



GEOMETRIC ANALYSIS OF MUQARNASES IN CENTRAL ASIA (BASED ON THE ARCHITECTURAL SCROLL "DAFTAR-I GIRIH")

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Abstract

This study examines the geometry and architectural significance of muqarnas in Islamic architecture, with a particular focus on historical manuscripts and scrolls such as the Daftar-i Girih. Muqarnas, a distinctive element of Islamic ornamentation, are explored through their etymology, classification, structural composition, and geometric principles. The research adopts a multidisciplinary approach combining comparative, chronological, experimental, and geometric analyses with 3D modelling to unravel the complexities of design and construction. By analysing manuscript sources from Uzbekistan, Central Asia, and the Middle East, including the works of traditional architects, the study identifies key structural elements of muqarnas such as the shams, kosa, poya, and taxt. The findings also highlight the importance of two-dimensional construction drawings (taxbins) for interpreting three-dimensional forms. Beyond historical analysis, the study emphasizes the potential of these principles in contemporary design, suggesting their value in restoration practices and modern architectural innovation.

Keywords: Muqarnas, Islamic architecture, Timurid dynasty, Geometric analysis, 3D modelling, Heritage conservation, Restoration, Contemporary applications

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INTRODUCTION

Muqarnas, a unique element of Islamic architectural decoration, has long fascinated both scholars and architects for its intricate geometric patterns and structural complexity (Muhammad Usman Ghani & Usman Ghani, 2021). Islamic art and architecture, enriched with geometry and calligraphy, play a vital role in shaping the cultural and aesthetic identity of historic cities. Their preservation is therefore crucial not only for heritage conservation but also for cultural tourism and sustainable urban development (Baydoun et al., 2023, 2024; Dariyadi et al., 2022). Originating in the early Islamic period, muqarnas developed into a highly sophisticated art form that embodies the fusion of mathematics, craftsmanship, and architectural design. Despite their widespread use, the origins, classification, and underlying geometric principles of muqarnas remain contested topics in scholarship (Muhammad et al., 2025).

The purpose of this study is to address these research gaps through the analysis of historical manuscripts and archival sources from Uzbekistan, Central Asia, and the Middle East. It aims to safeguard traditional techniques of muqarnas construction that are at risk of disappearing with the decline of master builders and limited documentation of their knowledge. Using comparative, chronological, experimental, and geometric methods, this research uncovers the principles of muqarnas design and evaluates their applications in both historical and modern contexts.

The scientific contribution of this research lies in its systematic approach to classifying muqarnas. It also highlights the importance of two-dimensional construction drawings (*taxbins*) in understanding three-dimensional muqarnas structures a concept often overlooked in previous studies. By combining manuscript analysis with 3D modeling, the study creates a framework that not only enhances scholarly understanding but also supports conservation and contemporary architectural practice.

LITERATURE REVIEW

Important insights into the creation and restoration of muqarnas in Islamic architecture can be found in the treatises of encyclopaedic scholars, as well as in manuscripts written by master architects from Uzbekistan, Central Asia, and the Middle East. Many of these are preserved in national archives and major libraries worldwide (Asiva Noor Rachmayani, 2015; Dold-Samplonius & Harmsen, 2015; Fukami, 2017; Zer & Reyhan, 2023). These sources contain valuable geometric diagrams and practical methods, though in many cases the information is incomplete or scattered across texts.

Scholarly interest in muqarnas has grown significantly in recent decades. Earlier studies provided important foundations for understanding girih and muqarnas, yet they often remain general in scope and do not fully address

issues such as typology, modular development, and restoration challenges (Basiri, 2024; Safaeianpour & Valibeig, 2024). For example, while these works shed light on construction methods, they frequently overlook the practical difficulties faced by craftsmen or the role of regional variations in shaping design. Manuscript sources from Central Asia, particularly those held in Bukhara and Tashkent, have also received less attention and rarely been subjected to detailed geometric analysis.

History of studying Muqarnas, classification, and theories of analysis

Research on the etymology and classification of muqarnas is diverse. Some scholars suggest the term derives from the Arabic “qurnas” or “qirnas,” meaning vaulted ceiling (Dinçer & Yazar, 2021). Others connect it to the Greek *korōnís* or the English *cornice* (Carrillo, 2016). Despite differences in terminology, most agree that muqarnas consist of a common set of structural elements: the *shams* (sun), *kosa* (bowl), *poya* (stem), and *taxt* (scaffold), which occur in various combinations and subtypes such as *toranj*, *taseh*, *parak*, and *shaparak*. Understanding these basic elements is crucial, as they form the building blocks of increasingly complex three-dimensional compositions.

Historical Evolution of Muqarnas Geometry

Before the Timurid era, Muqarnas were mainly constructed using modular systems, especially the *rectangular type*, while irregular forms were rare. These structures were typically designed from regular octagons, rectangles, and triangles, and examples remain preserved in Bukhara, Samarkand, Kunya-Urgench, and partly in Termez. Although no manuscripts from Uzbekistan explicitly document this typology, comparative studies have identified parallels in neighboring regions. One of the earliest known examples is the 13th-century Muqarnas at Takht-e Sulayman in Iran (Röhrs et al., 2022) (Figure 1).

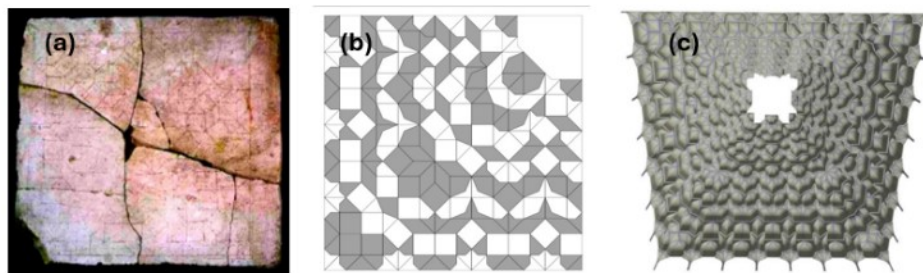


Figure 1. Muqarnas Plan Found at Takht-i Sulayman (Iran, 13th century)

Source : <https://www.geogebra.org/m/dmwdvmsm>.

Geographic Comparisons

While studies of muqarnas in Uzbekistan are relatively limited, broader research reveals rich regional traditions across the Islamic world. In Iran, Safavid-era manuscripts such as those from Isfahan and Yazd illustrate advanced polygonal methods (Koliji, 2016). In Anatolia, Ottoman architects employed muqarnas extensively in portals and domes, with examples like the Sultanhanı caravanserai showing both structural and decorative functions (Dinçer, 2022). Egyptian Islamic architecture also demonstrates innovative uses of muqarnas in transitional dome zones, particularly during the Mamluk period (Fukami, 2017). In Andalusia, the Alhambra in Granada represents one of the most celebrated examples, where muqarnas not only embellish interiors but also symbolize cosmological order. These comparative perspectives highlight the adaptability of muqarnas to different cultural and structural contexts, enriching our understanding of their global architectural role.

Contemporary Scholarship

Modern researchers continue to analyze muqarnas using digital and mathematical approaches. The analysis of early “taxbins” (construction diagrams) shows their connection to vault-building traditions. Giyasaddin al-Kāshī’s *Miftah al-Hisab* remains one of the most detailed historical sources, proposing modular calculation methods for rectangular-based muqarnas (Kāshī et al., 2022). Recent studies using 3D modeling and parametric design have further advanced this field (Brotherton, 2023). However, scholars note that while manuscript analysis offers valuable insights, it also risks narrowing focus to texts alone. Additional case studies from monuments provide a necessary balance, linking theoretical diagrams with real-world construction (Ganikhodjaev & Husain, 2018).

Recent publications in *Planning Malaysia Journal* highlight the cultural and design principles of Islamic architecture in contemporary contexts. Baydoun et al. (2023) examined the role of Islamic art and design in shaping Putrajaya, Malaysia, while Baydoun et al. (2024) explored placement principles of calligraphy in historic palaces. These studies demonstrate how Islamic decorative traditions including muqarnas remain relevant to modern architectural identity, offering useful frameworks for linking heritage knowledge with urban design practice.

RESEARCH METHODOLOGY

This study employs a multidisciplinary methodology that combines comparative analysis, chronological study, geometric examination, and experimental reconstruction. These approaches are supported by two main types of sources: **historical manuscripts** and **architectural sites**. Manuscripts such as the *Daftar-i Girih* provide detailed construction drawings, while fieldwork at monuments in

Bukhara, Samarkand, and other Central Asian cities offers physical evidence of how these diagrams were translated into built form. The inclusion of site-based observations ensures that the research is not limited to textual sources but also engages with architectural practice.

A key feature of this methodology is the integration of **3D modeling**. Digital tools were used to reconstruct muqarnas from historical drawings, allowing researchers to visualize how two-dimensional diagrams (*taxbins*) become three-dimensional architectural elements. This process not only validates the accuracy of manuscript instructions but also reveals hidden geometric relationships that are difficult to detect on paper. By comparing digital reconstructions with surviving architectural examples, the study bridges the gap between theoretical design and practical construction.

The scope of the research includes four main areas:

1. **Origins and etymology** – tracing how the term and concept of muqarnas developed across different regions.
2. **Classification and structure** – identifying recurring geometric modules and categorizing them into groups (rectangular, radial, and mixed).
3. **Manuscript analysis** – decoding historical texts and diagrams, particularly the Bukhara and Tashkent scrolls, to recover lost construction knowledge.
4. **Site comparisons** – examining surviving muqarnas in Uzbekistan, Iran, Turkey, and Egypt to validate and contextualize manuscript findings.

Interviews with traditional craftsmen further enriched the methodology, providing practical insights into materials, tools, and step-by-step construction processes. This combination of textual, digital, and field-based evidence ensures that the study offers not only theoretical classifications but also practical applications relevant to heritage conservation and contemporary architecture.

RESULTS AND DISCUSSION

Analysis of Muqarnas Based on the *Daftar-i Girih* Manuscripts

The *Daftar-i Girih* manuscripts preserved in Bukhara and Tashkent offer some of the most detailed historical diagrams for constructing muqarnas. These texts illustrate how craftsmen used two-dimensional drawings (*taxbins*) as the foundation for complex three-dimensional forms. For example, Figure 2 shows the basic structural elements *shams* (sun), *kosa* (bowl), *poya* (stem), and *taxt* (scaffold) arranged in rhythmic patterns. Such diagrams allowed master builders to determine the number of rows, proportions, and decorative rhythm of a muqarnas vault.

Our study identified several types of **Muqarnas** and found that, despite their variations, they all share a common structural system composed of four basic elements:

1. **Shams** (sun),
2. **Kosa** (bowl) – also known as *kosagi* in Persian,
3. **Poya** (stem), and
4. **Taxt** (plank or scaffold).

Each of these elements has its own variations, such as *toranj*, *taseh*, *parak*, *shaparak*, *g'ozpoya*, and others (Figure 1).

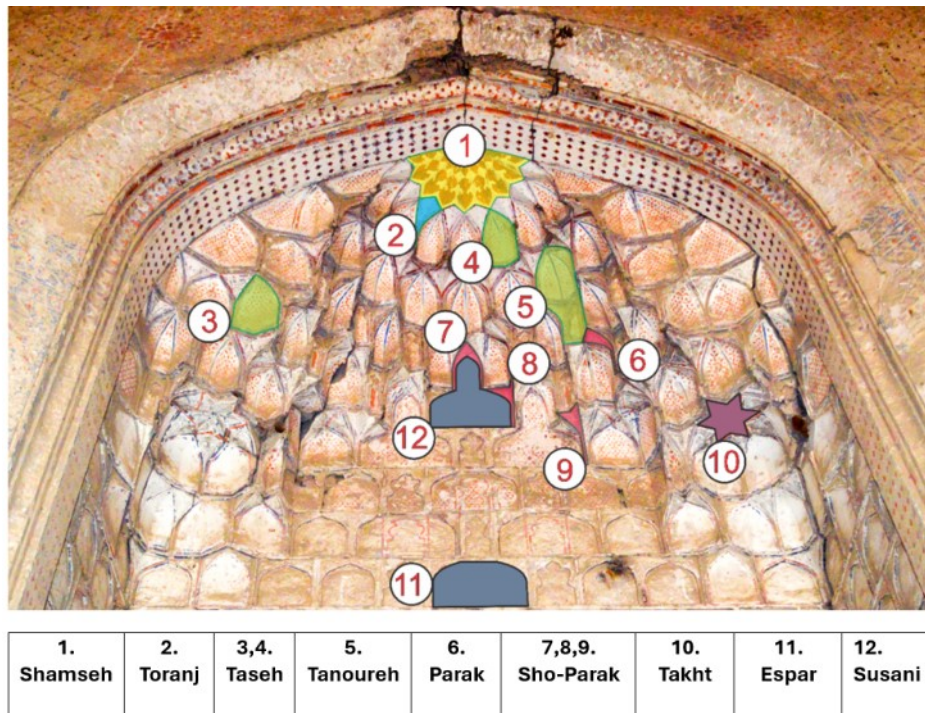


Figure 2. The constituent elements of muqarnases

Source: According to Sh.Sh. Mustafayev.

Geometric Principles and Simplification

The geometry of muqarnas often appears intimidating because of its many layers and repetitions. However, manuscripts reveal that these designs are based on simple geometric shapes such as squares, hexagons, and octagons. By dividing circles into equal segments and linking points with straight lines, craftsmen

generated star polygons that formed the backbone of the design. Figure 3 demonstrates how a rectangular base can be divided into modular cells, later “stacked” into three-dimensional niches.

This simplification makes muqarnas more understandable: what seems like a highly complex vault is in fact a repetition of a few geometric modules carefully scaled and combined.

A key point is that the essence of Muqarnas construction lies in the taxbin (construction drawings). Skilled craftsmen rely on taxbins to understand the type of Muqarnas, determine the number of rows, and design the rhythmic composition of taxts that create the overall flow of the structure (Figure 3).

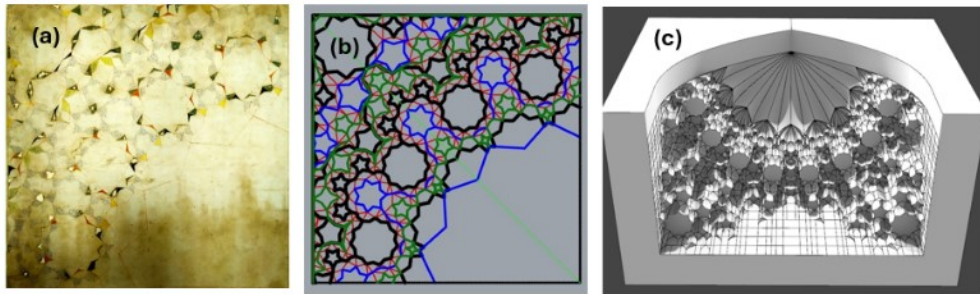


Figure 3. From two-dimensional taxbin to three-dimensional niche form. Structure, analysis, and three-dimensional view based on “taxt” of muqarnas

Source: Daftar-i Girih" No. 2/1, according to Sh.Sh. Mustafayev.

Integration of Site Evidence

While manuscripts are invaluable, relying solely on them creates a limitation. To address this, we compared manuscript diagrams with **architectural sites**:

- **Uzbekistan (Samarkand, Bukhara):** The Registan’s Sher-Dor Madrasa and Bukhara’s Abdulaziz Khan Madrasa show direct applications of manuscript-based diagrams, with muqarnas decorating iwans and domes.
- **Iran (Isfahan):** The Sheikh Lotfollah Mosque demonstrates how Safavid builders transformed polygonal diagrams into elaborate domed transitional zones.
- **Egypt (Cairo):** The Sultan Hasan Mosque and later Mamluk structures employed muqarnas in dome transitions, proving their adaptability in different structural contexts (Fukami, 2017).
- **Spain (Granada):** The Alhambra’s Hall of the Two Sisters illustrates the decorative potential of muqarnas, where geometric order is transformed into symbolic cosmology.

These comparisons demonstrate that although the visual styles vary, the underlying geometric logic remains consistent across regions. This validates the

Daftar-i Girih as not just a local but a broadly applicable guide to muqarnas construction.

In global scholarship, works by Shiro Takashi and Hamidreza Kazempour are particularly notable. They classified Muqarnas into three categories: (1) Rectangular-based Muqarnas, (2) Radial-ring Muqarnas, and (3) Mixed Muqarnas (Figure 4.) (Brotherton, 2023; Kamyab et al., n.d.).

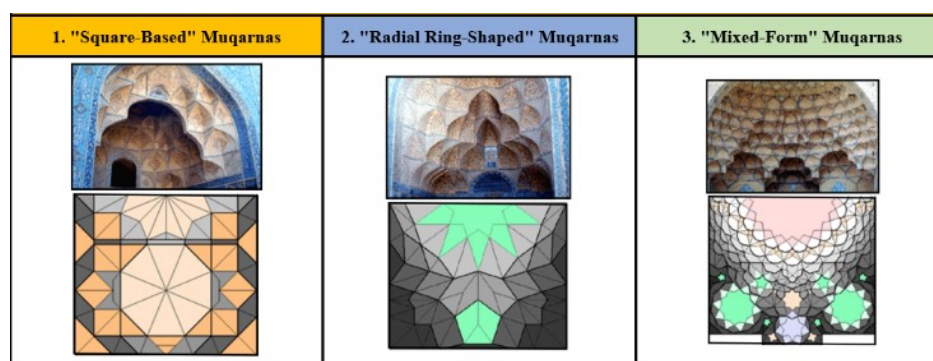


Figure 4. Square, radial and mixed muqarnas

Source : <http://www.shiro1000.jp/muqarnas/default-.htm>.

Building on historical manuscripts and surviving monuments, our study also proposes dividing Muqarnas into three groups and subgroups. While additional subgroups may be identified in different regions, this study focuses on Uzbekistan only. These groups are illustrated in Figure 5.

Comparative Analysis of Muqarnas in Manuscripts of the Islamic World

Understanding the geometry of **muqarnas** the intricate three-dimensional decorative elements of Islamic architecture requires both design knowledge and an awareness of construction techniques. This section compares manuscript sources that explain muqarnas design, with examples from Uzbekistan, Iran, Turkey, and beyond. By broadening the scope, we place these traditions within the wider context of Islamic art, linking them to developments in the Middle East, North Africa, and even parts of Europe where Islamic architectural influence spread.

Early Origins and Manuscript Traditions

The use of geometric patterns in architecture has deep roots. According to the Metropolitan Museum of Art (2004), some of the earliest examples may trace back to Byzantium and the Sassanian Empire (Bartman, 2022). Later, in the Islamic world, scholars such as mathematicians and astronomers refined these geometric systems, laying the groundwork for muqarnas.

Historical manuscripts including those by **Ghiyāth al-Dīn al-Kāshī** and **Abu'l-Wafā' Būzjānī** demonstrate the careful arithmetic behind muqarnas. These texts reveal how simple tools like a compass and straightedge could generate highly complex patterns. Al-Kāshī's *Miftāḥ al-Ḥisāb* (The Key to Arithmetic) remains one of the most important works, valued not only for mathematics but also for its architectural applications (Kale, 2020).

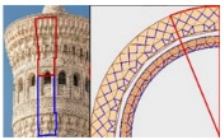
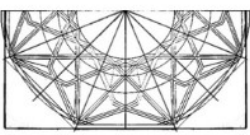
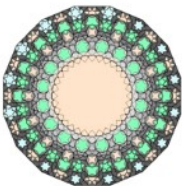
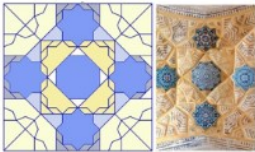
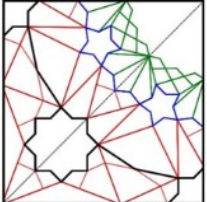
I. MUQARNAS	II. IROQI	III. MIXED «CHORZAMIN»
I.1. "Square-Based"	II.1. "Rasmi bandi"	III.1. Type "Mixed" Muqarnas
		
I.2. "Radial Ring-Shaped"	II.2. "Kaseh sazi"	III.2. Type "Mixed" Muqarnas
		
I.3. "Aviz"	II.3. "Yazdi bandi"	
		

Figure 5. Structural groups of Muqarnas
Source: According to Sh.Sh. Mustafayev.

Geometric Groups of Muqarnas

Researchers often classify muqarnas into three main groups:

1. **Muqarnas Group** – Based on polygons such as 12-, 7-, and 5-sided stars. Their designs rely on precise ratios and careful layering of rows, as seen in Al-Kāshī's manuscripts (Figure 6).

2. **Iraqi Group** – Simpler in form, often constructed from squares and octagons. Rotational symmetry plays a key role, producing structures that could easily be raised into three-dimensional forms (Figure 7).
3. **Chorzamīn or Mixed Group** – Formed by blending principles of the previous types. These often reduce the depth of arches and introduce ellipsoidal rays, asymmetry, and more complex three-dimensional cavities (Figure 9).

Through these methods, scholars codified the hidden rules of proportion that guided craftsmen across the Islamic world.

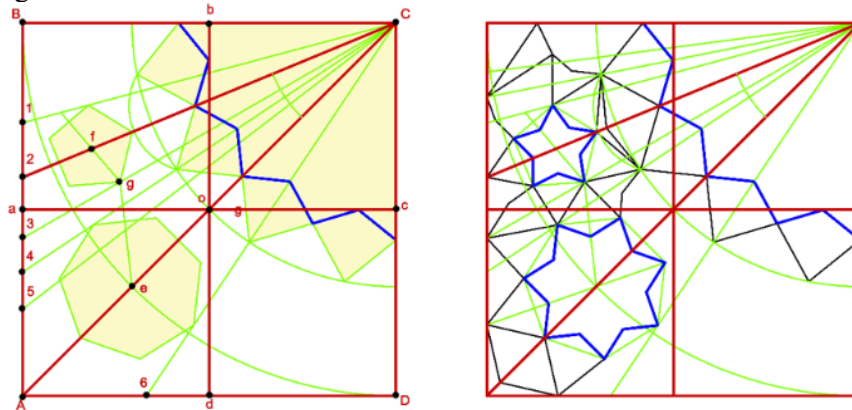


Figure 6. Method of Geometric Analysis of plans for the "Muqarnas" Group
 Source: According to Sh.Sh. Mustafayev. (Manuscript of Giyath al-Din al-Kashi and A. Sharbaf)

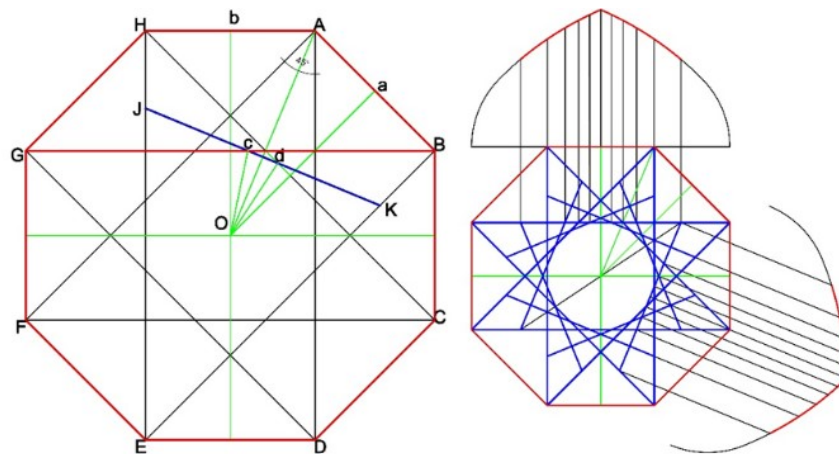


Figure 7. Method of Geometric Analysis of plans for the "Iraqi" Group
 Source: According to Sh.Sh. Mustafayev. (Manuscript of Giyath al-Din al-Kashi and A. Sharbaf)

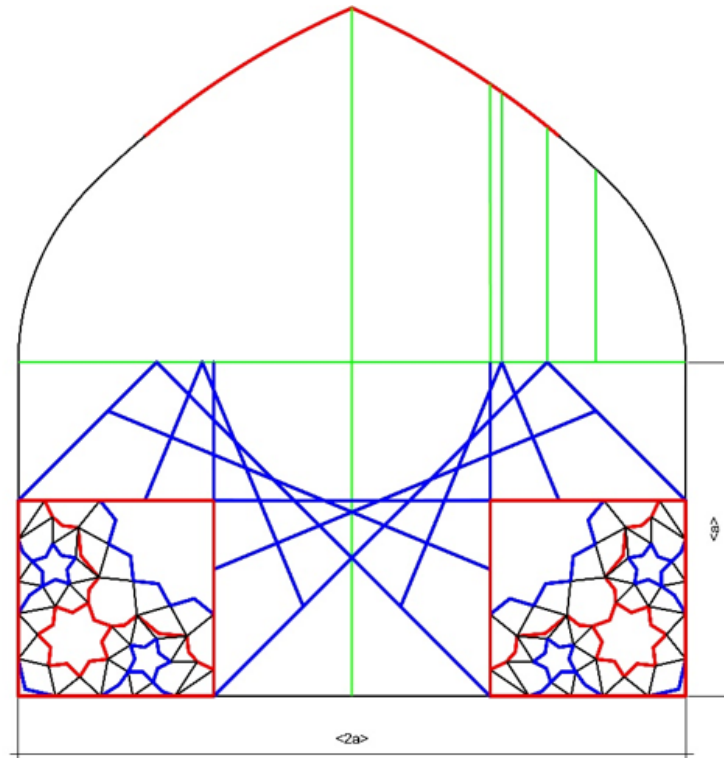


Figure 8. Method of Geometric Analysis of plans for the "Chorzamin or Mixed" Group
Source: According to Sh.Sh. Mustafayev (Manuscript of Giyath al-Din al-Kashi and A. Sharbaf)

Broader Geographical Context

While manuscripts from Uzbekistan, Iran, and Turkey are especially detailed, similar traditions appear across a much wider area:

- **Egypt and North Africa** – The muqarnas of the Fatimid and later Mamluk periods show local adaptations of the geometric principles recorded in manuscripts.
- **Al-Andalus (Spain)** – The Alhambra in Granada contains some of the most celebrated examples, showing how the science of muqarnas traveled westward.
- **Central Asia and India** – Timurid and Mughal architecture integrated muqarnas into monumental gateways and domes, proving their importance along the Silk Road.
- **Modern Conservation Practices** – Today, manuscripts like those in the Topkapi Palace (Necipoğlu, 1986) are not only studied by historians but also guide digital restoration and conservation worldwide.

By comparing these regions, it becomes clear that muqarnas were never isolated to one cultural center. Instead, they formed part of a shared scientific-artistic language across the Islamic world, later influencing European Gothic vaulting and other global traditions.

Significance for Research and Practice

Al-Kāshī and other scholars did more than preserve knowledge they systematized it, making it usable for builders. Their diagrams helped craftsmen calculate row sequences, star patterns, and even parabolic surfaces for domes.

Archaeological evidence shows that even when manuscripts were lost such as during the Mongol invasions builders still relied on sketches and geometric knowledge. The **Topkapi Manuscript** (15th–16th century) stands out with over 100 geometric patterns, including 83 muqarnas diagrams. Written in a single hand and richly illustrated, it highlights how artisans from Iran to Anatolia created a unified system of design.

Together, these manuscripts confirm that muqarnas design combined art, mathematics, and a degree of secrecy. They remind us that Islamic architectural heritage was global in scope, continuously evolving across regions and centuries.

Contemporary Applications

Understanding the geometric basis of muqarnas also has **practical relevance today**. For instance:

- **Restoration projects based on UNESCO grants** have employed digital reconstructions of *taxbins* to repair damaged niches, ensuring fidelity to original design principles.
- **Modern architecture** such as proposal projects for interior and exterior decoration of the Islamic Civilization Center (Tashkent).
- **Parametric design** tools now allow architects to generate muqarnas-like patterns for façades, ceilings, or even urban installations, preserving traditional aesthetics while embracing modern materials.

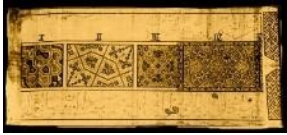
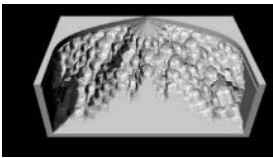
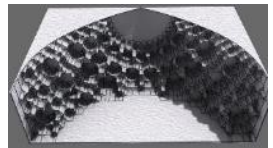
These applications show that muqarnas are not confined to history; they continue to inspire innovative approaches to design and conservation **Table 1**.

CONCLUSION

This study clarified the geometry, classification, and cultural significance of muqarnas by combining manuscript analysis with site-based evidence and digital modeling. The research confirms that all types of muqarnas are based on takhbin(plans), which are based on simple geometric modules. If we translate

these 2D plans to 3D through taxbins, we form the foundation of highly complex three-dimensional vaults. Comparative examples from Uzbekistan, Iran, Turkey, Egypt, and Andalusia demonstrate both shared principles and regional adaptations. Beyond historical scholarship, the findings show how muqarnas knowledge can support restoration, digital reconstruction, and innovative applications in modern architecture. Future research should extend geographic comparisons and employ advanced technologies to further connect traditional methods with contemporary practice.

Table 1

Contemporary Applications		
Restoration projects	Modern architecture	Parametric design
		
		

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