The Design of Cairo's Masonry Domes

Bernard O'Kane

Over sixty masonry domes have survived from pre-modern Cairo. There are several reasons for this number, unequalled by any other Islamic city. Continuing debate by the ulema on the lawfulness of building tombs meant that it was often politic for a patron to incorporate them within a larger religious complex. The benefit of building a religious complex was not just the main one, that of assuring one's place in heaven, but probably also, by means of the *waqf ahli* (family endowment), of putting the family finances out of reach of the government should a patron, as not infrequently happened to amirs who backed a wrong candidate, fall into disfavour.[1]

Serious study of the designs our main topic began with the publication in 1976 of Christel Kessler's classic: *The Carved Masonry Domes of Medieval Cairo*.[2] This was particularly concerned with the ways in which decoration and construction were at first uncoordinated, but gradually were adapted to each other in increasingly sophisticated ways with the development of designs from ribbed, to zigzag, to geometric, and to arabesque patterns. This was such an authoritative publication that it was not until almost 30 years later that another milestone occurred, a workshop at MIT entitled *The Mamluk Domes of Cairo*.[3] A number of related publications soon appeared, notably by Barbara Cipriani[4] and Christophe Bouleau.[5]

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[1] See, for instance, Doris Behrens-Abouseif, *Cairo of the Mamluks: A History of the Architecture and Its Culture* (London, 2007), 18.

[2] American University in Cairo Press, Cairo.

[3] http://web.mit.edu/akpia/www/sympdomes.html (accessed 4 June 2012) program, with some abstracts. I am happy to record here the detailed discussions I have had on the topic with one of the speakers at this conference, Dina Bakhoum, which have been of great assistance.

[4] *Development of Construction Techniques in the Mamluk Domes of Cairo*, MA thesis, Massachusetts Institute of Technology, 2005 http://dspace.mit.edu/handle/1721.1/33745 (accessed 4 June 2012); with Wanda Lau, "Construction Techniques in Medieval Cairo: the Domes of Mamluk Mausolea (1250 A.D.-1517A.D.)," http://www.arct.cam.ac.uk/Downloads/ichs/vol-1-695-716-cipriani.pdf; with John Ochsendorf, "Construction Techniques in Medieval Cairo: the Domes of Mamluk Mausolea," abstract, (http://www.dapt.ing.unibo.it/nuovosito/docenti/gulli/seminario_gulli/Abstract%20Giustozzi/2-STORIA%20E%20SCIENZA/Cipriani-ocksendorf.pdf) (accessed 4 June 2012).

One of the main questions regarding these domes has been that of whether they were carved on the ground or in situ on the dome. This is a still unresolved matter to which I do not have any definitive solution, but it is a topic that will come up again in the course of this paper. I will also refer to other topics mentioned in the sources above, but I will be principally concerned with a slightly different approach to the geometry of Cairo's dome design: that of the number of repetition of units of design around the circumference of a dome, and the ways in which this fits, or does not fit, with the layout of the windows and niches of the drum or zone of transition below it. The natural assumption is that of Barbara Cipriani, who wrote that "The decoration of Mamluk domes is in a tiling pattern which is repeated until it forms a sphere. This repetition is based on multiples of 4 (4, 8, 16, 32) in all Cairene brick ribbed domes and decorated carved stone domes." However, this, as we shall see, is far from being the case. A similar assumption was made in a recently published drawing of what is arguably the finest of all carved stone domes, that of Qaytbay in the northern cemetery, where the pattern is shown to have been repeated 16 times (fig. 1);[6] this too, as we shall see, is incorrect. I will be discussing the design options that were open to the makers, and by makers here I include those who may have designed the decoration as well as those who carved and assembled it, as they may not have been the same people. I hope to show that there was a much greater variety than has been realized up to now in the pattern generation, and also to highlight the frequently surprising lack of correspondence between the design of the dome decoration and what immediately precedes it on the building at a lower point, namely the drum and its arrangement of windows and blind niches.[7]

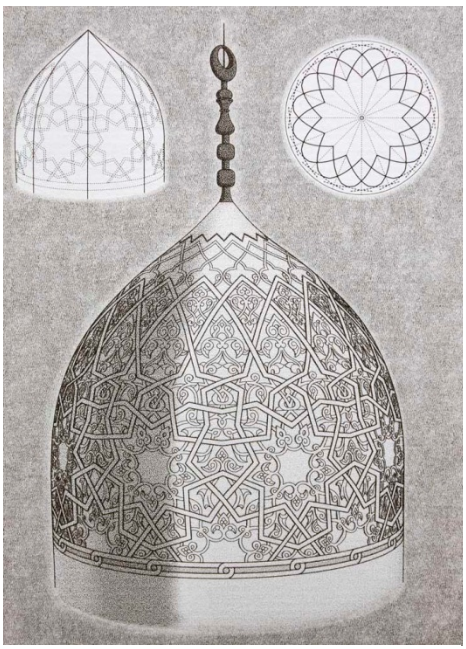

Figure 1: Dome of Qaytbay mausoleum, northern cemetery (after Sutton).

[5] "Bâtir une coupole en pierre de taille. La coupole du mausolée de l'emir Khayr Bek au Caire: dessin, construction et décor," *Annales Islamologiques* 41 (2007), 209-228.

[6] Daud Sutton, *Islamic Design: A Genius for Geometry* (Glastonbury, 2007), 47.

[7] Two comments, one on methodology and one on presentation. First, ideally for every building we would like to have the carefully measured drawings that the restorers of buildings in the Aga Khan project have produced, where, as at the dome of Khayrbak (Fig. 7), the location of every ashlar is recorded faithfully. Sadly this option was not available to me, and I have had recourse to counting the units of patterns from photographs. This is not a simple matter; it entails at least three photographs of a quarter

I group the Cairo domes into the following four categories, based on whether the number of repetition of units of design around the circumference of the dome is based on a power of 2 (regular) or not (irregular), and whether the dome design is aligned with the axis of the square base of the dome chamber (regular) or not (irregular). We thus have four categories:

1) Regular geometry, regular orienting

2) Regular geometry, irregular orienting

3) Irregular geometry, regular orienting

4) Irregular geometry, irregular orienting

which I will deal with in turn. I will not discuss all of the examples of each type, dwelling on some that present particular points of interest.

1) **Regular geometry, regular orienting**

The earliest variation on the smooth masonry dome in Islamic architecture is the ribbed design,[8] and the earliest examples of these, at Ukhaidir, Qayrawan (Fig. 2) and Tunis, are indeed based on multiples of four.[9] The same applies to the earliest Islamic ribbed domes

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circumference of a dome orientated on the main axes and on the diagonal. Secondly, I have usually greatly increased the mid-level contrast of the accompanying photographs in order to show more clearly the joints between the ashlars. However, it is a tribute to the skill of the masons that these joints are usually invisible to the naked eye from ground level.

[8] Arguably because, in the reconstruction of the Prophet's mosque at Madina by the Umayyad caliph al-Walid in the early 8th century, a shell-shaped dome was incorporated in the space above the ante-mihrab bay: Nuha N. N. Khoury, "The Meaning of the Great Mosque of Cordoba in the Tenth Century," *Muqarnas* 13 (1996), 90-91.

[9] Ukhaidir, 32 ribs: K. A. C. Creswell, *Early Muslim Architecture*, 2 vols. (Oxford, 1932-40), 2: 59, fig. 40; Great mosque of Qayrawan, 24 ribs (Fig. 2); Zaytuna Mosque, Tunis, 16 ribs. The Qayrawan example, unlike the others in the 4, 8, 16, 32 series, is not a power of two, and, unlike the others, is divisible by thee. I treat it as irregular. It may be mentioned, however, that at Qayrawan the impression of regularity is enhanced by the arched windows on the main and diagonal axes, and the same-sized niches between them, also 24 in number and directly aligned with the ribs above. In the case of the mihrab dome of al-Hakam II's extension to the Cordoba mosque, where the dome is literally shell-shaped, the emphasis on just one axis, from the entrance to the back of the mihrab room, resulted in the designers making the concave rib on that axis larger than the other nine flanking it to either side, resulting in a unique dome with 19 ribs:

Figure 3: Great Mosque of Qayrawan, Tunisia. Detail of dome (photo: B. O'Kane).

Figure 3: Sultaniyya complex, Cairo (Photo: Creswell archive, American University in Cairo).

in Egypt, from the Fatimid dynasty, for example at Sayyida Atika (16 ribs) and Yahya al-Shabihi (24 ribs).

Two other early Mamluk brick domes, al-Sawabi (c. 1285) and Sanjar (1302), also each have 32 ribs. The first stone dome in the sequence, that of Ahmad al-Qasid (c. 1335), much smaller than any of the previous examples, has a mere eight.[10]

Dating from c. 1360, the Sultaniyya twin-domed mausoleums (Fig. 3) have several features that place them apart from the Cairo series. They have muqarnas at the base of the ribs, a typical feature of Iranian ribbed domes. Also typical of Iranian brick double domes are the inner brick buttresses that can be seen in a pre-restoration photograph; these are not needed in stone dome construction, and most of the Cairene series, if they have a double dome, have much less space between the inner and outer shells than here. The 32 ribs are exactly aligned with the 16 windows in the drum.

The twin domes of the complex of Faraj ibn Barquq (1400-11) (Fig. 4) are the largest masonry domes in Cairo, at 14.4m diameter. Rather than the usual flat wooden roofs, the prayer halls of this complex are covered with brick masonry domes. It has been suggested that this was because wood was less affordable after the damage caused to the Mamluk economy by Timur's invasion of Syria in 803/1401-2. This in turn might argue for methods of reducing centering suggested by Cipriani and Lau.[11] However, as they

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http://artencordoba.com/MEZQUITA-CATEDRAL/FOTOS/INTERIOR/MEZQUITA_CATEDRAL_MIHRAB_06.jpg (accessed 10 June 2012).

[10] The dome has a plaster coating, and it must be admitted that it is not clear whether it is in fact made of brick or stone.

[11] *Construction Techniques*, 712, fig. 12.

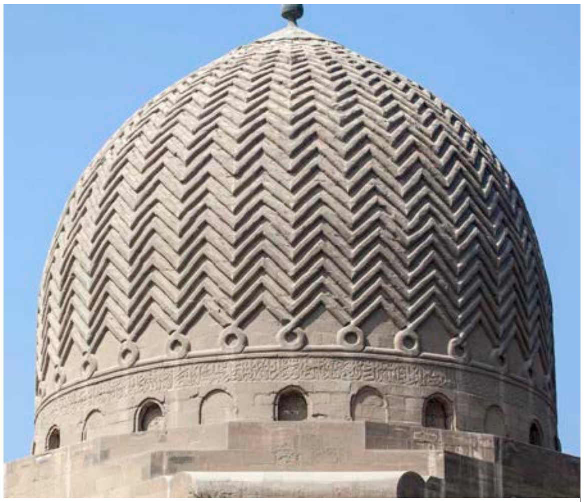

Figure 5: Faraj ibn Baquq complex, Cairo (photo: B. O'Kane).

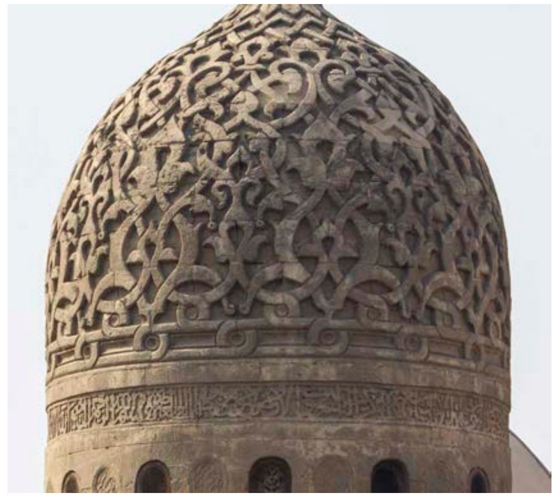

Figure 4: Madrasa of Jawhar al-Qunuqbayi (photo: B. O'Kane)

also point out, the paintings on the inside of the dome here indicate that centering must have been in place. If this expense was undertaken at a time of economic hardship, it is more likely that it was because it was an essential part of dome construction. Each of the domes here has 32 ribs, which are integrated with the *mim*s[12] at their base. The drum below has 24 niches, of which 12 are windows. Unusually, the windows are placed on the diagonal axes, which means that on the main axes blind niches are found.

At the madrasa of Jawhar al-Qunuqbayi, (Fig. 5) attached to the mosque of al-Azhar before 1440, the pattern is one of the earliest arabesques. This also has a drum of 24 niches, half of which are blind and half windows, but here the windows are on the main axis. The arabesque pattern is coordinated with the *mim*s that are also placed above the windows on the main axis.

There are many more examples of domes with regular geometry and regular orienting,[13] but more interesting in many ways are those with irregular orienting that follow.

[12] I use this term, meaning the letter "m" in Arabic, for the knotted loops at the bottom of the ribs. The same loop is often found as a decorative element on mouldings.

[13] The brick masonry examples include al-Sawabi (c. 1285) with 32 ribs and 16 niches in the drum, 8 of which are windows oriented on the main and diagonal axes; Sanjar **(**1302) with 32 ribs and 24 windows in the drum; *khanqah* of Qawsun (c. 1335) with 32 ribs; Khawand Tughay/Umm Anuk (1348) with 32 ribs and 24 niches in the drum; Anonymous, north of Tankizbugha, southern cemetery (c. 13500 with 16 ribs and flanges; Khawand Tulbay (1363) with 32 ribs and flanges and 16 niches in the drum, half windows. The stone masonry examples include Aydamur al-Bahlawan (1346) with 16 ribs and eight windows in the zone of transition; Abdallah al-Dakruri (1466) with 32 ribs and flanges, the ribs oriented above the four windows in the zone of transition; Sudun (c.

Regular geometry, irregular orienting

Figure 7: Complex of Tatar al-Hijaziyya (photo: B. O'Kane).

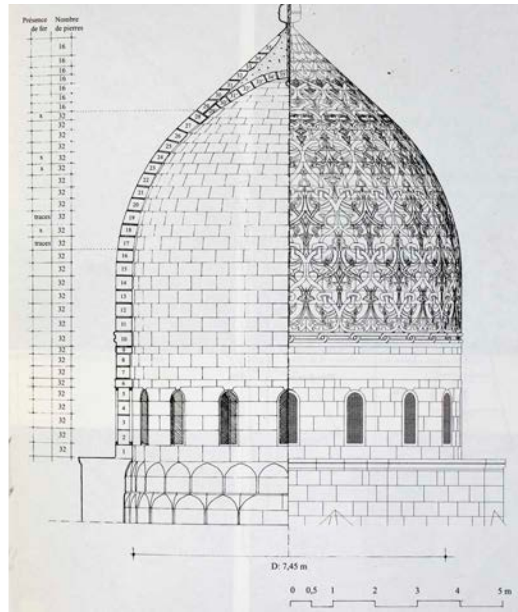

Figure 7: Fig 7 Khayrbak complex (after Bouleau).

The dome at the complex of Tatar al-Hijaziyya (1360) (Fig. 6) has 32 ribs and flanges, and 16 niches in the drum, half of them windows, oriented on the main axes. The ribs and flanges have scallops at their base, with the flanges aligned with the points of the scallop. But neither the scallop points nor the mid-point of their curves are aligned with the niches of the drum below.

Thanks to the work of the team of Christophe Bouleau, we have drawings of every stone of the Khayrbak dome (1502) (Fig. 7). It has a 16-sided arabesque pattern, at the base of which are 16 *mim*s exactly aligned with the 16 windows of the drum. But the arabesque pattern itself is placed unmistakably with its axis halfway between the *mim*s. Given the emphasis on absolute symmetry in general in Islamic art and architecture, and on dome design in particular, this lack of correspondence is all the more surprising.

At the dome of the Qanibay complex (1503) (Figs. 8 and 9) at the foot of the citadel the lack of correspondence is more subtle, and even more surprising. There are 32 niches on the drum of which half are windows. The mouldings above and below the inscription that is immediately above the windows each have 16 *mim*s. The lower *mim*s are situated exactly above each of the 16 windows on the drum. The upper *mim*s are spaced exactly with the 16-sided arabesque pattern of the dome. But the two are very

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1505) with 32 ribs and 16 windows in the drum and Baybars al-Khayyat (1515) with 32 zigzags and 16 windows in the drum.

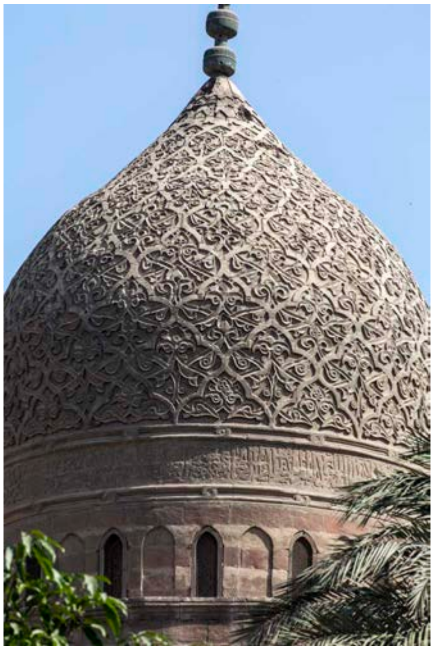

Figure 9: Qanibay complex (photo: B. O'Kane).

Figure 9: Qanibay complex, detail of dome (photo: B. O'Kane).

slightly out of alignment. It's almost as if another team of masons took over the work when the patterning on the dome began, and, even though the pattern had been worked out carefully beforehand to fit exactly, they were careless of, or oblivious to, the lower axial correspondence – or it simply didn't matter that much to them.

Further up this dome we see a feature that is found on several others that I shall mention later. Between many of the risers we see unusual infilling of plaster, as if the stones of the horizontal courses were cut before they were placed in position, but when hoisted up it was found that large vertical gaps remained between them. Does this make it any more likely that the pattern was carved on the ground, partially or completely, before being put in position on the dome? We can return to the evidence for this later.[14]

[14] One other dome in the category of regular geometry with irregular orienting is that of Tankizbugha at Muqattam (1362) with 32 ribs not quite aligned with the 16 niches (half of which are windows on the main axes) on the drum below.

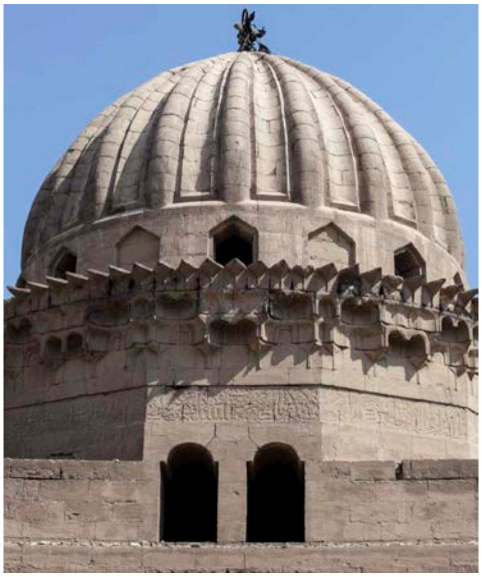

Figure 10: Tankizbugha mausoleum (photo: B. O'Kane).

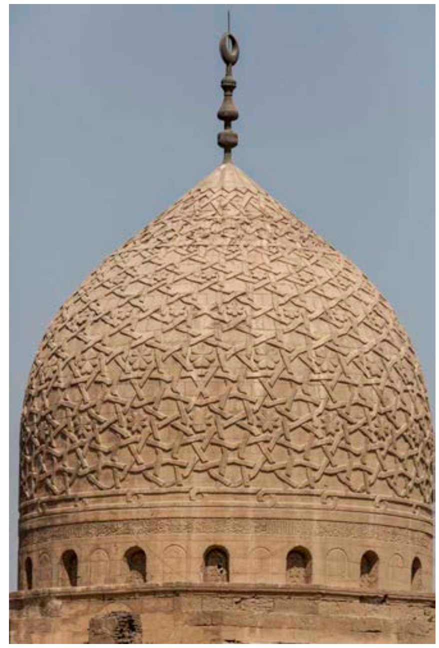

Figure 11: Complex of al-Ashraf Barsbay (photo: B. O'Kane).

Irregular geometry, regular orienting

This category can be divided in turn into domes that have patterns based on a multiple of 5, 6 or 7.

Multiple of 5

Like its slightly later companion in the *khanqah* at Muqattam,[15] the dome of Tankizbugha in the southern cemetery (1359) (Fig. 10) has alternating convex and concave ribs, evenly spaced. Here however, there are 20 of each. The drum has 16 niches, half of which are windows on the main axes. The convex ribs are oriented above the four orthogonal axes, but, despite the mismatch of 20 ribs and 16 niches, the even spacing of the ribs contributes to apparent visual regularity in that the concave ribs are thus aligned exactly on the diagonal axes.

The mausoleum of al-Ashraf Barsbay at his complex in the northern cemetery (1432) (Fig. 11) is the subject of a major analysis by my colleagues Ahmad Wahby and Dina Montasser in this same conference proceedings. It is indeed a landmark, being the first example of a geometric star pattern on one of Cairo's domes. It also has other interesting features. There are 32 niches on the drum, half of which are windows. It has a 20-sided star pattern, which coincides with the *mim*s at the base. On the orthogonal axes the *mim*s are above the windows of the drum, on the diagonal they flank evenly the drum windows. The ashlars courses are spaced to match the vertical alignment of the star pattern, as was the case with the earlier zigzag patterns, but at this experimental stage, the

[15] See n. 14 above.

Figure 12a: Complex of al-Ashraf Barsbay. Detail of dome (photo: B. O’Kane).

Figure 12b: Complex of Qaytbay. Detail of dome (photo: B. O’Kane).

horizontal divisions are still arbitrary, awkwardly cutting across the geometric lines of the pattern (Fig. 12a).

The cynosure of Cairo’s carved domes is indeed that of Qaytbay (Fig. 12b) in the northern cemetery, elegantly, and uniquely,[16] combining geometric with arabesque patterns. It has 16 windows in the drum, but the pattern on the dome is a 20-sided one, marked by the *mim*s at the base. However, the pattern is different above each alternate *mim*, so there are four ashlars at the base before the pattern begins to repeat.[17]

Multiple of 6

The mausoleum of Janibak (1432) (Fig. 13) in the northern cemetery has a complicated pattern on the dome. The upper half of 6 12-pointed stars appear at the base, with two rows of smaller 10-sided stars and one row of 10-sided stars further up. This 12-sided pattern is reflected in the 24 *mim*s at the base. Here there is an exact match with the 24 niches on the drum, with its 12 windows directly below each of the *mim*s.

[16] When I delivered this paper a second time at the Netherland-Flemish Institute in Cairo, Jere Bacharach raised the question why there were not more domes that combine arabesque and geometric patterning. One speculation: Qaytbay found it so appealing that he forbade his amirs from copying it. This is impossible to prove, but it is indeed surprising that, while there were many subsequent arabesque domes, none combined it with a geometric pattern, and no other explanation occurs to me.

[17] Two other examples of irregular geometry with regular orienting are, firstly, Inal al-Yusufi, 1392, which has, like Tankizbugha’s two domes, alternating concave and convex ribs. Its 20 *mim*s correspond with the bases of concave ribs, making a total of 40 ribs in all. There are 24 niches in the drum, half of which are windows. Secondly, Tarabay (1503-5), which has 40 zigzags and 8 windows in the drum.

Figure 15: Mausoleum of Janibak (photo: B. O'Kane).

Figure 15: Mausoleum of Janibak, detail of dome showing wooden pegs (photo: B. O'Kane).

Close examination of the ashlars on the dome reveals another interesting feature that was commented on for the first time by Bouleau and Cipriani in their discussion of the Khayrbak dome:[18] one face of very small wooden pegs are visible, two usually being usually placed towards either side of the base of an ashlar, within the mortar course (Fig. 14). At the *Masons at Work* conference, John Ochensdorf mentioned that similar pieces have been observed in the masonry of the chapel at King's College. Their function, as noted by Cipriani, was probably to help level the blocks. They would also have helped to spread the mortar between them more evenly. Cipriani also noted that they appear at different locations on the inner and outer faces, indicating that they do not do go all the way through.[19] This is the earliest example of this feature that I have noted; it may well not be the earliest actually employed, with others disguised by a coating of plaster.

This is another dome, like that of Qanibay mentioned above, where there are large gaps in the risers of the ashlar (Fig. 15). Here the feature is even more pronounced, suggesting much more was allowed than necessary for the decrease in diameter towards the top of the dome.

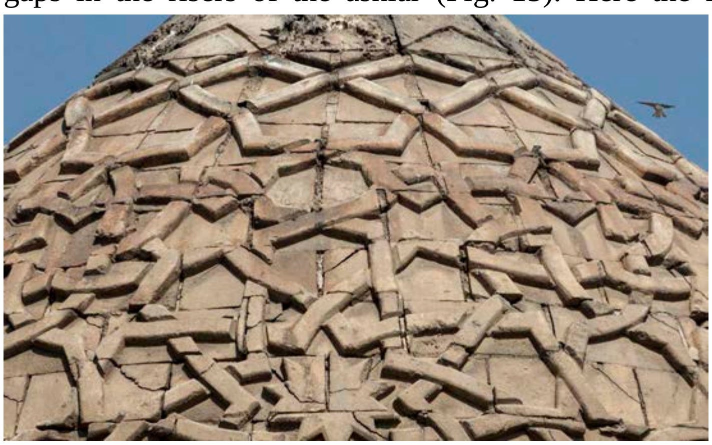

Figure 13: Mausoleum of Janibak, detail of dome (photo: B. O'Kane).

The dome of Qansuh Abu Sa'id in the northern cemetery (1499) (Fig. 16) has 24 niches in the drum, now all blind, but half of which were probably windows originally. The pattern on the dome is 12-

[18] Bouleau, "Bâtir une coupole," 214, fig. 20; Cipriani, *Development*, 23-4.

[19] *Development*, 23.

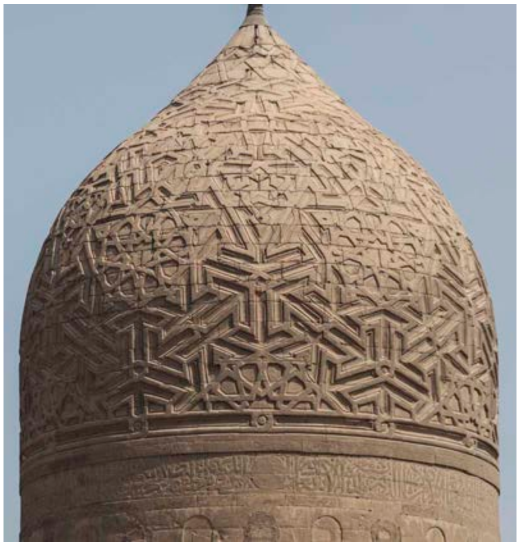
Figure 16 Mausoleum of Qansuh Abu Sa'id (photo: B. O'Kane).

sided, but an unusually complicated one which at the base alternates 10-pointed stars (the upper half alone is visible) with a triple-arrow motif. Above the triple arrows are 9-pointed stars, a most unusual example of an odd-numbered star in a geometrical pattern.[20] Unlike other domes with complicated arabesque or geometric patterns, where the pattern repeats after four ashlars at the base, this is the only one that needs six.[21]

Multiple of 7

The mausoleum of Inal, built by him in 1451 when he was an amir, and before he enlarged his complex on attaining the sultanate, has 32 niches on the drum, of which 16 are windows. It has 28 zigzags which are integrated with the *mim*s; the latter are made more striking by having dark- and light-blue glass globes inserted within them.

The zigzag was one of the most popular patterns after it appeared at Mahmud al-Kurdi (1394-5); some fourteen examples subsequently use it. However, this has a novel feature. Kessler lauds the first example of the zigzag, at Mamhud al-Kurdi, as the first dome where decoration and structure were properly coordinated, with "the equidistant disposition of the jointing…used as a reference grid for the pattern."[22] However, while here and subsequently, the ashlars were cut so that the vertical joints were in alignment with the pattern, this was certainly not the case with the horizontal joints. But here at Inal the pattern of the zigzag is so carefully planned so that the horizontal join is at exactly the same place all the way up (Fig. 17a), very close to the inner part of the V-shape, in such a way that the ashlars could be inverted and still fit into the pattern. "All the way up" is a slight exaggeration, even if the drum is proportionally taller than most other domes. But it is also exceptional how, even when the dome begins to curve and the ashlars become

[20] Perhaps the most celebrated example of this was on Ayyubid doors at the lower *maqam* of the Aleppo citadel, displaying 11-sided stars: Ernst Herzfeld, *Inscriptions et Monuments d'Alep, Matériaux pour un Corpus Inscriptionarum Arabicarum. Pt. 2, Syrie du Nord I-II* (Cairo, 1955-6), 126, fig. 56.

[21] Like others mentioned above, this also has wooden pegs visible at several places between the ashlars.

[22] *Carved Masonry Domes*, 18.

Figure 17a: Mausoleum of Inal, detail of dome (photo: B. O'Kane).

Figure 17b: Mausoleum of Barsbay al-Bajasi, detail of dome (photo: B. O'Kane).

smaller, the horizontal alignment of the zigzag pattern remains exactly the same, until it is replaced by triangles five courses from the top.

The slightly later dome of Barsbay al-Bajasi (1456) (Fig. 17b) also has a 28 sided zigzag with the *mim*s at the base emphasized by glass bosses. It has 24 niches in the drum, 12 of which are windows. Here there is also a careful attention to the proportionality of the horizontal jointing, but the design repeats only on every second course rather than on each one as at Inal.

Irregular geometry, irregular orienting

Here again I divide this category into domes that have patterns based on multiples of 5, 6 or 7.

Multiple of 5

We saw above how the dome of Qaytbay's mausoleum in the northern cemetery was based on a 20-sided pattern. The Gulshani dome (c. 1470) (Fig. 18) that he built nearby when he was an amir is also based on a multiple of five, reflected in the 20 *mim*s at the base of the design, although the design itself at the base alternates between arabesques and the upper half of 12-pointed stars (with curving sides[23]). There are eight windows on the drum, directly above the eight sides of the zone of transition, aligned neither with the arabesques nor the star pattern.

[23] The pattern on the minbar from the mosque of al-Ghamri (1446; now installed in the complex of al-Ashraf Barsbay in the northen cemetery) provides the closest ptorotype. For a photograh see the slip cover of *The Cairo Heritage: Essays in Honour of Laila Ali Ibrahim*, ed. Doris Behrens-Abouseif (Cairo, 2000).

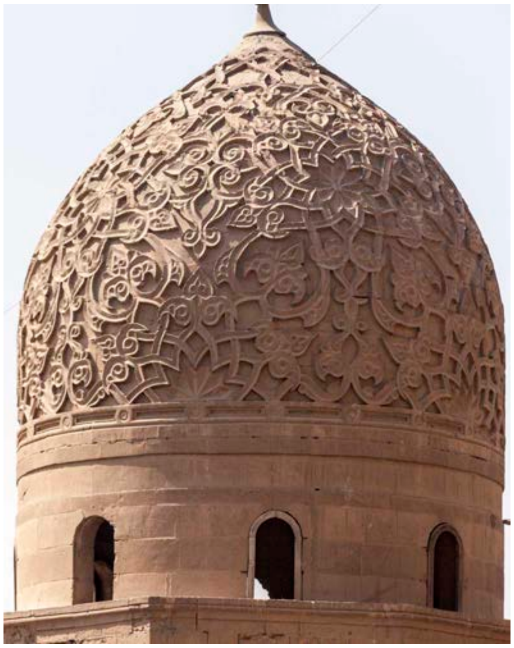

Figure 18: Gulshani mausoleum (photo: B. O'Kane).

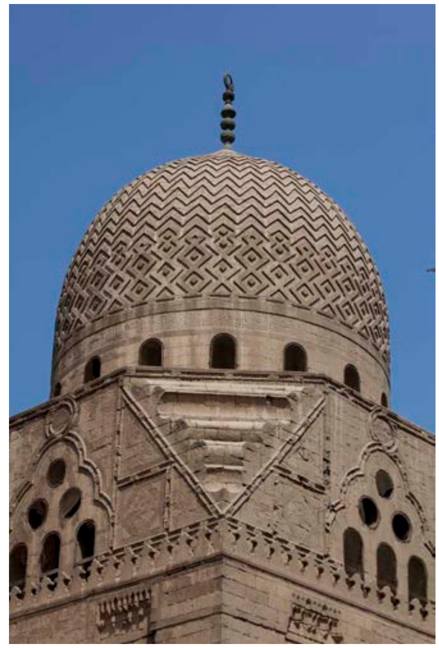

Figure 19: Complex of Qurqumas (photo: B. O'Kane).

The dome of Qurqumas (1506) (Fig. 19) at his complex in the northern cemetery is one of the most intriguing for its combinations of mismatches. There are 40 lozenges at the base (which change to a zigzag when the dome beings to curve), and 16 windows, but the main surprise is the number of *mim*s at the base, 42. It is difficult to think of any logical reason for this. Neither the lozenges nor the *mim*s are aligned on the main axes. The *mim*s with their mouldings are made up of individual ashlars,[24] of a different size than the band below that separates them from the inscriptions on the drum. This difference in size means that at several point the ashlars of the *mim*s cannot be placed at the optimum point for strength of bond with the course below, i.e. at the mid-point of the lower course. This could be another reason to suggest that a different team of masons was responsible for the dome construction.

Another peculiarity is the irregularity of some of the lozenges (Fig. 20). Where they meet the adjacent ashlar there is a slight bump (mostly visible on the lozenges on the west side of the drum), for which I can think of no other explanation than that the ashlars were sculpted before they were put in position and the work of smoothing out the irregularities was never finished.[25]

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[24] Unlike many others (e.g. the small dome of al-Ashraf Barbay's complex in the northern cemetery; Qansuh Abu Sa'id), where they are split horizontally in two, the upper half being part of the pattern on the dome.

[25] Ahmad Wahby and Dina Montasser in their presentation also commented on one of the small diamond shapes in the middle of the large lozenges that was clearly, unlike its

Figure 20: Fig. 20 Complex of Qurqumas, detail of dome (photo: B. O'Kane).

Multiple of 6

In the courtyard within the complex of al-Ashraf Barbay in the northern cemetery (1432) (Fig. 21) there is a smaller funerary dome chamber. It has 24 niches in the drum, half of which may have been windows originally. The pattern on the dome is a complicated one, with the upper half of 6 12-pointed stars at the base, with a row of smaller 8-sided stars and one row of 12-sided stars further up. The 8-pointed stars and the *mim*s (of which there are 12 in all) are aligned with the diagonal axes, but the main 12-sided star pattern is off-axis. This was certainly deliberate, for the ashlars at the base of the dome pattern, beginning with the *mim*s, are a different width than the ashlars of the inscriptions band on the drum below. This again leads many of them to be positioned off-centre, at less than optimum position for strength of bond. It also suggests again that a different team, whether specialized masons, or masons and designers, was responsible for the planning and execution of the dome.

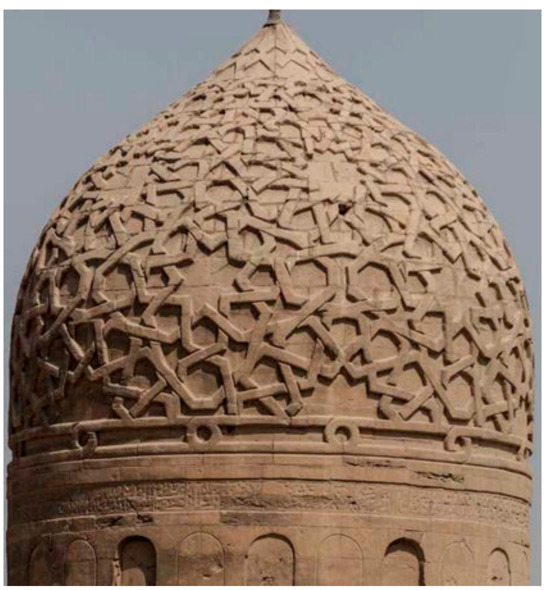

Figure 22: Complex of al-Ashraf Barsbay, courtyard dome chamber (photo: B. O'Kane).

Figure 21: Complex of al-Ashraf Barsbay, detail of courtyard dome chamber (photo: B. O'Kane).

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neighbours, unfinished. Another example in the category of irregular geometry, irregular orienting is the dome of the Janibak madrasa complex which has 24 niches in the drum, half of them windows, and 20 unaligned *mim*s corresponding to the base of the zigzags.

Like its exact contemporary, the nearby dome of Janibak, this also displays surprisingly large gaps between the risers of the ashlars towards the top of the dome (Fig. 22).

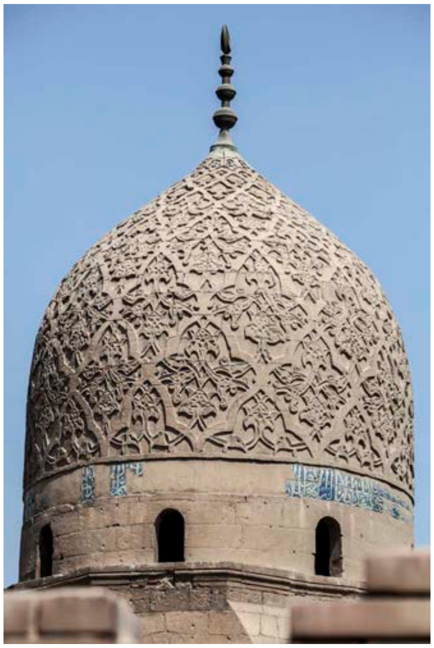

Figure 23: Mausoleum of amir Sulayman (photo: B. O'Kane).

The Amir Sulayman dome (1544) (Fig. 23) in the northern cemetery is the only Ottoman one in our series. It has a 12-sided arabesque pattern on the dome above eight drum windows, with the pattern aligned with neither the main nor the diagonal axes. Kessler noted the lack of correspondence here of the design with the ashlars, and concluded that that by then the masons' knowledge of coordinating the design with the ashlars had been lost: "The stone workers employed were deficient both in skill in handling the chisel and in know-how of pattern adaptation – there are mistakes in the symmetry of the design in the weave of the interlace and the pattern is not spaced evenly, especially at the base of the dome."[26]

Multiple of 7

The dome of Yunus al-Dawadar (c. 1385) (Fig. 22) is one of the most unusual in Cairo, with its elongated drum and tall narrow proportions. It is also the only other ribbed dome than Sultaniyya that has muqarnas at the base of its ribs. It has 12 niches on the drum, half of them windows, and 28 ribs unaligned with them.

Figure 24: Mausoleum of Yunus al-Dawadar (photo: B. O'Kane).

Finally, a mention of two which do not fit into any of the other categories. The first is Muzaffar 'Alam al-din Sanjar with 18 ribs above a drum with 12 niches (half of them windows). The second is Aljay al-Yusufi (1373), with 34 ribs above 32 niches (half windows).

[26] *Carved Masonry Domes*, 36.

Figure 25: Isfahan Friday Mosque, north dome (photo: B. O'Kane).

Figure 26: Basin, Qaytbay period, Museum of Turkish and Islamic Art, Istanbul (after Şahin).

Figure 27: al-Azhar mosque, dome of al-Hafiz (photo: B. O'Kane).

Spherical geometry

The problems involved in designing domes were faced by other craftsmen. One of the most spectacular examples from the Mamluk period is a basin from the Qaytbay period in the Museum of Turkish and Islamic Art, Istanbul (Fig. 26). This has a 12-sided star on its base and six half-stars aligned around the edges. But here the craftsman had to produce a pattern in which the central star at the base matched the half-stars on the circumference, as both could be seen simultaneously. This was never the case with the carved stone domes, where it could have been matched only by a bird's eye view.

One of the surprises of the inventory above was the substantial number of domes that have patterns based on a multiple of five. There is a major precedent for this, in the design on the inner surface of the north dome of the Isfahan Friday mosque (1088), which has a five-sided star, oriented with the two windows at the base of the dome (Fig. 25). Another Saljuq dome chamber with an inner star pattern is the mausoleum of Sultan

Sanjar (mid-12th century), with a more conventional 8-sided star pattern.[27] The Turbat-i Shaikh Jam dome chamber of 1236 also uses ribs to make a smaller octagon at its apex.

The six-sided pattern is also unusual, but there is one Fatimid example of the pattern on the inner side of a dome, at the entrance to the narthex of al-Azhar, added by the caliph al-Hafiz (Fig. 27). It displays six unusual polylobed arches that merge to form a six-sided scalloped circle, with a six-sided star at the apex.

Conclusions

What can we conclude from this mass of material? Firstly, the use of small wooden pegs that was first discovered by the restorers of the Khayrbak mausoleum, started much earlier, and was probably widespread in Cairene domes from at least the earliest example noted, that of Janibak, datable to around 1432.

Most importantly, we should note that the pattern generation of Cairene domes was more sophisticated and more varied than has been previously thought. But the often surprising lack of accord between the design of the dome chamber up to the level of the windows of the drum, and the part above it, can, I think, most easily be explained by them having been the work of two different teams of masons and/or designers.

Is there anything in this material that brings us closer to understanding whether the patterns were carved in situ on the dome, on the ground beforehand, or a mixture of both?[28] The coordination of design and structure could have made it easier for carving to have been done in on the ground. The large gaps between ashlars noted in several dome chambers (the smaller dome at al-Ashraf Barsbay's complex in the northern cemetery; the nearby Janibak dome; Qanibay) could also be explained most easily by them having been cut and carved mostly first on the ground, and not in situ, although the degree to which this applies to the other domes chambers, in other words, most of them, where this is not present, is still a matter of speculation. Other mistakes, such as the irregularities on the Qurqumas dome noted above, could similarly be more easily explained by the ashlars having been cut to a pre-determined pattern before they were assembled on the dome itself.

Against this, however, we know, from the unfinished carving of the façade of Sultan Hasan, that it was worked on in situ with the aid of scaffolding. The masons in charge of dome design are hardly likely to have been afraid of heights. And surely the

[27] Mukhammed Mamedov, *Mausoleum of Sultan Sanjar* (Istanbul, 2004), 146, fig. 10.

[28] This is a topic that is also discussed in these proceedings by my colleagues Ahmad Wahby and Dina Montasser.

coordination of the pattern would have been easier if done in situ on the dome? One would also have thought that the masons could just as easily have worked from a blank slate, i.e. a smooth stone surface, as on the façade of Sultan Hasan, which just needed guidelines lightly incised to aid the carving. But the latest in the sequence, the Amir Sulayman dome (1544), perhaps argues against this: its ashlars and pattern were no longer coordinated, resulting in irregularities in the spacing of the pattern.

Perhaps there is no need to argue strictly for one or the other. The known dimensions of the circumference and its division into the units of repetition would have enabled the ashlars and basic patterning to be blocked out ring by ring on the ground first; most of the detailing of the carving could then have been finished in situ.

Finally, as noted by John Ochsendorf, there are still many unanswered questions regarding the construction of Cairo's stone domes including the most basic one; how do such tall thin structures manage to stand at all, contrary to the known laws of mechanical engineering? Other questions that need investigation include the necessity and use of centering. I hope this paper will encourage other interested scholars to explore this fascinating body of material further.