Digital Applications in Archaeology and Cultural Heritage 40 (2026) e00494

Contents lists available at ScienceDirect

Digital Applications in Archaeology and Cultural Heritage

journal homepage: www.elsevier.com/locate/daach

Geometric reconstruction of ribbed domes covering the Ishrat-Khana Mausoleum in Samarkand

Muhammed Emin Akyürek

Department of Architecture, Istanbul Sabahattin Zaim University, Türkiye

ARTICLE INFO

Keywords:
Turkestan
Timurid architecture
Samarkand
Karbandi
Tashkent scrolls

ABSTRACT

Ishrat-Khana Mausoleum in Samarkand, a Timurid artifact, represents a significant example of the 15th century with its ribbed domes, opening a new era in the region's architecture. However, it was surveyed only once by hand drawing and has been standing in ruins due to its geometric complexity. Subsequent restoration attempts, on the other hand, contain serious faults. This study is about the geometric reconstruction of Ishrat-Khana's superstructure to contribute to possible restorations. The study offers one of the first comprehensive studies on ribbed domes in Transoxania, filling a significant gap in the literature. The geometry of the ribbed domes has been analyzed according to some design parameters inspired by historical drawings. The analyses revealed that restorations in the central hall and the masjid contain methodical errors, while the restitution drawings are also incorrect for the southern hall and the basement. As a result, a specific formulation for drawing a potential comprehensive restoration has been proposed.

1. Introduction and research aim

Arches, vaults, and domes have characterized masonry buildings. From Ancient Rome to Romanesque, barrel arches-vaults and round domes are common. With the Islamic civilization, especially in the Andalusian Umayyad period, there was a significant leap in *girih* (geometric knotwork used in Islamic art) geometry, reflected in structural forms such as arches, vaults, and domes. For example, new forms were created in the Great Mosque of Cordoba (961): interlocking and overlapping arches and a ribbed dome. The ribbed dome, which has qualities such as increasing rigidity by directing loads, enhancing the aesthetic impact, and facilitating the construction of surface fill by its ribs (Mainstone, 2001: 131; Ainechi and Valibeig, 2020), flourished in many great mosques in North Africa, such as Taza and Tlemcen (Fuentes and Huerta, 2010; Almagro, 2015; Alkadi, 2016). Then they were spread to Iran and Turkestan and called “karbandi” and “zarba-linga”, referring to intersections, respectively. In this region, the ribbed dome is used structurally, decoratively, or in two ways (Naeeni et al., 2017). The ribbed domes became elegant and complex, with brick as the dominant building material in these regions. The domes, which can be traced to the Jameh Mosque of Isfahan and the Tomb of Sultan Sanjar from the Great Seljuk period became widespread in important cities such as Tabriz, Shiraz, and Mashhad in different periods. During the rise of Timurids (14th century), these domes were brought to Samarkand by inviting influential architects from Isfahan and Tabriz. However, they were adopted during the Shaybanid period and attracted particular attention in the capital Bukhara. Likewise, during the rise of the Ottomans (15th century), they began to be built in Anatolia by architects invited from Tabriz (Necipoğlu, 1995). Although this form was not popular in the Ottoman Empire, it can be seen in buildings such as Behram Pasha Mosque (Diyarbakır), Gazi Mihal Bath (Edirne), Mevlana Mosque (Konya) and Tiled Kiosk (Istanbul).

Ribbed domes are still being constructed in Iran and Turkestan using traditional or contemporary methods. The first known drawing/design records of the ribbed domes are the scrolls of Tabriz and Bukharan masters dating back to the 16th century and have been handed down from generation to generation (Notkin, 1961; Necipoğlu, 1995). However, this tradition was interrupted in the last century due to the invention of reinforced concrete and steel. Recently, thanks to the renewed focus, several design methods have been introduced for restoration or innovative construction using contemporary materials. For example, Ahmadi (2014) has addressed these ribbed domes according to specific design parameters based on some artifacts in İran, and Mohammadi et al. (2018) on the vaults in spaces with irregular geometry. This academic group also analyzed prominent edifices in Iran with ribbed domes (Mohammadi et al., 2019). Some studies examine the geometric construction of the ribbed domes through individual buildings (see Garofalo, 2016). Ainechi et al. (2019; 2020) discussed the

E-mail address: muhammed.akyurek@izu.edu.tr.

https://doi.org/10.1016/j.daach.2026.e00494
Received 15 August 2025; Received in revised form 24 November 2025; Accepted 4 January 2026
Available online 12 January 2026

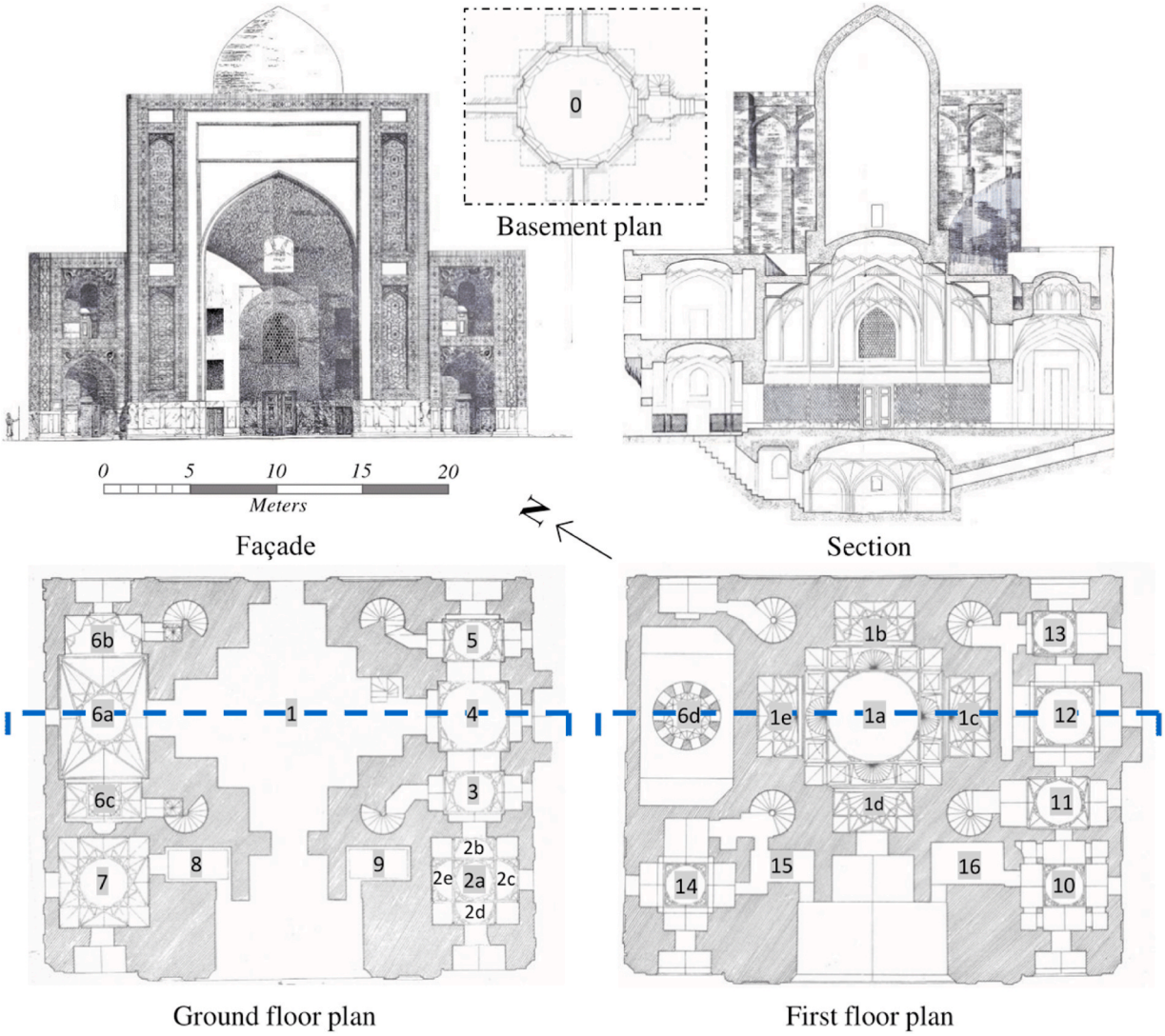


Fig. 1. Restitution project of the Ishrat-Khana; plan, section, and façade (formatted according to Pugachenkova).

structure and construction method of the ribbed domes according to the brick type commonly used in Iran and Turkestan. Chenaghlou et al. (2017) studied the structural morphology and performance of the vaults covering one of the squares (timche) of Tabriz Bazaar. There are also buildings such as the Rome Mosque and Putrajaya Zainal Abidin Mosque and academic studies where the ribbed dome is reinterpreted with novel materials and technologies (see Afify and El Moghazy, 2016). However, these studies are focused on Iran, and analytical studies on ribbed domes in Turkestan (Transoxania) are insufficient.

The Ishrat-Khana Mausoleum was a landmark of its time in terms of balanced proportions, advanced techniques, and exquisite ornamentation. According to Pugachenkova and Rempel, eminent architectural historians of the region, its ribbed domes are the most significant structural revolution in Central Asian architecture (Pugachenkova and Rempel, 1965). Unfortunately, a significant part, such as the central dome, collapsed in 1902 due to the earthquakes. Moreover, the studies on this monument are insufficient. This study aims to provide concrete data on the possible restoration of this building and to fill the gap in the literature on ribbed domes in Turkestan. While the geometric principles of the supporting arches of Ishrat-Khana have been recently analyzed in detail (Akyürek, 2025), this study focuses exclusively on the methodical geometric design of the ribbed domes, superstructure. In addition to on-site investigations, the drawings of Pugachenkova (1958, 1963), who in 1939 made the only comprehensive restitution of the building to date, have been relied upon.

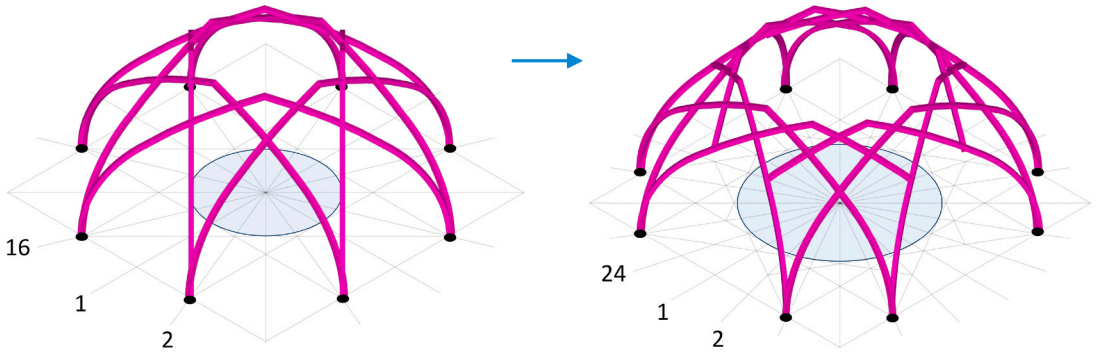
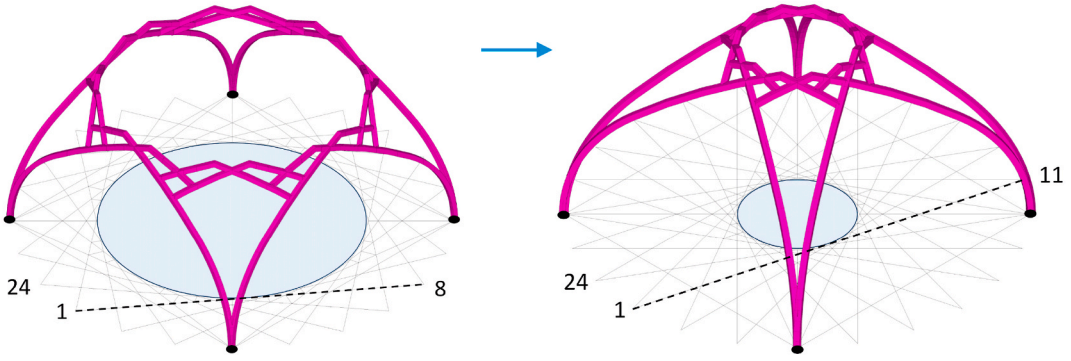
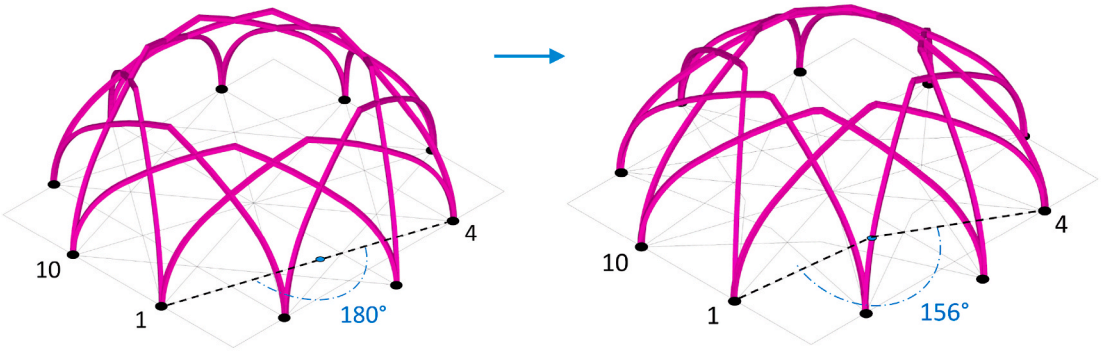
In analyzing the ribbed dome geometry, period drawings of the 16th-20th centuries and the studies above published by the Iranian school in recent years have benefited. First, the plan geometry of the ribbed domes in the Ishrat-Khana has been deconstructed. Then, the domes covering each space have been gradually defined according to some design parameters through plan and perspectives. While primary ribs transfer loads, secondary intricate ribs often function as applied ornamentation; however, both follow unified geometric logic which is essential for the graphical reconstruction analyzed in this study. Thus, errors in the restitution project and restoration practices have been discussed and corrected. As a result, the dome geometries in the Ishrat-Khana have been rediscovered with the design methods of its period, and a new hypothesis has been presented.

2. Material and methods

The Ishrat-khana Mausoleum is covered with ribbed domes of different dimensions, ratios, and forms. Bottom corners of these ribs, where they join the dome to the walls, are decorated with pendentives or *muqarnas* (stalactite-like transition element). The domes above the ribs are usually segmental (shallow), allowing an upper floor with less material and construction height. Some of these domes are divided into slices like a fan, and the lower corners of the ribs are usually shaped with

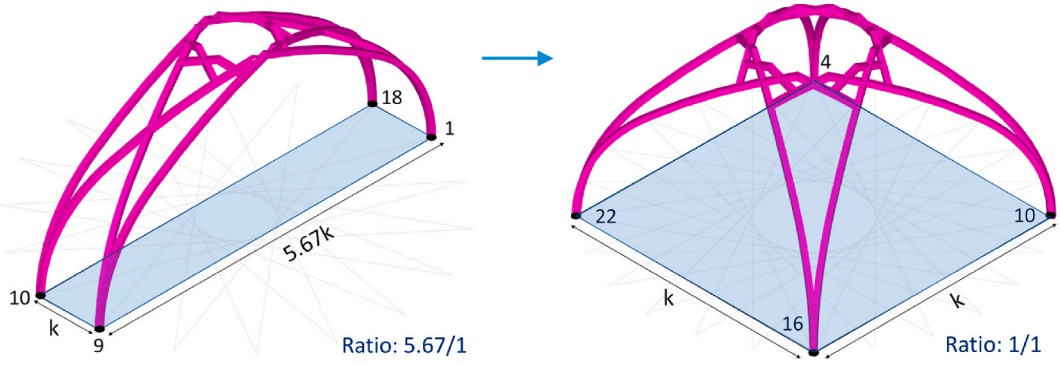
Fig. 2. Current status of the interior domes: (a–b) Ruins of the central hall (Space 1a); (c) The reconstructed segmental dome of the masjid (Space 6a); (d) Original ribbed vaulting above the mihrab; (e–f) The preserved dome in the southern hall and its details (Space 3); (g) The basement (Space 0) showing saline damage.

Table 1
Basic parameters of the ribbed dome through examples.

	Number of peripheral points: Different support points and domes are formed due to peripheral points dividing a circle. The dome span enlarges as the number of peripheral points increases.
1	
	Arch/dome span: If the number of peripheral points is constant, the dome span enlarges as the opposite points of the rays (1-8 on the left and 1-11 on the right), forming the pattern, get shorter.
2	
	Arch axis/ angle: Usually, the rays representing the plan of the ribs (arches) are straight (180º). The pattern varies if the rays (rib) are rotated from the central axis and angled.
3	

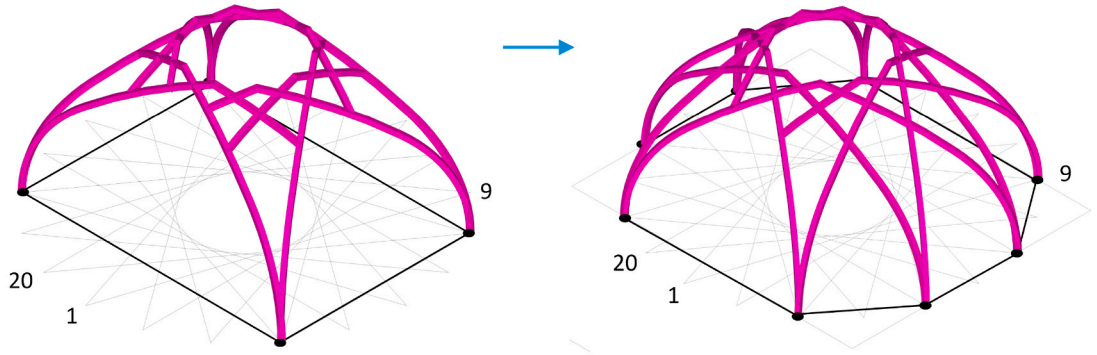
Spatial boundaries (ratio): Points on the pattern are potentially a support of the ribbed dome. First, the space ratio is defined based on these points; then, the rib geometry is drawn based on the pattern.

4



Number of support points: The pattern of the ribbed dome can be varied according to the number of support points, depending on whether they are at the corner or the edge.

5



Dome (tambour) edges: Tambour geometry can be in a polygon or a star form. This also defines whether the dome is pyramidal, polygonal, or circular.

6

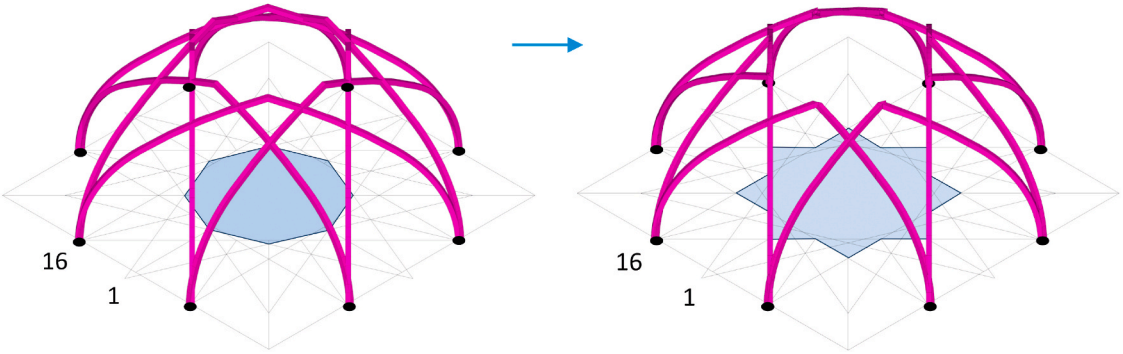
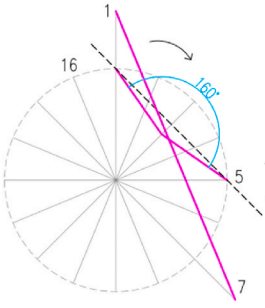
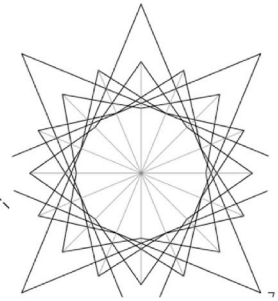
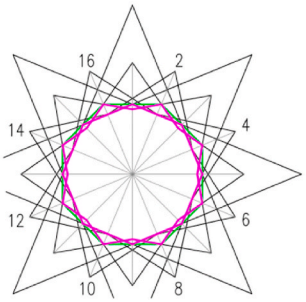
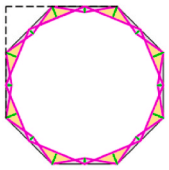
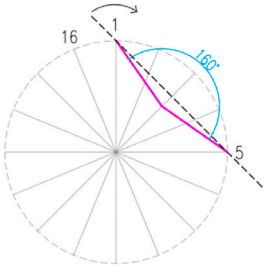
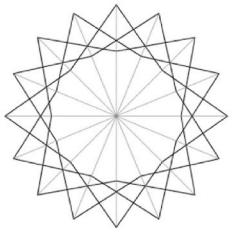
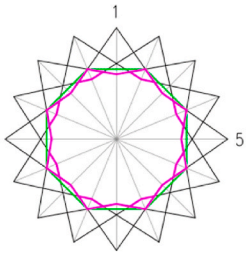
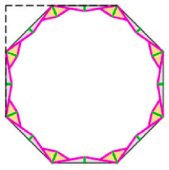
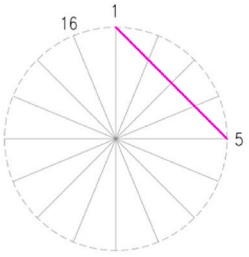
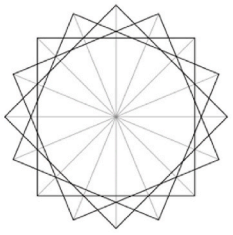
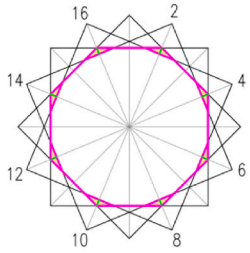
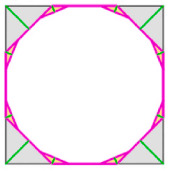
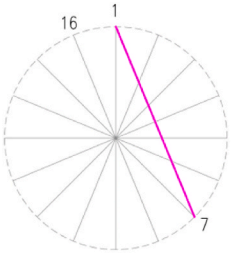
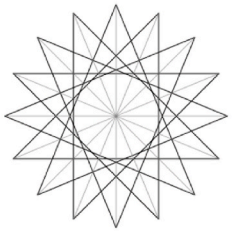
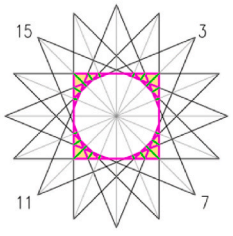
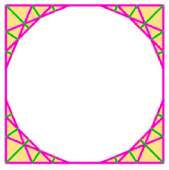
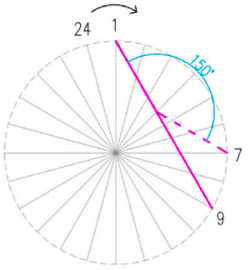
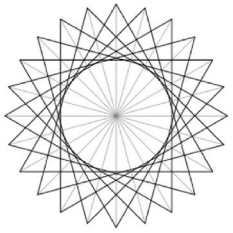
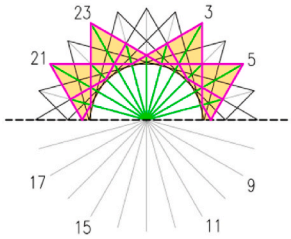
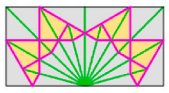
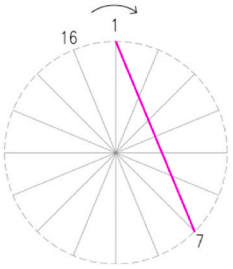
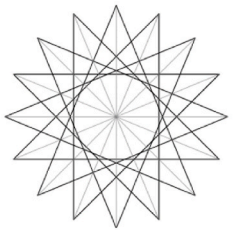
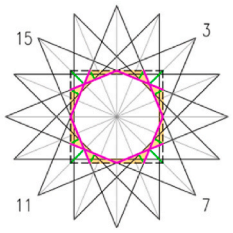
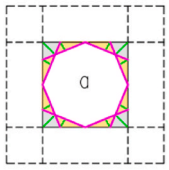
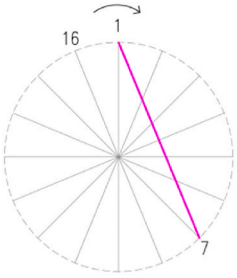
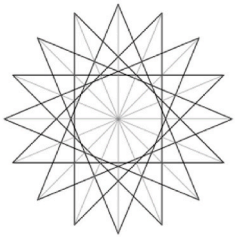
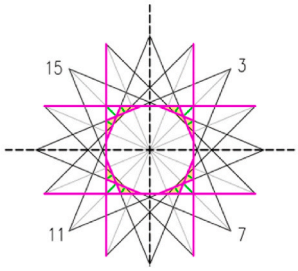
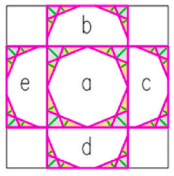
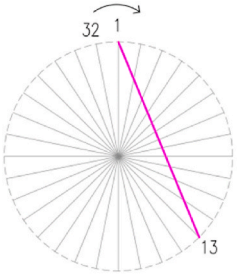
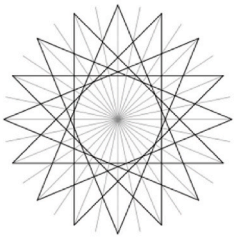
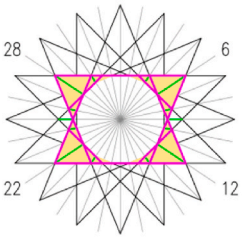
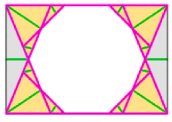
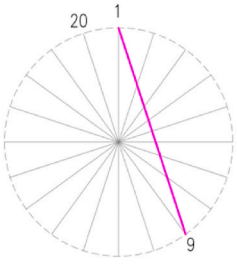
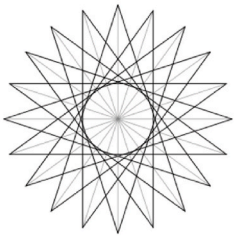
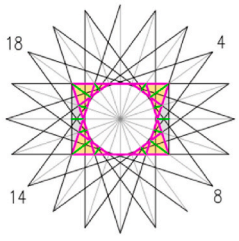
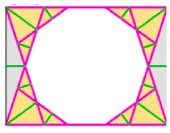
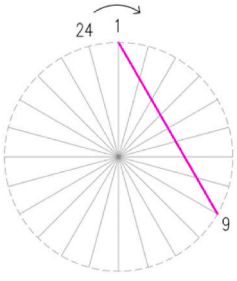
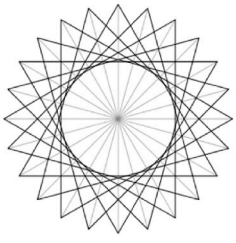
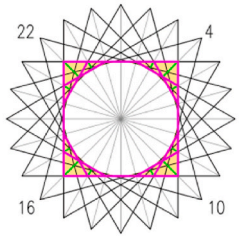
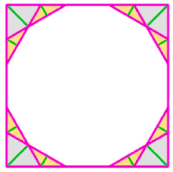


Table 2
The geometric configuration of the ribbed domes covering the Ishrat-Khana.

Space		Formation stages of ribbed domes			
0	Restitution				
	Current status				
1a	Restitution				
	Current status				
1 b-e	Restitution				

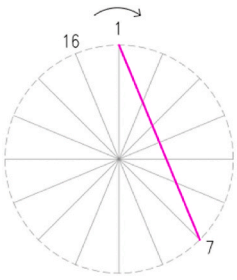
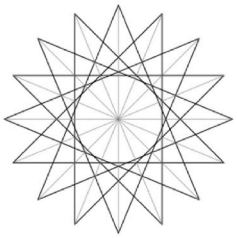
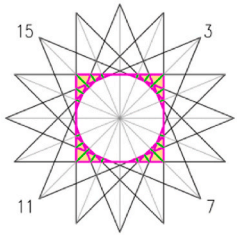
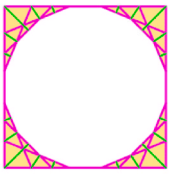
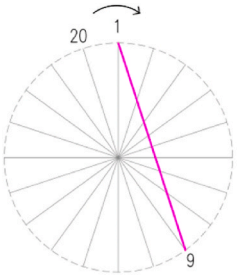
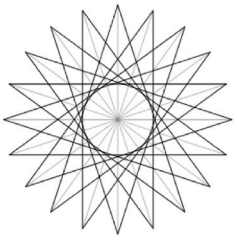
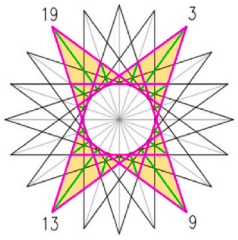
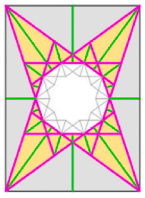
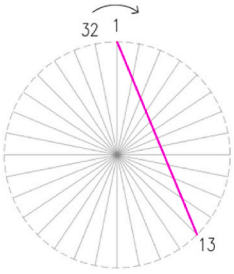
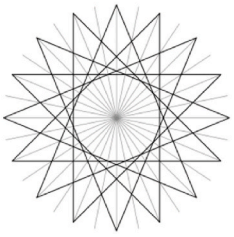
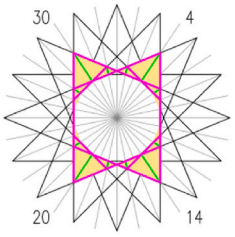
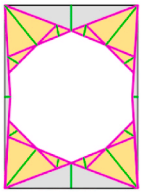
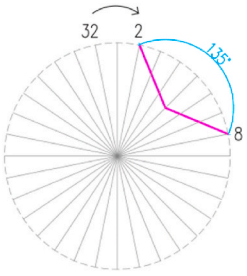
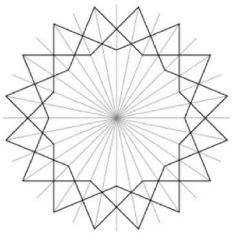
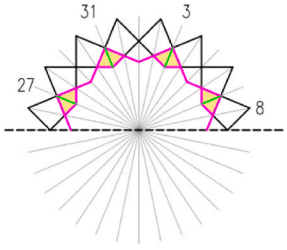
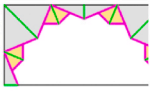
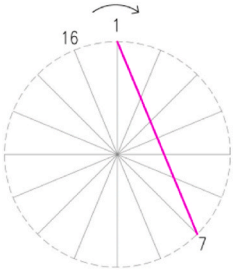
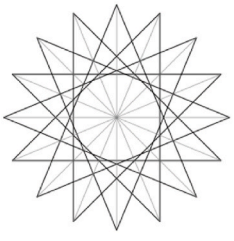
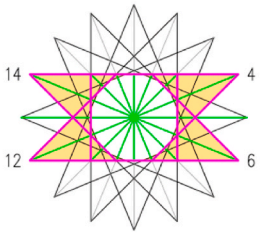
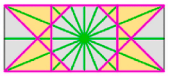
(*continued on next page*)

Table 2 (*continued*)

Space		Formation stages of ribbed domes				
2a	Restitution					
2 b-e	Restitution					
3, 5	Restitution					
	Current status					
4, 10, 12, 13, 14	Restitution					

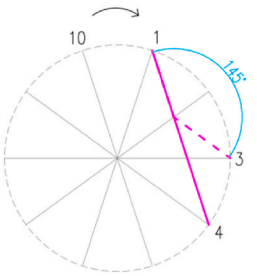
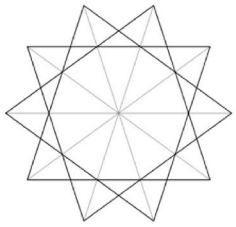
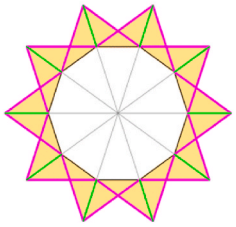
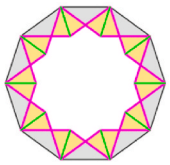
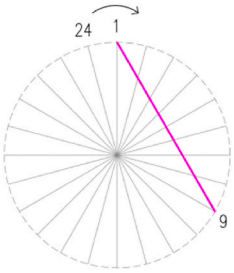
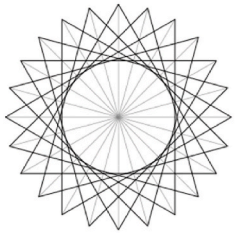
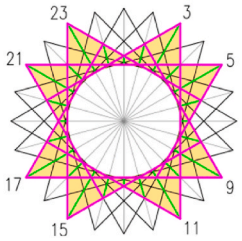
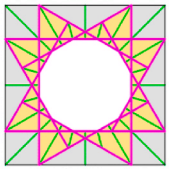
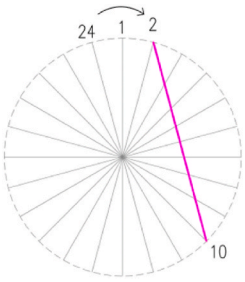
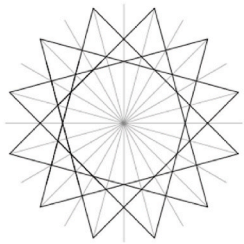
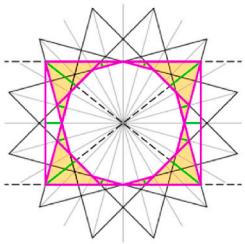
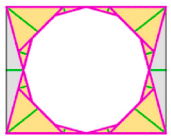
(*continued on next page*)

Table 2 (*continued*)

Space		Formation stages of ribbed domes			
	Current status				
6a	Restitution				
	Current status				
6b	Hypothesis				
6c	Concordant				

(*continued on next page*)

Table 2 (*continued*)

Space		Formation stages of ribbed domes				
6d	Restitution					
7	Concordant					
11	Restitution					

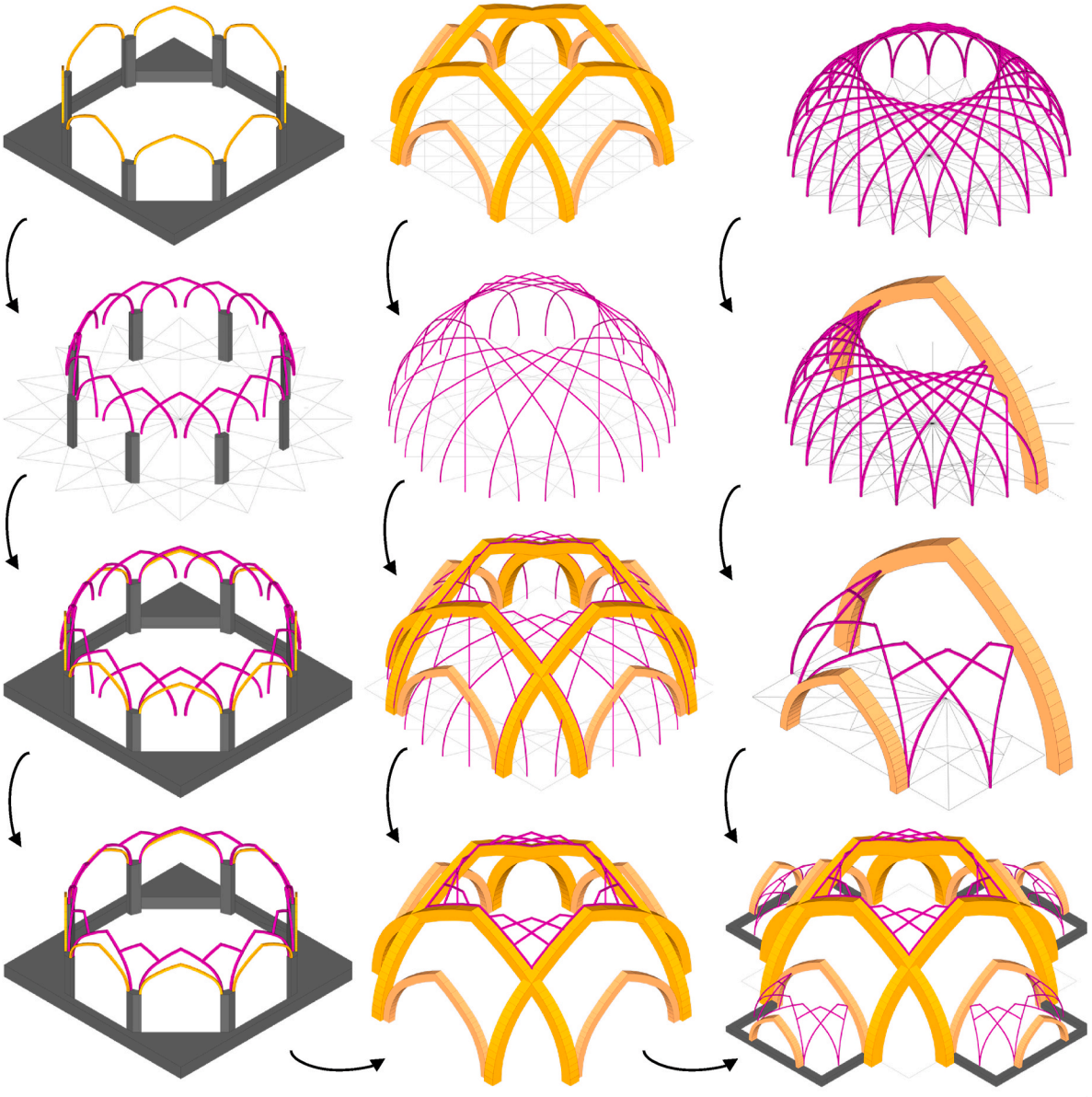
muqarnas. According to some ruins, the surfaces were plastered and decorated with gold leaf and paints. There are also four barrel vaults covering on both floors (Figs. 1–2).

Currently, there is no existing dome on the upper floor. Basement (Space 0) and the ground floor (Spaces 2-9) are covered with domes and vaults, although damaged. Since 1996, many interventions carried out gradually on the directives of the Ministry of Civilization of Uzbekistan. The central dome (space 1a) collapsed, and some of the corner ribs underneath are restored. The only indication of the lower half domes (spaces 1b-e) is the rib barely marks under the arches. This is also valid for the half dome of the masjid (space 6b). The central dome of the masjid (space 6a) is partially repaired, while the dome above the *mihrab* (a niche in the wall indicating the direction of prayer) (space 6c) remains original (below). The spaces (3–5) in the south are also original. The decorations of one of these domes are renovated to represent an example. The space in the southwest corner (2) is inaccessible because the doorway is blocked by a wall. The dome of the northwest corner (space 7) is plastered and survived intact. The dome of the basement (space 0) remains original, although its surface was deteriorated. For nearly 30 years, these restoration interventions have only been aimed at protecting the ruins against water and collapse. Eventually, its restoration has not been properly completed due to the uncoordinated execution of the work by non-specialist brickworkers (Fig. 2).

It is known that the first records of technical geometry in Islamic geography date back to the 9th century through the works of al-Farabi and al-Khwarizmi. The studies of 10th-century scholars Abu al-Wafa, Ibn Haytham, and Omar Khayyam laid the fundamentals of intricate geometry in Islamic architecture and were applied mainly in Seljuk and Timurid architecture (Özdural, 1995, 2000; Koliji, 2016; Akbar et al., 2017; Necipoğlu, 2017; Ebrahimi and Tooranpoor, 2022). Drawings directly describing architectural geometry occur in an anonymous treatise dated to the 11th-12th century (Necipoğlu, 1995). Although it is assumed that the descriptions of the geometric formation of ribbed domes, which became widespread in Seljuk and Timurid architecture, date back further, the oldest surviving drawing is the “Topkapı scrolls” in Topkapı Palace, Istanbul. Discovered in 1986, these scrolls are presumed to be products of the Timurid tradition and were brought to Istanbul by artisans from Tabriz. Another drawing is the “Tashkent Scrolls” in the Institute of “Oriental Studies in Tashkent," drawn in the 17th-18th century and discovered in the 1930s. It is known that these drawings created by the artisans of Bukhara, originally belonged to the collection of the Bukhara Museum, which became the capital after the Timurid period and hosted numerous ribbed domes. In Iran, 18th-19th century drawings of Mirza Akbar, the state (chief) architect of the Kajar period, have an expression enhanced by their colorful painting. These drawings were acquired in 1876 from Tehran by British freemason Sir Caspar Purdon Clarke after Akbar's death, donated to the South Kensington Museum, and then transferred to the Victoria & Albert Museum, London. The drawings by Bukharan master Shirin (Shirin Muradov), born in 1850, show the preservation of the tradition in Turkestan during the 19th century. The latest records on the subject are traced from Zasypkin's (1961) drawings published in the last century.

As the classical Muslim masons/artisans used compasses to draw the lines of polygons and intricate forms, the circles on the plan divide radial lines (rays) and assign the necessary points of the arch's projections that form the ribbed dome. The ribbed dome used to be constructed based on this plan. Although the drawing method has been promoted with the help of CAD programs, the construction technique is still used in Iran and Turkestan. Zasypkin (1961), who conducted the most notable analysis of the ribbed domes in Turkestan, focused on constructional

Table 3
The geometric construction of the ribbed domes covering the basement (space 0) and central hall (spaces 1a-e).

Basement (0)	Central hall (1a)	Side niches (1b-e)
		
		

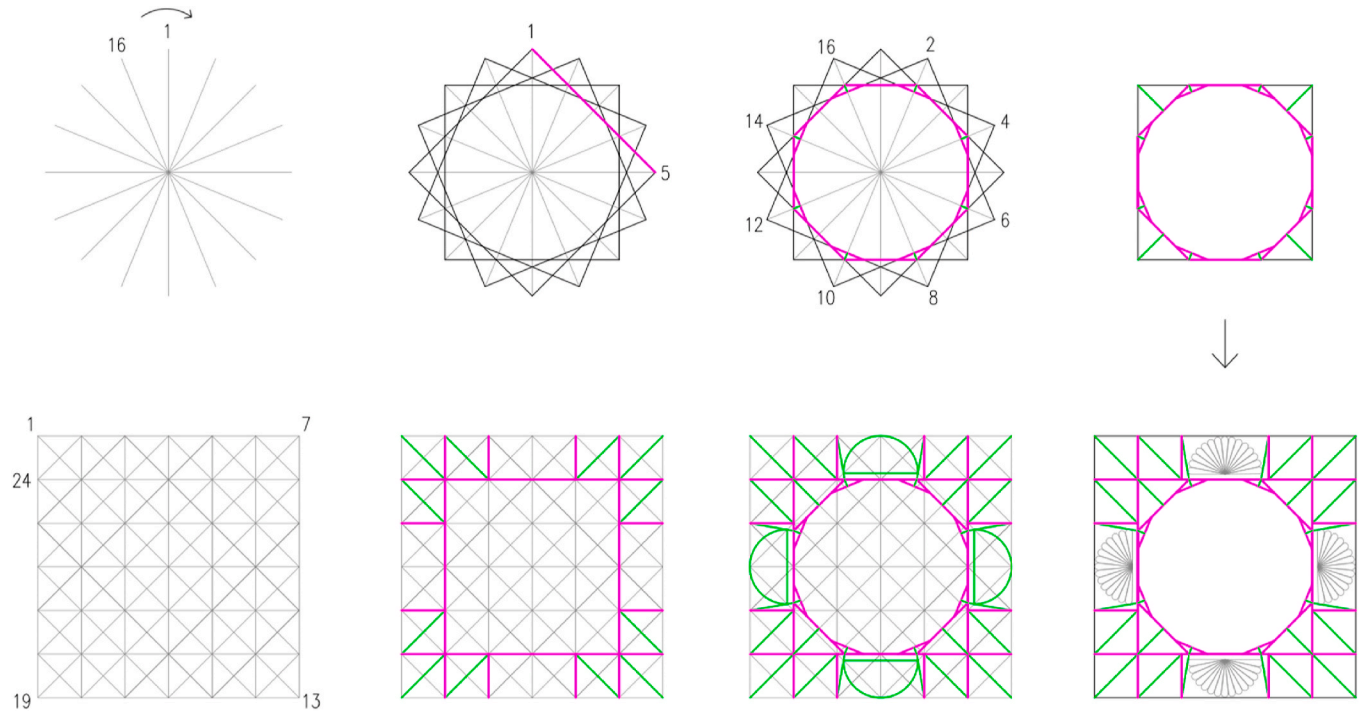


Fig. 3. Geometric generation of the central hall's dome (Space 1a): (Top row) Step-by-step division of the circle to define the peripheral points and formation of the star pattern connecting the radial lines; (Bottom row) Determination of the square grid infrastructure and the overlapping layout of the main and rib arches positioned on the grid.

features with limited samples and did not consider Ishrat-Khana. The only study about the ribbed domes of the Ishrat-Khana is Bulatov's (2022) two schematic drawings in plan. Nevertheless, Table 1, which has been formulated benefited by the Iranian school Ahmadi (2014); Chenaghlou et al., (2017); Mohammadi et al., (2018)], will now be used to describe the construction of forms and ratios according to the basic parameters in the design of the ribbed dome. Table 1 illustrates a plan and a perspective of two different cases for each parameter defined above it. The design of the ribbed dome consists of a center point around which radial lines and peripheral points are regularly connected. Each line represents an arch in the third dimension.

Although preliminary manual measurements established the general scale, this study prioritizes proportional analysis over absolute metric documentation, as relying solely on point-cloud data for ruined structures risks misinterpreting the original design intent. Based on visible facts derived from high-resolution imagery and extensive on-site observations in Samarkand, the proposed models reconstruct the intended design geometry rather than surveying current deformations. Furthermore, since the geometric generation of decorative and structural ribs originates from the same plan layout, both are treated within the same proportional framework in this reconstruction. In this context, as noted by Ainechi et al. (2019), the traditional use of adjustable full-scale templates (*chablon*) often resulted in slight constructional variations that this idealized geometric modeling aims to rectify. Consequently, given that Timurid karbandi systems allow for multiple configurations, these solutions represent reasoned interpretations rather than definitive facts.

3. Results

The geometric investigation of the Ishrat-Khana Mausoleum was conducted through a systematic comparison between the historical restitution drawings and the building's current status. This analysis revealed that while the central dome follows consistent geometric logic, significant deviations occur in the lateral chambers regarding rib configurations and arch profiles. The findings are detailed below, categorized by spatial units and hierarchical geometric tiers, starting from the two-dimensional plan layouts (Table 2) and progressing to three-dimensional reconstructions.

In Table 2, the restitution has been relied upon for spaces 1b-e, 2, and the upper floor spaces (10–14), which were ruined, or their ribs are not recognizable. The remaining ribbed domes (spaces 0, 1, 3–7) can be followed in Figs. 1–2. Where the restitution and current status match, they are indicated in the table as concordant.

In the first stage, the number of peripheral points is defined and shown on the circle. In the second stage, the distance between the two endpoints of the lines forming the relation of the construction is found and highlighted with pink. All points are mutually matched according to this distance and clockwise flow at this stage. The resulting diagram identifies the support points, emphasizing the dome construction. In the fourth stage, the background required for the construction is removed, and the parts defining the ribbed domes are highlighted in yellow. The spaces defined in gray are the infill surfaces of the ribbed dome, formed “shield-like" pendentive or muqarnas. The lines defined in green divide the infill parts in the third dimension, indicating their direction and curvature. Sometimes, as in “1b-e” and “6c”, they divide the dome into slices (Table 2).

4. Discussion

The basement (space 0), which corresponds to the bottom of the central hall (space 1a), has an octagonal plan and has been primarily preserved. However, the wall surfaces have severe staining and salinization, and the space needs to be addressed. The restitution and the current status of the domes are slightly different. Pugachenkova has shown one of the two rib arches intersecting side by side as angled (oblique) and the other as nonangled (parallel). In this case, when observed from the façade, the parallel arch should appear wider than the angled one. However, as shown in Fig. 2, the current status of all rib arches is equal in size. Moreover, when the form in the restitution is

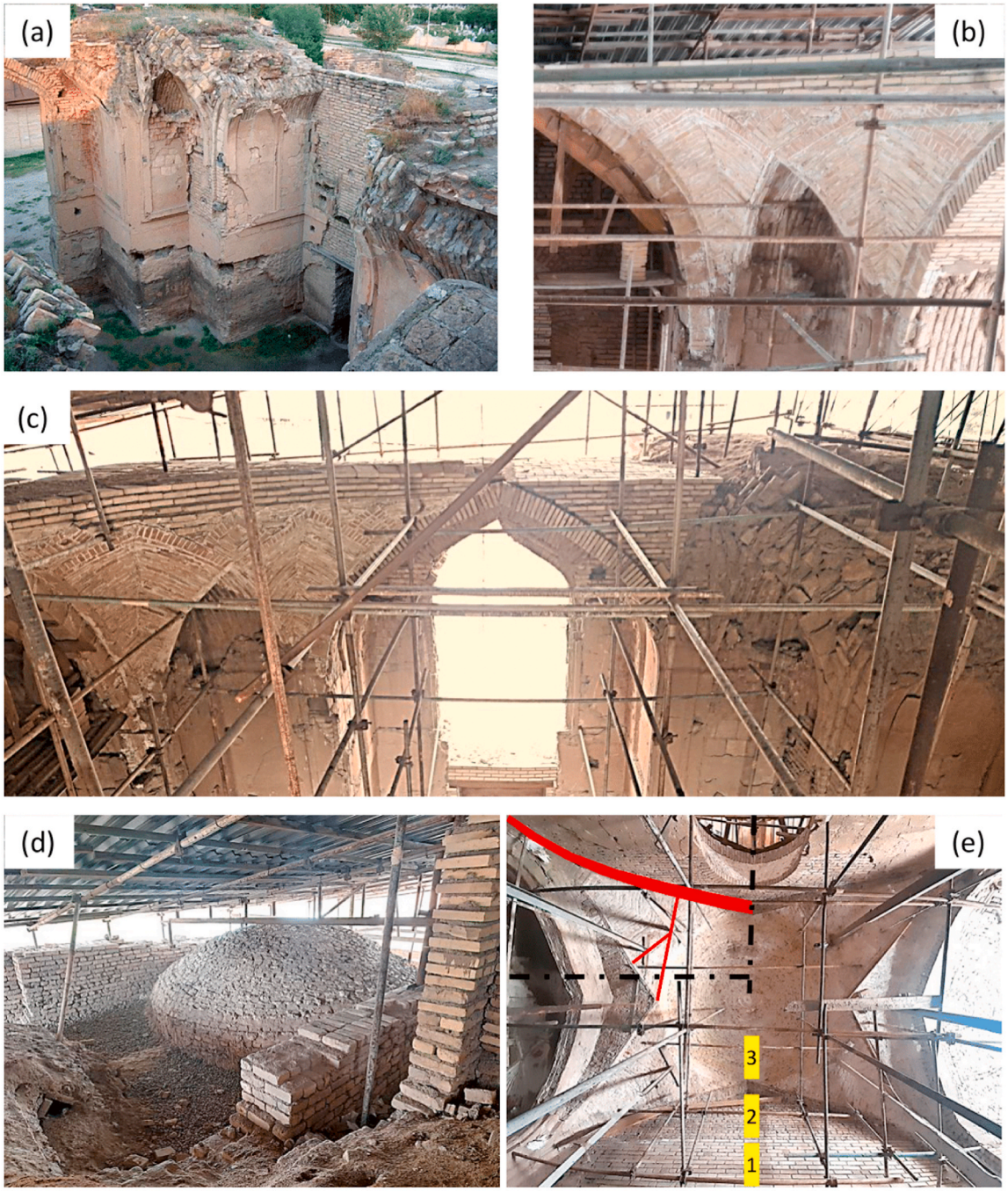


Fig. 4. Ruins of main arches from the photos taken in 2003 (by S. Mikhalkov) (a) and in 2024 (by author) (b, c); Reconstructed middle dome of the masjid (space 6a) without second tier (d), and different brickworks and irregular arches (e).

deconstructed and methodically generated, two plans must be drawn and overlapped, as seen in Table 2 (space 0). According to these two arguments, the dome comprises equidimensional angular arches. Hence, as shown in Table 3, main arches (marked in yellow) are positioned on an octagonal plan. Then, 16 rib arches (marked pink) are placed obliquely around the center. Rib arches, which are the lower points, are not supported and are trimmed, and the required rib pattern is obtained. Consequently, this dome is the only example with a polygonal plan geometry on the building and is one of the four examples (spaces 0, 1b-e, 6b, 6d) where the third design parameter of the ribbed dome (see Table 1) was applied. By applying this parameter, which refers to angled arches, the dome area was narrowed, a segmental dome was built, and the construction height of the floor on the top was considerably reduced.

On the other hand, this scheme works well in theory, is problematic when raised to the third dimension. According to the restitution, the rib arches (in pink) have the same cross-section as the main arches (in yellow). As seen in Table 3 (space 1a), The rib arch that does not rest on the main arches is trimmed. Thus, the desired form can be achieved, although a defined geometric design cannot be created with the method in Table 1. Two other constructions deviate from the mentioned method: the central dome of the space 2 and 11 (Table 2). In both cases, the boundaries of the space are determined by the points that intersect the two central axes instead of the corner points. The half domes (Table 2 (spaces 2b-e)) articulated to the central dome (space 2a) at the corner expand the space by two floors in both directions.

According to the restitution, the dome of the central hall (space 1a)

Table 4
The geometric construction of the ribbed domes covering the prayer hall (spaces 6a-c) on the north.

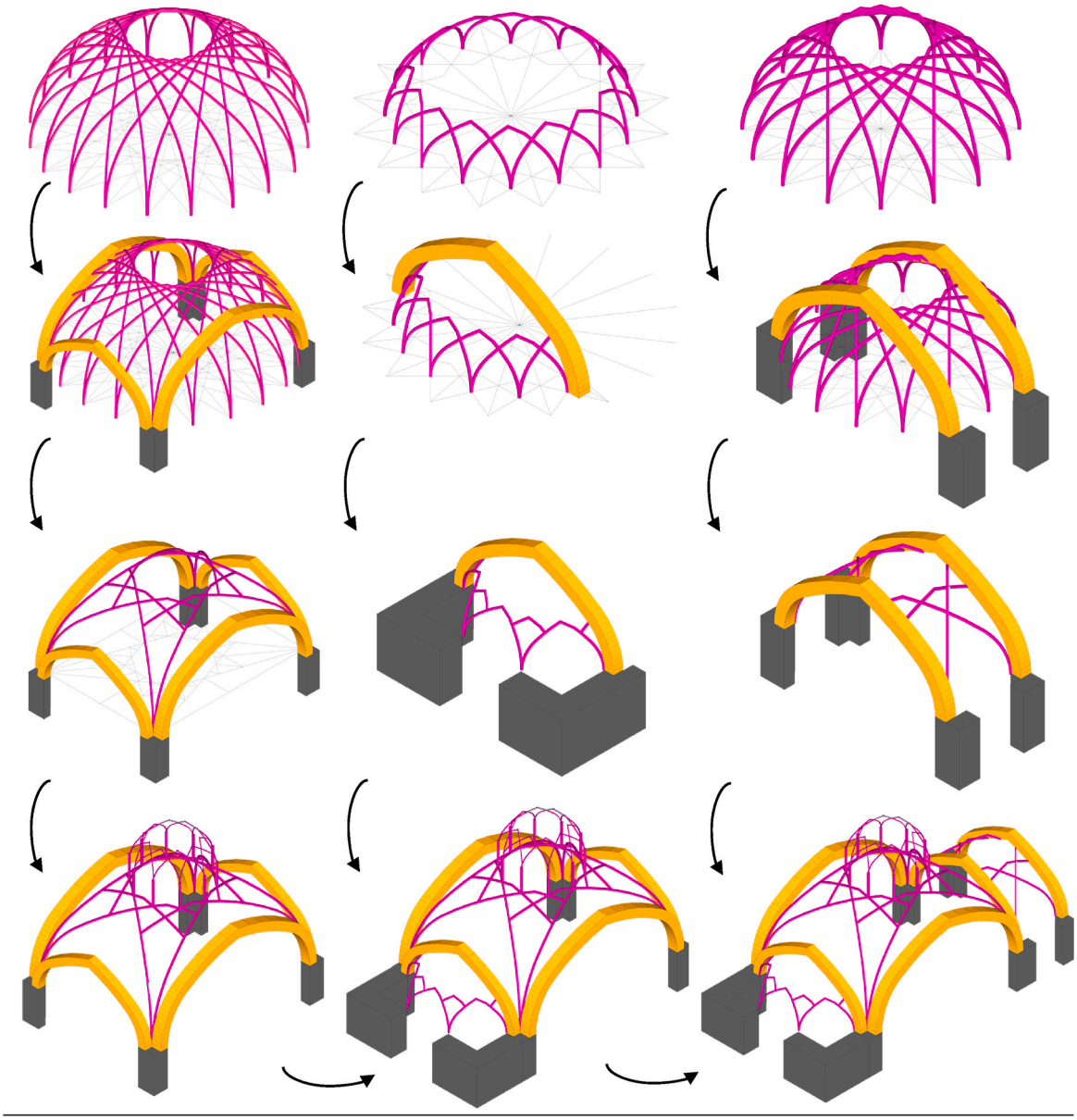
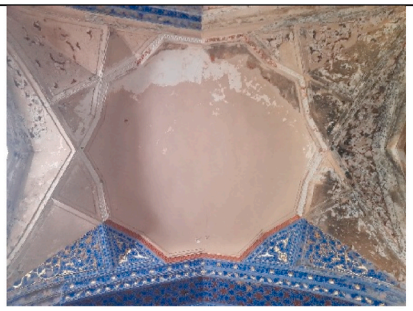
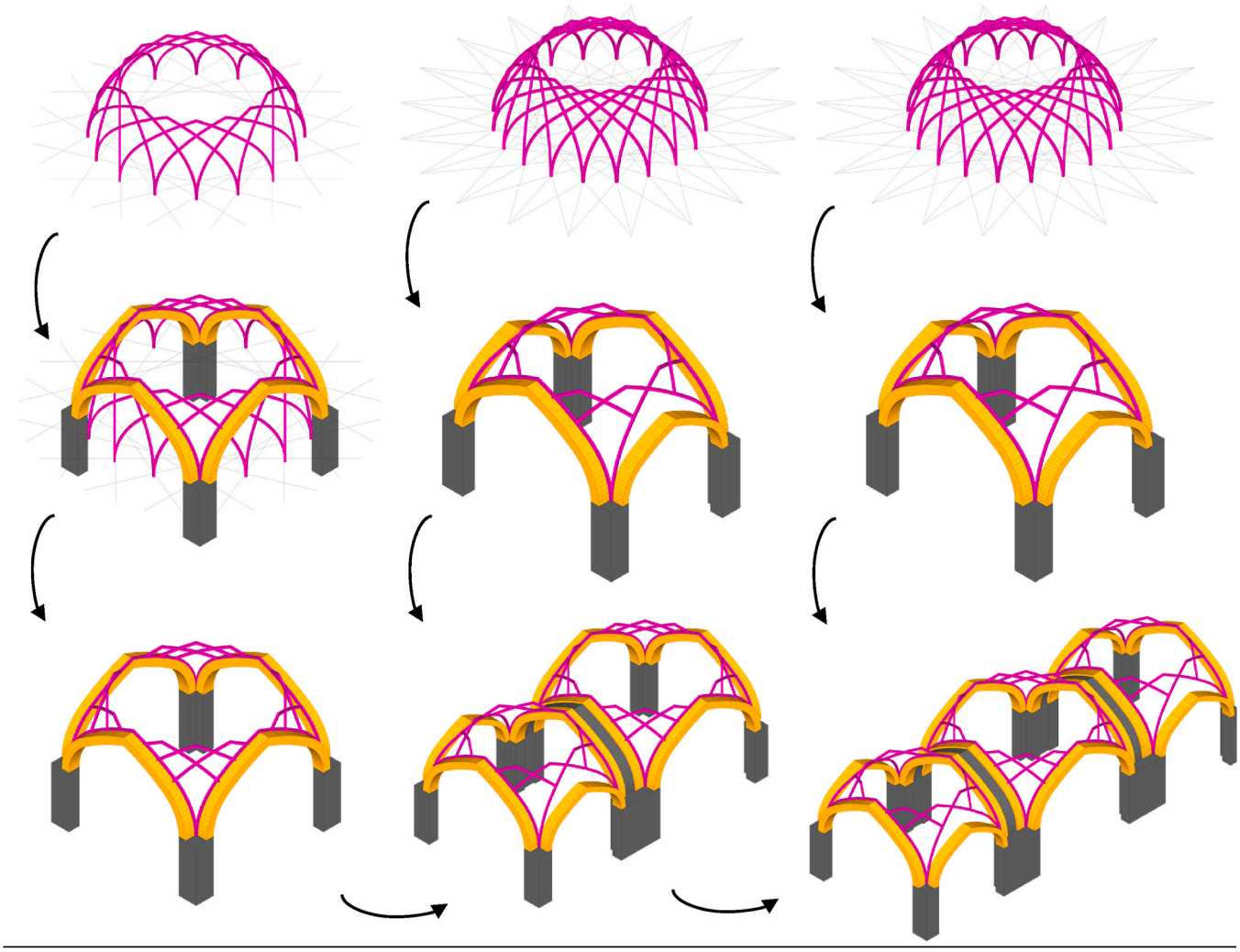
Middle portion (6a)	East portion (6b)	West portion (6c)
		
		

Table 5
The geometric construction of the ribbed domes covering the hall (spaces 3–5) on the south.

Middle portion (4)	West portion (3)	East portion (5)
		
		

has three tiers. The first tier consists of half domes expanding towards the four sides (Tables 2 and 3 (spaces 1b-e)). The second tier was designed according to a different scheme that deviates from the method in Table 1. The second tier is designed using a distinct geometric scheme. Theoretically, the square plan is subdivided into a modular grid consisting of 6x6 units (1–7, 7–13, 13–19, 19–24), totaling 36 modules (Fig. 3). The main arches framing the central space (1a) are then generated by offsetting the perimeter arches inward by one grid module. The intersection points of these offset arches at the corners determine the position of the muqarnas elements. In this configuration, the central hall was covered with a ribbed dome on the third tier, and the outer parts of the central axes in both directions were covered with segmented half domes. A segmental dome was placed over the ribbed dome, forming the third tier.

The current status of the central hall (space 1a) is different from the restitution. The section from the main arches to the dome tambour has been transformed with new brickwork (Fig. 4a and b). Considering the different brick layers in this section, it has been restored several times.

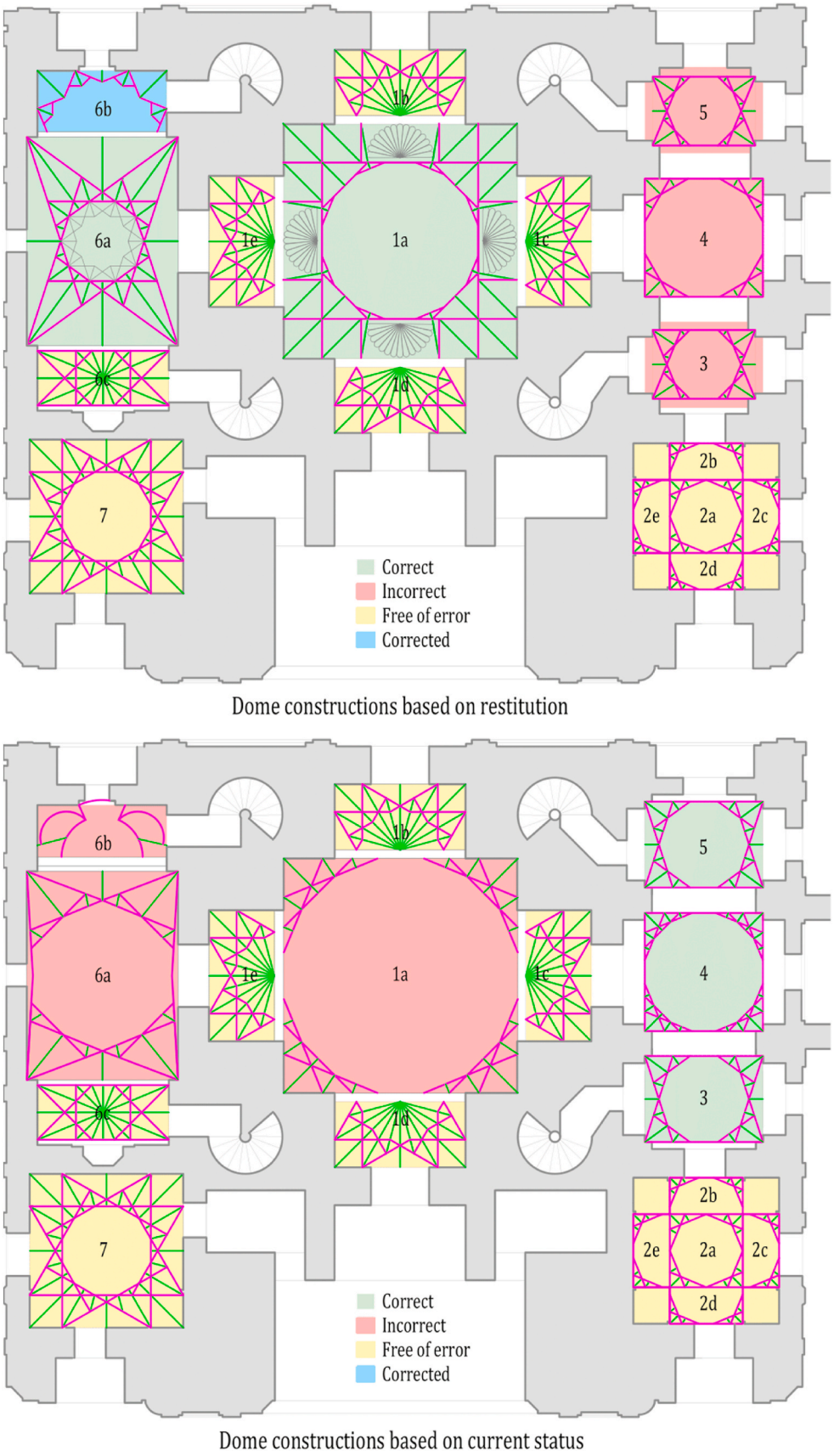


Fig. 5. Plan of the ribbed domes on the ground floor of the Ishrat-Khana according to the restitution (above) and the current status (below).

Presently, the ribs of the dome are reconstructed, although there are no ruins of the dome surface. Therefore, the plan geometry of the current status has been derived depending on the ribs (Table 2 (space 1a)). According to the restitution, however, the dome rests on additional main arches connecting the half domes and narrowing the central dome (Table 3 (space 1a)). This is precisely the same as the restitution of Aksaray drawn by Pugachenkova. Judging from the photo records of Aksaray before the restoration, this restitution is correct. However, it is doubtful that the ruined Ishrat-Khana has the same structure. Indeed, Gunbad-i Sabz in Turbat-i Shaikh Jam (15th century), the Langar Ata (15th century) in Kashkadarya province, the Qasim Sheikh (16th century) Mausoleum in Navai (Navoiy), and the Namazgah Mosque in Samarkand (17th century), which have similar plan geometry, were built with differing dome constructions (Golombek, 1971; Yusupova et al., 2010). Nevertheless, photographic records from the early second millennium, before the latest interventions in the Ishrat-Khana, and two preserved corners, seen on Fig. 4a and c, show traces of the springer of the arches connecting the half domes. As highlighted in Fig. 4b, the unusual orientation of the rib arches at the corner joints suggests that the partial reconstruction is faulty. In addition, the fact that some main arches are located above the dome tambour while others are located below (see Fig. 2) raises the possibility of faulty restoration and strengthens this argument. Eventually, it clearly indicates that restitution (although not definite) is more accurate than the current status.

Another dome designed in tiers is the middle-upper dome of the masjid (space 6; Tables 2 and 4 (space 6a). This dome's first tier (6a) is formed by combining the corner points 3, 9, 13, and 19 of the line pattern with a distance of 9 points clockwise on 20 peripheral points. The second tier (6d) is formed by a line pattern with a clockwise distance of 4 points on the formed decagonal tambour. The second tier is positioned on piers with a certain height; the tambour was simplified and given a star form, and a segmental dome was placed on it. Unlike the other spaces, this space has no upper floor. Currently, this upper tier (6d) does not exist, and the bottom tier (6a) is partly reconstructed by a segmental dome (Fig. 4d). Moreover, the dome's diameter is not as small as in the restitution and is quite close to the walls parallel to the *qibla* (direction of prayer toward Mecca) (Fig. 4e). In this case, both the main and rib arches forming the dome are angled irregularly (highlighted in red), and the geometrical construction of the dome can be analyzed manually rather than in a methodical way. On the other hand, there are at least three different brickwork interventions up to the dome (highlighted as 1, 2, 3), and only the lowest part of the wall (not visible in the photograph) is original. The constructional features of the dome suggest that it was incorrectly reconstructed. This raises the opinion that Pugachenkova's restitution is more accurate. According to the restitution, the second tier of this central dome (Table 2 (space 6d)) has a star-shaped dome edge. This dome can be formed with planar arches as in 1b-e or 145° angled arches.

The dome to the eastern space (6b) also differs from the restitution (Tables 2 and 4). Currently, this space is covered with a half dome and tromps at the corners. Based on the ruins of muqarnas and ribs on the lower part and the half dome construction, which is randomly reconstructed and does not match the geometry of the space, this part was also constructed later and erroneously. However, when derived analytically, the dome indicated in the restitution must give specific plan proportions, as in the fourth parameter of Table 1. Nevertheless, acquired plan geometry, derived this way, does not match the space ratio shown in the restitution. This suggests that the drawing in the restitution may have been made incorrect. In fact, when the arches' angle is slightly rotated per the third parameter in Table 1, the ratios settle into the plan, and the geometry can be deconstructed. The only original dome remaining in the masjid is above the mihrab (Tables 2 and 4 (space 6c)). In this part, a sliced half dome is on the bottom of the octagonal tambour, and a muqarnas is beneath it. The rib arches forming the octagonal tambour have the same cross-section as the main arches and are trimmed where inserted into these. Space 7, in front of the masjid, has been preserved and corresponds to the restitution (Table 3; Fig. 4). The surfaces in this space are plastered with no decoration. The bottom corners of the ribs are equipped with muqarnas. Since the upper story is in ruins, restitution is the only way to examine the cover.

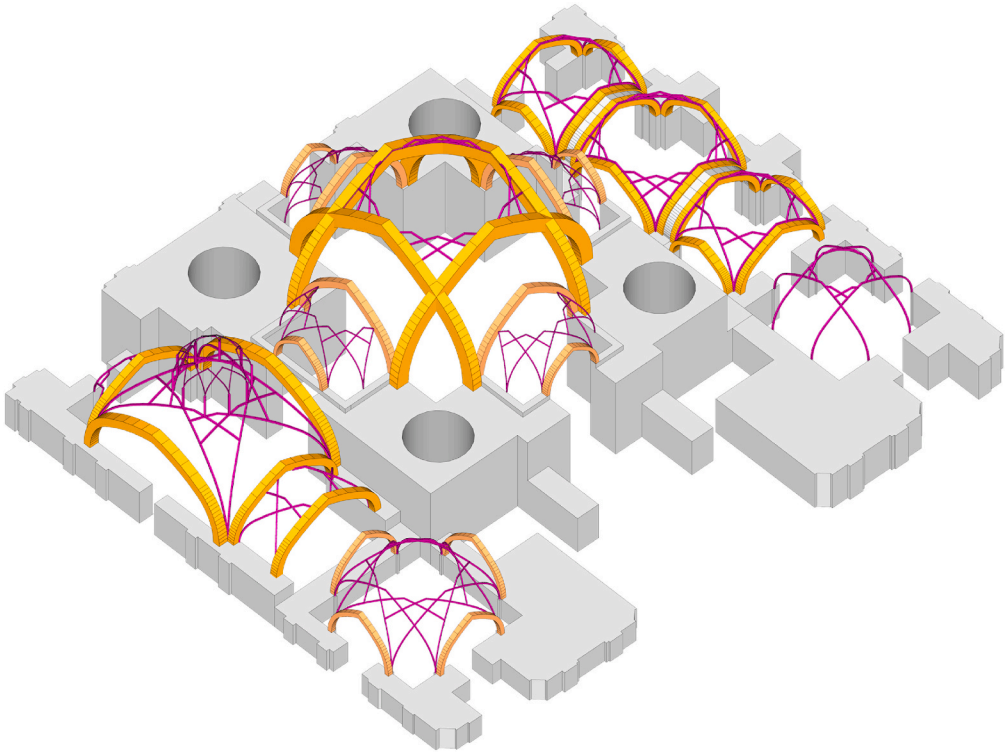


Fig. 6. 3D axonometric reconstruction of the surviving ribbed domes. The walls are rendered in a stepped cutaway style to expose the geometric hierarchy between the main arches (yellow) and the intersecting ribs (purple).

The three-domed space in the south (spaces 3–5), which is entered through an *iwan* (vaulted hall open on one side) leading to the building, is the best-conserved part of the building. Based on the brick construction and the quality of the decorations, this space has yet to be restored from the original construction. It can be seen from the photograph in Fig. 2 "spaces 3 and 4″ are two different domes with the same longitudinal span and equilateral dome tambour. However, "space 3" is planned narrower than "space 4" in restitution, and the dome tambour is not equilateral (Tables 2 and 5). Although the plan form (square) and dimensions of "space 4" in restitution match the current status, the number of tambour edges is indicated as a dodecagon instead of a hexadecagon. Therefore, drawing the current status rather than the restitution should be considered correct. A similar situation applies to equal-sized and shaped domes on both sides of this space (spaces 3 and 5). Although there is no difference in the number of edges between the restitution and the current status, the dimensions are different. According to the restitution, the two opposite sides of the tambour have a larger size than the remaining eight edges. The widths of the vaults on both sides of the dome extending to the façade wall and the staircase are larger than the current status. However, in the current status, each edge is of equal width. Considering that one of these spaces has been preserved up to its embroidery, it has not been reconstructed and is more accurate than the restitution. Hence, as can be seen in Table 5, both main and rib arches of all domes are identical; the central part (space 5) covers a square plan on a hexagonal tambour, while the sides (spaces 3–4) cover a rectangular plan with hexagonal drums.

Due to accessibility constraints, the three-dimensional analysis was limited to the critical structural components (Tables 3–5), excluding the non-existent top floor (Spaces 10–14) and the simple unribbed barrel vaults (Spaces 8, 9, 15, 16). According to the summary presented in the plan scheme (Fig. 5)—where the upper section evaluates the Restitution and the lower section assesses the Current Status:

- Seven out of thirteen domes on the ground floor (marked in yellow) show alignment in both cases and are considered "Correct/ Concordant".
- The domes of Space 1a and Space 6a (marked in green on the upper plan/restitution and red on the lower plan/current status) are identified as 'Incorrect' relative to the existing reality
- The dome of Space 6b is partially incorrect regarding the arch angle in the restitution and fundamentally divergent from the current status.
- Conversely, the domes of Spaces 3–5 appear incorrect in the restitution drawings but maintain geometric integrity in their current status.
- Space 0, whose plan and photographic documentation are shown in Fig. 2, exhibits a similar discrepancy (see Tables 2–3).

The geometric heterogeneity observed across the lateral chambers aligns with the documented multi-regional origins of the Timurid construction workforce. While the central dome conforms to the dominant Transoxanian typology, the distinct rib configurations in the peripheral rooms (e.g., Spaces 3–5) likely stem from the specific construction habits of artisans recruited from different regions, such as Khorasan or Azerbaijan. Consequently, the lack of a standardized geometric modulus in these secondary spaces should be interpreted not as an inconsistency, but as the integration of distinct regional techniques within a single structural program.

To synthesize these geometric analyses and visually demonstrate this structural complexity, a comprehensive three-dimensional model of the ground floor superstructure has been generated (Fig. 6). This axonometric reconstruction employs a stepped cutaway technique to reveal the complex interplay between the structural ribs and the supporting masonry. While the model aims for holistic integrity by including the corner units (Spaces 2 and 7), it should be noted that the geometry of Space 2 (southeast corner) represents an approximate reconstruction due to inaccessibility. Furthermore, the basement level (Space 0) has been excluded from this visualization to preserve the clarity of the primary dome configurations.

5. Conclusions

In the Ishrat-Khana Mausoleum, there are four of the fourteen different spaces are covered with barrel vaults, while the other ten are covered with twenty-three ribbed domes. Twelve domes of different dimensions, ratios, or forms have been identified based on the design parameters. Rathen then this, the dome of the central hall (space 1a) is designed by placing an additional ribbed dome on top of a ribbed lattice. The central dome of the masjid (space 6a) is formed by stacking two ribbed lattices with different geometries. The spatial boundaries of the other two domes (spaces 2a and 11) can be manually identified. Ultimately, it has been concluded that the complex domes of the Ishrat-Khana could only be designed and executed gradually and methodically. Furthermore, it has been revealed that the geometric configuration of the dome determines the spatial proportions and the dome (tambour) diameter.

The results revealed some errors in the restitution project and restoration interventions. Judging by the current status of the building, the central hall (no 1a) and the masjid (spaces 6a-b) were restored incorrectly. The error in the central hall has been identified by comparing the building's precedents, restitution, and old photographs. The errors in the masjid were due to the lack of methodical design. In this regard, the rear part of the masjid (space 6b) is also incorrect according to the restitution. So, the drawing of this part has been corrected by considering the traces of ruins in the current status. According to the restitution, the domes in the southern hall (spaces 3–5) are incorrectly drawn in terms of their dimensions and the edge number of the tambour, and the basement (space 0) is incorrect due to the negligence of the equidimensional of the rib arches. In some cases, it has been realized that plan analyses are not sufficient, and a 3D analysis is necessary. For example, since the rib arches of the central hall will be formed in the same proportion but different sizes with main arches, there is a gradation from part to whole rather than from whole to part, as is customary. It is expected that the results will lead to a corrected and comprehensive restoration of the building and pave the way for the study and restoration of many similar buildings.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

None.

Acknowledgements

I thank the esteemed professors of the Architecture and Civil Heritage faculties of Samarkand State Architecture and Construction University, particular Professor Axtam Uralov and Nodira Fayzullayeva, for providing restitution projects, recent restoration updates, and other valuable documents.

References

Afify, H.M.N., El Moghazy, Z., 2016. Development of the idea of woven arches in modern mosque architecture. In: *Proc. 1st Int. Conf. Mosque Architecture*, Dammam. Univ. of Dammam, Saudi Arabia.

Ahmadi, M.P., 2014. A basic method for naming Persian Karbandis using a set of numbers. Nexus Netw. J. 16, 313–343. https://doi.org/10.1007/s00004-014-0192-x.

Ainechi, S., Valibeig, N., Tehrani, F., 2019. Karbandies' traditional construction technique in tabriz and Isfahan. Int. J. Architect. Herit. 13 (5), 706–725. https://doi.org/10.1080/15583058.2019.1618971.

Ainechi, S., Valibeig, N., 2020. Comparative and contrast study of Karbandie's masonry ribs brick arrangements. Curved Layer. Struct. 7, 166–177. https://doi.org/10.1515/cls-2020-0013.

Akbar, S.A., Asghar, J., Qobad, K., 2017. Visual particularities in the works of qavam al-Din Shirazi. Art-Sanat (7), 143–159.

Akyürek, M.E., 2025. Discovering arches of Timurid architecture: the case of Ishrat-Khana mausoleum. Nexus Netw. J. 27, 741–759. https://doi.org/10.1007/s00004-025-00838-8.

Alkadi, R.M., 2016. The Origin of the Islamic Ribbed Vaults Famed in North Africa and Spain. Tech. Univ. of Madrid. https://doi.org/10.20868/UPM.thesis.47687. Ph.D. dissertation.

Almagro, A., 2015. The great mosque of Tlemcen and the dome of its maqsura. Al-Qanṭara 36 (1), 199–257. https://doi.org/10.3989/alqantara.2015.007.

Bulatov, M.S., 2022. Geometric harmonization in the architecture of Central Asia (9Th-15th centuries). L. Sattarova, Trans. İstanbul, Türkiye: IRCICA.

Chenaghlou, M.R., Mohammadi, A.A., Asefi, M., Vazifeh, P.A., 2017. Structural morphology of a masonry space dome in historical tabriz bazaar complex. In: Bögle, A., Grohmann, M. (Eds.), Proc. IASS Symp. 2017 "Interfaces: Architecture. Engineering. Science. Hamburg, Germany: IASS.

Ebrahimi, A.N., Tooranpoor, M., 2022. Geometry and mathematics in timurid architecture: Abu'l-Wafa and Shirazi. Nexus Netw. J. 24, 843–867. https://doi.org/10.1007/s00004-022-00612-0.

Fuentes, P., Huerta, S., 2010. Islamic domes of crossed-arches: origin, geometry and structural behavior. In: Chen, B., Wei, J. (Eds.), Proc. 6th Int. Conf. Arch Bridges (ARCH'10). Fuzhou University, Fuzhou, China.

Garofalo, V., 2016. The geometry of a domed architecture: a stately example of karbandi at Bagh-e dolat abad in Yazd. Nexus Netw. J. 18, 169–195. https://doi.org/10.1007/s00004-015-0286-0, 2016.

Golombek, L., 1971. The Chronology of Turbat-i Shaikh Jam, vol. 9, pp. 27–44. Iran.

Koliji, H., 2016. Gazing geometries: Modes of design thinking in pre-modern central Asia and Persian architecture. Nexus Netw. J. 18, 105–132. https://doi.org/10.1007/s00004-016-0288-6.

Mainstone, R.J., 2001. Developments in Structural Form. Architectural Press, Oxford, UK.

Mohammadi, A.A., Asefi, M., Ebrahimi, A.E., 2018. The geometric regularization for covering irregular bases with karbandi. Nexus Netw. J. 20, 331–352. https://doi.org/10.1007/s00004-018-0373-0.

Mohammadi, A.A., Ebrahimi, A.E., Shahbazi, Y., 2019. Geometric design of a masonry lattice space dome titled KARBANDI in Persian architecture. Int. J. Space Struct. 34 (1–2), 22–39. https://doi.org/10.1177/09560599198456.

Naeeni, D.S., Esfahani, H.A., Hosseini, I.M., 2017. Recognising Karbandi in Iran's Architecture and a Review of its Decorative-Structural Role, vol. 56, pp. 173–183. https://doi.org/10.1080/05786967.2017.1406789. *Iran*.

Necipoğlu, G., 1995. In: Bloomfield, J., Reese, T.F., Settis, S. (Eds.), Topkapi Scroll: Geometry and Ornament in Islamic Architecture. The Getty Center Publication Programs, Santa Monica, CA, USA.

Necipoğlu, G., 2017. Ornamental geometries: a Persian compendium at the intersection of the visual arts and mathematical sciences. In: Necipoğlu, G. (Ed.), The Arts of Ornamental Geometry. Brill, Boston, MA, USA.

Notkin, I.I., 1961. *Buxarskaya Rez'Ba Po Ganchu v Rabotax Usto Shirina Muradova*, Tashkent, USSR: Gosudarstvennoe Izdatel'stvo Xudojestvennoy Literaturi UzSSR (in Russian).

Özdural, A., 1995. Omar Khayyam, mathematicians, and conversazioni with artisans. J. Soc. Archit. Hist. 54, 54–71. https://doi.org/10.2307/991025.

Özdural, A., 2000. Mathematics and arts: connections between theory and practice in the medieval Islamic world. Hist. Math. 27, 171–201. https://doi.org/10.1006/hmat.1999.2274.

Pugachenkova, G.A., 1958. Arxitekturnaya Xarakteristika Mavzoleya Ishrat-xona. In: *Mavzoley Ishratxona*, Tashkent, USSR: Sbornik Statey, pp. 49–78 (in Russian).

Pugachenkova, G.A., 1963. Ishrat-Khaneh and Ak-Saray, two timurid mausoleums in samarkand. Ars Orient. 5, 177–189.

Pugachenkova, G.A., Rempel, L.I., 1965. Istoriya Iskusstvo Uzbekistana. USSR: Iskusstvo, Moscow (in Russian).

Yusupova, M., Rakhimova, M., Ibragimova, O., 2010. *Sufiyskie Tradisii V Iskusstve Maverannaxra XV-XVII vv: Arxitektura, Miniatyura, Muzika*. Tashkent, Uzbekistan: San'At (in Russian).

Zasypkin, B.N., 1961. Svody v arkhitekture Uzbekistana. Arkhitektumoe Nasledstvo 13, 139–168 (in Russian).