The Ornamented Domes of Cairo: the Mamluk Mason's Challenge

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Introduction

The ornamented domes of Cairo's Mamluk architecture are unique and have never been equaled since in the Muslim world. They represent a challenge not only in terms of their structural boldness but for their distinctive decoration programs. From the mid 14th to the early 16th c. A.D. there was increasing sophistication in the development of carved decoration on Mamluk stone domes which reached a climax by the use of elaborate arabesque motifs and geometrical patterns; the most distinguishing of which are the interlacing stars. Despite the fact that there was a paradigm shift in dome architecture during the Mamluk era in terms of construction materials and decoration programs, historical information is scarce—if not totally silent—regarding the design and implementation process of these unique themes of decoration. This paper is concerned with the design principles and techniques employed in the creation of the carved decorative geometric star patterns on Cairene Mamluk domes in an attempt to investigate the likely participants who might have collaborated to apply these patterns on the semi-spherical surfaces of the domes and answer whether they were executed before or after the dome was assembled. The paper also draws attention to the knowledge and skills of designers and masons who conceived of and constructed Mamluk architecture and how the designs of such architecture might have been transmitted to the many parties involved in the construction process. The study is based on reviewing historical sources and scholarly papers, site survey of the domes' stone courses and decorations as well as making drawings to understand the underlying grids, upon which the unique star pattern interlaces, were created.

Literature Review

Christel Kessler's publication *The Carved Masonry Domes of Medieval Cairo* is the earliest survey to outline the evolution path of the decorative patterns of the Cairene Mamluk stone domes. Kessler demonstrates that the early constructed Bahari Mamluk domes were imitations of the former Fatimid convex ribbed brick domes, e.g., Ahmad al-Qasid dome (c. 1335).[1] The ribbing continued to be the decorative fashion of Bahari domes and went through exclusive variations that never been a common trend, such as the convex ribs verses concave flutings, the twisted and bent ribs, and the ribs rising from muqarnas brackets projecting from the circumference of the drum of the dome in an Iranian style. (Fig. 1) Through these variations, masons were in a constant process of improving the quality of domes construction and decoration by developing the techniques of cutting and assembling the stone blocks as well as

[1] Kessler 1976, 6-8.

enhancing the appearance of the vertical joints between the blocks either by plastering or regularizing the spacing between them. The last time the ribbing fashion used as a decorative device was on the dome of the mosque of Inal al-Yusufi (1392-93).[2] (Fig. 2) However, the ribs of this dome were reduced in width to form molded relief bands interlocking into loops which are interlinked in a chain-like band at the base of the dome. According to Kessler, the decoration of this dome represents an apparent disregard for all previous ribbing experience.[3] In fact, this looped band was refined and became the base of all decorative themes carved on later Circassian Mamluk dome.

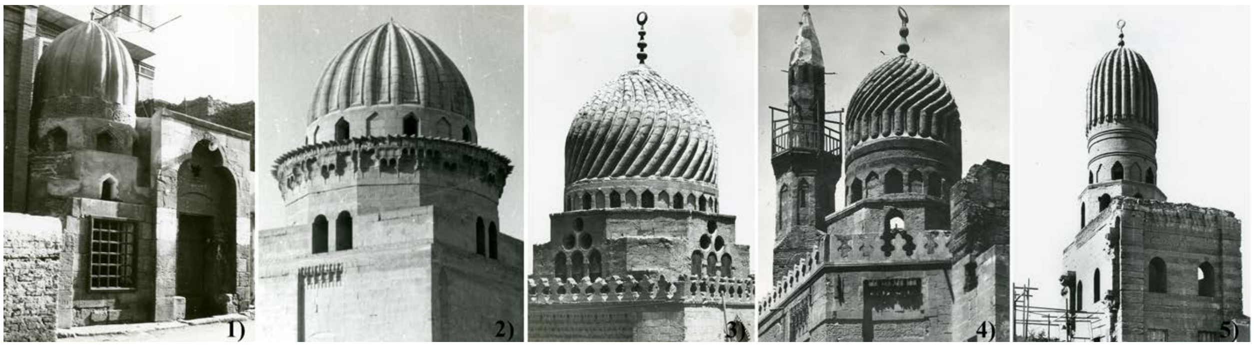


Fig. 1: 1) Ahmad al-Qasid (c. 1335); 2) Tankizbugha (c. 1359); 3) Ulgay al-Yusufi (1373); 4) Aytmish al-Bajasi (1383-84); 5) Yunis Dawadar (1382) (after Kessler).

Fig. 2: Inal al-Yusufi (1392-93) (after Kessler).

Circassian Mamluk domes were lavishly decorated and the most popular decorative theme used was the horizontal chevron (*zigzag*) pattern, e.g., Farag ibn Barquq dome (1400–7). According to Kessler, “the equidistant disposition of joining was used as the reference grid for the pattern;” and the *zigzag* sustained as a decorative device on Circassian Mamluk domes up to the end of the Mamluk era because the *zigzag* direction was easily to be coordinated with the vertical joints of ashlars and its design and execution wasn’t requiring a skillful craftsmanship.[4] Subsequently, with the advancement in coordination between stone structure and decoration and the refinement in craftsmanship, the patterns carved on Circassian domes evolved from *zigzag* to geometric and foliage arabesque to the extent that each dome is displaying a new unique decorative theme. (Fig. 3) Kessler assumed that Cairene masons were using the uniform grid

[2] Ibid. 9-16.

[3] Ibid. 10.

[4] Ibid. 18-22.

pattern of stone joints generated after the dome was constructed to layout the decorative pattern on the exterior shell of the dome, and the decline in dome decoration during the second decade of the 16th c. was due to that “no regular grid of joints was available to guide its distribution over the shell.”[5]

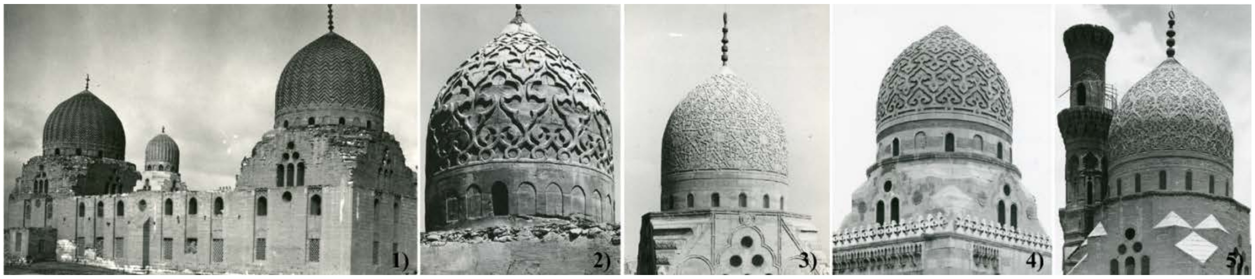


Fig. 3: 1) Farag ibn Barquq (1400-7); 2) ‘Abdallah al-Manufi (end 14th-mid 15th c.); 3) Qatbay (1474); 4) Azrumuk (1503-5); 5) Khayrbek (1502) (after Kessler)

Later research works were carried out readdressing the construction and decorative changes of the Mamluk domes. Cipriani, by studying the ribbed as well as the carved domes, states that the system of decoration in Mamluk stone domes was “based on the repetition of a slice of decoration for a number multiple of 4 (4, 8, 16, 32)”, and the number of stone ashlars per masonry course (ring) either equal to the number of the slices or multiplies. This suggests the possibility that the design of the decorative motif of a slice of a dome was prepared on a drawing and the stone ashlars per slice were calculated and carved before the dome was assembled.[6] Contrary to Cipriani, Bouleau argues that a careful study of the floral tracery of the dome of Khayrbek mausoleum shows the inextricable link between the structure and decoration, which indicates that the dome was already built and the joints were realized when the carver takes to burn the decorative program, which lines are incised in the joints of the building. Consequently, the intervention of the builders of the stone structure and the stone carver were successive forming two separate working groups. Nevertheless, the perfectly alignment of the decorative motif, repeated 16 times, with the vertical construction joints suggests that both groups coordinated their works in a preparation phase.[7]

Dome Examinations

Quick field observations of some Circassian Mamluk domes attest the assumption that the decoration program was executed after the dome was built. The first is the unfinished state of the floral carving on the first stone course of the dome of ‘Asfur (c. 1506) (Fig.4). This means that the construction and decoration were two different phases. Had the carving been done on the ground, only the finished stones would have made their way to the dome and if the work stopped

[5] Ibid. 23-36.
[6] Cipriani 2005, 31-32 and Cipriani and Lau 2006, 700, has focused her investigation on the Bahari Mamluk ribbed dome of Umm al-Sultan Sha’ban (1368-69), the carved zigzag decorated dome of the Circassian Mamluk Faraj b. Barquq (1400-7), and the late Mamluk Khayerbek dome (1502), with its intertwined carved arabesques.
[7] Bouleau 2007, 215.

for any reason, then the dome would not have been completed. Second is the dome of Qaraqmus that was erected in front of the gate of al-Hakim mosque, which was later (in the 20th c.) moved to the northern cemetery, stands like a bare structure with no decorations.[8] (Fig. 5) In spite of the fact that some might argue that the dome was intended this way; it is tempting to conclude otherwise since Qurqumas built for himself another dome in the northern cemetery, which was decorated with a *zigzag* pattern.

Fig.4: ‘Asfur dome (c. 1506) (photo: authors)

Fig.5: Qurqumas (1507) (photo: authors)

Fig. 6: Qansuh Abu Sa'id (1499) photo: authors)

Fig. 7: Azrumuk (1503–5) (after Kessler)

[8] رزق 2003، 1884-98

Third example is the dome of Qansuh Abu Sa'id (1499), which demonstrates the unfinished relief carving although the whole design of the decoration was incised on its exterior surface. (Fig. 6) Finally, there is the dome of Azrumuk (1503–5); although the grid of its stone ashlars shows regularity, its sunken arabesque floral relief does not adhere to it, which contradicts with Kessler's notion that the grid of stone blocks was essential for proper laying out of the decorative patterns. (Fig. 7) These observations called for revisiting the still disputing question whether the decorative programs of Cairene Mamluk domes were designed and executed before or after the dome was assembled by exploring the unique decorative theme appeared on Circassian domes that is the star pattern.

Fig. 8: Barsbay dome (A.D. 1432)
(photo: authors)

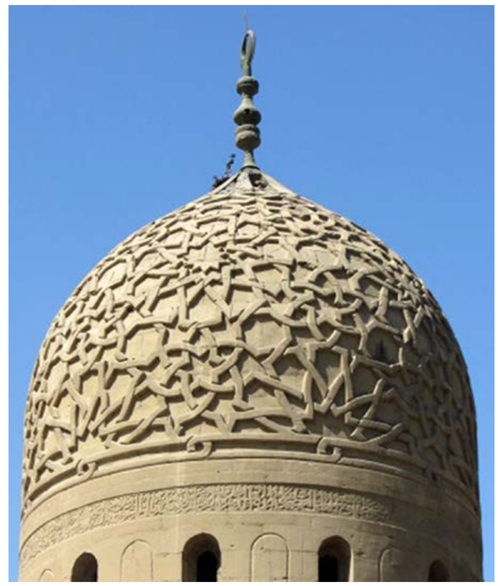


Fig. 9: Ganibek dome (A.D. c. 1432)
(photo: authors)

Geometric analysis

The dome of the mausoleum of sultan Barsbay, in his funerary khanqah in the northern cemetery (1432) is the earliest Circassian dome to be carved with a geometric star pattern. (Fig. 8) The same theme, but with different compositions, was used to decorate smaller domes of other mausoleums built in the graveyard of the same khanqah for the sultan's members of his family and court officials, among which is that of his amir Ganibek (c. 1432). (Fig. 9) By comparing the quality of the stars interlacing of Barsbay's dome with that of the smaller one of Ganibek, Kessler claimed that the former represents an experimental use of the star pattern design while the later displays a development in the quality of the design and craftsmanship assuming that the builders "availed themselves of a specialist in design."[9] In order to understand the geometric

[9] Kessler 1976, 23.

structure of the interlaced stars of both domes, it was indispensible to draw the star composition of each dome in a two-dimensional format.[10]

Both domes are single shell domes. Their internal and external profiles are drawn on two centers forming a shape of a pointed dome. (Fig. 10) They were constructed by successive courses (rings) of dressed stones of a uniform height using regular and thin joints. From the base moving upwards, the interlaced star pattern of Barsbay's dome are composed of eight-pointed, seven-pointed and six-pointed stars arranged above each other respectively, while Ganibek's dome exhibits half twelve-pointed star at its base, ten-pointed star indirectly above and six-pointed star positioned in between. The loop at the base of the ornamented part of each dome, divides the circumference of Barsbay dome into 20 equal segments and that of Ganibek into 12 ones. If we extend straight lines from the loops at the base of both domes to the center of the stars, we found that these lines are in coordination with the vertical joints of the stone blocks and divide the body of the dome into equal slices. However, unlike the dome of Khayrbek, which Cipriani & Bouleau analyzed, the complete single motif is not included in one slice; rather, a whole star is included within two slices that were repeated using the principle of radial symmetry.[11] Examining the masonry of both domes, we found that the horizontal and vertical joints have no relation with the interlaced stars except the vertical joints that are in alignment with the centers of the stars. (Figs. 11 & 12)

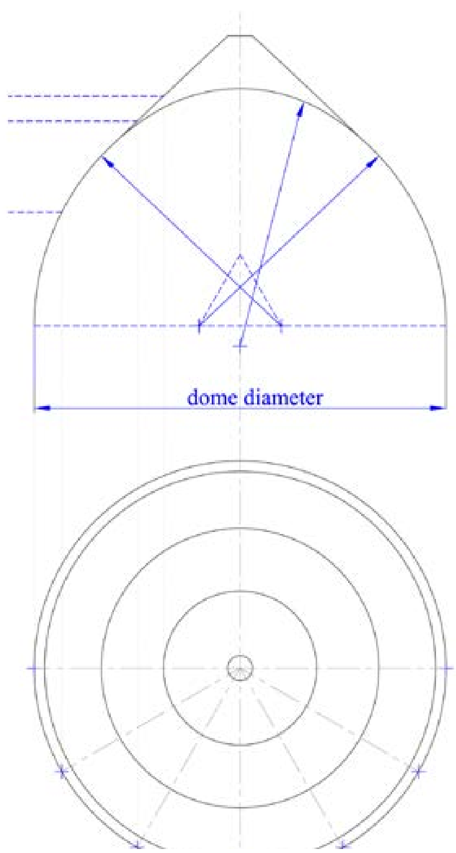


Fig. 10: Pointed profile of Mamluk dome (drawn by D. Montasser)

[10] All spherical polygons are drawn in their Euclidean formats for pattern exploration only.

[11] Critchlow 1976, 74.

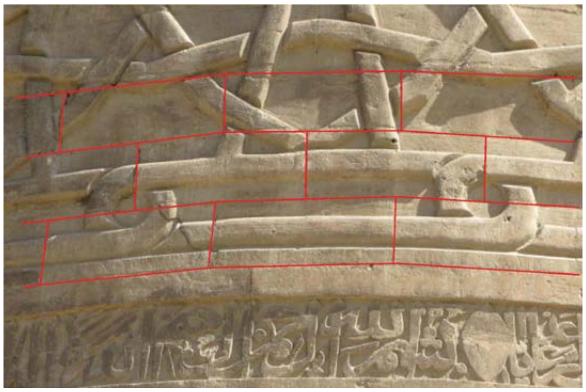


Fig. 11: Detail of Barsbay dome (photo: authors)

Fig. 12: Detail of Ganibek dome (photo: authors)

Connecting the stars' centers, we discovered that a semi-regular tessellation grid composed of squares and triangles is the hidden structure of the star pattern of Barsbay's dome (Fig. 13).[12] The square grid is used on the straight-rising lower part of the dome while the triangle one is used on the upper curved section.

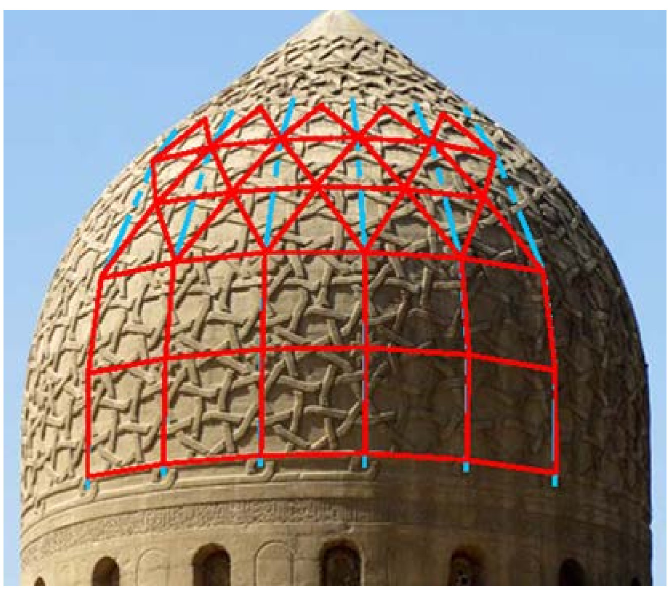


Fig. 13: Tessellation grids on Barsbay dome (drawn by D. Montasser)

On the upper part, when the mid points of the edges of the triangle grid crossed over at 60°, the six-pointed stars and hexagonal petals set up.[13] The eight-pointed star, on the lower part, formed by creating a four-fold theme composed of two vertical hexagons and two horizontal ones in each square module, and the composition of four squares produces the eight-pointed star. (Figs. 14 & 15) The connection between the lower square grid and the upper triangle grid generates an irregular seven-pointed star, which gives the effect that the ornamentation is horizontally divided into two zones and not perfectly fit on the profile of the dome. In fact, Critchlow states that "because of the layered nature of this particular grid, it is more

[12] Ibid. 117-19.

[13] Ibid. 136.

suited to border designs than to use as a repeating pattern."[14]

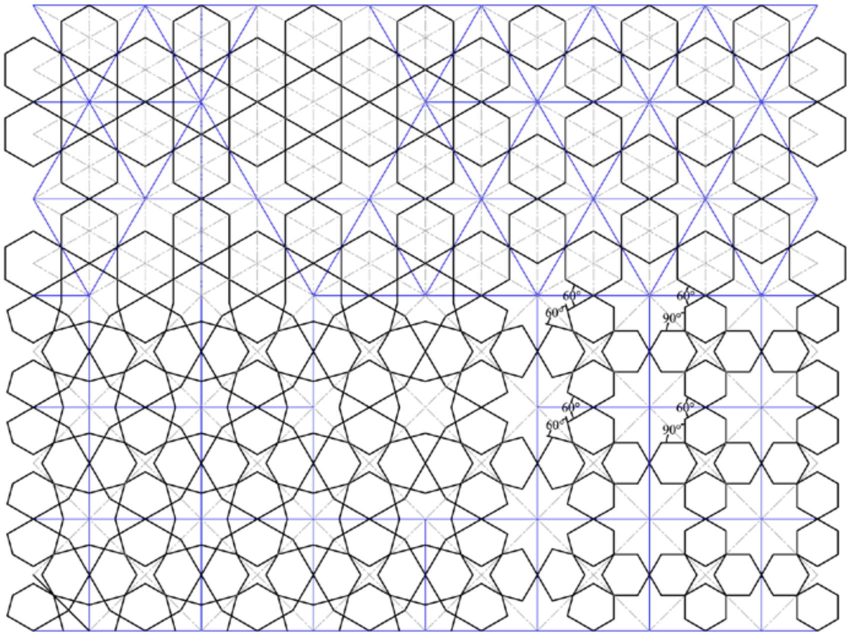
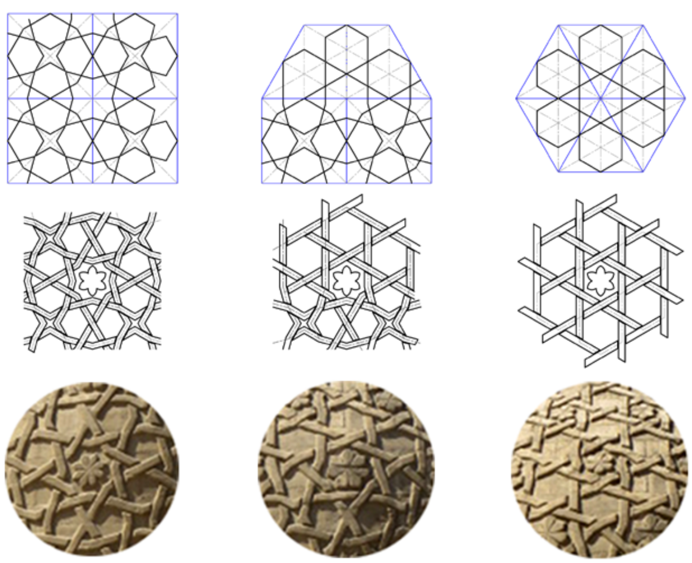


Fig.14: The geometric structure of Barsbay stars interlacing (drawn by D. Montasser)



a) b) c)

Fig. 15: a) 8-pointed, b) 7-pointed and c) 6-pointed stars of Barsbay dome (drawn by D. Montasser)

[14] Ibid. 138. The four-fold theme used in this geometric analysis is different from the one drawn by Critchlow.

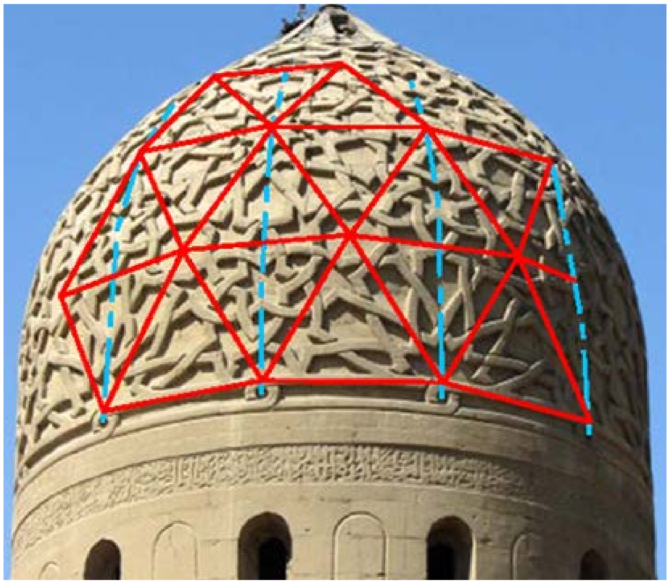


Fig.16: Tessellation on Ganibek dome (drawn by D. Montasser)

Unlike Barsbay's dome, the twelve-pointed, ten-pointed and six-pointed stars composition of Ganibek's dome is entirely based on the regular tessellation of the equilateral triangles, the icosahedron tessellation. (Fig. 16) Yet, the integration of the 10-pointed star, which generates from two pentagons (a decagon) with the 6-pointed and 12-pointed stars that are constructed based on the triangle and hexagon, which are self complementary is still bewildering and needs further investigation.[15] (Fig. 17)

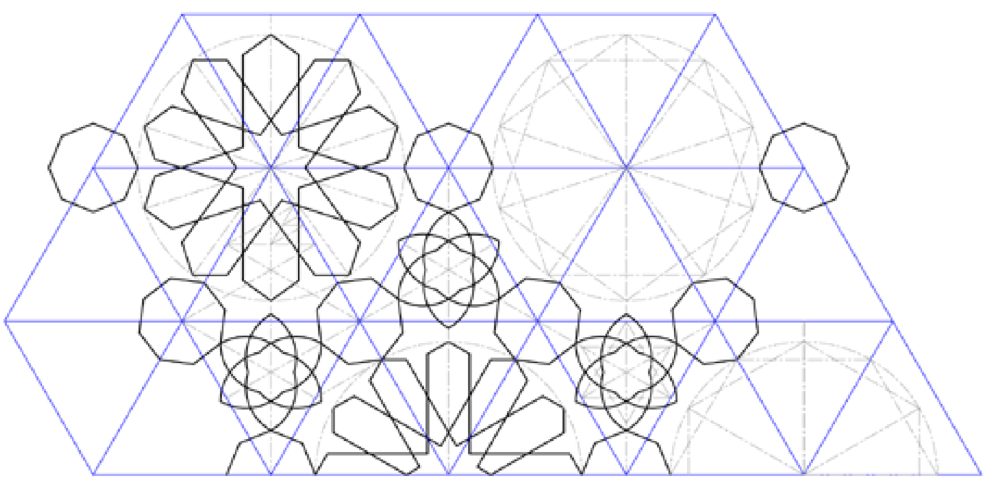


Fig. 17: The geometric construction of Ganibek stars interlacing (drawn by D. Montasser)

[15] Ibid. 34; Critchlow dedicates chapter 5 for discussing the geometric properties of the pentagon, 74-103.

In light of the above field observation and the geometric analysis of the decorative compositions of both domes of Barsbay and Ganibek, we can agree with Cipriani that the decoration was designed on drawing before implementation. Also, we can state that in the case of the star pattern, the uniform grid of the stone joints was used not to layout the decorative pattern, as argued by Kessler and Bouleau, but might have been used to guide laying out the tessellation grid on the surface of the dome on which the star pattern composition shall be incised. Tessellating different polygons on a dome shows basic understanding and utilization of spherical Geometry on behalf of the designer and executer.[16] However, to perfectly fit the structure grid with the size and profile of the semi-spherical dome, we assume that both the designer and executer availed themselves of a specialist in geometry (*‘ilm al-handasah*), particularly the sophisticated spherical geometry.

Medieval knowledge of Spherical geometry

It is documented that Arabs were advanced in mathematics and geometry and they have worked greatly on non-Euclidian geometry. Ibn Khaldun (1332–1406) acknowledged the importance of geometry to the craftsmanship; he stated that a “carpentry needs a good deal of geometry of all kinds. It requires either a general or specialized knowledge of proportion and measurement, in order to bring the forms (of things) from potentiality to actuality in the proper manner, and for the knowledge of proportions one must have recourse to the geometrician.”[17] Many treatises concerning the spherical geometry are known to us today, and the most important of all is that of the Persian mathematician Abul Wafa al-Buzjani (940–998). He was the first medieval mathematician to study the geometric constructions of ornamental patterns and the projection of these patterns onto a sphere in his treatise *The book on what the artisan requires of geometric constructions* (*Kitab fima yahtaju ilayhi al-sani' min a'mal al-handasa*).[18] He presented in his treatise how a sphere can be tessellated using the properties of “Platonic and some Archimedean solids.” The most interesting remark is that he was using two-dimensional illustrations to explain how to tile a sphere using multiple number of a polygon (triangle, hexagon, square or pentagon) in its spherical form as well as how to tile a sphere using different spherical polygons, such as triangles and squares.[19]

It is recognized that the transmission of geometric knowledge between mathematicians/ geometricians and the master craftsmen happened during meetings, *conversazioni*.[20] Al-Buzjani stated that he was “present at some conversazioni [*majilis*] held among a group of artisans and geometers.”[21] Also, a 10th c. mathematician cum astronomer called Ibrahim bin

[16] Sarhangi 2006, 552.
[17] Özdural 1998, 709
[18] id. 1995, 54; Sarhangi 2006, 551.
[19] Sarhangi 2006, 554-59.
[20] Özdural1998, 700
[21] id. 1995, 55

Sinan (908–46) wrote in his autobiography that "he had written a book about gnomons on spherical surfaces and had passed it on to one of the artisans (*ba'd al-sunna'*) in a language different from the one he had used for his own book," and he explained that he sat with the craftsman and gave him instructions on how to implement some rule of geometry.[22] So, it is evidently that since the 10th c. A.D., it was customary for "artisans to meet with mathematicians to seek advice on certain problems concerning the application of geometry to architecture and related arts,"[23] which verifies our assumption that the geometricians were essential to the design and application of the geometric and arabesque decoration on Cairene Mamluk domes because the average craftsmen could not have sketched and applied the intended decorative theme independently.

The tessellation grids of the domes of Barsbay and Ganibek clarify that both domes were treated like spherical polyhedrons, which implies that the designers and craftsmen of both domes might have had a basic knowledge of spherical geometry, but was not enough in the case of Barsbay dome to divide the surface of the dome into properly proportioned spherical polygons without gaps or irregularities. So, later on, a geometrician might have joined the design and application process of the star pattern interlace of Ganibek. The questions that arise here are who among the participants in the construction industry during the Mamluk era, particularly Circassian period, acquired the knowledge of geometry (*'ilm al-handasah*) and who were the geometrician(s) that might have assisted them?

Muhandis, mu'alim and geometrician

As demonstrated earlier by both Behrens-Abouseif and Rabbat, the parties involved in the building industry during the Mamluk period were the craftsmen, *muhandis al-'ama'ir* or *ra'is al-muhandisin*, *shad al-'ama'ir*, *mi'mar*, *mu'alim* and *mu'alim al-mu'allimin*, which was a new term used in the 14th c. The title 'design architect' as we nowadays understand, or as was common during the Renaissance period, was not yet in use during the Mamluk period.[24] A craftsman is mostly anonymous unless he acquires a range of technical abilities related to a basic art and/or theoretical knowledge; just then, he was promoted to the titles *kabir al-sunna'* (chief of building craftsmen), *mu'alim* (teacher and/ or master) and/ or *muhandis* (engineer or architect); examples were *mu'allim* Muhammad ibn al-Zain, who was active in late 13th and early 14th c. and skilled artist in brass inlaying as well as blacksmithing;[25] and *muhandis* Muhammad ibn 'Abd al- Karim al-Harithy (d. 1204) who was originally a carpenter and a stone carver and then skilled in geometry, medicine as well as poetry.[26]

[22] Saliba 1999, 641.
[23] Özdural 1995, 55
[24] Behrens-Abouseif 1995, 308; Rabbat 1998, 31-32.
[25] His famous work is the basin known as the Baptistere de St. Louis (ibid. 31).
[26] Al-Harithy was known for making the doors of *bimaristan* (hospital) of al-'Adil Nur al-Din ibn Zengi, built in 1154 (ibid. 35).

According to Behrens-Abouseif, the title *muhandis* “was used in the Mamluk period when engineering was involved, such as in the building of bridges, dams, canals and aqueducts;” also, *muhandis* was documented as a land surveyor “who had to deal with fixing the boundaries of lots and houses and estimating the value of houses and rents.”[27] It is documented in the 14th c. sources that *muhandis al-‘ama’ir* or *ra’is al-muhandisin* was listed among “the craftsmen holding official positions at the [Bahri Mamluk] court (*arbab al-waza`if min ahl al-sina'at*) along with the chiefs of the physicians, the ophthalmologists and the navy,” which allowed Behrens-Abouseif to suggest that the *muhandis* might have been responsible for supervising the execution of the craft and controlling the qualifications of the craftsmen involved.[28] However, it is unreasonable to consider that the *muhandis* during the Mamluk period was only working on civil projects and not on architecture because first, there were no boundaries between disciplines during the medieval era, and second, civil projects too require the ability to invent. For example, *al-ra’is* ‘Alam al-Din Qaysar al-Katib al-Hanafi (1179–1251) was a polymath of a late Ayyubid period; he was a theologian (*faqih*), scribe (*katib*), geometrician, mathematician, astronomer and *muhandis*. “He is credited with building a mill on the Orontes for the Ayyubid king of Hama, al-Muzzafar Mahmud (d. 1244), and an un-specified number of towers around the city, for which he invented a number of engineering devices, or perhaps designs (*hiyal handasiyya*).”[29] Also, there was a *muhandis* called Hujayj who along with his craftsmen accompanied the Mamluk amir Aqbugha to Syria in a mission to inspect the architecture for the goal of simulating it in Cairo.[30] Accordingly, as per our present understanding, a *muhandis* during the Bahari period would have been a civil engineer, a site engineer and/ or a design architect.

The designation *mi'mar*, in the Arabic language nowadays means ‘architect;’ however, it appears in the Mamluk historical sources as “a specialist for repair and restoration works.”[31]

The exact difference in capability and experience between the Bahari Mamluk *muhandis al-‘ama’ir* and *shad al-‘ama’ir* is not easy to be identified except that the latter was a first rank Mamluk amir representing the patron, communicating between the patron and *muhandis*, supervising the parties involved in a royal construction and controlling the budget,[32] as per the present-day professional language a construction manager.

During the Circassian period, it seems that the tasks of both *muhandis al-‘ama’ir* and *shad al-‘ama’ir* were diminished and replaced by that of *mu’alim al-mu’alimin*.[33] Although both professions were official positions within the royal entourage for the sake of accomplishing a certain royal construction project, the difference between *shad al-‘ama’ir* and *mu’alim al-mu’alimin* is that the former was a royal amir with a military background while the latter was a

[27] Behrens-Abouseif 1995, 294.
[28] ibid., 293,
[29] Rabbat 1998, 35.
[30] Behrens-Abouseif 2007, 43.
[31] id. 1995, 296.
[32] ibid. 295; Rabbat 1998, 32.
[33] Behrens-Abouseif 1995, 297 and 303; Rabbat 1998, 32.

civilian and celebrated independent professional. *Mu'alim* in the Arabic language means the most skilled craftsman who works independently without being affiliated with or authorized by an organization or employer,[34] and "mason's signature on an architectural element, such as the signature of Ibn al-Qazzaz on al-Mu'ayyad minaret and that of al-mu'allim Ibrahim al-Mahdi on the portal of al-'Attar in Tripoli in Lebanon" suggests an avant-garde mason and emphasizes professional independency.[35] Thus, *mu'allim al-mu'allimin* of the Circassian Mamluk period had a hands-on rather than theoretical experience. The most notable example is the six members of the Tuluni family, who were "in the building craft as heads of stone cutters and masons,"[36] and occupied the position of royal *mu'alim al-mu'alimin* from the beginning of Barquq's reign (1377) to the end of al-Ghuri's (1517); the last one, Ahmad ibn al-Tuluni, was among the Cairene notables who expatriated to Istanbul by the Ottoman sultan Selim I after he conquered Egypt and abolished the Mamluk sultanate.[37]

In light of the above overview, we can say that the *muhandis* and *mu'alim* were the only jobs that indicate professional experience as well as theoretical and practical knowledge of geometry, and consequently ability to design and build suggesting that the *muhandis* and *mu'alim* might have been the designer and contractor respectively for the civil and architecture projects during the Mamluk period. However, in the medieval culture, the structure of sophisticated architectural elements, such as domes, "necessitates the artists [designers] and artisans [craftsmen] to rely on mathematicians."[38] The mathematician al-Isfizari during the 8th c. A.D. tells us that "geometry is the basis for architecture; that is why the geometer with his science constitutes the foundation. He is followed by the master builder [*mu'alim*] who in turn is followed by the wage laborer (bricklayer). The geometer commands the second (i.e., master builder) and the master builder commands the wage laborer, while the wage laborer busies him-self with water and clay."[39] So, if the *muhandis* (design architect) in collaboration with geometrician agreed to the wished-for design, how this design was transmitted from the *muhandis* to the *mu'alim* (executor) and how it was executed on the shell of the dome?

Design drawings

Mamluk historical sources are silent regarding the existence of preparatory sketches or drawings relating to any Mamluk artifact or building, and we are only left with speculation on how such projects were designed and communicated to the patron as well as the craftsmen. Unlike medieval Europe where one finds instructions regarding construction methods documented in albums and even as graffiti on monuments themselves, archeology on Cairene Mamluk monuments has revealed no evidence of any geometric traces on ground plans or elevations that could help to shape a constructive will. Therefore Bouleau speculates that the intention of the

[34] المعجم الوجيز، 432
[35] Behrens-Abouseif 2007, 77.
[36] id. 1995, 297.
[37] ibid. 303; Rabbat 1998, 33.
[38] Sarhangi 2006, 560.
[39] Özdural 1998, 712.

patron was communicated verbally and the start of construction was entirely managed by the trades, in which the group of master masons and supervisors occupied the central function of design, which is definition of the form and structure, the coordination and execution.[40] In spite of the rationality of Bouleau's explanation, the current absence of materialistic evidence does not totally rule out the possibility that drawing plans were in use.

Actual plans and architectural drawings are known to survive starting from the 13th c. and became relatively common in the 15th c. A.D.[41] Necipoğlu-Kafadar has shown that architectural plans of the 16th c. Central Asia were generated based on square grid system in which the square represented a unit of measurement (cubit). This grid module determines the dimensions of the architecture and ornamentation details and must be related to brick and/or stone size.[42] However, Mamluk buildings, from evidence deduced from the unrelated variation in dome diameters[43] or madrasa[44] and mosque iwans were based on the principle of proportion rather than on a fixed measured unit. Yet, the total absence of architectural plans demonstrating building practices of Mamluk Egypt should not imply that it was entirely based on oral and practical transmission. *Muhandis* Hujaij's visit to Syria, abovementioned, was to copy the architecture of one of its buildings, which suggests that the *muhandis* must have done sketches or drawings to refer to once he was back home. The absence of such drawings could be attributed to the fact that unlike the Ottoman foundations which were mostly state buildings that were supervised and maintained by state institutions, Mamluk buildings were more personal in terms of their founding and keeping. In other words it was not an official business that required keeping and filing of documents or they were not executed in faraway provinces that required official and proper communication of plans and designs. Furthermore, drawings were part of the trade's secrets and since the building craft, like many other Cairene trades of the time, was a family business, the secrets must have been well guarded and transmitted from one generation to another.

This suggests that in the planning stage, the *muhandis* (design architect) in collaboration with the geometrician might have calculated the size of the spherical polygons that shall divide the surface of the dome relative to its radius and draw the intended design based on the calculated areas of polygons on a two-dimensional drawing. The *mu'alim* must have had the skill of projecting the two-dimensional drawing of the design of ornamentation directly onto the surface of the dome. During the execution phase, the *mu'alim* with the supervision of the *muhandis* and/or geometer might have tessellated the structure grid on the exterior of the dome using ropes and wooden pegs, which Bernard O'Kane discovered that they were "placed towards either side of the base of an ashlar, within the mortar course", on both Ganibek and Qansuh Abu Sa‘id

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[40] Bouleau 2007, 211.
[41] Bloom 1993, 21.
[42] Necipoğlu 1986, 233.
[43] Cipriani and Lau 2006, 696 demonstrates that the diameters of the domes of Umm al-Sultan Sha'ban, Faraj b. Barquq, and Khayerbek are 5.30, 14.43, and 7.46 m. respectively.
[44] Eilouti and Al-Jokhadar 2007, 7-30.

domes; and, the resulting areas could have been first directly incised on the surface of the dome and after that carved as the dome of Qansuha Abu Sa'id demonstrates.[45]

Conclusion

In light of the extensive geometric analysis of the compositions of the star patterns carved on both Barsbay and Ganibek domes and the aforementioned review of all the participants that might have been involved in the building trade during the Mamluk period, we can advocate that the sequence of the constructing and decorating of a medieval Mamluk dome was as follows: stone blocks were cut to the required size and dressed by stonecutter (*nahhatin*), constructed by a builder (*bana'*) and then decorated in situ by a master carver (*mu'alim*, in the current language: *oymagi*) who must have been skilled in geometry.[46] The design might have been previously done by a *muhandis* (design architect) in collaboration with geometer. Then, the master carver (*oymagi*) observes and measures the original decoration to be produced, and when he identifies the detail and its dimensions, he draws its pattern on the dressed stone surface directly then roughly carves the shape by recessing the surface of the background [bas relief]. After the recessed surface is smooth, he adds the required shape to the decorative elements [incision]. So, we can easily bear out the hypothesis of both Kessler and Bouleau that the decoration of Mamluk domes was done after the dome was assembled and not before as Cipriani suggested, but counter Kessler's assumption that stone joints were used to layout the decoration on the surface of dome as they have no relation except that the vertical joints are sometime in alignment with the centers of the decorative motif, in our case study, the stars. The stone joints with the wooden pegs inserted into them might have been used to fix ropes for applying the tessellation grids on the surface of the dome.

Kessler and later Cipriani argue that the sudden appearance of the star patterns indicates the patron's choice and aesthetics preference;[47] for which, in our point of view, he might have brought foreign specialists; e.g., geometricians or he might traveled with his consultants, e.g., *ra'is al-muhandisin* to explore innovative architecture and decoration ideas as the case of *muhandis* Hujayj and amir Aqbugha. It seems also that Barsbay was in favor of the geometric star pattern even before he became a sultan; this is illustrated in the frontispiece and binding of the earliest Mamluk Quran that named after him (1304–6).[48] Moreover, the appearance of the star patterns on this Quranic manuscript put emphasis on the notion that the decorative patterns

[45] Cipriani 2005, during her investigation of the Khayrbek dome has firstly observed the presence of wooden pegs between the stone courses and some times in the decoration. She attributes their presence to the need to level the stones as they were placed in their courses. However, she briefly points out that they might have had something to do with the decoration. Although O'Kane, in his presentation *The Design of Cairo's Masonry Domes* stated that the use of these pegs was started earlier than Khaybek and probably was common in Cairene domes, a careful study of the locations of these pegs in relation to the decorative pattern is still required to either prove or negate this suggestion, 23.

[46] Dobrowolska 2005, 17-30.

[47] Kessler 1976, 27; Cipriani 2005, 34.

[48] Sultan Barsbay Quran, http://www.baybarsquran.com/

of the domes might have designed on papers and communicated between the patron, *muhandis*, *mu'alim* and a geometrician before being projected on domes.

Although the star pattern appeared later on Qaytbay dome (1474), it exemplifies different taste and distinctive ideas and most likely new skills and techniques. Qaytbay was in favor of floral motifs and refinement of proportions. His dome established the idea of the intertwining between two layers of stars interlacing, one carved in straight-line and the other translated into foliage arabesque. In general, Circassian Mamluk rulers were known for propagandizing and glorifying their power and wealth through their buildings. This visually appeared on their buildings: in the extensive use of several architectural and decorative features that never been used during the Bahari period,[49] among which is the high, narrow and richly decorated domes that provide an overall royal image to the passerby.[50] Although this paper presents further knowledge on Mamluk domes, the more you look at them, the more you get puzzling questions yet need to be explored.

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[49] Montasser 2009, 203.

[50] Al-Sayyad 2011, 146)

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