Geometry and Bonding Rules Position Analysis in the Formation of Traditional Iranian Architectural Brick Facades

Nima Valibeig¹ · Hanieh Mohammadi¹

Published online: 16 March 2016
© Kim Williams Books, Turin 2016

Abstract Over time, architectural ornaments have had a variety of forms that are created from a combination of different types of materials and factors. Brick decorations are one such example, a type of ornament that is often formed on the exterior façade of buildings. Investigating covert rules and brick bonds geometry can reveal a part of the ancient architectural secrets and ways used to reduce the ravages upon new brick façades. Shaped bricks in traditional Iranian architecture directly affect the placement, size and brick arrangement rules. This article is the first attempt to study the effects of geometry and the principal rules of arrangement that help to shape the formation of brick façades specifically, as well as analysing the samples of brick façades taken from monuments, field recordings and discussion with the workmen themselves. The analysis has revealed that permanent rules govern the bonding of brick façades, along with the size and dimensions of the brick effects, which shape the final look of the decoration.

Keywords Iranian brickwork · Bonding rules · Bonding geometry · Base cut · Façade decoration

✉ Hanieh Mohammadi
H.mohamadi191@yahoo.com

Nima Valibeig
n.valibeig@aii.ac.ir

¹ Department of Architectural and Urban Conservation, Faculty of Conservation, Art University of Isfahan, Isfahan 1744, Iran

Introduction

Building façades have always maintained a special place within different architectural styles. Through a combination of accessible materials, locations of buildings, the style of cultural architecture as well as the design capabilities of the architect themselves, these are the dominant factors to help shape the façade. In this regard, one of the most widely used materials is brick, which is one of civilization's first steps towards self-preservation, once man moved out of the caves. The technique of making bricks has, of course, progressed from its first origins some thousands of years ago; however the basic principle of manufacture itself has remained the same to this today. From combining earth, fire and water to making the brick in the first place, and to the size and cut of the brick and the way it's placed, it has helped form the aesthetic design of the façade.

Geometric analysis of ancient architecture has only been able to reveal some of the forgotten mysteries of the past techniques used. However it can demonstrate the mastery of geometric science. The treatment plans of the monuments that are in need of repair can also benefit from these types of analyses to retrieve the knowledge of the brick bonding used. Using both the data from the analysis of brick bonding used and the knowledge gleaned of past architectural skills it can help offer inspiration to future modern processes, such as the patterns of new building façades. So the key questions of the present investigations are thus:

- Is it possible to achieve specific principles in brick façade, bonding and sizes?
- How has optimization occurred in material and labor consumption in traditional Iranian architecture?
- How do the various cuts of brick affect the final form of façade and which one of them is more common?
- What do the basic mathematical calculations represent in the bonding of traditional Iranian brick façades?

This study was carried out based on library and field studies; also by drawing an analysis of different case studies it intends to answer the above questions.

Literature Review

Some researchers have studied the chronology of brickwork during world history and throughout different civilizations (Lynch 2007; Campbell and Pryce 2003). Others chose to categorize different brick types based on their manufacturing methods used and consumption types in the buildings (Chudley et al. 2011; Hodge and Thorpe 2006; Barry 2001). Another group of researchers studied different brick arrangements and its methodology in structures (Neufert and Neufert 2012; Chudley et al. 2011; Jupp 2002; Nash 2002; Barry 2001).

A number of researchers have utilised the data from the analyses conducted and reviewed the data ranging from the way the brick was manufactured, construction

methods used and the mortar and tools used in the brickwork of various parts of buildings (Hodge and Thorpe 2006; Jupp 2002).

Some have looked at the implementation types and methods used for stylising the decorative brick bonds (Nash 2002). While some others have studied the maintenance and conservation of different kinds of brick buildings (Lynch 2007; Sowden 1990).

Thus far, most researchers have been studying bricks in terms of building construction, whereas decorative bonds have been less noticed. On the other hand, none of the mentioned researchers had examined the principles of brick bonding. The present investigation, for the first time, is studying the arrangement of brick façades and bonding principles used in traditional Iranian architecture.

Research Methodology

In this research, buildings with outstanding features in their brick bonds were analyzed. Samples were taken with consideration of the variety of bonding used in different eras and locations. We were also looking at different geometric forms of the order and placement of bricks when they were together. Moreover, different buildings applications as well as external and internal surfaces were considered in sampling.

After the selection, the samples have been carefully recorded where the dimensions of bricks and mortar sizes were calculated and then implemented into the graphical software. The analyses of the frame size and brick dimensions were done by using basic mathematical calculations. Alongside the samples taken, interviews were conducted with various brick-bonding masters on how to form and arrange bricks. The reliability of the results was confirmed by the interviews with the masters from different generations and locations.

In addition, selected samples for calculation have been chosen from different buildings in terms of function and construction. Analysis revealed that the methods used by the masters and the rules of arithmetic and analysis were very close together and as a result they were only a few details different.

Unfortunately, written sources relating to the geometric capabilities of building masters and their methodology used were not available; we tried to overcome this problem in interviews with masters who have done brickwork for several generations.

Concepts

In this regard, there are several terms such as brick, brickwork, brick bond and pattern which are defined as follows:

Brick: a solid masonry unit, usually of clay, molded into a rectangular shape with plastic and then treated in a kiln at an elevated temperature to harden it, so as to give it mechanical strength and to provide it with resistance to moisture after

being removed from the kiln. The brick is said to be burnt, hard-burnt, kiln-burnt, fired or hard-fired (Harris 2005, p. 137), as well as other similar definitions used for it (Bucher 1996, p. 65; Burden 2004, p. 34)

Brickwork: masonry of brick and mortar (Harris 2005, p. 139), and also masonry construction composed of bricks and mortar (Bucher 1996, p. 65).

Brick bond: An arrangement of masonry units (headers and stretchers) laid in a pattern that provides a brick wall with strength, stability, and in some cases, beauty, depending on the pattern (Harris 2005, p. 138).

Pattern: Generally, there are several brick-bonding formats:

1. “mohri” brick: the brick with outstanding or dent impressions which are made by hand or mold.
2. Framed brick: before placing the adobe in the oven, it is given form in any way that is necessary with a special mold and then baked in the oven.
3. Cut brick: which is divided into two categories (A) and (B):
 - (A) brick with a base cut, which itself is divided into two categories:
 - Circular: Arabesque patterns
 - Embowed: embowed geometry (vertical and horizontal elements)
 - (B) Non-base cut bricks, which do not have a specific geometric shape and are used in combination with tiles.

In this research only base cut bricks with embowed geometry have been studied.

Brick Dimensions

In historical architecture, bricks had two forms, a cuboid with a large square base and a cuboid with a large rectangular base, but generally bricks with a large square base which have been used on the building façade were converted into rectangular forms too.

Bricks With a Large Square Base

The calculations of this brick kind were based on the dimensions of basic brick, which is generally used for $4a \times 4a \times a$ and in some cases $5a \times 5a \times a$ proportion. The typical bricks used with these ratios are shown in Tables 1 and 2.

Bricks With a Large Rectangular Base

Bricks with large rectangular bases are used more in building façades and are axed and used in various dimensions. In Table 3, these types of bricks are introduced based on the dimensions ratio.

It is essential to note that, because the number of brick pieces needed in this pattern (brick with a base cut) is so many, there is no possibility of using multiple

Table 1 Brick dimensions with ratio of $5a \times 5a \times a$

Shape	Amount of “a” (cm)	Brick dimensions
$a = 5$	$25 \times 25 \times 5$
	$a = 4$	$20 \times 20 \times 4$
	$a = 3$	$15 \times 15 \times 3$

Table 2 Brick dimensions with ratio of $4a \times 4a \times a$

Shape	Amount of “a”	Brick dimensions
$a = 5$	$20 \times 20 \times 5^a$
	$a = 4$	$16 \times 16 \times 4$
	$a = 3$	$12 \times 12 \times 3$

^a The most common Iranian bricks were those with $20 \times 20 \times 5$ dimensions

Table 3 Brick types with large rectangular bases (base cut)

Shape	Name	Dimensions ratio
Whole ^a	$a \times 2a \times 4a$
Three-quarter Closure ^b	$a \times 2a \times 3a$
Half or bat ^c	$a \times 2a \times 2a$
Quarter closure ^d	$a \times 2a \times a$

^a Tamam
^b Se-charak
^c Nime
^d Charak

frameworks in different sizes in different regions of Iran. There is not enough wood available for frameworks in Iran. For this reason, bricks have been cut by using human labour.

Brickwork Rules

In most countries, such as England, Holland and Denmark, simple and standard samples of bonding exist. However Iranian brick bonding includes many forms with more complex patterns in which the brick dimensions are directly affected by the frame and arrangement. But despite the bonding diversity the same rules are followed in Iranian brickwork.

Due to most of the rules governing the construction of the brickwork not being written down, the research, such as surveys, observations and studies, is backed up by interviewing the masters of different generations and different disciplines to provide validity to the descriptions of the rules shown in Table 4:

Rule 1 explanation: if it is necessary to use two adjacent bricks of the same size (besides each other), they should have different colours and/or one of them be outstanding, and the other one dent.

Rule 2 explanation: less cuts means less labour and lower costs, which ultimately leads to less dumps.

An important principle of ancient architects was to not waste cut bricks, which means they were trying to equalize the number of Three-quarter closure bricks and quarter closure bricks as far as possible. Because there is no problem for whole and half bricks, the whole brick can be used anywhere and half bricks have two equal parts and at the end of the brickwork design only one extra half of brick remains. Therefore, the discarded part was created only in the three-quarter Closure bricks

Table 4 Rules observed in the brick bonding of Iran

Value	Shape	Rule
1	In no case allow the use of two bricks with the same base cut beside each other, either vertically or horizontall	
2	The number of cut bricks should be minimized so the most beautiful design may be implemented with the least number of cuts	

Table 5 General form of façade brick bonding

	Non-visible intermode samples	Visible intermode samples
Shape
Height calculation	$A = na \text{ n}N$	$B = na + mb \text{ n}N^a$

^a Usually $b = 1$ cm. So $na + mb$ can be rewritten as $na + m$

Table 6 Parameters and units introduction

Parameters	Units
S	cm ²
M	g
ρ	g/cm ³
V	cm ³

and Quarter Closure bricks. However, this rule is appropriate only while it would not have negative effects on the construction of the general plan.

Case Study Review

Initially, as it is presented in Table 5, the general form of brick bonding can be considered in two general categories, with visible internode and non-visible internode. Thus, to calculate the weight and area of samples with visible internode the weight and area of mortar should be taken into account too (Table 6).

In all samples (with visible and invisible internodes as presented in Tables 7, 8, 9, 10, 11) the number of each brick type were determined separately according to the type of base cut. In calculating the surface area, the brick volume that is used in each sample can be calculated by using the formula 1, and then its weight, according to the formula 2.

$$V = S \times w$$

(1)

$$M = \rho V$$

(2)

where v is volume, S is area, w is width, M is weight, ρ is density, and their units will be mentioned in Table 6.

In this calculation, bricks and mortar density is considered 180 and 140 g/cm³ respectively.

The expense of each plan can be explored by using the formula 3 to calculate the number of bricks used per unit of area. This means that a higher number of bricks leads to more cutting and ultimately more cost of construction.

$$N = \frac{N_t}{S_t}$$

(3)

where N is the brick number per unit of area, N_t is the total number of bricks and S_t is the area.

Sample One—Visible Internode Samples (Fig. 1)

See Table 7.

Drawn Model	3d Model	Hakim Mosque, Safavid Period

Fig. 1 Sample one (authors)

Table 7 Sample one calculations

Brick type	Whole	Three-quarter closure	Half	Quarter closure	Area	Volume	Mass
Ultramarine	–	52	52	576	20,900	104500	18,810,000
Turquoise	–	23	69	262	11,725	58,625	10,552,500
Buff	16	248	216	410	41,250	206,250	37,125,000
White	–	–	–	188	4700	23,500	4,230,000
Black	–	–	–	14	350	1750	315,000
Mortar	16	323	337	1450	16,800	84,000	11,760,000
Total					95,725	478,625	722,085,000

$$N = \frac{16+323+337+1450}{9.5725} = 222$$

Drawn Model	3d Model	Khaju Beidge, safavid period

Fig. 2 Sample two (authors)

Sample Two—Non-Visible Internode Samples (Fig. 2)

See Table 8.

Table 8 Sample two calculations

Brick type	Whole	Three-quarter closure	Half	Quarter closure	Area	Volume	Mass
Ultramarine	–	–	–	559	13,975	69,875	12,577,500
Turquoise	–	–	192	444	20,700	103,500	18,630,000
Buff	–	589	448	250	72,825	364,125	65,542,500
Total	–	589	640	1253	107,500	537,500	96,750,000

$$N = \frac{589+640+1253}{10.7500} = 230$$

Fig. 3 Sample three (authors)

Table 9 Sample three calculations

Brick type	Whole	Three-quarter closure	Half	Area	Volume	Mass
Ultramarine	64	–	–	16,925	84,625	15,232,500
Turquoise	16	16	–	10,800	54,000	9,720,000
Buff	24	114	503	39,650	198,250	35,685,000
White	–	–	–	5550	27,750	4,995,000
Black	–	–	–	2650	13,250	2,385,000
Total	106	130	503	75,575	377,875	68,017,500

$$N = \frac{106+130+503+1211}{7.5575} = 258$$

Sample Three—Non-Visible Internode Samples (Fig. 3)

See Table 9.

Sample Four—Non-Visible Internode Samples (Fig. 4)

See Table 10.

Fig. 4 Sample four (authors)

Table 10 Sample four calculations

Brick type	Whole	Three-quarter closure	Half	Quarter closure	Area	Volume	Mass
Ultramarine	140	68	174	1468	64,500	322,500	58,050,000
Turquoise	–	14	54	333	12,075	60,375	10,867,500
Buff	156	208	534	72	59,700	298,500	53,730,000
White	108	38	362	235	37,625	188,125	33,862,500
Total	404	328	1124	2108	173,900	869,500	156,510,000

$$N = \frac{404+328+1124+2108}{17.3900} = 227$$

Fig. 5 Sample five (authors)

Sample Five—Non-Visible Internode Samples (Fig. 5)

See Table 11.

Table 11 Sample five calculations

Brick type	Whole	Three-quarter closure	Half	Quarter closure	Area	Volume	Mass
Ultramarine	16	120	116	414	26,750	133,750	24,075,000
Turquoise	–	7	95	212	10,575	52,875	9,517,500
Buff	56	146	72	136	23,550	117,750	21,195,000
White	48	32	32	172	13,100	65,500	11,790,000
Yellow	–	24	108	20	7700	38,500	6,930,000
Total	120	329	423	954	81,675	408,375	73,507,500

$$N = \frac{120+329+423+954}{8.1675} = 223$$

Results

The analysis has revealed that despite the diversity of brick façade arrangements, they have all followed the same rules. Over time, ancient architectures have particularly used repetitive principles in the construction of brick bonds, which have always been considered as the permanent principles (see Table 4).

The case studies indicate that the bricks made different forms with their vertical and horizontal arrangement and four types of base cut. These various forms have been created only by the brick placement styles and making dents and outstanding in them. On the other hand, the mathematical relations among brick dimensions illustrates the wide use of quarter closure and, after that, half brick in the case study examples. Due to calculating the number of bricks used per unit of area, it could be realized samples 1 and 5 are more costly and sample 3 is a less costly pattern in brickwork.

Conclusion

The research undertaken on various brickwork cases demonstrates some significant rules that have been applied iteratively in Iranian brick bonds. Moreover, these studies show the principles used in the brickwork of Iranian façades have directly led to a reduction in materials consumption and cutting the waste from dumped bricks. This, by itself decreases the labour requirements and ultimately would lessen financial costs. These rules could be observed in most brickwork cases, so if any of them has not been respected in a brick façade, it would indicate a lack of knowledge and inappropriate technique for building architecture. In addition, in regards to brick bonding, Perimeter frame dimensions would be specified according to the bricks size, placement and their pattern type. Consequently, brick bond and brick size, which arise from the straight-line geometry of the design, have directly affected the final form and brick façade. Finally, it is possible to use the methodology of this research for other cases or even other territories to achieve a more comprehensive understanding of covert masteries in ancient architectures.

References

- Barry, Robin. 2001. *The Construction of Buildings*. New York: Wiley.
- Bucher, Ward. 1996. *Dictionary of Building Preservation*. New York: Wiley.
- Burden, Ernest. 2004. *Illustrated Dictionary of Architectural Preservation*. New York: McGraw-Hill Professional.
- Campbell, James W.P., and William Pryce. 2003. *Brick: A World History*. London: Thames and Hudson.
- Chudley, Roy, Roger Greeno, Mike Hurst, and Simon Topliss. 2011. *Construction Technology*. New Jersey: Pearson Education.
- Harris, Cyril M. 2005. *Dictionary of Architecture and Construction*. 4th Edition. New York: McGraw-Hill Education.
- Hodge, J.C., and Malcom Thorpe. 2006. *Brickwork for Apprentices*. London: Routledge.
- Jupp, Edmund W. 2002. *Brick Watching*. Wiltshire: Cromwell Press.
- Lynch, Gerard. 2007. *The History of Gauged Brickwork: Conservation, Repair and Modern Application*. London: Routledge.
- Nash, W.G. 2002. *Brickwork*. 3rd edition. Cheltenham: Nelson Thornes Ltd.
- Neufert, Ernest, and Peter Neufert. 2012. *Neufert Architects' Data*. 4th Edition. Hobokon: Wiley–Blackwell.
- Sowden, A. Maurice, ed. 1990. *The Maintenance of Brick and Stone Masonry Structures*. London: Taylor and Francis.

Nima Valibeig He is professor assistant of Art university of Isfahan in architectural and urban conservation department, until now, he has published many articles in different journals and had some presentations in some conferences and workshops in Uk such as British Institute of Persian Studies, he is specialist in geometrical issues in architectural field.

Hanieh Mohammadi She is Ph.D candidate in Art university of Isfahan in architectural and urban conservation department. She is working on Persian garden geometry as her dissertation. Also she is lecturer in art university of Isfahan.