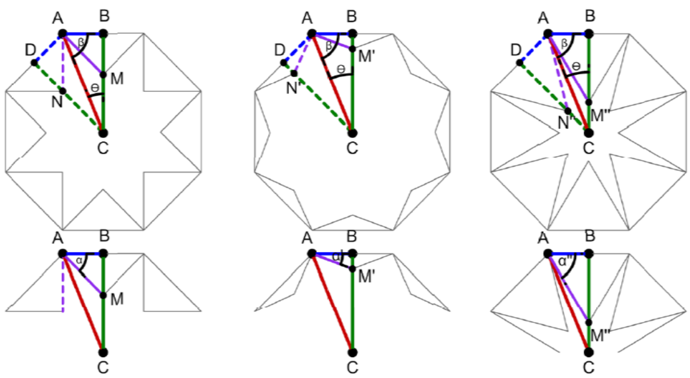


Fig 22 Identification of the common modulus between three octagonal Shamsah and analyzing geometric and mathematical relations based on fixed and variable parameters

Relation 1: $\theta = \frac{180}{n}$

Relation 2: $\beta = 90 - \theta$

Relation 3: $0 < \alpha < \beta$

After identifying the common modulus and the formation factor of the Shamsah (AM line), it was possible to redefine it in algorithmic language and transfer it to the computer to draw up a variety of polygonal Shamsah. In this section, using the Grass Hopper graphic programming language, the authors redefine the geometric algorithm of different Shamsah based on three parameters of the regular polygon side length, the number of regular polygon sides and the angle between the sides of roundel (α). It is noteworthy that only with the above three parameters, it is possible to draw the AM line from all polygon vertices and there is no need to mirror and rotate it around the center.

9. Algorithm steps to draw Shamsah

1. Draw a regular n-side polygon with the center of O and the side length of L.
2. Draw a line from the middle of the sides of the n-side polygon to the center of it.
3. Draw a line from the vertices of n-side polygon to the center of it.
4. Draw a line from the vertices of n-side polygon with an angle of α [the beginning of the angle with respect to the sides adjacent to the vertices] in order the drawn lines cut the lines drawn from center to the center of the shape.
5. Draw n-side polygon with the center of O and side length of L from the intersection of the points of the created lines.
6. Repeat steps 2 to 4 n-times through creating a loop.

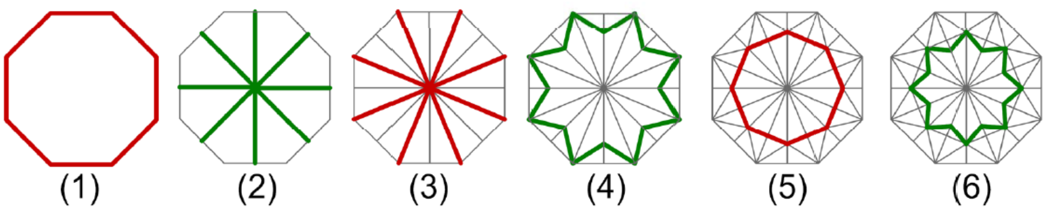


Fig 23 Drawing the steps of the algorithm proposed for the production of an octagonal roundel and its generalizability (Source: Authors)

The obtained algorithm can be considered as a smart geometry-based and generative algorithm, since this algorithm allows the use of different angles for parameter α to achieve Shamsah with different geometric forms based on their polygons. Using steps 5 and 6 of the algorithm, it is also possible to reproduce inner-oriented Shamsah within the shapes themselves. This process can be generalized to a desired number by creating a loop (Table 4). Then, using the proposed algorithm for different polygons, geometric shapes and various Shamsah can be drawn and produced in the short time (Fig 5, 6, and 7).

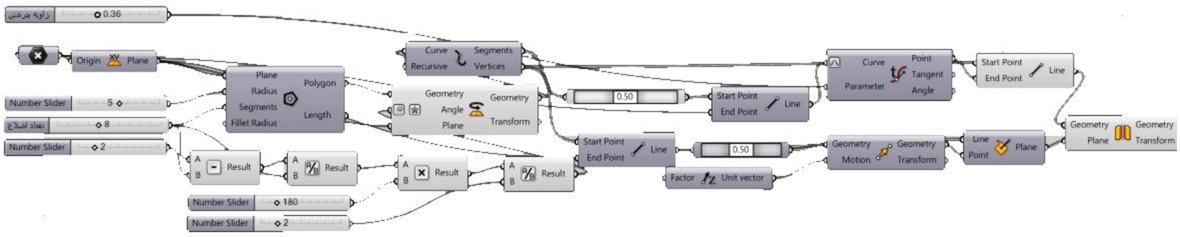
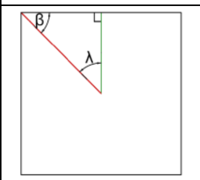
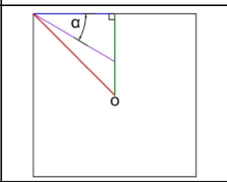
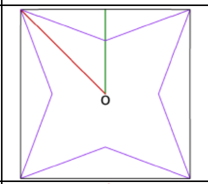
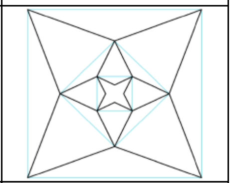
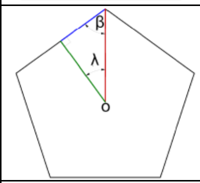
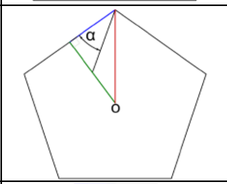
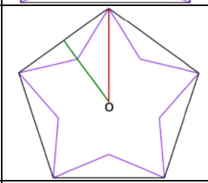
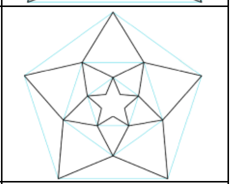
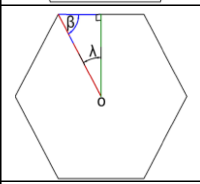
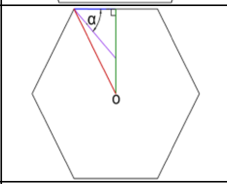
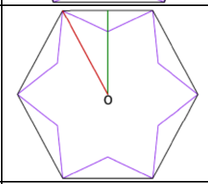
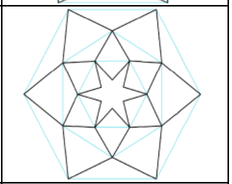
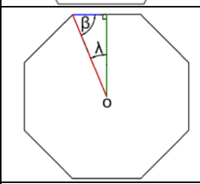
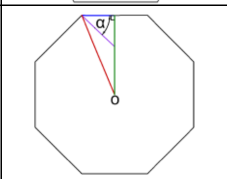
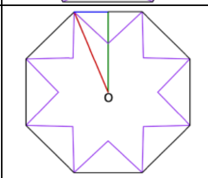
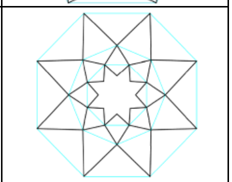
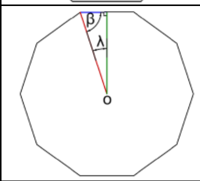
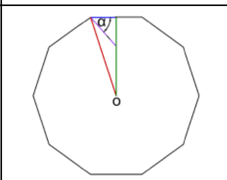
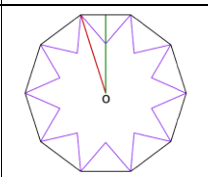
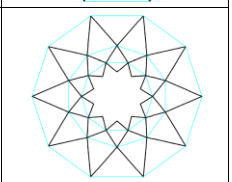
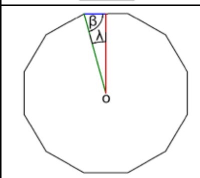
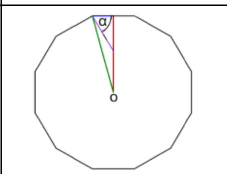
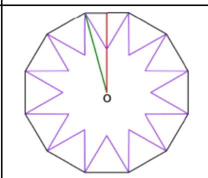
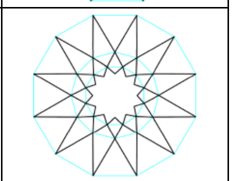


Fig 24 Drawing the steps of the algorithm in the Grass Hopper plugin (Source: Authors)

Table 5 Process of the formation and generalizability of the Shamsah pattern in regular polygons based on the parameters of the number of sides and angles between the sides

	Internal angels	Variable angle parameter	Angle values	Base module	Replication of the shapes inside the roundel (3 times)
Regular tetragon			45ϴ= 45β= 45<α<0		
Regular pentagon			36ϴ = 54β= 54<α<0		
Regular hexagon			30ϴ = 60β= 60<α<0		
Regular octagon			22.5ϴ = 67.5β= 67.5<α<0		
Regular decagon			18ϴ = 72β= 72<α<0		
Regular dodecagon			15ϴ = 75β= 75<α<0		

10. Conclusion

In this study, in the first step, techniques for the implementation of pottery in various periods of history, especially Seljuk and Ilkhanid periods were examined. The two techniques of under-glaze and in-glaze paintings were of the most important decoration techniques of potteries. The motifs of these ceramics (terracotta) were mostly composed of Shamsah and multi-point stars in the form of painting. In the next step, the architectural decoration of the Ilkhanid and Seljuk monuments was examined and evaluated. The use of two elements of brick and plaster (stucco), both individually and in combination with each other, by the Muslim artists provided the opportunity to create various geometric patterns. In relation to the techniques used with bricks, different types of bricks, especially pre-cut, and molded bricks were used for making knots in the monuments, especially during the Seljuk era. Another material used in this period was plaster (stucco). It was used in decorations of buildings (monuments) by designers, especially the artists of the Ilkhani era, using the techniques of low stucco relief (hollow and filled), high stucco relief and a combination of tiles and paints. The third field of art discussed in this research is the art of carpet weaving, due to the lack of quality works from the pre-Safavid period, the elements used in the carpets of the 10th and 11th centuries AH were reviewed. In the carpet texture of this period, two techniques of symmetric knotting (Turkish) and asymmetric knotting (Persian) were common. The motif of bergamot is one of the most used motifs in the decoration of carpets of this period. In the last step, the geometric patterns of the works of the three aforementioned art fields were examined by computer tools in a two-dimensional evaluation. The results of the analysis showed that despite the differences in the time periods of these works as well as the differences in the manner of implementation and taking into account the formation of motifs, materials and tools for their implementation, the geometric patterns used in these three fields of art have common and fixed features that have been used by artists for centuries.

According to the results, scripting languages enable designers to create algorithms and geometrical grammar of shapes based on their constituent parameters. The most important difference between algorithm and non-algorithmic applications is the execution of commands by designers in the design modeling process. In non-algorithmic applications, commands are formed and executed separately step by step. However, the execution of commands is a continuously integrated process in algorithmic applications. The distinct feature of algorithmic applications is that designers can make forms parametric based on the input data. The parametric feature enables designers to use a system in which a group of relationships interact with each other between several variables contributing to a larger unit. In this method, it is possible to change or modify every command packet. In other words, if an error occurs in the selection of the input data by the designer, it will not be necessary to restart all of the commands and redo the modeling process. In fact, it is possible to modify and change every command whenever necessary. Another useful feature of this methods is the use of algorithmic design to achieve the smart geometry, in which a mechanism is defined to redefine geometrical grammar and regulations of shapes in a series of variables and mathematical relations by suing the scripting language. Therefore, constant and variable algorithms can be used in the algorithm to form a particular style of geometry which can operate smartly toward changes in variables. This system relates the geometrical grammar to the mathematical relations of shapes. If the parameters of a shape are changed, the modification can be reflected on the variables of other dependent shapes to change the primary features and specifications of the form. The third and final feature of the research process was the generative quality of the resultant geometry. The quality of being generative can bring about novel forms by changing input data. Such novel forms are beyond a designer's prediction and imagination.

However, the non-algorithmic design of the initial forms should be developed mentally by designers to some extent. They can then employ applications to draw and edit the initial forms. Another useful feature of the generative geometry is the generalizability or expandability of the written algorithms. Generalizability provides an environment in which direct and curved lines, dots, surfaces, and volumes can be transformed into each other. Moreover, changing the existing parameters can bring about morphogenic shapes, which comply with specific principles.

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