IS THERE ANY GEOMETRICAL GOLDEN RATIO IN TRADITIONAL IRANIAN COURTYARD HOUSES?

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Abstract
The traditional architecture of Iran always places heavy emphasis upon beauty and harmony. This architecture is renowned for detectable principles such as modular design, geometry and specific systems of proportion. This paper involves analyzing these principles, especially geometrical golden ratio embedded within traditional houses, to confirm whether or not they are a perfect match with for the proportion system and modular design used. Eighty traditional courtyard houses in Iran were selected as a case study. The research employs the qualitative method involving archival documents, direct observation, on-site documentation and design analysis. This paper presents a detailed analysis of both proportioning and geometrical principles utilized in the facades of traditional houses and courtyards and their respective roles in creating harmony and beauty. This article concludes that despite the fact that public traditional buildings were made based on geometry and a proportioning system, this is not the case for courtyard houses. The vital factors in this case are the repetitive scale and module of openings in most traditional houses being crucial to the creation of harmony and beauty.

Keywords: Geometry; Modular; Proportion; Traditional Courtyard Houses; Openings

INTRODUCTION
Scholars have recognized the fact that geometry is imperative to the traditional architecture of Iran (Ardalan & Bakhtiar, 1979; El-Said et al., 1993). The comprehensive understanding of geometry and its relevant terms enabled Iranian architecture to present more durable and stable forms based on the circle and square, or rectangular geometrical characteristics. The utilization of these geometrical aspects, proportions and measurements assisted the architects in the development of the concept for modular design (Vakili-Ardebili & Boussabaine, 2006). The geometrical basis in Iranian design is present in many facets of the architecture: in the proportion of spatial design, in the creation of three-dimensional geometric objects and in two-dimensional surface decoration. Any system of proportion functions via creating a united design, making the product aesthetically pleasing. Writers have pointed out that there is no particular set of proportions that is innately preferred by the human psyche. Experiments designed and conducted to prove otherwise, such as those undertaken to elucidate the properties of the “golden section”, have at best been inconclusive. The popularity of the “golden section” is owed to its flexibility. The Islamic system of proportion, which utilizes irrational numbers, is based on the geometrical proportion of the square, the double square, the equilateral triangle and the pentagon (El-Said et al., 1993).

There has been mounting evidence that classical Greek architecture used a system of geometric proportion, which was most probably retrieved from the intermediary of Euclid’s treatise on geometry (Hartshorne, 2000). The Arabs then adopted this approach, and it was
further enhanced during the Islamic Era. Early Arabic treatises on mathematics paid special attention to the needs of the architect, and in these works, the aesthetics of architecture were discussed. Despite the fact that nothing rivals Vitruvius’s treatise on architecture, there are some works dealing with geometry for the architect, geometric designs for craftsmen, and comments throughout general texts on mathematics that can be related to architectural practice (Golombek et al., 1988).

Beauty always possesses holistic qualities, as it is constituted by a figurative balance of order in diversity. It is holistic in a way where all figurative principles and levels are attuned to one another. Beauty is present in the ensemble effects, and the proportions are vital in their constituents, because it guides the intermediation between order and diversity, along with other unifying principles. This statement is valid and adapted to establish teachable systematic design principles that must see future advancements. Proportion is one of the determinant architectural criteria in the context of harmony. Grütter (1987) said that harmony is the discipline and regularity which exists between components of phenomena. Vitruvius & Morgan (1960) pointed out that when it is assumed that a building is beautiful, it implies that the proportion among the components is rigidly defined. Le Corbusier (1931) said that geometry is intertwined with rhythms and the language of men, and forms the basis of all activities (Elam, 2001).

The beauty of proportions is derived from the geometry of regular polygons. People will inevitably be able to see the clarity or crystalline-like order in proportioned architecture derived from regular geometry. The majority of the thousands of treatises on art and architecture appearing in Antiquity and between 1450 and 1850, place emphasis on the importance of proportion for beauty, similar to the philosophy of Antiquity, Middle Ages and Modern times.

The emphasis of Iranian architecture was on beauty and harmony. Proportion and module in components are visible on many parts of the buildings, mostly intended to decrease the sizes of the components and simplifying construction. But most of the Iranian architectural principles highlighted by scholars are applicable in traditional public buildings. In Courtyards and facades of mosques, palaces, schools and gardens, there are proportioning and geometrical principles such as human scale and modularization. There is not specific evidence for traditional houses in Iran. They supposed to repeat all of these geometrical principles. This paper involves analyzing these principles, especially geometrical golden ratio embedded within traditional houses, to confirm whether or not they are a perfect match with for the proportion system and modular design used.

This present paper contains the following parts: 1) a brief outline of the systems of proportions and some Iranian systems based on literature review. 2) a brief geometrical analysis and the use of the science of geometry in design of traditional Iranian buildings, such as mosques, palaces, and gardens. 3) an analysis of the eighty traditional houses via their courtyards, circulation, openings and facades.

GEOMETRY AND PROPORTION
Architecture depends on geometry (Frith, 2010). According to the 10th century philosopher, Abu Nasr al-Farabi, the fundamental of architecture were derived from mathematical science. Furthermore, the basic science of architecture was the knowledge of hiyal. This term is difficult to translate without reference to Farabi’s discussion of the sciences, from which hiyal emerged from. Literally hiyal mean “skill, art, cunning”, concerning the ingenious and artistic manipulation of geometric forms (Golombek, Wilber, & Allen, 1988). Thus, geometry was the foundation of an architect’s training.

Proportion is strongly linked to geometry (although non-geometric procedures for proportion are possible). Practical geometry in the building crafts are regarded as self-guiding methods of regular and statically proven design. Proportion and geometry primarily regulate the extensional order of buildings. Symmetry controls invariants of figurative relations in regard to mirror axes, rotation, stretching, or shrinking; mirror symmetry is by far the most important symmetrical pattern.
in architecture. Proportion and symmetry are regarded as complementary (even if buildings are not symmetrical).

Proportion in geometry, architecture and art can be said to be a harmonious relationship between the parts, with and within the whole. Proportion refers to the relationship between one part of a design and another part or to the whole design. It is a comparison of sizes, shapes, and quantities. Vitruvius (1960) wrote in his Ten Books on Architecture, which is the oldest surviving work in this context, that symmetry is a proper agreement between the members of the work itself, and the relationship between the different parts and the whole general scheme, based on the standard selected parts. Furthermore, due to the fact that nature has proportioned the human body, this needs to be replicated in buildings as well. From systematic proportions, each and every part is correlated, resulting in an aesthetically pleasing and workable design (Frings, 2002).

The selection and use of systems of proportions are vital to artists and architects. There were not only specific ratios used, particular systems of proportions were preferred over others. Some systems of proportions were based on the musical intervals, the human body, and the Golden Ratio.

**Golden Ratio**
The Golden Ratio (also called as the Golden Proportion, Golden Section, Golden Mean, Divine Ratio, and Divine Proportion) (Markowsky, 1992) is a suprarational or transcendent ratio found in fundamental forms: plants, flowers, viruses, DNA, shells, planets and galaxies. Although the Golden Ratio is primarily regarded as a proportion, not a number; as a numerical quantity it is defined to be 1.618 (Hejazi, 2005) (see Figure 1).

\[ \varphi = \frac{1 + \sqrt{5}}{2} = 1.6180339887... \]

Figure 1: Numerical Quantity of Golden Ratio

The Golden Ratio is the unique ratio of two terms when the ratio of the larger term to the smaller term equals the smaller plus larger to the larger. It symbolizes the regeneration and progression and extension from the Unity, due to the fact that every generation is connected to its ancestors. It is also regarded as the perfect division of the Unity. The Golden Ratio has some unique properties:

- The Fibonacci sequence is a set of numbers: 1,1,2,3,5,8,13,21,…
- The relationship between two successive numbers of this series tends to approach 1.618. This series can be found in many places in nature where self-generating patterns are in effect.
- The human body illustrates the Golden Ratio.

**Iranian golden ratio**
For the best solution to form the buildings, Iranian architects relied on geometrical shapes with commensurate ratio to design most spaces in traditional houses. This system is more advantageous in terms of geometrical perception, along with the provision of its building structure and quicker completion time (Bozorgmehri, 1981; Memarian, 2008; Pirnia, 2005). They selected a regular hexagon formed by regular triangles (see Figure 2). The levels of scales are realized via the accurate utilization of the ratio known as the Golden Ratio. This is evident in the architecture of countless cultures.
Units of Traditional Measurement in Iran

Utilization of specific units in traditional measurements is a well-established practice in the design of traditional structures. The utilization of specific module allows architects and designers to harmonize the elements. These units were derived from human scale, such as the dimension from fingers to elbow in a medium-size person, or an open hand (Bozorgmehri, 1981; Pirnia, 2005).

Specific units were used for the majority of the parts in a traditional building. An example of this is the usage of the specific brick size. This is done for the purpose of harmonizing various buildings put together. The measurement unit in Iran is called Gaz (see Table 1). All elements, especially openings used to be built based on this unit and its proportion.

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<tr>
<td>1</td>
<td>One Gereh = 1/16 Gaz = 6.66 cm</td>
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<tr>
<td>2</td>
<td>One Gaz = 16 Gereh = 106.66 cm</td>
</tr>
</tbody>
</table>

Table 1. Units of Traditional Measurement.

IRANIAN TRADITIONAL ARCHITECTURE

Iranian architecture adhered to certain principles, observable in traditional buildings (Pirnia, 2007), which are currently absent (Curatola & Scarca, 2007). Iranian architecture principles are presented based on the attention of various levels in design. The natural element in environment is one of the vital factors that Iranian architecture focuses on (Vakili-Ardebili & Boussabaine, 2006).

These principles have influential roles in traditional buildings, with some of them being specified for houses. For example: to be in accordance with human scale, modular unit, structural rigidity.

Traditional Houses

In Iran, traditional courtyard houses represent the most prominent types of houses (Pirnia, 2005; Daniel, 2006; Moradi & Akhtarkavan, 2008).

A courtyard provides security, privacy, and comfort (see Figure 3). Rectangular courtyard houses typically are organized around an inner courtyard (Nabavi et al., 2012). The courtyard allows for outdoor activities with protection from the wind and sun (Ghobadian, 2006). Designing different spaces with various functions and a big courtyard in the heart of a house helped them live in suitable situations (Ardalan & Bakhtiar, 1979).
GEOMETRICAL ANALYSIS OF TRADITIONAL IRANIAN BUILDINGS

The Geometrical analysis of many Iranian traditional buildings proved that a complete knowledge of proportions, in particular the Golden Ratio, was applied extensively in Iranian architecture and forms the basis of Iranian aesthetics.

In many traditional Iranian buildings, both the plan and elevation were defined within a framework of squares and equilateral triangles, with the intersecting points being important, such as the width and height of doors, the width, length and height of galleries, the position of inscriptions, etc. this means that the size of each part within the structure is correlated with a defined proportion. A building was not defined as a jumble of wired components, but is regarded as a harmonious configuration of proportionally related elements, which are aesthetically pleasing and provide elegant spaces (Bozorgnia, 2005; Pirnia, 2005).

For example, the Golden Ratio has been masterly used in the design of the Taj-al-Mulk dome dated 1088 AD, in Jaml mosque in Isfahan (see Figure 4).

The elevation of Ghasr-e-Khorshid as shown in Figure 4, has a complete relationship with the Golden Ratio and Golden Rectangle (see Figure 5).
METHODOLOGY

For the purpose of this paper, the study employs a case study approach because it is a strategy of inquiry in which the researcher explains in depth a particular process (documents, direct observation and audiovisual material). The case study subjects are eighty traditional houses in Iran which are registered as valuable buildings in the Cultural Heritage Organization of Iran.

In July and August 2011, the researcher made a trip to Iran and collected documentations related to eighty traditional houses from the Cultural Heritage Organization. Some of the houses lack formal planning, but according to the conditions being discussed, eighty of the traditional houses in Iran were selected. It was followed by direct observation of most of these houses (see Figure 6).

Archival research from the Cultural Heritage Organization in Iran has helped to identify eighty traditional courtyard houses in Iran. All these traditional houses selected were registered in the Cultural Heritage Organization in Iran as heritage buildings, and represents the best examples of the finest Iranian traditional houses. They were located in three ancient provinces of Iran – Yazd, Isfahan, and Shiraz.

The study tries to have a geometrical analysis of traditional houses (Haider & Moussa, 2015). A detailed analysis of both proportioning and geometrical principles utilized in the facades of these eighty traditional houses and courtyards and their respective roles in creating harmony and beauty.

For each identified house, there are some write-ups on the history of the house, basic information such as house address, owner, year built and the site location. Technical information such as scaled floor plans, sections and elevations are also available.

Geometrical analysis started with the courtyard and after that, the openings of the main rooms which surrounded the rectangular courtyard (see Figure 7). Based on the literature review,
in designing the traditional buildings, architects have used different proportion systems and the Golden Ratio.

All the courtyards were checked for the golden proportion and the Iranian Golden Rectangle. In the next step, most of the geometrical common rules and systems of proportions used in traditional Iranian architecture were analyzed in all eighty houses. The most important part of this paper’s analysis was about openings which made the harmonious facades around the courtyards.

RESULT AND DISCUSSION

After analyzing eighty traditional houses in Iran, it can be concluded that some Iranian architectural principles are applicable in these houses. However, unlike the public traditional buildings (such as palaces, mosques and schools), the principles employed in traditional houses are different in that:

• All of these houses have an inner rectangular courtyard with the main spaces surrounding the courtyard. A courtyard is commonly made up of a central pool, small gardens around the pool, and the water pathways, which differs in shapes and sizes due to differing weather and environments. All of the shapes are rectangular (see Figure 8).

Figure 7. Geometrical analysis of traditional houses (courtyard, openings) (Source: Authors).

Figure 8. Rectangular Courtyard with Pool and Plants (Source: Authors, 2012).
• This geometry imposes a corresponding hierarchy on its different spaces. The most important point here is the hierarchy starting from the main door, which can find in all eighty traditional houses. It is repeated in all the cases being analyzed (see Figure 9).

![Figure 9. Hierarchy in Traditional Houses (Cultural Heritage Organization, Iran).](image)

• Although there is a geometrical harmony in the plan layout of all these eighty traditional houses, there is no specific ratio about courtyards (Golden Ratio: 1.61 or Iranian Golden Ratio: 1.73). From the eighty samples, there are five courtyards based on the Golden Ratio (see Figure 10) and ten courtyards with the Iranian Golden Rectangle (see Figure 11). The proportions of these rectangular courtyards were analyzed and they range between 1.2 to 1.8 (see Table 2).

Table 2. Analysis the proportion of Courtyards (Length/Width) (Source: Authors).

<table>
<thead>
<tr>
<th>Courtyard ratio (length/width)</th>
<th>Number of the houses</th>
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<tr>
<td></td>
<td>1.2</td>
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<tr>
<td>Total (%)</td>
<td>13.8%</td>
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Archnet-IJAR, Volume 10 - Issue 1 - March 2016 - (143-154) – Regular Section

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• There is a meaningful proportion between the two main rooms in the traditional houses – the bedroom (with three openings) and living room (with five openings). The dimensions of these rooms are related to their respective function, *sedari*; which is a room with three doors was smaller than a living room, and is suitable for people of average height (see Figure 12).
According to literature review, rooms are classified according to their corresponding morphology (Mirmoghtadaee 2009), and the number of doors or windows: *panjdari* (see Figure 13), is a room with five doors, and functions as a living room. Bedrooms were designed in accordance with human height, and enough space for a man to lie in the room. All these spaces are rectangular in a traditional layout, and according to their function, *panjdari* is bigger than *sedari*, with a ratio between their respective widths and lengths (Pirnia 2005).

If a room was built larger than another, its height, as well as its architectural elements such as the arches, the shelves, and the doors, would need to be built bigger following the same ratio. Thus all of the elements of any architectural space would be proportionate to the size of the place (Mirmoghtadaee, 2009; Soltanzadeh, 2005).

• The openings of rooms are examined, and the traditional measurements were checked as well (see Figure 14). All opening widths were equal to 14 *Gereh* (93.2 cm), which is suitable for the passage of a normal-size person (see Figure 15). These types of opening are present in almost all parts of a traditional house. For example, for *panjdari* (living room) five of them are placed right next to each other, and three of them for *sedari* (bedroom). They play an important role in providing harmony in the main façades of traditional houses that surround a courtyard. As per the literature review; the openings in the traditional houses match the size of an average person (Memarian, 2008; Pirnia, 2005).

They were suitable and quite large enough for a person to pass through, and also allow ample daylight in. An opening in an Iranian courtyard house is composed of multiple details that are salient towards the optimizing of daylight. Furthermore, the defined proportion of openings increases the speed of construction, due to the exact dimensions of the different rooms.
All of these openings were infilled using a lattice frame, and a beautiful wooden frame with unique motifs to control daylight, especially intense sun rays in the hot summer. These frames are covered with colorful glasses.

Figure 15. Proportion of the opening (Source: Authors).

CONCLUSION

From the eighty samples studied in Iran, it can be concluded that there are many different ways for utilizing the module in a traditional house. By and large, there are logical proportions and scales in important spaces of the traditional houses in Iran. These include building forms, courtyards and important rooms for family members and guests. It is suggested that these techniques have improved the speed of construction, while also harmonizing and beautifying these houses.

The present research involved geometrical analysis of the traditional courtyard houses in Iran, and checking the different systems of proportions in various spaces of these houses. Was there any geometrical golden ratio used in proportioning the courtyards? What are the proportional rules in creating harmony in the elevations and facades of these traditional houses?

After analyzing all eighty traditional houses, it was found that there are just five courtyard houses based on the Golden Ratio (1.618) and ten courtyards with Iranian Golden Rectangle (a rectangle in a regular hexagon formed by regular triangles).

This means that although there is geometrical harmony in the plan layout of all these eighty traditional houses, there is no specific ratio for the courtyards. Generally, there is a rectangular courtyard which is made up of a rectangular central pool and small gardens around the pool.

It is also concluded that there are harmonious facades around the courtyard of these houses. Most of the openings followed a certain proportional unit based on the human scale which has a vital role in creating modular elevations.

After analyzing the eighty courtyard houses, it can be identified that architects and designers of traditional architecture of Iran had followed certain geometrical rules and instruments to improve the quality of their creations through proportion and harmony. Regular shapes, proportional sizes and hierarchy played important roles to achieve this purpose.

REFERENCES


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