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Form and Geometry in Decorative Tile Work in Khayyatha Mosque, Isfahan

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Abstract

Decoration has always had a pivotal role in Persian architecture. Since long time ago, for example, tile work has had a special place for most architects around the world especially Persian architects. Close examination of Persian tile work, in terms of form and geometric features, reveals the architects' mastery over this art, geometry as well as mathematics. The analyses of tile decorations and fretworks, formally and geometrically, may indicate that how the tile work accomplished structurally. One of the famous mosques in Isfahan enjoying a rich variety of tile work is Khayyatha Mosque. Examination of forms used in tile work in of the mosque revealed the geometric structures and proportions, the workforce needed and the number of tiles applied in each inscription based on specific colors. So far, little study has been carried on tile fretwork in terms of form. The present study examined, for the first time, the tile fretwork in Khayyatha Mosque. After introducing the mosque, the tile fretwork used in the mosque was studied and the patterns were analyzed mathematically. The methodology was mainly based on quantitative analyses using mathematical calculations as well as geometric drawings. The result indicated that the nature of form and geometric proportions of tile work has had a direct impact on the workforce needed and on the kinds of tiles applied. Also, the most frequently used tile works, in terms of form and pattern, were identified.

Keywords: Form, geometric proportions, tile work, Khayyatha Mosque.

Introduction

The foundation of Persian traditional architecture is based on geometry and thorough drawing techniques. The importance of this has been so much so that it was highly imperative for the architects to master mathematical rules as well as various drawing techniques in practice (Molavi,2002). Generally speaking, the essence of art and architecture is geometry and proportions (Bemanyan,2011). The history of Khayyatha Mosque, placed in Isfahan Great Bazaar, dates back to Safavid era. The mosque enjoys a wide variety of decorative tile patterns along with different beautiful tile fretworks. Consisted of diverse formal and geometric modules (called as mohre), each piece of fretwork has its own geometric specifications.

Through examination of individual tile modules in fretworks, the geometric proportions applied may be identified. Similarly, by analyzing the tile patterns, the geometric specifications applied in tile fretworks and the number of tile modules used in mosque may be determined. This may help to preserve the existing tile works and to encourage such Persian tile works in today's construction activities. The article tried to answer the following questions:

1. Is it possible to determine the number of tile pieces used in inscriptions of the mentioned mosque through examining the tile fretworks?
2. What kind of tile fretworks has been more commonly used than others?
3. How is it possible, based on mathematical calculations, to identify the workforce involved in making tile fretworks of the mosque?

Review of Literature

So far, tile fretworks have been studied extensively from different aspects. Some masters, for example, have studied tile fretworks in terms of drawn patterns (Lorzade, Maher-o-Naghsh, Shaarbaf,

Shafaie, Fereshtenejad…); some in terms of construction methods as well as implementation techniques (Peernia and Bozorgmehri) and still others in terms of different ways of constructing wooden fretworks (Tasooji). Also, the authors of the present article carried out a similar research on Masjed-e- Safavi-ye-Shishe-ye-Isfahan (Glass Safavid Mosque of Isfahan) the objective of which was to identify, compare and develop mathematical proportions hidden in the patterns. This study, however, aimed to identify tile fretworks and their mathematical as well as geometric proportions in Khayyatha Mosque.

Methodology

The methodology has been based on library, analytic and field studies. Khayyatha Mosque was selected as the intended structure. All the patterns of tile fretworks in the mosque were considered as the statistical population. The picture of each pattern was taken. Also, patterns were dismantled mathematically and drawn through computerized modeling. Then, individual fretworks were analyzed into its constituents (mohre). The surface, perimeter and the frequency percentage of individual forms were calculated using relevant soft wares. Then, the workforce needed for different tile fretworks for each pattern was estimated and compared. Also, the number of tiles used, for each given color, in various inscriptions was determined. In this article, the drawing methods used by distinguished masters (Lorzade, Maher-o-Naghsh and Shaarbaf) were followed.

Gere (knot)

Gere (knot/ fretworks) refers to interwoven patterns existing for a very long time. In the course of time, with the help of geometry science, the rudimentary forms became more geometrically organized and intricate, represented as one of the artistic forms related to architecture (Fereshtehnejad, 2012). Fretworks are of different kinds accomplished in different backgrounds. In addition, fretworks have the ability of reproductivity meaning that new patterns can be created based on the basic ones (Raieszadeh,1). The important point for the fretworks is that each piece of fretwork is restricted to its own frame. In other words, the overall form of a piece of fretwork follows the general form of its frame (Sharbaf, 2006). Fretworks are of two and three dimensional kinds the constituents of which are similar (Sharbaf, 2006). One of the characteristics of fretworks is that a new piece of fretwork can be built within the other one creating new form called as gere dar gere (intricate fretworks). In some techniques, chains of gere (given number of knots) are arranged sequentially in an alternate fashion, one knot recessed and the other one projected. This alternate fashion may be also repeated in terms of color. In tile work, often a blue stripe, called as daval, separates the other tile stripes from each other (Raieszadeh, 1995).

Khayyatha Mosque

Khayyatha Mosque, also locally called as Masjed-e- pa derakht-e-Soukht-e- Zanjani (Zanjani's Burnt Log Mosque) is considered as one of the small-scale mosques of Safavid era in Isfahan. The only recognizable date of the mosque is the one inscribed on the old door reading as 975 Hijri (1567) (Haji Ghasemi,2004). The mosque was built by order of King Tahmasb's son, Abol Fath Sultan Ahmad Mirza, whose name is visible in the inscription over the mosque door (Rafiee Mehrabadi, 1973).. In August 20th, 1998, Khayyatha Mosque was recorded, under registration number 2154, as one of the National Monuments of the country.

Examination of tile patterns in Khayyatha Mosque

Various kinds fretworks or gere have been accomplished in Khayyatha Mosque some of which (including shesh tond-e-zamine hasht; Gol sabounaki; kond-e-sorme dan roo alat; kond-e-sorme dan ghenas koochak) are totally made of tile. Others are made of a combination of tile and brick including kond-e- dow panj; shesh tond-e-zamine dah; Moj-o-shamse inscription.

Fretwork of kond-e- dow panj or omm-ol-gere(mother of fretworks)

The fretwork of kond-e- dow panj is the base of many other fretworks especially different kinds of fretwork 10(Raieszadeh,Mofid,1995). This pattern has been accomplished in the middle spandrel of the southern side and in the lateral spandrels of the northern side of the mosque (Figures 3 and 5).

Drawing Method

The first step in drawing a fretwork is designating its frame/background. To do so, the width of the frame is defined. Then, a line is drawn perpendicular to one end of the width line. Next, the resultant right angle should be divided into 5 equal parts. Now, to define the length of the frame, another line is drawn perpendicular to the other the end of the width line. The intersection point of the latter perpendicular line and the third lateral divided line (resulted from the previously divided right angle) creates a reference point called here as point R. Now, to define the total area of the frame, a line should be drawn in parallel with the lower width of the frame. Lines resulted from the equally divided right angle are called as khat geer (literally line catcher). The lines, from bottom to the top, are named as the 1st, 2nd, 3rd and 4th line catcher(s). Also, to draw the fretworks, another line-technically called as khat-e-ramaz (literally secret line) is needed. Khat-e-ramaz, in each fretwork, is separately obtained. For the fretwork of kond-e- dow panj, khat-e-ramaz is the perpendicular bisector of the frame's width. Next, several circles are drawn the centers of which are lower left and upper right. The radii of the circles are respectively equal to the distance between the corner and the intersection point of the khat-e-ramaz and the 1st line catcher and that of the khat-e-ramaz and 2nd as well as 3rd line catchers. Then, the intervals between line catchers and khat-e-ramaz are filled with zigzag lines drawn with the help of khat-e-ramaz. Finally, the zigzag lines are expanded in their own directions to obtain the vageere (fixing element) of the fretwork (Figure 1) (Raieszadeh,Mofid,1995).The final form is created by expansion using a symmetrical axis (Figure 2).

In tables 1 and 2, the perimeter, area and frequency of each form of the fretwork of kond-e-dow panj have been given separately.

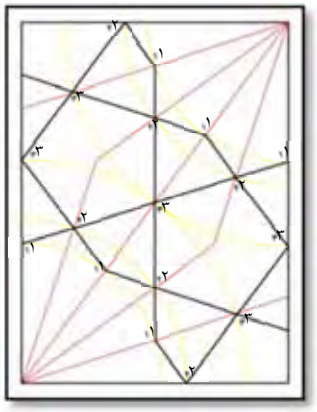

Figure 1: vageere

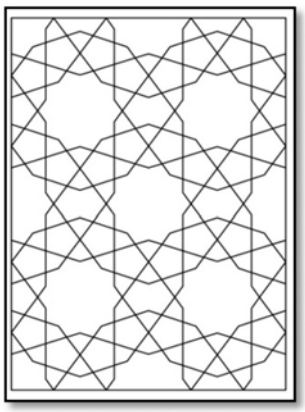

Figure 2: Expansion of a gere (knot)

Formula1. Workforce = perimeter × frequency
Workforce in the spandrel of picture 3 =1097+1672+2712+228=5709
Workforce in the spandrel of picture 5 =612.5+931+1536+128=3207

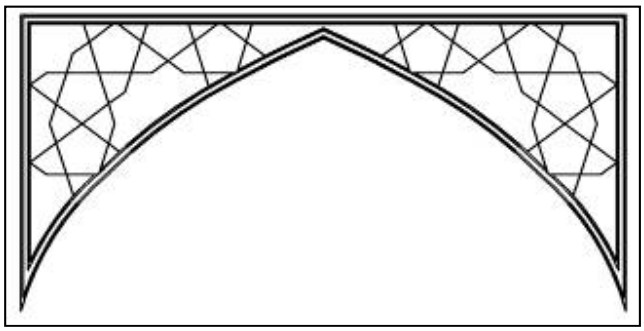

Figure 3: gere accomplished in the southern side

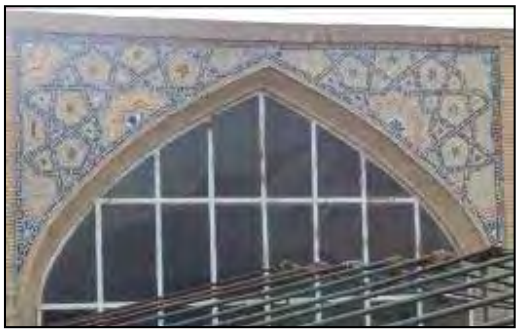

Figure 4: gere in a form of spandrel

Table 1.The geometric specifications applied in the fretwork of kond-e- dow panj. southern side

Frequency × perimeter	Mohre area Spandrel area	Mohre area Vageere area	Frequency in the spandrel	Perimeter (cm)	Area(cm2)	Mohre
1097	12065 68744	12065 16373	2.5	439	12065	
1672	2140 68744	2140 16373	9.5	176	2140	
2712	723 68744	723 16373	24	113	723	
228	3253 68744	3253 16373	1	228	3253	

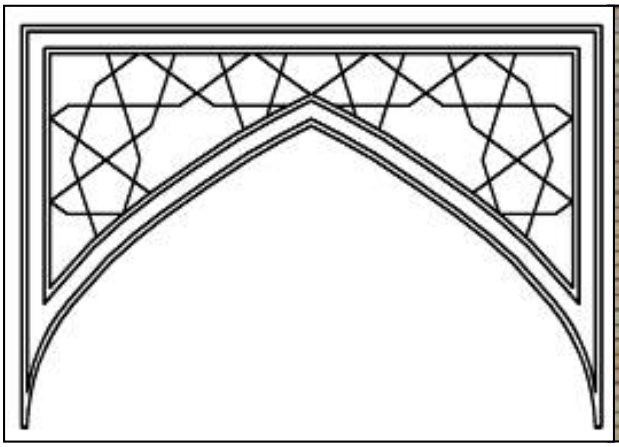

Figure 5: gere accomplished in the southern-side spandrels

Figure 6: gere in a form of spandrel

Table 2.The geometric specifications applied in the fretwork of kond-e- dow panj. Northern side.

Frequency × perimeter	Mohre area Spandrel area	Mohre area Vageere area	Frequency in the spandrel	Perimeter (cm)	Area(cm2)	Mohre
612.5	3742 20550	3742 5265	2.5	245	4742	
931	664 20550	664 5265	9.5	98	664	
1536	230 20550	230 5265	24	64	230	
128	1022 20550	1022 5265	1	128	1022	

Fretwork of shesh tond-e-zamine dah

This fretwork has been accomplished in the spandrel of the middle ivan, in northern side and in side ivans of the southern side (Figures 9, 11 and 13).

Drawing Method

The first step in drawing the fretwork is defining the frame. To do so, the frame is designated as wide as the area onto which the fretwork is supposed to be accomplished. Next, a line is drawn perpendicular to one end of the width line. The resultant right angle, called as angle A, is divided into 5 equal parts. To determine the frame, from the point C on the fourth line, several lines are drawn perpendicular to the sides of angle A. Similarly, the angle C is divided into 5 equal parts. The diagonal BD intersects the 2nd and 4th lines of the angle A at E and F and so does the 1st and 4th lines of the angle C at G and H. From the point H a line is drawn in parallel with the side BA intersecting the 3rd line of the angle C at I and so does the 1st and 3rd lines of the angle A at J and K respectively. Points I and F are connected to each other and expanded from both ends. From the point E a line is drawn in parallel with AB and from G a line is drawn in parallel with the 4th line of the angle A crossing the 1st line of the angle A at M. From M a line is drawn in parallel with BD intersecting the side AB at N. Similarly, from N a line is drawn in parallel with the 2nd line of the angle A crossing the line HK and the 1st line of the angle A at J. Also, from K a line is drawn in parallel with line IF crossing the line AD at L.

From the point L a line is drawn in parallel with the 4th line of the angle A crossing the line ES at P. The lines drawn in triangle ABC are repeated, by the same token, in triangle CBD. Now, the final shape is formed as shown by bold lines in Figure 7. The final shape is expandable using a symmetrical axis (Figure8) (Maheralnaqhsh, 1983).

Given that the mentioned fretwork has been accomplished in three different backgrounds, the area, perimeter and frequency of individual shapes used in the fretwork of shesh tond-e-zamine dah have been calculated (tables 3, 4 and5) and then the workforce needed was estimated .

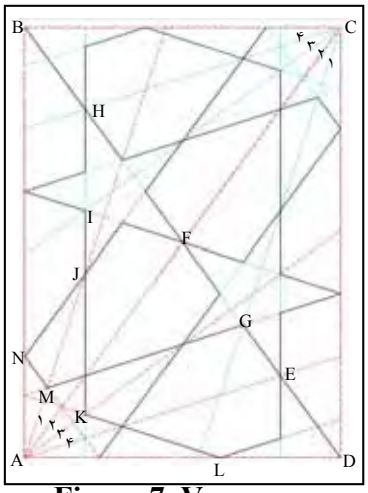

Figure 7. Vageere

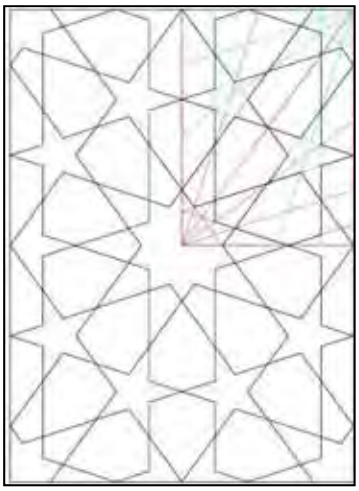

Figure 8. Expansion of a gere (knot)

Figure 9. gere accomplished in the western-side spandrel

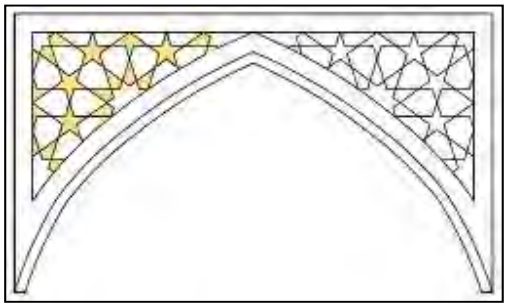

Figure 10. gere in a form of spandrel

Table 3.The geometric specifications applied in the fretwork of shesh tond-e-zamine dah. Western side.

Frequency × perimeter	Mohre area Spandrel area	Mohre area Vageere area	Frequency in the spandrel	Perimeter (cm)	Area(cm2)	Mohre
290	523 13280	523 3038	2.5	116	523	
755.2	189 13280	189 3038	8	94.4	189	
1632	306 13280	306 3038	24	68	306	
408	137 13280	137 3038	6	68	137	
840	85 13280	85 3038	20	42	85	

Figure 11. A gere accomplished in the southern-side spandrel

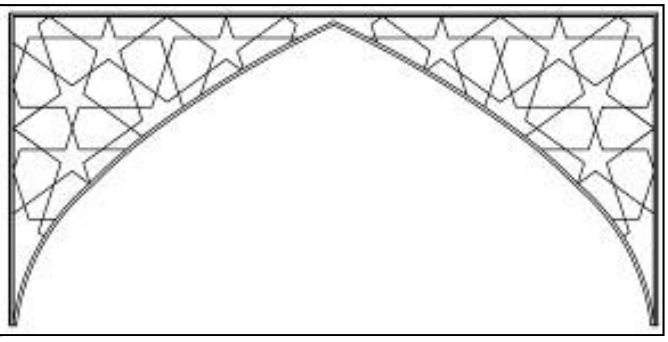

Figure 12. A gere accomplished in the southern-side spandrel

Table 4.The geometric specifications applied in the fretwork

Frequency × perimeter	Mohre area Spandrel area	Mohre area Vageere area	Frequency in the spandrel	Perimeter (cm)	Area(cm2)	Mohre
777.5	3723 87803	3723 21618	2.5	311	3723	
2008	1347 87803	1347 21618	8	251	1347	
4368	2180 87803	2180 21618	24	182	2180	
1092	975 87803	975 21618	6	182	975	
2240	602 87803	602 21618	20	112	602	

Figure 13. A gere accomplished in a form of spandrel

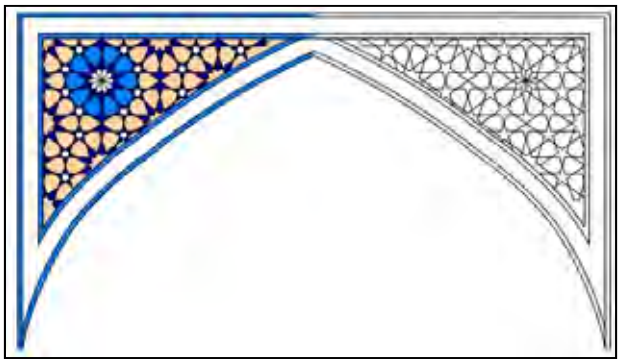

Figure 14. A gere accomplished in a form of spandrel

Table 5.The geometric specifications applied in the fretwork

Frequency × perimeter	Mohre area Spandrel area	Mohre area Vageere area	Frequency in the spandrel	Perimeter (cm)	Area(cm2)	Mohre
240	61 10888	61 354	6	40	61	
1024	22 10888	22 354	32	32	22	
1702	36 10888	36 354	74	23	36	
322	15 10888	16 354	14	23	16	
1008	10 10888	10 354	70	14.4	10	

Fretwork of shesh tond-e-zamine hasht

This fretwork, totally in tile, has been accomplished in the western side of the mosque. In its regular octagonal pattern, the shape of Ali (the name of the first Imam of Moslems) is visible.(Figure 15-17)

The area, perimeter and frequency of individual shapes used in this fretwork have been calculated (table 6) and then the workforce needed was estimated (formula 2). Given that the mentioned fretwork has been accomplished in tile, the number of tiles used for each distinct color was determined which was equal to the total frequency of mohres of a given color multiplied by the area (formula 3).

Figure 15. vageere

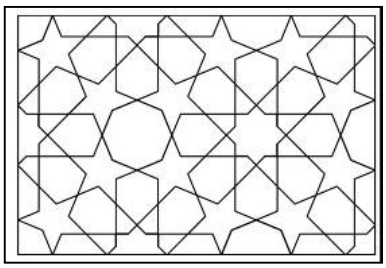

Figure 16. Expansion of a gere (knot)

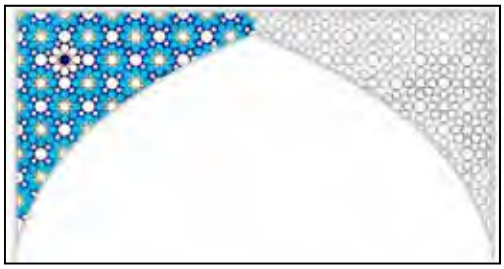

Figure 17. Colors used in the patterns

Formula 2. Workforce = perimeter × frequency
The workforce needed in the spandrel of figure 17 =168621080+6300+3496+4884+1102 =16862

Formula 3. The sum of (perimeter × frequency) = the area of tiles used for each color
The area of turquoise tile used=8520(cm2)
The area of dark blue tile used= 76+2970=3046 (cm2)
The area of white tile used= 1444+480+1470=3994(cm2)
The area of ochre tile used= 2128 (cm2)

Table 6.The geometric specifications applied in the fretwork

Frequency × perimeter	Frequency × area (cm2)	Mohre area Vageere area	Tile color	Frequency in the spandrel	perimeter (cm2)	area (cm2)	Mohre
1080	1444	38 259	white	38	27	38	
	76		dark blue	2			
6300	8520	30 259	turquoise	284	21	30	
	480		white	16			
3496	2128	7 259	ochre	304	11.5	7	
4884	2970	30 259	dark blue	2.3) 148(	33	30	
	1470		white	1.3) 148(			
1102	2394	63 259	-	38	29	63	

Fretwork of kond-e-sorme dan roo alat

This fretwork has been accomplished totally in brick (Figure 20).

Drawing Method

A line, called here as AB, with desired length is drawn. From two ends of the line (points A and B) two other lines are drawn perpendicular to the end points so that the right angles, A and B, are formed. The two right angles, each, are divided into 5 equal parts. Supposing B as the centre, and BE as the radius (E is just in the middle of AB), an arc is drawn. This arc intersects the 2nd line of the angle B at F and does so the 4th line at G. From the point F two parallel lines are drawn; one in parallel with AB, and the other with the 4th line of the angle B. The latter line intersects the 1st line of the angle B at I and does so the perpendicular bisector of the AB at H. From H a line is drawn in parallel with AB intersecting the sides of the angles A and B at C and D forming the rectangle ABCD. Then, two points I and K (the intersection point of corresponding 4th lines of the angles A and B) are connected to each other and expanded from two ends. Now, from the point G two parallel lines are drawn; one in parallel with the 2nd line of the angle B intersecting CD at L, and the other in parallel with the 1st line of the angle A. From L a line is drawn in parallel with the 3rd line of the angle A. The lines drawn for the angle B are repeated for the angle A. The final form is now ready (Figure 18) and expandable using a symmetrical axis (Figure 19) (Maheralnaqhsh, 1362).

The fretwork was analyzed into its constituents and the specifications of each were given (table7). The workforce was also estimated using the formula 4. In addition, considering the frequency and the area of each mohre, the number of tiles used for each specific color was calculated (formula 5).

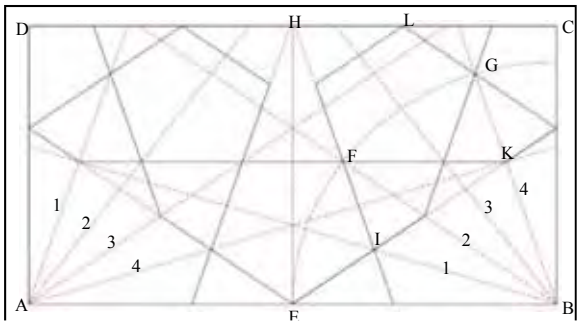

Figure 18. vageere

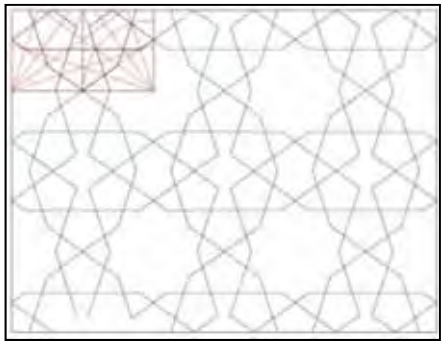

Figure 19. Expansion of a gere (knot)

Figure 20. A gere accomplished in the western side

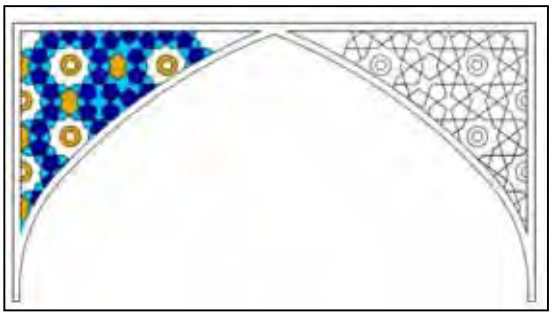

Figure 21. Colors used in the patterns

Formula4. Workforce = perimeter × frequency
The workforce needed in the spandrel of figure 20 427.5+912+1107+171.5+304= 2922

Formula5. The sum of (perimeter × frequency) = the area of tiles used for each color
The area of turquoise tile used=765+316=1081 (cm2)
The area of dark blue tile used= 1200(cm2)
The area of white tile used= 1269 (cm2)
The area of ochre tile used= 266 (cm2)

Table 7.The geometric specifications applied in the fretwork

Frequency × perimeter	Frequency × area (cm2)	Mohre area Vageere area	Tile color	Frequency in the spandrel	perimeter (cm2)	area (cm2)	Mohre
427.5	1269	141 233	white	9	47.5	141	
912	1200	25 233	dark blue	48	19	25	
1107	765	8.5 233	turquoise	90	12.3	8.5	
171.5	266	38 233	ochre	7	24.5	38	
304	316	39.5 233	turquoise	8	38	39.5	

Fretwork of kond-e-sorme dan ghenas koochak

This fretwork has been accomplished in the spandrels of western side of the middle ivan (Figure 24).

Drawing Method

The drawing method for this fretwork is similar to what was said for the fretwork of kond-e-dow panj or omm-ol-gere (1-4). The 2nd line catcher intersects the 1st line catcher of its corresponding angle. By drawing a line in parallel with the length of the frame which crosses the middle of the 2nd line catcher, khat-e-ramaz is obtained (Figure 22) (Raieszadeh,Mofid,1995).

The area, perimeter and frequency of individual shapes used in this fretwork have been given (table 8) and then the workforce needed was estimated (formula 6). In addition, the number of tiles used for each specific color was calculated.

Figure 22. vageere

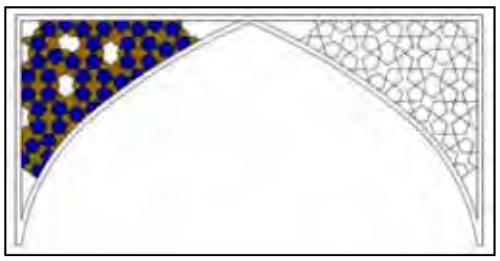

Figure 23. Expansion of a gere (knot) in a form of spandrel

Figure 24. A gere accomplished in the

Formula 6. Workforce = perimeter × frequency
The workforce needed in the spandrel of figure 23 44.5+1296+184+1008=2934

Formula7. The sum of (perimeter × frequency) = The area of tiles used for each color
The area of dark blue tile used= 1584 (cm2)
The area of white tile used= 123+273=395 (cm2)
The area of ochre tile used= 272+980=1252 (cm2)

Table 8.The geometric specifications applied in the fretwork

Frequency × perimeter	Frequency × area (cm2)	Mohre area Vageere area	Tile color	Frequency in the spandrel	perimeter (cm2)	area (cm2)	Mohre
45	123	123 221	white	1	45	۱۲۳	
1296	1584	22.2 221	dark blue	72	18	22	
408	272	7.8 221	ochre	34	12	8	
184	272	34 221	white	8	23	34	
1008	980	35.3 221	ochre	28	36	35	

Fretwork of Gol sabounaki

This pattern has been accomplished in rectangular fame in western and eastern side of the mosque (Figure 27).

Drawing Method

A square with desired sides is drawn and each side is divided into five equal parts. Based on the division made, the checkered network within the frame is drawn; bold lines in the picture of vageere (Figure 25). By repeating the module of vageere, the complete fretwork emerges (Figure 26) (Maheralnaqhsh,1983).

The fretwork consists of three distinct geometric forms. The specifications of each form (area, perimeter and workforce) were calculated (formula 7). Then, workforce used for each specific color was calculated (formula 8).

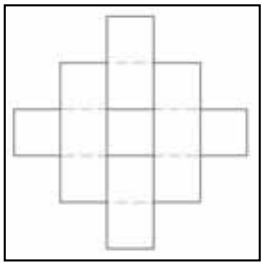

Figure 25. vageere

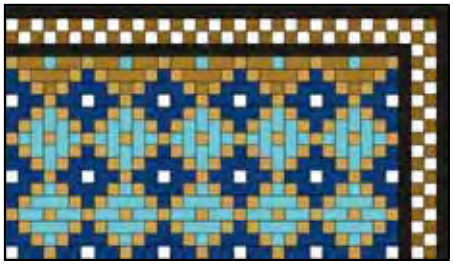

Figure 26. Expansion of a gere (knot)

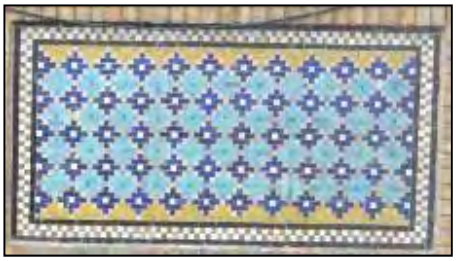

Figure 27. A gere accomplished in the frame

Formula 8. Workforce = perimeter × frequency
The workforce needed in the spandrel of figure 27 3291+2640+2786=8717

Formula 9. The sum of (perimeter × frequency) = the area of tiles used for each color
The area of turquoise tile used= 748+935+319=2002 (cm2)
The area of dark blue tile used=748+935+348=2031 (cm2)
The area of white tile used= 174 (cm2)
The area of ochre tile used= 150+374+127=651 (cm2)

Table 9.The geometric specifications applied in the fretwork

Frequency × perimeter	Frequency × area (cm2)	Mohre area Vageere area	Tile color	Frequency in the spandrel	perimeter (cm2)	area (cm2)	Mohre
3291	748	6.8 120	dark blue	110	13.6	8.6	
	150		ochre	22			
	748		turquoise	110			
2640	935	8.5 120	dark blue	110	10	5.8	
	374		ochre	44			
	935		turquoise	110			
2786	319	9.2 120	turquoise	110	6.8	2.9	
	127.6		ochre	44			
	348		dark blue	120			
	174		white	60			

Moj-o-shamse inscription

The inscription has been accomplished in eastern side of the mosque (Figure 28).

Figure 28. A gere accomplished in the frame

Conclusion

Examination of the fretworks in Khayyatha Mosque revealed the number of tiles used in the inscriptions. In addition to the size of the frame, form and geometric specifications of the fretworks affect the workforce needed. Through combining individual modules of the fretworks a wide variety of new forms may emerge indicating the workforce needed to build them. The fretwork of shesh tond-e-zamine hasht (3-4) had the highest workforce among other fretworks; a justifiable fact given the large area dedicated to this fretwork. Also, the workforce needed to make the fretwork shesh tond-e-zamine hasht in each square meter is, by far, more than that of other discussed fretworks. The second rank, in terms of workforce needed, goes to the fretwork shesh tond-e-zamine dah (2-4). In other words, the fretwork shesh tond-e-zamine hasht is the most time-consuming and technically demanding of all. This may help to choose the best possible fretwork desired in terms of expenses to be spent. Also, it was made clear that certain gerehs were more frequently used than the other ones.

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