

“Muqarnas in Damascus: A Forgotten Treasure’s History, Inception and Geometry”

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Abstract

The architecture of the Islamic world encompasses both religious and secular buildings that are unified by the use of a common architectural language, which includes architectural elements such as minarets, domes and arches, ornamental details, and vaulting with the use of muqarnas. The study provides a broad overview of the development of Islamic architecture, focusing on Damascus, the early Islamic period, the mid-Islamic period and the late Islamic period. The late Islamic period includes Ottoman art, with architecture influenced by Byzantine, Persian, Armenian, and Mamluk artefacts, but differs from their predecessors. The researcher undertook a geometric analysis of the muqarnas domes of al-Madrassa al-Nuriyya al-Kubra, the eastern entrance of the Citadel, the Madrasa-al-Zābirīyah, and the Umayyad Mosque in 3D. The creation of muqarnas today in Damascus is discussed, the researcher having communicated with craftsmen in the Radwan and Yaser workshops of the city.

Keywords: Islamic World, Islamic History, Religious Architecture, Islamic Culture, Dome.

INTRODUCTION

From the eighth to the nineteenth century AD in the Middle East and across the Islamic world, art and architecture were being produced based on existing Greek, Roman, Byzantine and Sasanian traditions, which in turn were affected and shaped by Islam (Lapidus, 2012; Robinson, 1996) As Oleg Grabar writes:

“Islamic art should always have an adjective attached to it to refer to its ethnic, cultural, temporal, geographic or religious origins. For example, ‘early’, ‘late’ ‘classical’, ‘Iranian’, ‘Arabic’, ‘Turkish’” (Grabar, 1987).

The architecture of the Islamic world encompasses both religious and secular buildings that are unified by the use of a common architectural language, which includes architectural elements such as minarets, domes and arches; ornamental details such as geometric mosaics, patterned brickwork, calligraphic adornments; and hybrid elements such as muqarnas vaulting that are able to fulfil both structural and ornamental roles (Blair & Bloom, 1996; Damadi, 2013; Embi & Abdullahi, 2012; Rashid, 2020).

The word ‘muqarnas’ is both singular and plural, the passive participle of the Arabic term

‘qarnīṣ’. Words listed under the root ‘qarnīṣ’ have many meanings.

“Various words are listed under both the *ṣīn* and the *sād* form of the root q-r- n-s/s. One of these words stands out as a very likely candidate for being the etymon of muqarnas. It is the geographical morphological term *qurnās* (also *qirnās*) which is defined as ‘something like a nose projecting in a mountain.’ Accepting this, “the verb *qarnasa* would mean something like ‘to furnish a structure with projecting overhanging elements’ and the part. pass. *muqarnas*, consequently, would originally have meant ‘(a structure) furnished with projecting overhanging elements.’” (Dold-Samplonius, 1992)

Muqarnas are three-dimensional (3D) compositions, created from a limited number of units that are repeated to form a seemingly complex whole. Also known as “stalactite” or “honeycomb vaults”, (Ahmed & OLA, 2022) they are typically used to adorn domes and half- domes in apses and iwans (portal arches) (Saremi Naeni et al., 2018). Islamic architecture’s mesmerizing 3D muqarnas have exquisite geometric designs. Such designs create complex 3D surfaces by layering together a number of fundamental components. A new method for interactively modelling muqarnas is presented in this work, and is based on their layered structure. Floor plans

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are utilized as guidelines for the modelling process. Additionally, how to update the generated models and automatically create new forms is discussed in detail (Hamekasi et al., 2011). Many architects and historians acknowledge that muqarnas forms are at serious risk of extinction, (Hamekasi et al., 2011) and the motivation for this paper was to study the development of muqarnas within their historical, architectural and cultural context, with the aim of demonstrating the geometries that make this art form possible.

Islamic Architectural History and Culture (AD 622-1924)

This section of the paper covers the period between AD 622 to 1924, a period which has been termed “the age of the Caliphates”. The first of these dates marks the birth of Islam, while the second marks both the birth of the modern state of Syria and the abolition of the Ottoman Caliphate. The section begins by giving a broad overview of the development of Islamic architecture with a focus on Damascus.

Early-Islamic period (AD 622-750)

The Islamic Calendar began on 19 April AD 622, when Muhammad and his followers migrated from Mecca to Yathrib, later renamed Medina. (Kennedy, 2022) They used Medina and Mecca as their bases to conquer and unite the Arabian Peninsula under Islam. The region was arid, with limited agricultural opportunities, and most indigenous people lived nomadic lifestyles. As a result, there were few settlements and little architectural development in the region (Denny, 1979).

After Muhammad died in AD 632, the role of Caliph was divided between four of his followers, leading to the Rashidun Caliphate (Abū Bakr (reigned 632–634), ‘Umar (reigned 634–644), ‘Uthmān (reigned 644–656), and ‘Alī (reigned 656–661). (Haberl, 2023) The empire expanded eastwards into the Sasanian Empire and westwards into the Byzantine Empire. The Rashidun Caliphate ended in AD 661 with the assassination of Ali Ibn Abi Talib (Abbas, 2021; Denny, 1979).

Ali’s successor as Caliph was Mu‘āwiyah ibn Abī Sufyān, who had previously been acting as the role of governor of the Levant (AD 639-661) (Denny, 1979). Mu‘āwiyah's first act as Caliph was to move the capital from Kufa to Damascus, leading to economic and architectural development in the city and surrounding regions (Wiryomartono, 2023). Umayyad architecture (661–750) fuses elements of Byzantine and Sasanian styles, with the Dome of the Rock in Jerusalem being the first example of Islamic architecture (Renima et al., 2016). The dome, 20 meters in diameter, is believed to have been inspired by neighboring Christian churches, but uses intricate patterns and geometric mosaics inspired by Sasanian architecture. It is a shrine, unlike many early Syrian mosques which were converted Christian churches, consisting of a 20 meter diameter dome and completed in AD 692 (Bloom, 2020; Denny, 1979).

Under the caliph Mu'awiya Ibn Abi Sufyan, a site in Damascus was chosen for prayers, initially a temple of the Aramaic deity Hadad. When the Romans ruled Damascus, it had been the site of the Temple of Jupiter (Akili, 2009). The temple walls hosted both the church and the first mosque, with the first mosque located between the southern doorway and the south- eastern gate (Sobczak, 2015). The building features a large courtyard (122.5 by 50 meters), which is surrounded by a portico and through which one enters the main prayer hall (Cytryn- Silverman, 2009). The Great Mosque of Damascus, built between AD 706 and 715, (Fiorentino, 2021) was one of Syria's first purpose-built mosques during the reign of the sixth Umayyad Caliph, Al-Walid ibn Abd al-Malik (Denny, 1979). Located on the site of a former Byzantine Christian cathedral, the architects recycled the church’s columns and arcades, integrating them into the new layout. The mosque features a large courtyard, a prayer hall with three arcades parallel to the southerly direction, and a central dome (the Dome of the Eagle). The Umayyad Mosque inspired many future mosques, including the Great Mosque of Córdoba (AD 784-786) (Anderson, 2013). The mosque features the world's first minaret, a converted Byzantine tower, and is an example of the hypo-style mosque, the first of the three principal mosque typologies (Denny, 1979).

Middle-Islamic period (AD 750-1517)

After the fall of the Umayyads (AD 750), Damascus was stripped of its capital city status, and Al-Mansur established Baghdad in Iraq as a new capital city. Al-Mansur, who in power from 754 up to 775 AD, was also called as, Abu Ja'far Abdallah ibn Muhammad al-Mansur. He was the second Abbasid caliph. There is an

opinion that al-Mansur was one of the most powerful and wise rulers of the Abbasid caliphate (Al, 1988). He is considered as one of the major historical figures in Islamic history particularly for establishing Baghdad as the capital of Abbasid Caliphate in the year 762 AD (Kennedy, 2016). The Abbasid Dynasty (AD 750- 1258) was heavily influenced by Persian culture, leading to early architecture influenced by Sasanian techniques, just 35 kilometers to the northwest of Ctesiphon in Persia (Riyadi & Putra, 2022). Buildings were constructed from mud brick, baked brick, or rough stone set into mortar, with walls covered in plaster for protection. Three new types of stucco decoration were invented in Samarra in Iraq, which served as the Abbasid capital between AD 836 and 892, and spread across the Islamic world (Sijpesteijn, 2022). One of these, known as the arabesque style, featured repeating patterns of intertwined lines (Denny, 1979).

The Abbasid era saw the development of two main architectural styles: the hypostyle and the four iwan mosques (Denny, 2010). The Great Mosque of Cordoba, built in AD 785, followed the same design as the Umayyad Mosque in Damascus (see Figure 1 for the entrance hall ceiling) (Gutierrez, 2022). The Great Mosque of Isfahan also modelled as a hypostyle mosque (Scerrato, 1994). Damascus' architectural development was limited after the fall of the Umayyads, but the treasury dome was added in AD 789 (Denny, 1979).



Figure 1. Damascus: Umayyad Mosque, entrance hall ceiling (Source: Author).

The Fatimid rule of Damascus and Syria ended in AD 1076 with the arrival of the Seljuqs. They were independent of the Sunni Abbasids but operated under their moral authority. The Seljuqs revived Damascus' fortunes and built numerous schools (madrasas) and hospitals with private funds (Blair & Bloom, 2006).

Damascus fell under the Ayyubid dynasty (AD 1171-1260), founded by Saladin. (Wong, 2019) Saladin adopted the Citadel of Damascus as his official residence and upgraded its defensive walls and residential buildings (Humphreys, 1977; Rabbat, 1995). After Saladin died in AD 1193, the Citadel was severely damaged by an earthquake in AD 1201, (Raphael, 2013) and was rebuilt between AD 1203 and 1214 by Al-Adl; Saladin's brother and eventual successor (Burns, 2007). The Eastern Gate, an exceptional example of muqarnas, was one of the most striking and ornate features of the new design (Denny, 1979). The Ayyubid architectural legacy is primarily military, as five of the nine crusades occurred during this period. Despite disruptions caused by regular attacks, Damascus continued to grow and develop on account of the court's involvement in building and endowing religious and charitable institutions, which began under the Seljuqs (Burns, 2007; Darwish, 2021). Following the death of Nur al-Din (AD 1174) (see Figure 2 of the Bimaristan Nur-al-Din in Damascus AD 1154), Damascus fell under the jurisdiction of the Ayyubid Dynasty (AD 1171-1260), founded by Saladin (Humphreys, 1977).

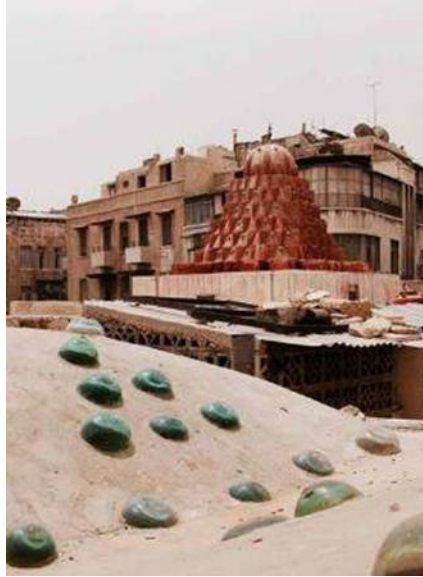


Figure 2. Damascus: Bimaristan Nur al-Din, AD 1154 (Source: Author).



Figure 3. Damascus: The eastern gate of the Citadel, AD 1203-14 (Source: Author).

The Mamluks, led by Al-Zahir Rukn al-din Baybars (Baybars I) (AD 1260-77), aimed to rebuild the centralized empire that Saladin had founded by investing heavily in transport infrastructure, building roads and bridges, and establishing a postal network (Fleck, 2022). The Mamluks built on the legacy of the Ayyubids and developed the city's infrastructural foundations, including an excellent water and sewage system. This allowed them to add to the city's collection of hammams (public bath houses), including Hammam al-Jadid, Hammam Qaimariye, Hammam Nur al-Din, and Muqaddam Hammam, which still function commercially today. However, the city's abundance of clean water did not prevent the spread of the Black Death, which afflicted the city between AD 1348 and 1349, resulting in half the population's death. The city's misfortune was further compounded in

AD 1400 when Damascus was besieged by the Turco-Mongol emperor, Timur, who aided construction projects in Samarkand, Uzbekistan (Asimov & Bosworth, 1992; Denny, 1979).

As Baghdad declined, Cairo became the new cultural and intellectual center of the Islamic World, with a flourishing of architectural investment (Denny, 1979). The skyline of Cairo was transformed by funerary domes and minarets, becoming prominent in Mamluk architecture. This trend developed as wealthy individuals erected their memorials, often integrating them into larger charitable institutions such as mosques, madrasas or maktabas (schools), bimaristans (hospitals), and public fountains. The fundamental disparity between the two institutions is rooted in the educational level and curriculum existed for madrasas and maktabas. Maktabas are primary schools in which fundamental education is provided and madrasas which offer higher education where emphasis is made on religious education (Denny, 1979).

Late-Islamic period (AD 1517-1922)

The Mongol threat, replaced by the Safavid Empire in Persia, was again replaced by the Ottomans in AD 1514. (Kunt, 2005) The Ottomans, led by Mehmed II, renamed their capital Constantinople as Istanbul, and Mehmed ordered an Imam to meet him at the Greek Orthodox Basilica of Hagia Sophia. The Imam chanted the adhan (a call for prayer), transforming the Christian cathedral into a Muslim Mosque. It marked a significant transformation, similar to the Umayyads’ previous transformation of churches in Damascus (Blair & Bloom, 1996).

Hagia Sophia, differed significantly from the architecture of Damascene churches because of its large dome and surrounding half-domes. The church was damaged during the sacking of Constantinople, requiring renovation and the addition of two minarets (Hart, 2003). It became a model for future mosques, such as the Selimiye mosque in Edirne, Turkey, completed in 1574, which was one of the greatest artistic achievements of the Islamic world (García et al., 2021). Ottoman art and architecture are influenced by Byzantine, Persian, Armenian, and Mamluk works, but differ from their predecessors (Peker, 2002). Ottoman architects created dynamic and complex structures using domes, semi-domes, vaults, and columns, with ornamental sculptures such as muqarnas. This contrasts with the decoration of structures in other Islamic cultures, which focused on simple features (Saoud, 2004).

The Tekkiye mosque in Damascus, completed in AD 1559, is a prime example of Ottoman architecture (Chevedden, 1977). The mosque follows the dome typology, and features ablaq, an architectural style popular during the first century of Ottoman rule (Darke, 2022). Damascene architecture was evident during the Classical Period of the Ottoman world, reaching the highest point of finest architectural achievements (AD 1437-1703) (Tiliouine et al., 2016). Notable examples from this period, which fall within the Middle or Modernization period of Ottoman architecture, include the Azm Palace (see Figures 4 and 5) and the Khan As’ad Pasha (see Figure 6) (Brzezicki et al., 2019).



Figure 4. Damascus: Azm Palace, 1749, with wooden ceiling muqarnas (Source: Author).



Figure 5. Damascus: Azm Palace, 1749., Wooden ceiling muqarnas (Source: Author).



Figure 6. Damascus: Khan As'ad Pasha (Source: Author).

Inception of the Muqarnas

This section focuses on the development of muqarnas.

Archaeological digs, led by Charles K Wilkinson in Nishapur, north-east Iran, discovered the earliest known muqarnas-like forms (1935-40 and 1947). Triangular pieces of concave stucco were reassembled to form a tripartite squinch. Yasser Tabbaa suggests this is supported by a similar tripartite squinch, built beneath the Arab-Ata mausoleum in Tim, Uzbekistan, and dating back to the tenth century AD. However, he concedes that this example:

“Is not so much of a muqarnas as of a dome that is well integrated with its substructure by means of a somewhat less obtrusive transition zone.” (Tabbaa, 2011)

He asserts the following:

“A study of muqarnas vaulting should focus simultaneously on the earliest occurrences of this decorative system and on those crucial junctures when a particular architectural form is so subsumed by subdivision (or quarnasa) that it must be described as muqarnas. This is not simply a matter of idle speculation, for in domes, muqarnas was first rather discretely applied only to the transition zones before completely subsuming the entire form.” (Tabbaa, 2011)

The Gunbad-i Ali, a minaret in Abarkuh, Iran, is an early example of a muqarnas form. It features three niche-like forms, forming a highly sculpted band of masonry. Although mortared rubble was used, most contemporary structures would have used brick (Denny, 1979). This form of masonry detailing may have originated from local building traditions, as seen in the Pir-i Alamdar tomb tower in Damghan, Semnan, Iran, dating from AD 1027 (Bloom & Blair, 2009).

Two early muqarnas-like forms were discovered at Qal-at Bani Hammad in Algeria, believed to date from the eleventh century. The first features a group of parallelepipeds, three-dimensional figures formed by six parallelograms. It is speculated that these forms combined to form pendants hanging from a flat roof corner. However, this hypothesis is not universally accepted (Tabbaa, 2011).

Egypt is a central location in the Islamic World, known as the origin of muqarnas. Small mausoleums and squat minarets from the eleventh and twelfth centuries, such as the Minaret of Badr al-Jamali and the façade niche hood and chamfered corner of Al-Aqmar Mosque, date from the Fatimid rule. These examples may have been developed by lesser patrons other than Fatimid caliphs or viziers (Tabbaa, 2011). Muqarnas were inspired by domes and minarets that once existed at the Haram of Makka (the Great Mosque of Mecca) (Blair & Bloom, 2006). In his chronicles, Ibn Jubayr (AD 1145-1217) describes the last of the four domes of the Haram as follows:

Over the portal is a large dome, remarkable because it is almost as high as the adjacent minaret. Its interior is covered with marvelous plasterwork and quarnasi carving that defy description. The exterior is also made of carved plaster, resembling interlaced drums. (Tabbaa, 2008)

Cairo, part of the popular pilgrimage route to Mecca via the Red Sea crossing, is inspired by the lost architecture of the Hejaz, which includes Mecca and Medina (Freitag, 2020).

Furthermore, a muqarnas dome dating from AD 1085 was once in the village of Dur, 70 kilometers north of Baghdad (Petersen, 1996). The shrine of Imam al-Dur featured an elongated cube, an octagonal drum, and three tiers of muqarnas topped by a small cupola. The dome was transformed into an octagon by four squinches and four arches, and consisted of four more eight-celled tiers with decreasing cell sizes, each with a 45-degree rotation. (Tabbaa, 1985, 2011)

Geometry

This section of the paper explains the geometry of traditional muqarnas compositions, looking at muqarnas in plan and studying how they work in two dimensions. The underlying geometry of muqarnas is described, before setting out how traditional muqarnas were, and are still, being manufactured. The geometry represented on the Ilkhanid Plate is studied. The two-dimensional (2D) plan of the muqarnas is translated into 3D, describing the various geometrical styles and architectural applications of muqarnas, and the section concludes with descriptions of four case studies of muqarnas compositions from Damascus.

The Muqarnas in Plan

A stucco muqarnas fragment was discovered at the former Ilkhanid palace in Takht-i Sulayman (Blair, 1993). It is now housed at the Islamic Department of the Iran Bastan Museum in Tehran. The muqarnas design features squares and rhombi (four-side polygon) with right-angled isosceles triangles, all 3.5 centimeters long, symmetrically arranged around a diagonal axis, and an irregular quarter-octagon in the upper right corner (Dold-Samplonius & Harmsen, 2005).

The Ilkhanid Plate, a complex geometric structure, appears to resemble Euclidean tiling patterns, but it is not a regular polygon. The plate consists mostly of squares and rhombi, which are not regular polygons. The interior angles of these rhombi are $45^{\circ}/135^{\circ}/45^{\circ}/135^{\circ}$, indicating that the tiling pattern does not belong to the periodic Euclidean or Aperiodic families. The rationale behind the geometry of the Ilkhanid Plate is attributed to the Persian astronomer and mathematician, Ghiyath al-Din al-Kashi (Dold-Samplonius & Harmsen, 2005; Garofalo, 2011; Necipoğlu, 1996).

Al-Kashi, the author of *The Key of Arithmetic*, published in 1427, is known for providing the oldest known definition of a muqarnas vault (Dold-Samplonius, 1992). He stated that:

“The muqarnas is a roofed (musaqqaf) vault like a staircase (madraj) with facets (dil’) and a flat roof (sath). Every facet intersects the adjacent one at either a right angle, half a right angle, or their sum, or another combination of these two. The two facets can be thought of as standing on a plane parallel to the horizon. Above them is built either a flat surface not parallel to the horizon or two surfaces, either flat or curved, that constitute their roof. Both facets, together with their roof, are called one cell (bayt). Between the roofs of two adjacent cells, a curved surface can be located in the form of a triangle or two triangles. Adjacent cells, which have their bases on the same surface parallel to the horizon, are called one tier (tabaqa). The measure of the base of the largest facet is called the module (miqyas) of the muqarnas.” (Dold-Samplonius, 1992)

A muqarnas is composed of two or more tiers (horizontal layers) (Yaghan, 2010). Each tier is composed of a number of adjacent elements. Depending on their geometric characteristics, these elements can be defined as either “cells” or “intermediate elements” (Dold-Samplonius & Harmsen, 2015; Gherardini & Leali, 2016). Muqarnas designs require at least three cells, with the highest face having three or four edges. Each cell has three or four vertical outer faces, with at least two having a length of one unit. Two curved outer faces have a width of one unit and are joined along the shortest edge (Al Jumaily). The remaining vertical faces are rectangular and the full height of the cell, making them the “back-faces” (see Figures 7, 8, 9 and 10) (Al Jumaily).

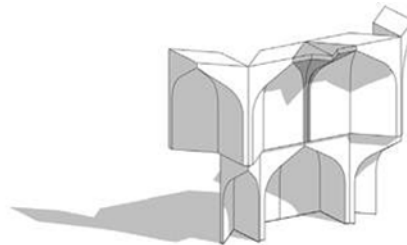


Figure 7: A muqarnas composed of three units, featuring two ‘tiers’(Source: Author).

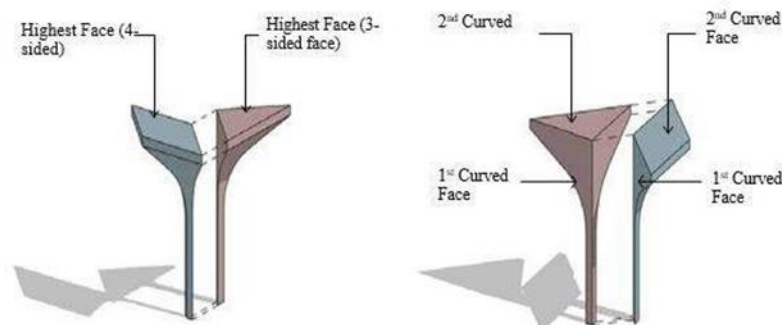


Figure 8: The defining attributes of intermediate elements.

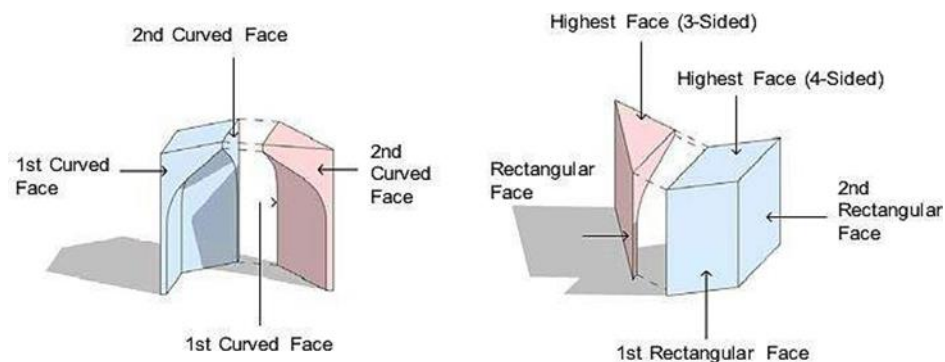


Figure 9: The defining attributes of cells (Source: Author).

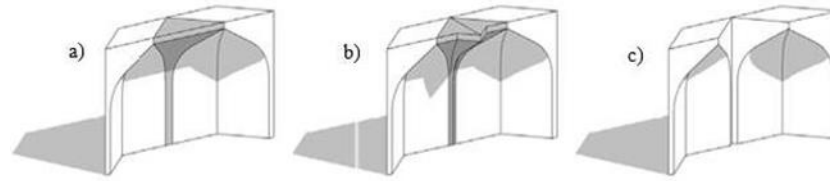


Figure 10: a) Two cells joined by an intermediate unit, (grey), b) Two cells joined by an intermediate unit (grey). (c) Two cells separated by an empty space (Source: Author).

Historical development of muqarnas in Damascus (1154-1924)

Current research has focused on the development of muqarnas in Damascus, with geometric analysis in 3D of muqarnas conducted in one building for each era chosen during the Zengid, Ayyubid, Mamluk, and Ottoman periods, highlighting the significance of these buildings in Islamic history.

Zengid Era

Name: Al-Madrasa al-Nuriyya al-Kubra

Type: Dome

Year: AD 1167

Use: School

Following the Zengid rule, Damascus experienced an urban revival, with the construction of independent schools and public institutions such as al-Madrasa al-Nuriyya al-Kubra. Nur al-Din rebuilt the city wall, supported it with rounded towers, and opened new gates such as al-Salam Gate (Peace Gate), (Alfares, 2021; Moaz et al., 2015) restoring the city's infrastructure, and promoting urban development (Burns, 2019). The hall or open space is vaulted, allowing for a view of the courtyard's aesthetics. This unusual use of four iwans is not common in Damascene architecture (Blair & Bloom, 1996; Herzfeld, 1942). The muqarnas niches inside the dome have different rows and levels, with transitions from square to octagonal and circular (Gonzalo & Alkadi, 2018). There are twelve tiers of muqarnas units, with the two bottom tiers consisting of the tarbia, a square-shaped component, modular unit and the rest consisting of two or three different units. The current research carried out the geometric analysis of the muqarnas domes of al-Madrasa al-Nuriyya al-Kubra. The relationship between interior and exterior muqarnas has been examined, and it was found that the lower six tiers are only visible inside the interior dome, while the upper six tiers are above the roof level and visible from the street (see Figures 11, 12, 13, 14, 15 and 16).



Figure 11. Damascus: Al-Madrasa al-Nuriyya al-Kubra, 1167. The exterior of the muqarnas dome (Source: Author).



Figure 12. Damascus: Al-Madrasa al-Nuriyya al-Kubra, 1167. Interior of the muqarnas dome (Source: Author).

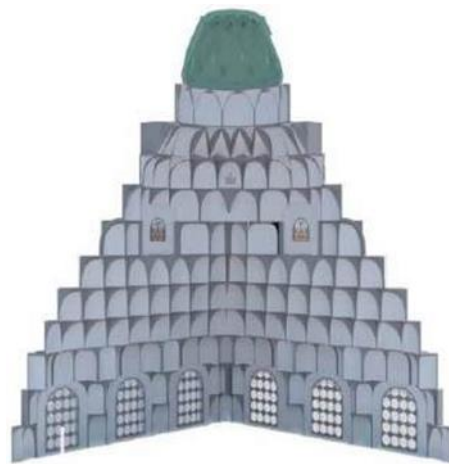


Figure 13. Digital model of the dome of Al-Madrasa-1 (Source: Author).

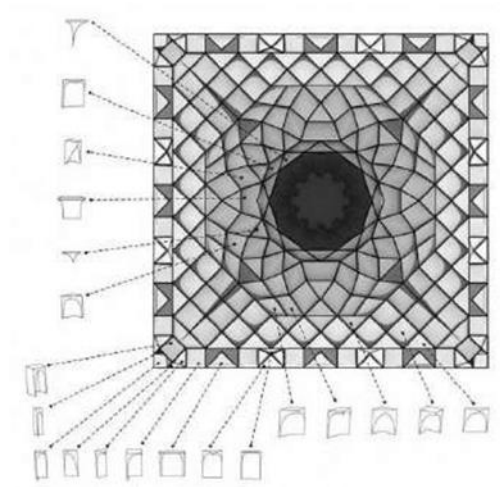


Figure 14. Digital model of the dome of Al-Madrasa-2 (Source: Author).

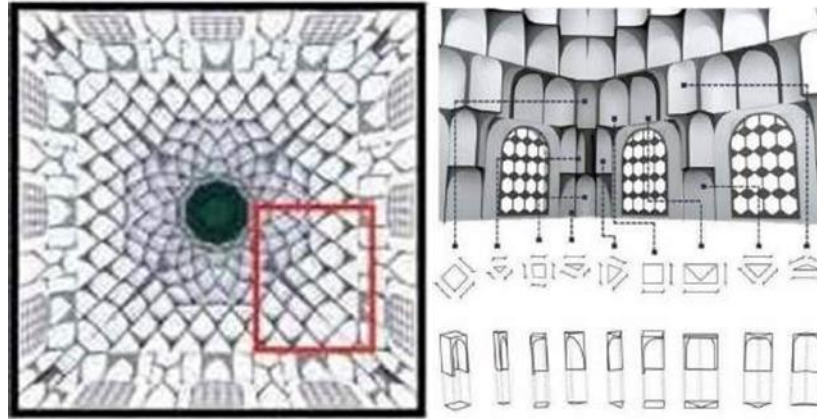


Figure 15. Geometry analysis of the middle part of Al-Madrasa dome (Source: Author).

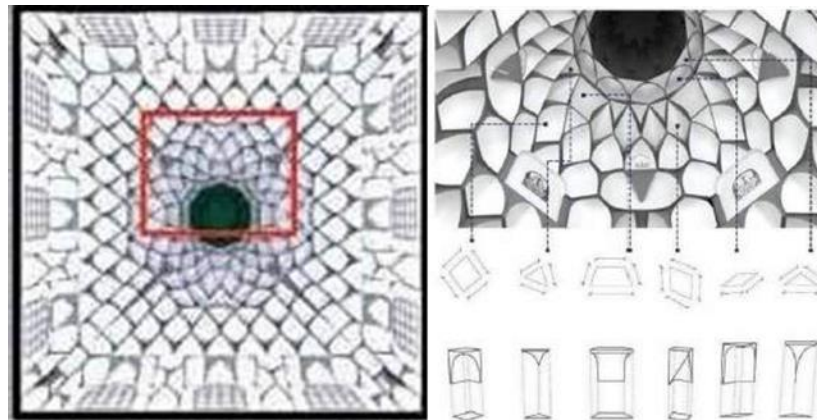


Figure 16. Geometry analysis of the top part of Al-Madrasa dome (Source: Author).

Ayyubid Era

Name: Damascus Citadel: eastern entrance

Type: Entrance portal

Year: AD 1203

Use: City gate

During the Ayyubid era, Damascus adopted a military-style: heavy, rustic architecture, exemplified in the Citadel of Damascus, designated a UNESCO World Heritage Site in 1979 (Moaz et al., 2015).

The Citadel's doorway is an exceptional example of the Ayyubid muqarnas entrance in Damascus, featuring muqarnas that are twice as wide and deep as the usual Syrian ones. The East Gate has an extra fourth tier, enlarging the capacity bound by the vault. The East Gate uses shallow cells of equal depth, leaving a large area for the semi-dome. The unique carved arabesque ornaments and twelve-sided polygons rotate to achieve the transition from square to circle geometry. The muqarnas at the eastern entrance of the Damascus Citadel is the second documented in the city's history. It consists of five tiers, with the fifth tier featuring a small cupola. At the East Gate, the muqarnas undergo a recessed half-dome, a feature that became common later (Adorni & Venturelli, 2010; Moaz et al., 2015). The muqarnas is still in its simplest form, with tiers repeating one or more units. This is the first time the fargheh (space) is created, composed by rotating the muqarnas units (Moaz et al., 2015). Two distinctive units emerge: the mihrab and the stalactite, which are later joined to form the modular muqarnas unit. The cells of the muqarnas are painted, making it a colorful and spectacular structure, unique in Damascus and among other muqarnas vaults of this era (Moaz et al., 2015; Necipoğlu, 1996). In this paper the

researcher conducted geometric analysis in 3D of the muqarnas domes in the eastern entrance of the Citadel in Damascus (see Figures 17, 18, 19, 20, 21, 22, 23 and 24).



Figure 17. Damascus: Eastern entrance of the Citadel, 1214. Looking up at the muqarnas (Source: Author).



Figure 18. Damascus: Eastern entrance of the Citadel, 1214. Detail of the muqarnas (Source: Author).



Figure 19. Damascus: Eastern entrance of the Citadel, 1214. Three-dimensional perspective (Source: Author).



Figure 20. Damascus: Eastern entrance of the Citadel, 1214. Plan perspective (Source: Author).



Figure 21. Damascus: Eastern entrance of the Citadel, 1214. Muqarnas dome deconstructed into its four layers (Source: Author).

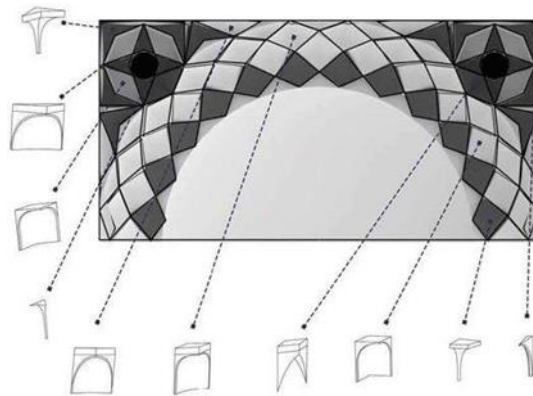


Figure 22. Damascus: Eastern entrance of the Citadel, 1214. Plan projection of the muqarnas dome with geometrical analysis of its units (Source: Author).

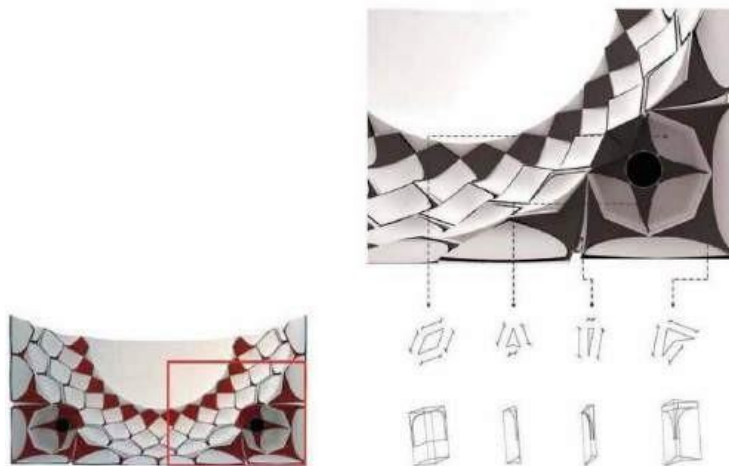


Figure 23. Damascus: Eastern entrance of the Citadel, 1214. Detail of the muqarnas with geometrical analysis of its units-1 (Source: Author).

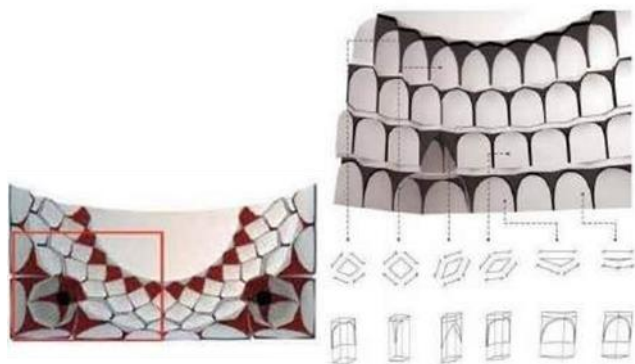


Figure 24. Damascus: Eastern entrance of the Citadel, 1214. Detail of the muqarnas with geometrical analysis of its units-2 (Source: Author).

Mamluk Era

Name: Al-Madrasa al-Zahiriyah

Type: Entrance portal

Year: AD 1281

Use: School and mausoleum

The Madrasa al-Zâhirîyah, a richly decorated school and mausoleum, serves as a central courtyard and domed chamber, with decorative work leading into an austere central courtyard (Rabbat, 1997). The Madrasa al-Zâhirîyah's muqarnas portal is a remarkable example of Mamluk muqarnas (see Figure 25), featuring alternating black and yellow stone bands with finely carved inscriptions. The half-dome over the entrance features impressive muqarnas stonework, transitioning from a rectangle to a semicircle shape (Rabbat, 1997). The grand Zâhirîyah portal has four tiers, the only four-tiered example in Damascus. The tiers are of equal height until the Zâhirîyah is reached, and the depth of cells varies with the portal (Sherif, 1988; Winter & Levanoni, 2004). The muqarnas portal exhibits an exquisite carving of muqarnas stone (Necipoglu, 1996). The researcher conducted a geometric analysis of the Madrasa-al- Zâhirîyah muqarnas dome in 3D (see Figures 26 and 27).



Figure 25. Damascus: Madrasa-al-Zâhiriyah, 1277. Looking up at the muqarnas portal (Source: Author).



Figure 26. Damascus: Madrasa-al-Zâhirîyah, 1277. Elevation view with a geometrical analysis of the bottom layer-1 (Source: Author).



Figure 27. Damascus: Madrasa-al-Zâhirîyah, 1277. Elevation view with a geometrical analysis of the bottom layer-1 (Source: Author)

Ottoman Period

Name: Umayyad Mosque

Type: Muqarnas mihrab

Year: AD 18th century

Use: Mihrab

The muqarnas mihrab of the Umayyad Mosque (see Figure 28) was the fourth Damascene muqarnas to be documented in the current research.



Figure 28. Damascus: mihrab wall in the Umayyad Mosque, Ottoman era (Source: Author).

The muqarnas mihrab belongs to the 18th century, contains sixteen layers, and is topped by a cupola (Kafescioğlu, 1999). The plan is almost half a circle, and the sharp edges of its geometrical units characterize the muqarnas as the curviness has disappeared in this area (Cytryn-Silverman, 2009). The researcher conducted a geometric analysis of the muqarnas mihrab of the Umayyad Mosque in 3D (see Figures 29, 30, 31, 32 and 33).



Figure 29. Three-dimensional perspective of the muqarnas mihrab in the Umayyad Mosque (Source: Author).

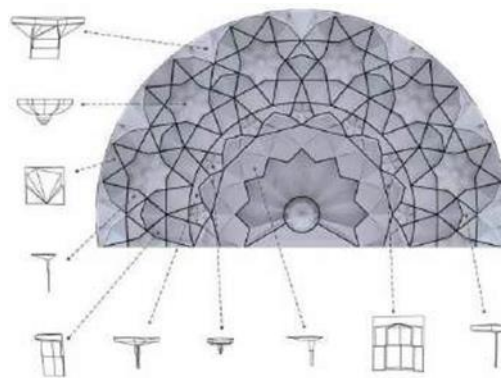


Figure 30: Geometrical analysis of the units of the muqarnas mihrab in the Umayyad Mosque (Source: Author).



Figure 31. The muqarnas mihrab in the Umayyad Mosque deconstructed into its six layers (Source: Author).

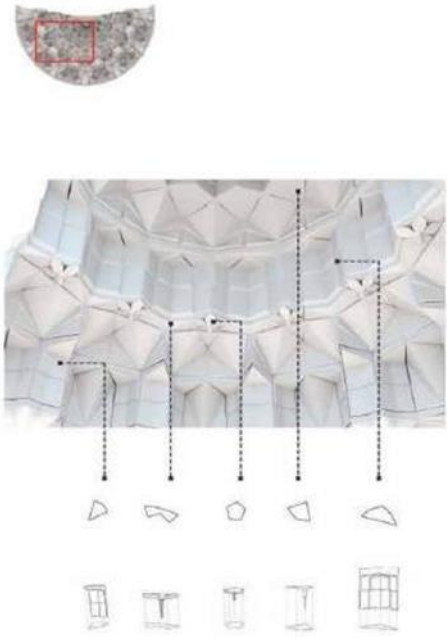


Figure 32. A close look at the bottom layers of the muqarnas mihrab of the Umayyad Mosque, with a geometrical analysis of the units. (Source: Author).

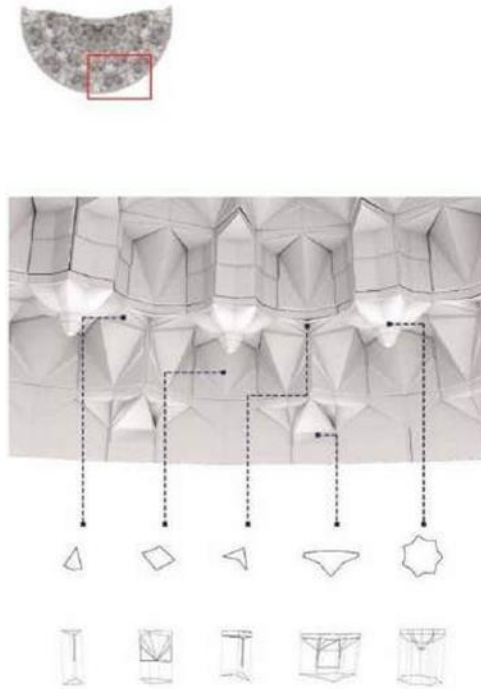


Figure 33. A close look at the top layers of the muqarnas mihrab of the Umayyad Mosque, with a geometrical analysis of the units. (Source: Author).

Tools, Materials and Workshops in Damascus

In this section, the researcher describes the tools utilized for the construction materials in the production of traditional muqarnas. For this purpose, two workshops, 1) The Radwan (Na'anoos) Workshop and 2) The Yaser (Alkahwahji) Workshop, were visited by the researcher, where a variety of Islamic patterns are produced, the most renowned of which is the muqarnas.

Tools

Arabic artists utilized traditional tools such as set squares, compasses, and a thread to design buildings and form patterns, ensuring harmonious and proportional relationships between dimensions, and ensuring a framework for harmonious construction (Necipoglu, 1996). As Alpay Özdural mentioned in his article, “An analysis of the geometry of stalactites”:

A tenth-century mathematician, Abu'l Wafa el-Buzani, informs us that in his time, craftsmen were using *konye* (set-squares) for drawing lines. An anonymous Persian craftsman-geometrician, possibly from the twelfth century, was actually using *konye* for 30° and 36° angles (Özdural, 1991).

Abu al-Wafa' Buzjani suggests that craftsmen, in addition to *konye* (set-squares), had access to drawing instruments such as *perjal* (compasses) and *mastra* (rulers), suggesting these tools were likely used for creating a muqarnas plan (Kheirandish, 2017; Koliji, 2016; Moghaddasi et al., 2022).

Since ancient times, surveying technology had not advanced significantly until the fifteenth century. Masons in ancient Egypt and Rome used the same tools for levelling (Shelby, 1961). These instruments were created using the same geometric rule: that an isosceles triangle's altitude separates it into two identical right-angled triangles (Lewis, 2001). Masons are currently using comparable tools in contemporary Iran (Dold-Samplonius, 2003; Williams & Ostwald, 2015).

Construction materiality

Stucco, a popular construction material in the Islamic World, has been used in ancient Egyptian, Mesopotamian, and Persian reliefs for thousands of years. Its advantages include its weather-resistance, lightweight nature, and

easy moldability, making it suitable for ceiling vaults and providing an ideal base for finishes such as paint or tiles. However, stucco is relatively fragile and prone to cracking, especially when a building settles or is impacted. Despite this, it can be reinforced with plant fibers or animal hairs, making it easy to repair if damaged. It is a good choice for construction (Wilber, 1949).

Brick or clay were popular materials for muqarnas because of their affordability and versatility. They could be used to form simple structures or more complex three-dimensional forms. The shrine of Imam Dur is primarily made of simple bricks, with its dome made from larger clay units stacked on top. Other muqarnas-like structures, such as the northeastern dome of the Friday Mosque of Isfahan, were also made from simple bricks. Although the structure was once called stucco-clad, it is more likely that the architect left the brick unadorned (Ghannad, 2003; Kadoi, 2015).

Stone muqarnas, similar to bricks, are structurally self-supporting and heavy enough to hang. They are developed from corbelling techniques that have existed since Neolithic times. Although stone is not suitable for intricate muqarnas compositions, its durability makes it a natural choice for building exteriors. Stone muqarnas were first developed in Syria during the 13th century, with early examples in Mashhad al-Husayn, the eastern gate of the Damascus Citadel, and the Madrasa al-Firdaws in Aleppo. Following the capture of Damascus by the Mamluks in 1260, similar multi-tiered portals appeared in Egypt that were likely introduced by Sultan Baybars Al-Bunduqdari (Kashef, 2017).

Wooden muqarnas, used in interior design, are typically found in smaller pieces such as mihrabs and friezes, and are commonly used in domestic interiors and furniture. Although large muqarnas units can be constructed from flat wood or board, they are more commonly carved from solid wood (Blair & Bloom, 1996; Bloom & Blair, 2009; Flood, 1997).

The researcher studied the origins of muqarnas and identified the following designs as being among the earliest known examples of this craft (see Table 1).

Table 1. Materials used in muqarnas. (Source: Author).

Name	Country	Type	Material	Date
Nishapur	Iran	Remains	Stucco	9th/10th centuries
Gunbad-i ‘Ali	Iran	Minaret	Mortared rubble	1056
Qal‘at Bani Hammad	Algeria	Ceiling	Stucco	11th century
Minaret of Badr al- Jamali	Egypt	Minaret	Stone	1085
Imam ‘Abdullah al- Dur	Iraq	Mausoleum	Brick	1085

Workshop visits

The researcher learned to understand traditional muqarnas and how they were constructed by visiting the Radwan (Na’anoos) and the Yaser (Alkahwahji) workshops (see Figures 34 and 35). The craftsmen of these two workshops were asked open-ended questions and their live work was observed to identify how muqarnas are currently being produced as a traditional craft, with the traditional designs, compositions and units being copied, and with the use of traditional tools and methods.

In spite of the war at the time of the observations, the workshops were, and still are, active. However, no work is done for Syrian clients; rather, the workshops export their products to other countries. The front of the workshops is filled with traditional elements of Islamic art, such as lamps, tables and cupboard doors, and in one of the workshops there is even a wooden mihrab muqarnas from the Mamluk era.

According to Radwan, muqarnas construction has always been seen as a craft in Damascus.

The researcher asked Radwan whether creating muqarnas required a sketch before the construction process began, and what tools were used for the work. For him, making a muqarnas does not need any pre-designed plan or sketch; it is the outcome of his imagination and creativity. He initially examines the space for the muqarnas and decides where to start the designs to reach the ceiling. He said that traditionally, plaster and a type of herbal rope made of teak were used to attach the muqarnas to the structure above, but that today metal is more commonly used.

The responses communicated by the craftsmen of Radwan and Yaser's workshops have been translated and are set out below:

Radwan Workshop Craftsmen

"The concept is in my head, and I have many bundles of different units in my workshop; I pick and choose from every bundle and create the parts which lead to the whole already imagined."

"The modular unit is called a tarbia, and it is called this because 'muraba' in Arabic means 'a square shape' and 'tarbia' in Arabic means a piece that has a square shape."

"There are two parts of the tarbia: the niche and the dangling part, which is called the stalactite. All the stalactite parts and all the niche parts should be put together."

"The edge above the stalactite and below the niche should fit with the other similar edge in other tarbia. When we put the stalactites together, and they appear dangling in a dome or mihrab, the muqarnas then appear to be complex. The color also adds to the complexity because it becomes difficult to distinguish components, one from the other."

"Each different combination has a different name according to the place in which it will be situated. For example, a certain combination of the components is called al-Sirwal, which is put only in the four corners of a ceiling."

"When layers are added on one side of the shape, the depth of the muqarnas changes. By changing the positions of the tarbia, one can produce a depth to the muqarnas and also depth in higher layers or any direction. This will create different compositions of muqarnas."

"There are different methods and ways that could be applied to achieve this depth. This depth is called a chamber (fajweh) and I can place them in a linear way in one horizontal layer, or in a diagonal way across the muqarnas. But I will need more components to be able to achieve this."

"When we put four components of tarbia together, it is called nafra, which means 'protruding'. If I had two more components here, I would have achieved a chamber (fajweh) next to the protrusion (nafra)."

Yaser Workshop Craftsmen

"All the modular units (tarbia) should be the same size, and the niche elements (fargha) and the 'nose' – stalactite (minkhar) should be the same size as all of the other components. Otherwise, it will not work because they will not be able to match; the tarbia size may vary."

"It could be 3 cm x 3 cm or 4 cm x 4 cm. Here, these are 4.5 cm x 4.5 cm. The craftsmen control the size of the modular unit tarbia. But the chosen size is definitely the size for all the pieces you make."

"Here the material of the wood took over and controlled the size of the component. For muqarnas made of wood, we use rumi – wood from the Ghouta of Damascus... Most muqarnas in Damascene houses are made of this kind of wood. This is a Syrian wood from Damascus Sghota that is cut in January."

"This composition is used when we want to have dangling parts of the muqarnas. I can make other compositions, such as a frieze on a wall. In a gap, floral patterns could be drawn, or pearls could be entered

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into the design. Also, using the same process, I can create another layer. Another variation I can make is by reorganizing the components to generate a bigger gap from the previous compositions.”

“This wood is cut only in December and January because it is dry at this time with no water, and it is firm, hard, and easy to handle. From experience, Damascene people know to cut it at this season. This will prevent the wood from rotting.”

“The wood shape differs completely if it is cut with or without leaves on it; if it has leaves, the wood will be fragile.”

Radwan envisions the final muqarnas design before construction, deciding on the form based on the space provided, taking into consideration depth and height. He determines the size of the muqarnas unit and the number of layers needed to cover the space. He chooses units from bundles in his workshop, which contain ready-made units of various shapes and sizes. As he works, he adds more components to his design, ensuring a well-designed and functional space. Radwan's meticulous attention to detail and careful consideration of space requirements ensure a well-crafted muqarnas.

It was observed from the workshop visits that the tarbia is a cuboid form that combines proportionality, consistency, and an integrated, balanced relationship between its parts. Its name derives from the Arabic word for square, which symbolizes proportionality and consistency. These characteristics are inspired by the Islamic religion's emphasis on simplicity, balance, and stability. Furthermore, muqarnas units, or wooden structures, are an architectural feature in Damascus, known for their unique configurations and their ability to withstand bombing. These units are often assembled in various ways, with each combination having a different name, depending on its location in the building.



Figure 34. Scenes from the Yaser workshop in Damascus. (Source: Author).



Figure 35. Scenes from the Yaser workshop in Damascus. (Source: Author).

CONCLUSION

The Islamic world's architecture has been heavily influenced by its predecessors' designs, including Roman temples and Byzantine Christian cathedrals. The Umayyad Mosque, for example, was built upon these structures and their layouts, which were based on a converted Christian church. This architectural style continued to shape other cultures and was influenced by external sources.

Workshop visits and conversations with craftsmen revealed that adding layers on one side of a shape alters the depth of muqarnas. Various positions of the *tarbia* can produce depth in higher layers or any direction, creating different compositions of muqarnas. In addition, to achieve this depth, methods are applied, such as placing chambers linearly or diagonally across the muqarnas. However, more components are needed to achieve this depth. Most muqarnas in Damascene houses are made of Syrian wood from the Damascus Ghouta, an oasis formed by the Barada River.

The construction of muqarnas was influenced by four distinct materials: stucco, mortared rubble, stone, and brick. By the mid-12th century, wood was added to the list. Despite sharing a common geometry, each material had unique characteristics and construction techniques. The Umayyad Mosque's layout was a prototype for future mosques, showcasing the interconnectedness of Islamic and Western architectural styles.

The Islamic world's architects and artisans demonstrated resourcefulness in appropriating existing styles and construction techniques for materials. When choosing a material and method for contemporary muqarnas, it is not necessary to limit oneself to historical materials and techniques. If ancient artisans had access to modern materials, they would have likely used them.

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