IMPROVING SOME ISLAMIC GEOMETRIC PATTERNS

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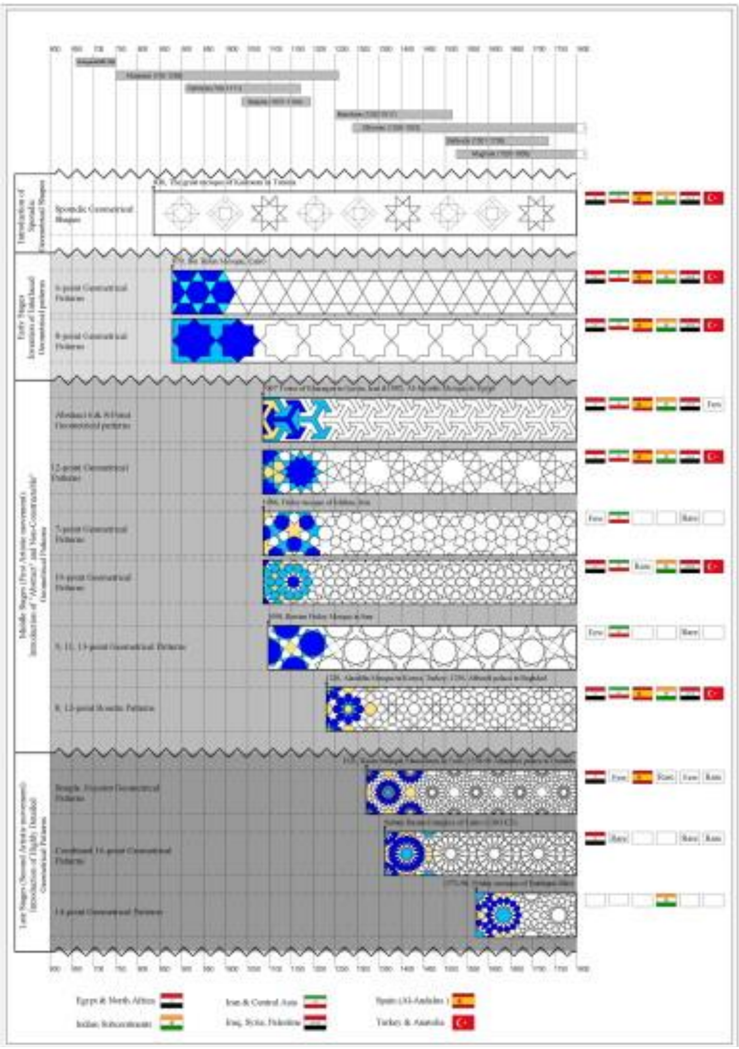
Annotation. This study examines IGPs from a historical and regional perspective to shed light on issues related to their suitability and proper use as decorative elements for buildings. This study chronologically and regionally traced the evolution of Islamic geometric patterns. The results show how regional influences and prevailing lifestyles during the ruling dynasties determined the diversity of Islamic designs and geometric designs. This study also illustrated the scientific progress and expansion of knowledge in the history of Islamic architecture. These developments began with simple geometric figures constructed from a circle and a set of tangent circles of the same radius, as was the case in the Great Mosque of Kairouan in the early 9th century. By the end of the 9th century, grids of circles were introduced into the Ibn Tulun mosque. Grids were used as a constructive basis for the simplest regular and semi-regular tilings with equilateral triangles, squares, hexagons and octagons.

Keywords: geometric patterns, Abbasid architecture, Seljuk architecture, Umayyad architecture, Ottoman architecture, Safavid architecture, Mughal architecture

Introduction. For centuries, Islamic Geometric Patterns (IGP) have been used as decorative elements on walls, ceilings, doors, domes and minarets. However, the lack of instructions and standards for the use of these ornaments often leads to inappropriate use in terms of accuracy of time scales and compliance with architectural style. This study examines IGPs from a historical and regional perspective to shed light on issues related to their suitability and proper use as decorative elements for buildings. The three questions that guide this work are as follows. (1) When were ISUs introduced in Islamic architecture? (2) When was each type of IGP introduced to Muslim architects and artisans? (3) Where and by whom were the models developed? Also presented is a sketch showing the evolution of ISU throughout the history of Islamic architecture. This study relied on descriptive approaches to collect data on extant geometric patterns and classify them based on temporal scale and regionalism. Such approaches provide dialectical answers to a wide range of philosophical and architectural questions, such as when and where a particular pattern was widely used. The literature review presents a selected collection of 100 well-known surviving buildings from West Africa to the Indian subcontinent ; Historically, the collection spans almost 12 centuries, from the early stages of Islam to the 18th century. It covers the most important treasures of classical architecture of the Islamic world. For this reason, this study made comprehensive use of not only architectural history encyclopedias but also regional/local architectural studies.

The spread and development of geometry through Islamic art and architecture can be attributed to the significant growth of science and technology in the Middle East, Iran and Central Asia in the 8th and 9th centuries; such progress was driven by translations of ancient texts from languages such as Greek and Sanskrit (Turner , 1997). By the 10th century, the original contributions of Muslims to science had become significant. The earliest written document on geometry in the history of Islamic science is a document written by Khwarizmi in the early 9th century (Mohammed , 2000). Thus, the history of Islamic geometric designs is characterized by a gap of almost three centuries, from the rise of Islam in the early 7th century to the end of the 9th century, when the earliest examples of geometric decoration can be traced in surviving buildings of the Muslim period. world (Table 1).

Table 1. Time diagram of the evolution of IGP throughout history.



Types of Islamic Geometric Patterns

Definitions and classifications of IGP are beyond the scope of this article, but a brief description of the types of IGP is provided.

For centuries, compasses and rulers were the only tools used to construct polygons and the required angles. Thus, all IGPs come from harmonious divisions of circles and are based on circular grid patterns. Some researchers have stated that the use of the circle is a way of expressing the unity of Islam (Critchlow , 1976 , Akkach , 2005). According to this doctrine, the circle and its center are the point from which all Islamic models begin; The circle is a symbol of a religion that emphasizes the One God and the role of Mecca, which is the center of Islam to which all Muslims turn in prayer.

Most IGPs are based on constructive polygons such as hexagon and octagon. Star polygons, which are the fundamental elements of IGP, are created by connecting the vertices of constructive polygons. From this category arose the first level of the ISU classification (El-Said et al ., 1993 , Broug , 2008). For example, all patterns whose basic elements consist of a hexagon or hexagram are classified as six-pointed geometric patterns; the star is called a six-pointed star (Fig. 1). Accordingly, the patterns are designated as 8-, 10-, 12-point geometric patterns. In Fig. 1 shows that at a certain level the sides of two adjacent rays of a six-pointed star become parallel or diverge, thereby creating a deformed hexagon (i.e., rosette petals). It is interesting that the evolution of IGP follows a complex path of construction, in which polygons are constructed from the simplest shape (i.e., hexagon) to more complex polygons and stars.

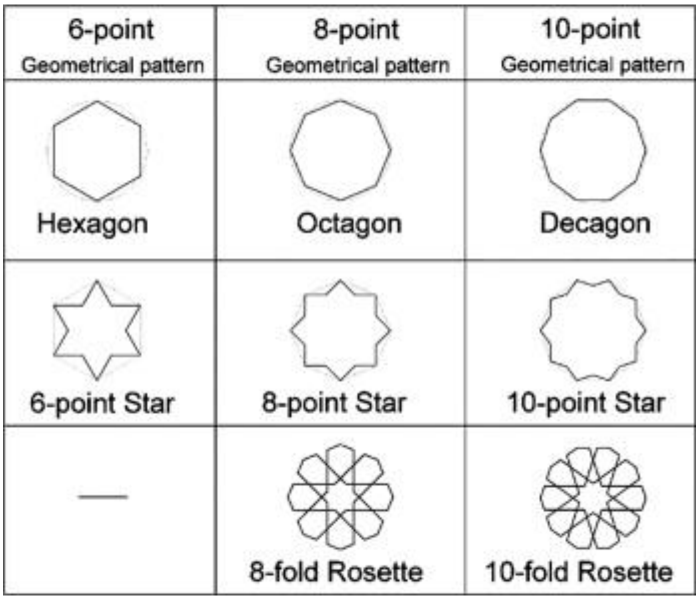


Figure 1. First level of IGP classification.

Umayyad architecture (660–750 CE)

By the late 7th and early 8th centuries, plant and floral designs derived from Sassanian and Byzantine architecture became commonplace in Islamic architecture. A popular surviving building from this period is **the Dome of the Rock** , built 688–691 AD. e. (Grube and Michell , 1995). This structure is lavishly decorated with floral and geometric motifs, but most of its designs, particularly the geometric motifs, are later additions and do not date back to the Umayyad era.

In 705 AD e. a significant part of the Christian temple in Damascus was converted into **the Great Mosque of Damascus** (Flood , 2001). The original decorative patterns were floral, reminiscent of the rich gardens and natural landscape of Damascus. The flooring of the yard was repeatedly repaired and updated; therefore his geometric designs are also later additions and not original. The finishing surfaces and facades of Umayyad buildings are predominantly stucco, mosaics and wall paintings with figurative and floral motifs. However, towards the end of the Umayyad era, the use of figural designs in mosques became limited. Our research has not revealed any evidence of the use of geometric motifs, but floral designs remain a common feature of Umayyad architecture.

Abbasid architecture (750–1258 CE)

The Great Mosque of Kairouan (Tunisia), originally built in 670 AD and rebuilt in 836 AD, is an excellent example of Abbasid-Aghlabid buildings. The ornaments of this building are made mainly with plant and floral motifs, but elementary geometric shapes are also observed. These single geometric figures (Fig. 2) are among the first attempts to use geometric patterns in Islamic architecture.

Fig. 2. Great Mosque of Kairouan; basic geometric shapes of interior decoration.

The simple 6- and 8-point geometric patterns used in **the mosque of Ibn Tulun** (876–879 CE) are among the earliest examples of woven geometric patterns in Muslim decorative arts (Fig. 3).

Fig. 3. Mihrab of the Great Mosque of Cordoba (left) and 9th-century carved stucco from Samarra in Iraq.

The Ibn Tulun Mosque is considered a milestone in terms of the introduction of geometric patterns into Islamic architecture. By the end of the 9th century, geometric motifs received a warm welcome from Muslim architects and artisans. The extensive influence of geometry significantly influenced other aspects of Islamic architecture.

For example, the transition from the naturalism of early Islamic designs to new levels of abstraction was a direct influence of geometry on floral designs. Samarra's plant motifs are a product of this era, during which the application moved from scrolling stems of continuously moving spirals (sinusoidal growth) to circular grids and tangential circles (Fig. 3).

The Abbasid Palace in Baghdad (1230 CE) and the **Mustansiriye Madrasah** (1233 CE) feature Muqarnas decorations and detailed geometric designs in carved brickwork and terracotta. These structures are excellent representatives of the architectural traditions and techniques of the late Abbasid and early Seljuk eras. Among such structures can be found some of the earliest examples of rosette petals, represented as 8- and 12-pointed stars (Fig. 4).

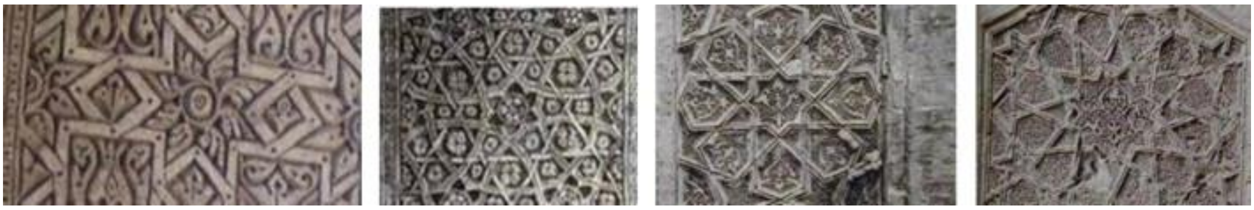


Fig. 4. Ibn Tulun Mosque in Egypt (first two panels on the left); Abbasid Palace in Baghdad (last two panels).

Architectural decorations and decorations such as wall paintings, carved wood, stone, stucco, terracotta and brickwork became very popular during the Abbasid era. Towards the end of the 8th and beginning of the 9th centuries, geometric shapes were introduced in surface decoration. However, woven geometric patterns (6- and 8-point patterns) only began to dominate Islamic architecture in the late 9th century.

Fatimid architecture (909–1171 CE)

Azhar Mosque (970–972 CE) was the first mosque and madrasa built by the Fatimids in Cairo. Parts of the original stucco molding (with floral motifs) and window screens (with geometric patterns) have been preserved. However, stucco above the windows and on the walls (with an abstract 6-point geometric pattern) was added under Caliph al-Hafiz (1129–1149). Another mihrab with significant geometric decorations was built during the Ottoman restoration in the 18th century (Behrens -Abuseif , 1992). The **Al- Juyushi** Mosque (1085 AD) in Cairo is a relatively small structure, the most significant surviving element of which is the richly carved mihrab stucco with floral and geometric designs. The abstract six-pointed patterns on the lintel of the mihrab are similar to the Seljuk style. The **Al- Aqmar** Mosque (1125 AD) in Cairo is an outstanding example of mature Fatimid architecture . Its facade is skillfully decorated with calligraphic, floral and geometric decorations. However, the motifs are repetitions of previously presented designs. Another remarkable Fatimid building is **the Al- Salih - Tala'i Mosque** (1160 AD), which is very similar to the Al- Aqmar Mosque in structure and decorative techniques (Fletcher and Cruickshank , 1996). As with the

Al- Aqmar Mosque , 6- and 8-pointed stars can be found in the form of sculptural decorations protruding from the walls. Above the Minbar is carved a perfectly proportioned pattern of 12 dots, an addition that appeared during the Mamluk era in 1300 AD. The carved wooden door, dating from 1303, is also decorated with 8- and 12-point geometric rosettes.

Decorative decorations of the early Fatimids usually consist of individual elements rather than entire patterns covering a surface. Geometric patterns became dominant due to the strong influence of Seljuk architecture during the late Fatimid era .

e (1501–1736 CE)

Safavid architects used geometric designs in both religious and secular buildings. An example of a non-religious building with geometric patterns is **the Ali Qapu Palace** in Isfahan (1598 CE), which has 8- and 10-point patterns on a high pillared balcony (Fig. 9). Another secular building characterized by extensive use of geometric patterns is the **Chehel Palace Sutun** (1645–1647 CE), also located in Isfahan. The wooden ceiling at the entrance is decorated with many geometric patterns consisting of different 8 and 10 point patterns. Typically, in secular buildings, the internal elements of geometric patterns are filled with plant motifs, while many surviving religious buildings of this period mix geometric patterns and calligraphic inscriptions. A remarkable example of this style is **the Hakim Mosque in Isfahan** (1656–1662 CE). Its facades are richly decorated with tiles and brickwork with geometric motifs as well as Nasta'liq calligraphy inscriptions . Like other buildings of this period, the mosque is predominantly decorated with 8- and 10-point patterns; other types of patterns are limited to either gratings or furniture (Fig. 9).

Fig. 9. From left to right: Ali Kapu Palace; Chehel-Sutun Palace ; Hakim Mosque in Isfahan; Friday Mosque of Isfahan.

Decorative patterns with geometric and floral motifs were widely used in both secular and religious buildings of the Safavids. These designs were applied to all internal and external surfaces using carved stucco, wood, colored glass, polychrome tiles, latticework and stone. Details of the processing of surviving Safavid decorative patterns show that these artisans favored 8- and 10-point geometric patterns. Unlike

Mamluk architecture, Safavid architecture has fewer combined patterns, but these complex patterns were still common throughout the 16th and 17th centuries in Iran and Central Asia.

Mughal architecture (1526–1737 CE)

Early surviving Mughal buildings, including the mausoleum of Sher Shah (1545 CE), are decorated with paintings and tiles with floral motifs. Some very attractive examples of 6 and 8 point patterns can be found on the marble floor, window grilles and balcony railings of Humayun's Mausoleum in Delhi (1566 AD). The dominant 6 and 8 point patterns are also repeated in the Red Fort of Agra (1580 AD). In addition, several examples of 12-point and very few simple 10-point models can be found in this complex (Fig. 10).

Fig. 10. From left to right: Humayun's tomb in Delhi; Red Fort in Agra ; Fatehpur Sikri Friday Mosque ; tomb of Etimad -ud- Daula ; Fort Lahore in Pakistan.

Towards the end of the 16th century, Mughal architects began to use 10-point geometric patterns more frequently. The Friday **Mosque of Fatehpur Sikri** (1596 AD) is a representative structure of this era. In addition to various graceful types of 6-, 8-, and 10-point patterns, the supports of its main dome are decorated with 14-point geometric patterns (Fig. 10); These models are the rarest of their kind. Over the following decades, geometric patterns became an important decorative element in Mughal architecture, in which plant motifs were in some cases used as supporting and filling decorative elements. **The Tomb of Akbar the Great** (1612 AD) and **the Tomb of Etimad -ud- Daulah** (1628 in Agra) are typical structures of this period. Both structures are completely covered in marble and sandstone inlay with 6, 8, 10 and 12 point patterns. In terms of geometric design, another notable Mughal structure is **the Lahore fort complex** , built in the 16th and 17th centuries. Attractive geometric patterns adorn the stone trim of the Sheesh Mahal floor, the fountain courtyard, and the mosaics of the surrounding wall (Fig. 10).

In Mughal architecture, red sandstone, white marble and polychrome tiles are the main cladding and decorative materials (Usher , 1992). IGPs are one of the key decorative elements of both secular and religious buildings. Unlike their predecessors, especially the Mamluks, Mughal architects avoided highly detailed geometric compositions such as 12- and 16-point patterns. Instead, they took great pains to create precise and perfect proportions of the shapes and angles of the pattern. However, rare 14-point geometric patterns can be found in some Mughal buildings. Another distinctive feature is that Mughal architects used geometric patterns in flooring designs and carved window railings more than any

Muslims of Spain

Important surviving Spanish Muslim buildings are **the Great Mosque of Cordoba** (785–987 CE), the **Aljafería Palace** in Zaragoza (mid-11th century), and **the Great Mosque of Seville** (1182 CE) (Goodwin , 1991). The **Alhambra** Palace (1338–1390 CE) in Granada is considered one of the most magnificent palaces built by the Muslims (Klevenot and Desgeorges , 2000). Almost all surfaces are richly decorated with the finest floral and geometric motifs. Although geometric designs were widely used with abundant colors and intricate designs, very complex patterns such as 7, 9 and 14 point patterns are absent. Even a template of 10 points could not be found and only the simplest template of 16 points was used (Fig. 11).

Fig. 11. Alhambra Palace in Spain with details of 6-, 8-, 12- and 16-point geometric patterns.

Conclusion

This study chronologically and regionally traced the evolution of Islamic geometric patterns. The results show how regional influences and prevailing lifestyles during the ruling dynasties determined the diversity of Islamic designs and geometric patterns. For example, the basic 6- and 8-point geometric patterns that emerged in the late 9th century are the most common Islamic designs. In addition to their originality, the ease of constructing these patterns prompted architects to use such patterns in almost all elements of buildings, from floor finishing to the surfaces of minarets. While the complexity of abstraction and the complexity of non-constructible geometric patterns limited their application to accessible elements (Qibla walls, window screens), especially in Iran and Central Asia. Another interesting result is that, unlike architects and craftsmen from other Islamic states , the people of Anatolia paid less attention to ornaments and geometric patterns; they focused more extensively on other aspects of architecture such as form and master plan. For this reason, only a few examples of complex and exquisite patterns (not counting the simplest ones) can be found in Anatolia.

The relatively stable government and economy of the Mamluk period encouraged architects to create very fine and detailed ornamentation, unique in complexity. Intricate 16-point patterns remained popular in North Africa and Islamic Spain, but had only minimal influence in eastern regions such as Persia, Anatolia, and the Mughal region.

Simpler designs were popular in the Indian subcontinent , which can be attributed to Indian artisans' passion for symmetrical designs and their insistence on covering all external surfaces with designs. This coverage will be difficult to achieve with complex templates.

Scientific progress

This study also illustrated the scientific progress and expansion of knowledge in the history of Islamic architecture. These developments began with simple geometric figures constructed from a circle and a set of tangent circles of the same radius (Crichlow , 1976), as in the Great Mosque of Kairouan in the early 9th century. By the end of the 9th century, grids of circles were introduced into the Ibn Tulun mosque. Grids were used as a constructive basis for the simplest regular and semi-regular tilings with equilateral triangles, squares, hexagons and octagons.

Then, concurrent with the rise of Persian philosophers and cosmologists from Abu Sahl Al- Tustari to Sohrawadi , who made important contributions to the study of the nature of numbers and their relationship with nature (Crichlow , 1989), the mystical motifs and symbols of the Tetractys merged with traditional geometric patterns. The result was the invention of abstract 6-pointed geometric patterns based on the Tetractys symbol , and 12-pointed star patterns that are associated with the 12 zodiac sectors. These decorative elements decorate the facades of the tomb of Kharakan (1067) in Iran. Another number associated with mysticism and cosmology was seven, which from an Islamic perspective represents the seventh heaven. In construction, this number is used to create a 14-pointed star, which is a symbol of the Fourteen Infallibles, especially for Shia Muslims. Thus, despite the difficulties of constructing a heptagon for which no specific method was established (non-constructible polygon), Muslim architects created decent approximation methods for constructing heptagons, seven-pointed stars and geometric patterns. This achievement coincided with the rise of Shia dynasties in the central provinces of Iran. The earliest examples can be found in the Friday Mosque of Isfahan (1086 CE).

The earliest 10-point geometric pattern also dates from the 11th century. The number 10 is not only associated with the Tetractys symbol , but is also the counterpart of the pentagon; a whole book could be written about the golden proportions and sacred properties of the pentagon.

The 9-dot geometric pattern is another example of the influence of cosmological ideas on Islamic geometric designs, especially in the 11th century. The Enneagram is associated with the Great Conjunction (the cycle of the conjunction of Jupiter and Saturn). The Enneagon is also a non-constructible polygon, but Muslim architects discovered a method for approximating it in the late 11th century. The introduction of techniques for approximating 7- and 9-sided polygons and stars helped Muslim architects and artisans invent practical approaches to depicting other non-constructible polygons and creating relatively accurate 11- and 13-sided polygons and their stars. Some of the earliest examples of these decorations can be seen at the Barsia Friday Mosque (1098 AD) in Iran.

By the end of the 12th century, techniques for constructing polygons, stars, and patterns based on simple or single-layer circular grids were known throughout the Muslim architectural world. This development was followed by the introduction of more complex and dynamic patterns based on grids of multiple circles. Simpler types have been developed using a sub-grid related to the original grid and center points, but on a different scale. This development further popularized the use of more detailed patterns in the early 13th century.

By the early 14th century, with the arrival of the wealthy Mamluk dynasty, more detailed patterns (such as 16 and 18 point geometric patterns) were developed using a variety of primary 8 and 9 point patterns. Finally, highly complex patterns were discovered, developing from many belts of different geometries. An exquisite example is the door panels in the Sultan Hassan Mosque (1363 CE), which depict a combination of a base grid for 16-point geometry and a sub-grid for 12-point geometric pattern.

The timeline in Table 1 depicts the evolution of the IGP from the early stages to the end of the 18th century. In this context, this study demonstrates the suitability of models for era-inspired buildings in terms of appropriate time scale accuracy and architectural style compliance.

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