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Research

Significance of Conical and Polyhedral Domes in Persia and Surrounding Areas: Morphology, Typologies and Geometric Characteristics

Abstract. The aim of this paper is to identify the unique features of the conical and polyhedral domes which topped a majority of distinct tomb towers during the early Islamic era. As opposed to previous general historic studies, this paper introduces a new analytical approach which allows the complete comprehension of the formal architectural language of conical and polyhedral domes based on an epistemological premise of their space syntax. Through an analytic review of selected examples, the paper suggests and addresses the origin of conical domes, their formal morphological compositions and typological forms based on the number of their external shells from the Seljuk era throughout the Timurid period in Iran and nearby regions. The theoretical framework for the formal language of conical and polyhedral domes sheds new light on undiscovered information about the essential characteristics of Persian domes in this region.

1 Introduction

Some of the most enduring signs of Seljuk architecture are the distinct types of polyhedral and conical domes which still stand in Azerbaijan, Turkey, Iran, Turkmenistan, and Uzbekistan. These edifices are commonly well-known as a primitive architectural formula for the Islamic funerary buildings topped with conical and polyhedral shells which mainly appeared in the Seljuk period. From the architectural point of view, such edifices are remarkable due to their influence on structural design and commonality of the huge and complex configurations of Islamic funerary architecture later. In comparison with the number of existing domes, the studies concerning the commonality of their typological and morphological features, that is, their formal architectural language, are scarce and suffer from the lack of in-depth analysis of their special characteristics.

In this matter, despite the pre-Islamic background of conical domes in this region, the main objective of this research is to discover the formal language of conical and polyhedral domes, including their origin, morphological features, and typological structure during Islamic periods. The central idea adopted in considering of the examples chosen in this study differentiates from the previous general historical analysis in that it dwells on the initial spatial features and their formal structure, which evolved naturally over time from the Persian culture from which it comes. To achieve such objectives, an understanding of their conceptual evolutions and style development over historical eras is also required.

Such a study can not only bring to light chronological issues regarding the development of the conical and polyhedral domes in Persia and nearby countries, but can also provide a new methodology for understanding the formal language of other sorts of

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traditional Islamic domes in this zone. Meanwhile, despite the simple architectural grammar of such domes, analyzing the powerful compositional relationship of their components and distinct styles helps to compile contemporary design criteria for the purpose of preserving the traditional aesthetical aspects in present-day dome design.

This paper is arranged into three parts as follows: 1) a historical outline of evolution of the polyhedral and conical domes since the early Islamic era, by reviewing famous examples; 2) elaboration of their derived common morphological features and typical components; and finally 3) classification of their common typologies based on the number of their internal and external shells.

2 Conical and polyhedral domes

2.1 Terminology

While the term of dome has been used similarly in different literatures both in the Eastern and Western architectures [Michell 1978; Pope 1965; Stierlin 2002; Smith 1971; Wilber 1969], there has been a major architectural contrast between the composition of their spatial elements. Structurally speaking, Eastern domes were supported on "squinches" which generally originated from Persia [Ashkan and Yahya 2009b], as opposed to Western domes, which were systematically erected on "pendentives" originally appearing in Turkey [Altin 2001].

Chronologically, the architectural compositions of Persian domes underwent major changes both structurally and aesthetically as they appeared in different dynasties, especially, during Islamic periods, eventually ending up with the appearance of three main typologies of domes: conical, pointed, and bulbous (fig. 1) [Ashkan and Yahaya 2009a].

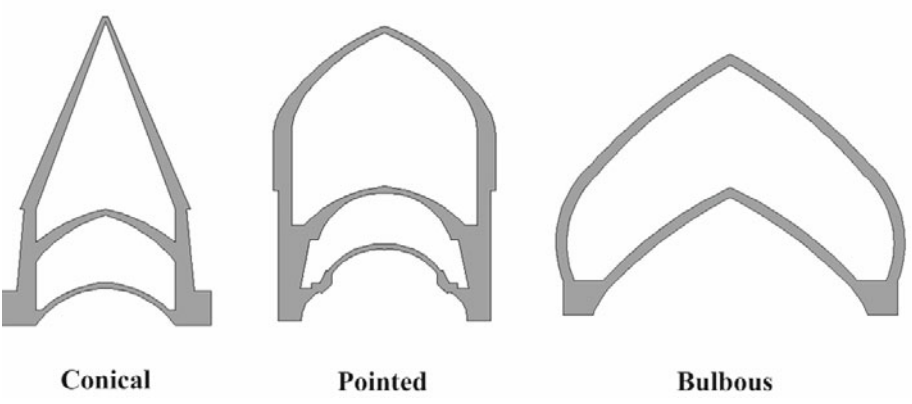


Fig. 1. Three main styles of domes in Iran and nearby regions. Drawings: Authors

This paper aims to shed light on architectural constitution of conical and polyhedral domes (as subsets of conical domes) which contributed remarkably to the establishment of essential features for the rapid development of the other, later types of Eastern domes.

2. 2 Origins and types

On one hand, conical domes display a great diversity in architectural compositions, materials, and configuration arrangements. They may be considered as a kind of spatial synthesis that evolved over a long course of socio-cultural developments beginning with the appearance of the Seljuks in the Middle East and Central Asia [Pope 1976; Grabar 1963] up to the end of fifteen century. Historically, the origin of the conical dome is still uncertain, though some historians believe they may have been influenced by sources as varied as Turkish tents, Sabian temples, Chinese watch-towers, and Palmyran tower tombs [Ayatollahi 2003; Hillenbrand 1994]. André Godard [1965] and Oleg Grabar [1963; 2006] believe some of these monuments were originally used as Zoroastrian fire temples (fig. 2) in Iran and nearby territories, and were then transformed into tomb towers (by adding a *mihrab*) during the early Islamic era.

Fig. 2. An example of the Zoroastrian fire temple, Sassanid period, *Amol*, Iran. Photo: Authors

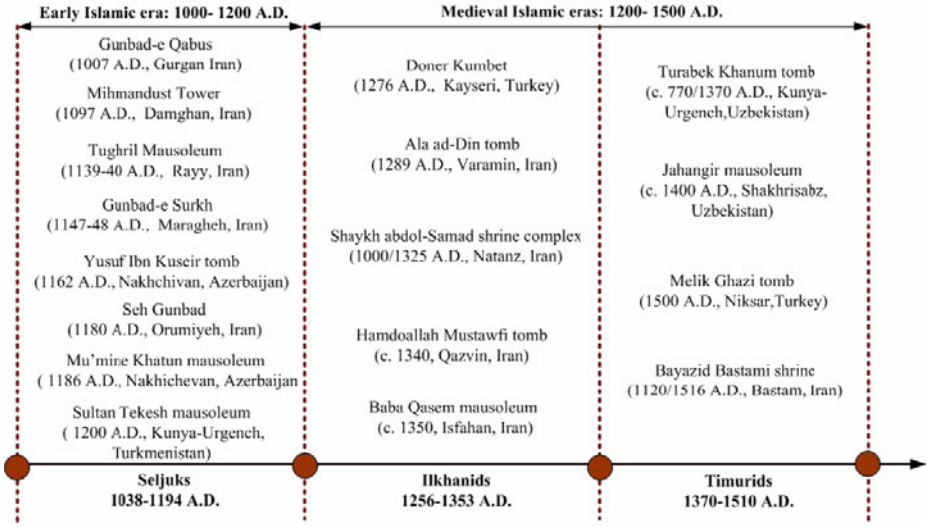


Fig. 3. Timeline of the development of conical and polyhedral domes and the selected dominant samples. Source: Authors

On the other hand, tomb towers topped with either a conical or a polyhedral shell are a primary typology of the memorial function edifices known as mausoleums which mainly appeared in the Seljuk era (1038-1194 A.D.) [Pope 1976; Bosworth 1996] and finally reached its acme in the Ilkhanid era (1256-1353 A.D.).

After that, their configurations were extensively enhanced in the Timurid period by the addition of lavish ornaments, especially in those edifices located in Iran and Central Asia [Wilber 1969]. In fact, these dynasties gave conical constructions their distinctive characteristics, as will be shown in the following brief survey of the dominant examples of each period (fig. 3). Essentially, the main reason beyond their rapid construction more likely lies in a small step beyond the traditional simplicity of burial practice, rooted in the dictates of the religious orthodoxy in the early Islamic epoch [Hillenbrand 1994; Ayatollahi 2003].

Historically, as a result of the flourishing of Persian architecture due to the rising power of the Seljuks [Creswell 1958], the great diversity of buildings used for funerary purposes (more than for religious purposes) were based on either cylinderal or cubed shapes topped by conical domes [Saoud 2003].

The famous Gunbad-e Qabus at Gurgan in Iran (1007 A.D.) is the earliest tomb tower (over 1000 years old) with a solid conical shell. It is the largest Seljuk dome with a 9.70m span and 57m height (fig. 4). Monumentally, its style holds an important place in the Seljuk architecture [Pope 1976], which was used later on as a model for developing cylinder or cube-based forms throughout Iran and surrounding areas [O'Kane 1998; Saoud 2003].

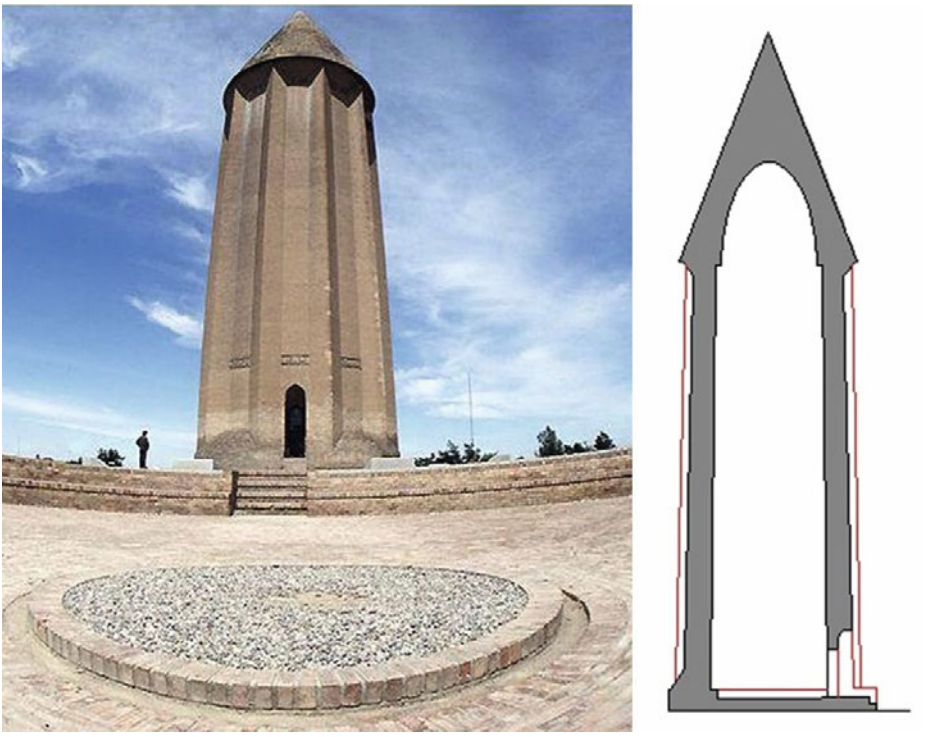


Fig. 4. The famous Gunbad-e Qabus tomb tower, Gurgan, Iran. Photo: Authors.

In the case of conical shells, although the external shell of the Mihmandust (1097 A.D.) tower with its cylindrical base is missing, Sykes [2003] stated that it was most likely topped by a conical shell. Another example is the Tuqril tomb tower (1139-1140 A.D.), which probably represents a more advanced and elegant architecture, distinguished from its origin, the Qabus tower.

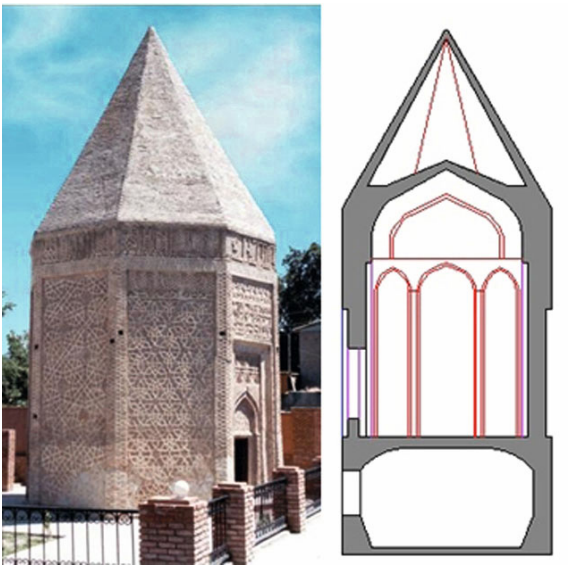


Fig. 5. An example of the early Seljuk tomb towers: Yusuf Ibn Kuseir tomb, Nakhichevan, Azerbaijan. Photo/Drawing: Authors

In addition, the construction of tomb towers went forward in Iran with the erection of the Red Dome tomb crowned by a polyhedral double-shell (Gunbad-e Surkh) (1147-48 A.D.). This building is the oldest of the five tomb towers erected in the city of Maragheh [Hatim 2000: 193-198]. It, in fact, is one of the earliest monuments decorated by using mosaic tiles [Godard 1965]. Soon after, the standing tomb of the Yusuf Ibn Kuseir (1162 A.D.) was built by the Seljuks in Azerbaijan [Hillenbrand 1994] (fig. 5). Though the Seh Gunbad (Three Domes; 1180 A.D.) was erected generally based on the tradition of tomb towers of the Maragheh city, André Godard [1965] noted that this building was basically transformed from the Zoroastrian fire temple into the tomb during the Islamic era.

By the end of the twelfth century, the Mu'mine Khatun mausoleum in Azerbaijan (fig. 6) and Sultan Tekesh in Turkmenistan might be considered as the tomb towers which reflected the dissimilar design patterns [Hoag 1987]. The tomb tower of Mu'mine Khatun (1186 A.D.) in the city of Nakhichevan, with its missing polyhedral shell is a reflection of the Armenian architectural style popular in Azerbaijan in this period [Michell 1995]. Its decagonal brick load-bearing system and lavish ornaments initially distinguished its architectural character from that of the Persian examples. The mausoleum of Sultan Tekesh (1200 A.D.), located at Kunya-Urgench in Turkmenistan, is also one of the few existing monuments from the pre-Mongol era with a height of 30 m. [Blair and Bloom 1995]. The flanged wall of its drum is approximately similar to its origin, the "Qabus tower" in Iran.

Fig. 6. An example of the Seljuk tomb towers surrounding regions of Iran: Mumine Khatun tomb, Nakhichevan, Azerbaijan. Photo: Authors

In the Anatolian district of the Seljuk Empire, tomb towers were structurally distinguished from the Persian ones through the deep influences of Armenian models [Stierlin 2002]. According to Hillenbrand [1999], these tomb towers, in some aspects, preceded Iranian samples as a model in which either pyramidal or conical shells rested on either cylindrical or polygonal bases. In contrast, their final distinct appearances correspond with respect to four main issues: 1) with use of local stone rather than bricks (common in Iran and the other regions); 2), compositional articulation between the cubic base and the cylindrical bearing system; 3) varying degrees of ornament; and 4) the use of an exterior ring of blind arches.

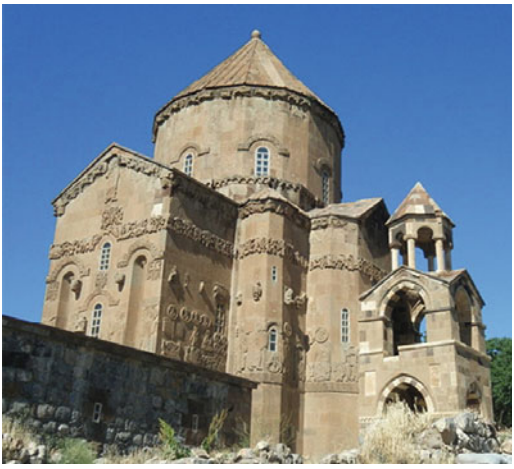


Fig. 7. Armenian Cathedral of the Holy Cross, Akhtamar Island, Turkey. Photo: Authors

Unsurprisingly, Christian influences are also marked in the final formal configuration of Anatolian towers rather than the other regions studied; this included the use of plain conical shell erected on a high drum, which originated from the standard contemporary Armenian churches [Hillenbrand 1994] (fig. 7). These all inspired local Muslim masters to employ vernacular elements rather than an architecture based on Persian vocabularies.

In this manner, indigenous Armenian models [Stierlin 2002] are strongly reflected in the construction of Doner Kumbet (1276 A.D.) at Kayseri, with its conical roof supported on a massive base [Blair and Bloom, 1995]. Additionally, the small surrounding fortification of the Mama Khatun (Hatun) mausoleum (c. 596-1200 A.D.) at Tercan might be considered a rarely-used pattern in comparison with the other examples studied [Petersen 1999]. But the complex manifests a strong correlation of the Christian impact which, as a whole, also echoes the sense of Turkic conical funerary architecture before the Mongol invasion.

During several Mongol invasions (beginning in 1219 A.D.) and "the genocide of Persian master builders" [Memarian 1988], a brief decline occurred in contributions of domed architectural design; but the material culture of the Middle East and Central Asia flourished again during the reign of later Mongol rulers, especially the Ilkhanids (1256 A.D.) and Timurids (1370- 1510 A.D.) [Michell 1978].

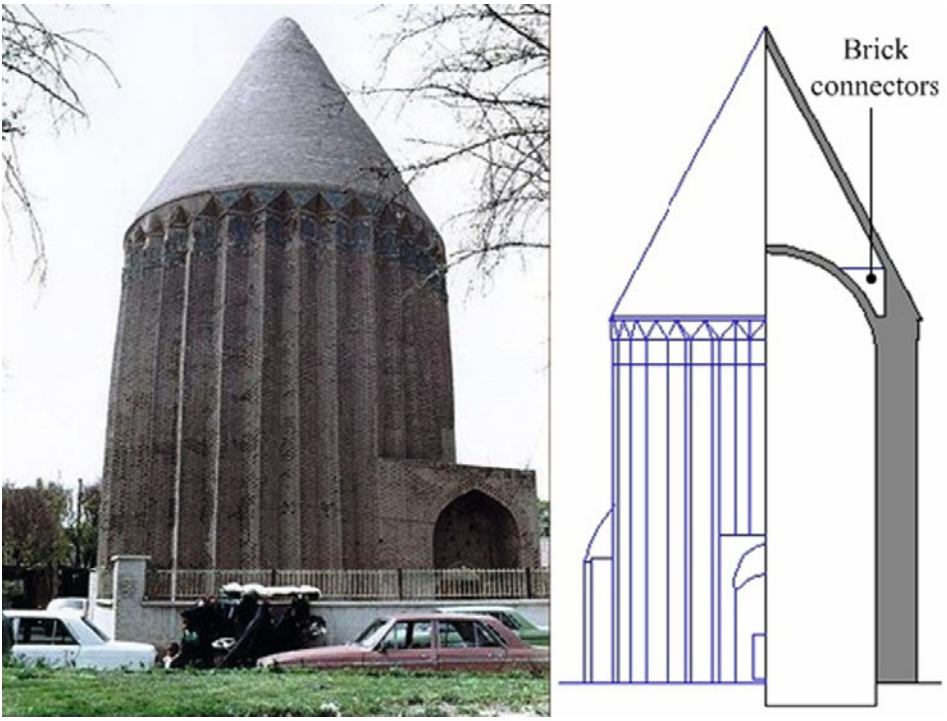


Fig. 8. Illustration of the Ilkhanids' "contribution into the structural configuration" of tomb towers; (a) Ala ad-Din tomb, Varamin, Iran. Photo/Drawing: Authors

Although the construction of conical and polyhedral domes decreased considerably in comparison with the Seljuk era, there were two specific architectural achievements during the Ilkhanid period. Structurally, small brick connectors were introduced for the purpose of attaching the internal and external shells at a regular distance, such as those in the Al ad-Din tomb (1289 A.D.) at Varamin in Iran (fig. 8), a flanged tower 18 m. heigh with a span of 9 m. [Pirnia and Memarian 2003]. These internal connectors between shells were developed compositionally as internal stiffeners and utilized again in the mausoleum of Jahangir (1400 A.D.) at Shakhrisabz in Uzbekistan [Golombek and Wilber 1988]. It is one of the super-dimension examples of conical domes with the height of 27m (fig. 9).

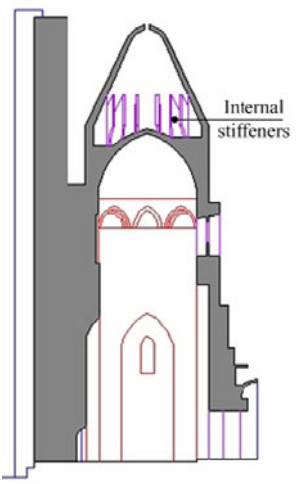


Fig. 9. Jahangir mausoleum, Shakhrisabz, Uzbekistan. Drawing: Authors

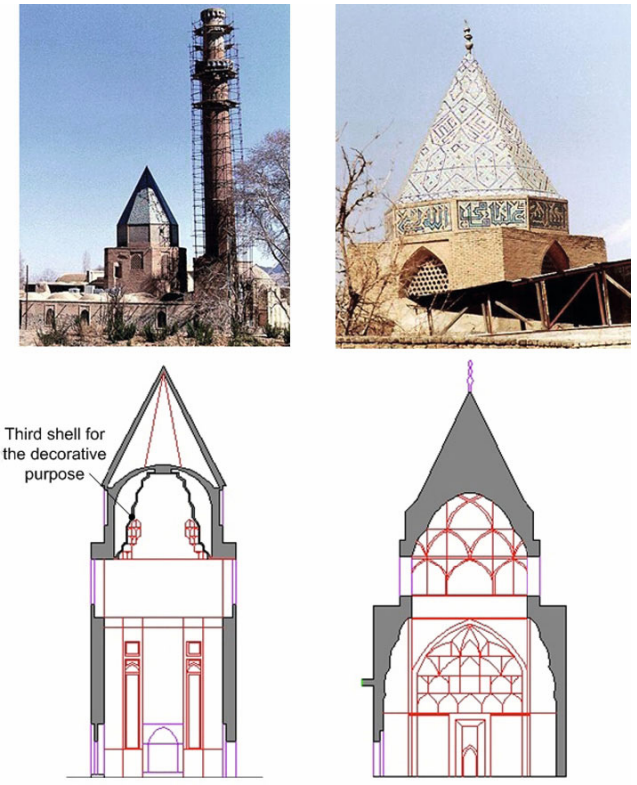


Fig. 10. Two examples of the use of turquoise tile works on the external shells of tomb towers, Ilkhanid, Iran. a, left) Shaykh Abdol -Samad shrine complex, Natanz. Photo: Authors; b, right) Baba Qasem tomb, Isfahan. Photos/Drawings: Authors

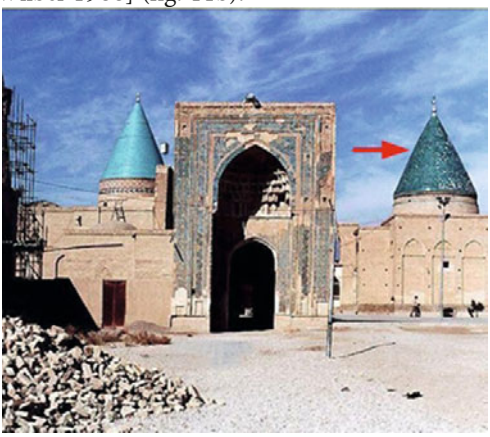
The second innovation was the extensive use of turquoise tile works for the decoration of the exterior face of external shells of towers and the rich interior works of muqarnas [Wilber 1969]. In this regard, the Iranian cases are, firstly, the Shaykh abdol-Samad shrine complex (fig. 10a; 1325 A.D.) within its triple-shell dome [Seherr-Thoss and Seherr-Thoss 1968] in Isfahan, which adjoined the unique Friday mosque of the historic city centre of Natanz; secondly, the Hamdoallah Mostawfi tomb (ca. 1340 A.D.), which is considered one of the novel Ilkhanid edifices in Qazvin. From the structural point of view, the construction of the Baba Qasem tomb (1400 A.D., fig. 10b) in Isfahan validated the consecutive erections of the solid polyhedral shells even throughout the Ilkhanid epoch.

The construction of conical and polyhedral domes became less important during the Timurid period due to two main reasons. First, by developing the use of pointed domes erected on mausoleums as a part of more complex urban units, the individual usage of funerary buildings was apparently abandoned, especially in the Central Asia. Second, with the introduction of the bulbous style resulting in the expansion of both structural and architectural designs in Iran, the construction of conical and polyhedral domes became an obsolete tradition [Ashkan and Yahaya 2009a].

Nevertheless, this era was mainly dedicated to the improvement of architectural and structural configurations of the prior samples, such as adding a shell, greater improvement of geometrical proportions [Ashkan and Yahaya 2009b], and attaching huge portals and sometimes terracotta panels [Hillenbrand 1999].

The primary example of such developments is the Turabek Khanum tomb (1370 A.D.) at Kunya-Urgench in Turkmenistan, which has a span of 9 m. (fig. 11a). Its rich decorations, huge portal, and the third shell are the certain testament of the Timurid epoch [Byron 1982: 121; Golombek and Wilber 1988] (fig. 11b).

The triple-shell dome of the Bayazid Bastami shrine complex (1516 A.D.) at Natanz in Iran, with a span of 8 m. and a height of 20 m., can be considered another novel example (fig. 11c) demonstrating the advancement of structural design by adding a third shell to enhance its stability [Hejazi 1997]. At the same time, in the Ottoman Empire in Turkey, the most popular shape of conical towers remained unchanged from that of the previous style, i.e., the cylinder form with the simple two-shell composition, such as the Melik Ghazi tomb (1500 A.D.) at Niksar in Turkey (fig. 11b).



Bayazid Bastami shrine complex, Bastam, Iran.
Photo: Authors

This building was restored or reconstructed by Ottoman rulers in the middle of the fifteenth century [Petersen 1999].

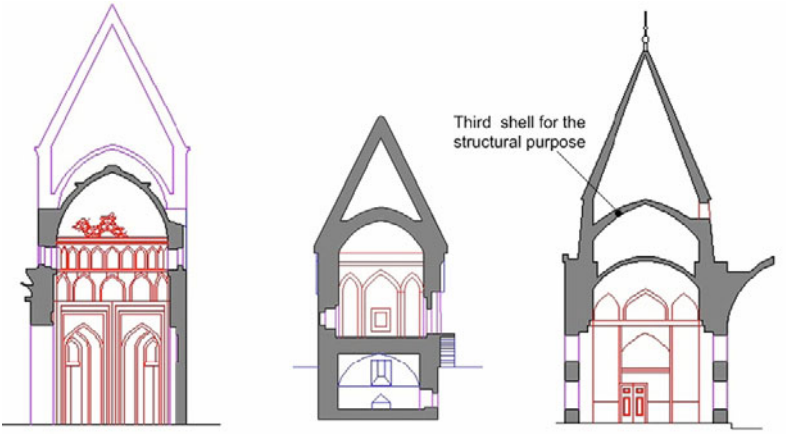


Fig. 11. Three samples of the conical domes in the Timurid era: a, left) Turabek Khanum tomb, Kunya- Urgench, Uzbekistan; b, center) Melik Ghazi tomb, Niksar, Turkey; c, right) Bayazid Bastami shrine complex, Bastam, Iran. Drawings: Authors

On the whole, the conical and polyhedral tomb towers in Iran, Uzbekistan, and Turkmenistan are twice or even three times larger in size than the examples in Turkey and Azerbaijan (whose heights vary between 10 m. and 15 m.). For sure, the number of cases and their distinct arrangements clearly proved that such domes were more popular in Iran than in the other regions studied.

In conjunction with the actual architectural and structural contrasts, the examples of two territories are particularly remarkable; these are Iran, Azerbaijan, Turkmenistan, and Uzbekistan, on one hand, and on the other hand, Turkey. The harmonic composition of Anatolian examples, in fact, are a reflection of their Christian roots, in contrast to the Zoroastrian tradition, which might have admittedly been a basis for the architectural archetypes of tomb towers in Persia and surrounding areas.

Regarding the interior designs of the studied cases, the domes in Iran and the Central Asia are much richer in the complicated stucco decorations and lavish tile works than are the edifices in Turkey and Azerbaijan, with their monochromatic reliefs. Nevertheless, the location of the crypts of the Turkish examples might be rooted in their Christian origin, while the chambers of graves of the Iranian and Central Asian buildings were chiefly placed underground.

The skillful use of the local, regionally available materials and the related well-developed construction techniques are predominant in the all of the cases studied, including the use of stone (e.g., in Turkey) and brick (e.g., in Iran and Uzbekistan).

3 Common morphological features of the conical and polyhedral domes

The final configuration of the conical domes resulted from the continuous development of four main components or "vocabularies". In this regard, if the traditional conical dome is contemplated as a sentence, its elements can be considered as the vocabularies by which the sentence is written and read. Morphologically, the common vocabularies of such domes are namely: load bearing system, transition tier, drum, and shells (fig. 12). Additionally, the incipient arrangements of the internal stiffeners and brick connectors mainly came to light in the Ilkhanid era, in order to connect the internal shell to the external shell. These structural elements have been prevented the collapse of the shells that used to take place frequently.

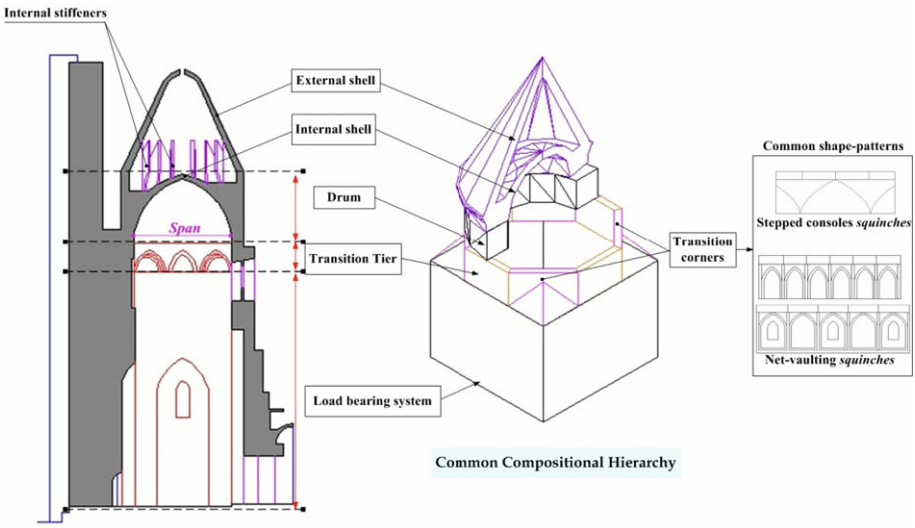


Fig.12. Illustration of the common morphological features of conical domes. Drawings: Authors

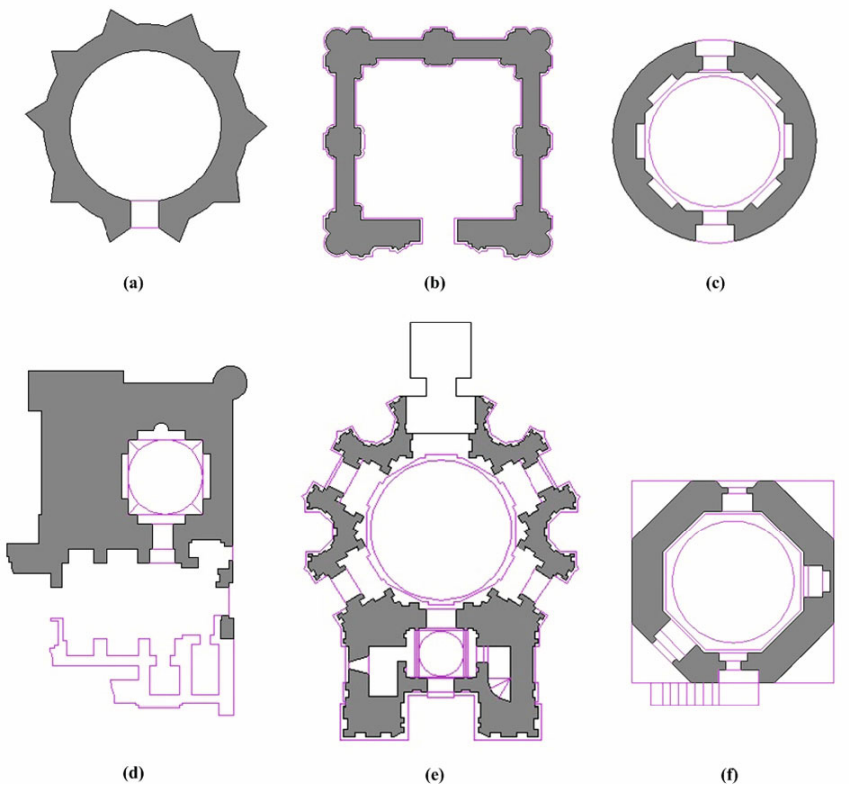


Fig. 13. Illustration of sample floor plans: (a) Gunbad-e Qabus, 1007A.D., Iran; (b) Gunbad-e Surkh, 1147-48 A.D., Iran; (c) Seh Gunbad, 1180 A.D., Iran ; (d) Jahangir mausoleum, 1400 A.D., Uzbekistan; (e) Turabek Khanum tomb, 1370 A.D., Uzbekistan; (f) Melik Ghazi tomb, 1500 A.D., Turkey. Drawings: Authors

– **Load bearing system:** the main body of the dome comprises the cylinder, octagonal prism, and cube formations with the approximately wall-thickness of 1.80m. According to the examined vertical sections, the main chamber encompasses a width equal to the span of the internal shell (fig. 12). Typically, the majority of floor plans of the main examples embrace a simple shape (fig. 13a, b, c, and f); conversely, in the Timurid period, they are frequently united as a part of the vast monumental complexes (fig. 13d, c). Nevertheless, these plans had no longer evolved based on a given pattern.

– **Transition tier:** the fundamental component of the dome which was used for transferring from the square form of the ground floor to the circular base of the dome. The common derived shape-patterns of this element are, firstly, the *squinch-net vaulting* which were composed of the rows of arches. These are almost always framed by the superimposed brick brackets; secondly, the console mini-arches or squinches that were gradually arranged together as the *stepped console squinches* (see fig. 12).

– **Drum:** the main element used to increase the overall height of the building; the drum was commonly accomplished in the tomb towers with the squared upporting system that were regionally popular in Iran and the Central Asia.

– **Shell:** in double-shell domes, the shells are classified as the internal and the external. The key in understanding of the diversities of shells is rooted in the consideration of their geometrical concepts, namely, "profile" [Huerta 2006]. This profile can be obtained by diminishing the thickness of the cross-section of both shells [Ashkan and Yahaya 2009a].

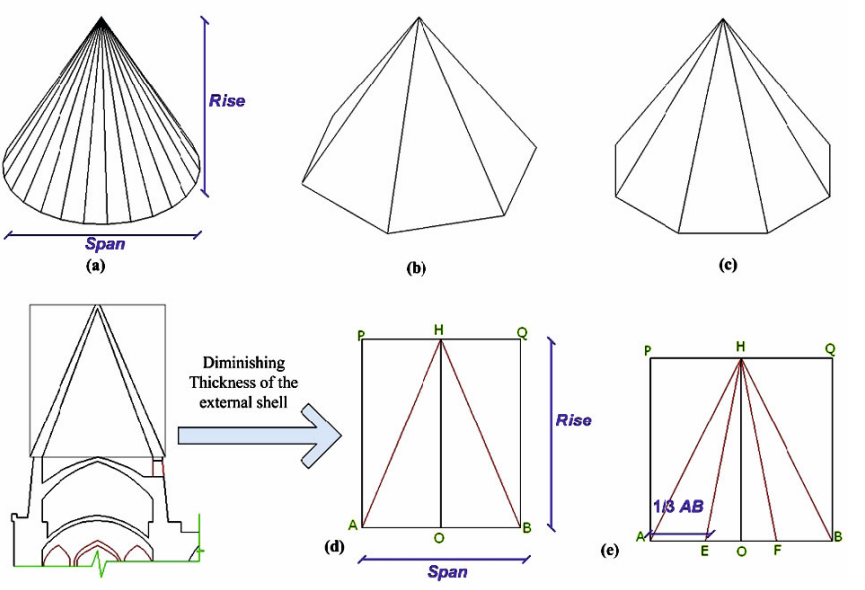


Fig. 14. Illustration of the typical geometrical prototypes of the external shells in two and three dimensions. Drawings: Authors

The external shell of a tomb tower, that is, what appeared from the outside of the edifice, is the only architectural item that was conceptually identified as a synonymous feature in the entire corpus of examples studied. In the three-dimensional analysis, the typical forms of this component are named as the conical (fig. 14a), hexagonal (fig. 14b), and octagonal (fig. 14c) in which the conical and the hexagonal patterns are extensively amalgamated as the most usual models throughout the periods studied.

By diminishing the thickness of the external shell, the couple of triangles are commonly derived based on certain geometrical relationships between the space and the rise of the domes; first, the isosceles (if the rise ≠ the span; fig. 14d), second, equilateral triangles (if the span = the rise; fig. 14e).

Owing to the profiles of the internal shells, the popular patterns are respectively gained as the saucer (Tughril mausoleum), the pointed as the most ubiquitous form (Turabek Khanum mausoleum, Jahangir mausoleum, Bayazid Bastami shrine, Yusuf Ibn Kuseir tomb), the semi-circular (Hamdoallah Mustawfi tomb) and finally the semi-elliptical as the earliest form of the internal shell (Gunbad-e Qabus). This diversity of patterns can undoubtedly verify the early attempts of master builders to find an appropriate model, both structurally and architecturally.

From the geometrical point of view, the pointed internal shell constitutionally consists of either two or four small arcs arranged proportionally according to a closed relationship between the span and the rise (fig. 15). A discussion of the traditional methods of geometrical designs, drawings of small arcs and their associated proportional designs is beyond the scope of this paper (for further references, see [Ashkan and Yahaya 2009a] and [Dold-Samplonius 2000]).

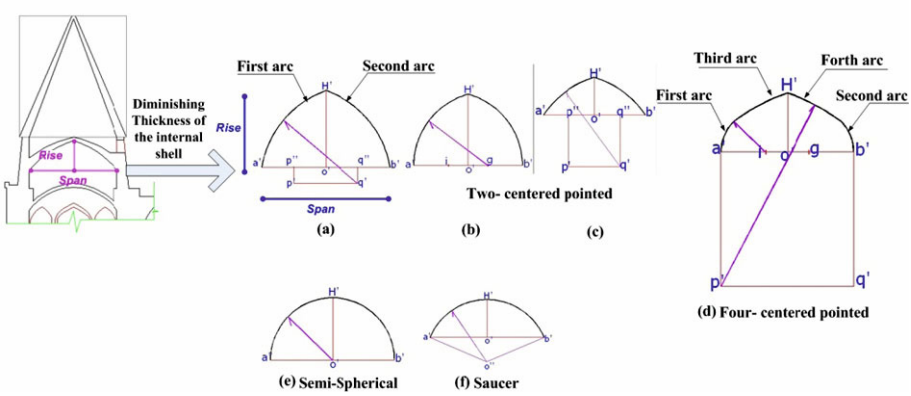


Fig. 15. Illustration of the derived geometrical archetypes of the internal shells: (a) Turabek Khanum mausoleum; (b) Jahangir mausoleum; (c) Bayazid Bastami Shrine; (d)Yusuf Ibn Kuseir tomb; (e) Hamdoallah Mustawfi tomb; (f) Tughril mausoleum. Drawings: Authors

4 Common typological styles of the conical and polyhedral domes

One of the motives for a morphological survey was essentially to determine the programmatic approach for clarifying typological commonality of such domes. Therefore, the typological study relies on an overall view of the common arrangements of the dome's spatial elements. The constitution of shells, which is derived as the

synonymous feature of the conical and polyhedral domes, is thus manipulated for the stylistic categorization of the conical and polyhedral domes. According to the number of the shells, these domes are classified as one-shell, double-shell, and triple-shell (fig. 16). The one-shell domes are more frequently found during the Seljuk than the other periods. Interestingly, the tomb towers topped by the solid octagonal and hexagonal shells were predominant over the other forms and also their constructions simultaneously continued until the Timurids in Iran and surrounding areas.

Overall speaking, the double-shell domes were the most common shape in the periods studied, especially in the Ilkhanid era. However, a few triple-shell examples can verify that they originated in the double-shell prototype in which a shell was frequently constructed for, firstly, a decorative purpose (Shaykh Abdol Samad shrine complex, see fig. 10a) and, secondly, for providing the structural stability, perhaps as a result of an improvement in structural knowledge, mainly during the Timurid era.

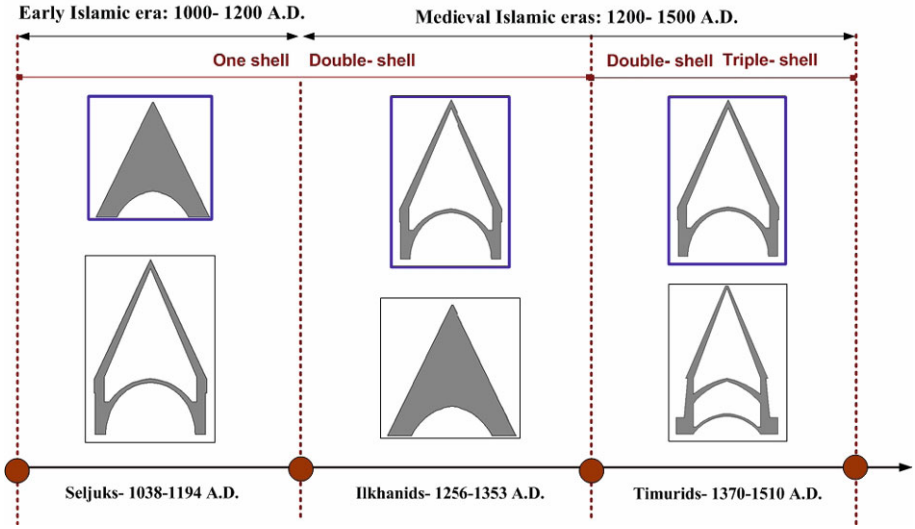


Fig. 16. Illustration of the typological classifications of the conical and polyhedral domes over historic era. Drawings: Authors

The tomb towers crowned by three shells might be considered as the last generation of the conical and polyhedral domes, by the end of the Timurids era, when the rapid developments of the pointed and bulbous domes had noticeably prevailed in Persia and nearby regions.

5 Conclusion

Conical and polyhedral domes are one of the distinctive aspects of Persian domes which constitute an essential milestone in the development of funerary monuments as a cultural tradition after the appearance of Islam in Iran and surrounding areas

As was stated at the beginning, conical and polyhedral domes chronologically underwent the systematic evolutions during the Seljuk, the Ilkhanid, and finally the Timurid periods, when they reached their acme. Morphologically, four main components – namely, the load bearing system, the transition tier, the drum, and the shells, which are divided into the internal and the external – were derived identically. In addition, the internal shell embraces the various models including the semi-elliptical, the

semi-circular, the pointed, and the saucer models. These shapes are geometrically compatible with the external shell shape, ensuring the structural stability of the whole configuration. This was also the purpose of the internal stiffeners also inserted between the external and internal shells; this approach was subsequently carried out in the compositions of other sorts of Eastern domes, such as the bulbous and the pointed domes in Iran and surrounding areas.

Typologically, the order of shells of the conical and polyhedral domes, which were grouped into single shell, double-shell, and triple-shell, also provide insight into the characteristics of structural designs of these imposing structures. By the identifying a set of attributes for these tomb towers, this paper has tried to show that the configurations of the conical and polyhedral domes are more or less similar, in spite of visual dissimilarities in designs.

The recognition of the formal language of such domes may shed new light on the principles of morphological and typological analysis of the traditional domes in Persia and nearby regions that can be used as design standards in contemporary architecture: firstly, to preserve the close relationship between the past and the present; secondly, to pursue the emergence of the specific aesthetic harmony in the traditional designs of the Iranian domes.

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References

ALTIN, M. 2001. The Structural Analysis of Domes: From Pantheon until Reichstag. Pp. 197-208 in Historical Constructions 2001. Possibilities of numerical and experimental techniques. *Proceeding of the 3rd International Seminar of Historical Construction,* 7-9 November 2001, P.B. Lourenço, P. Roca, eds. Guimarães, Portugal: University of Minho.

ASHKAN, M., and A. YAHAYA. 2009a. Discontinuous Double-Shell Dome through Islamic eras in the Middle East and Central Asia: History, Morphology, Typologies, Geometry, and Construction. *Nexus Network Journal* **12**, 2: 287-319.

———. 2009b. Persian Domes: History, Morphology, and Typologies. *International Journal of Architectural Research* **3**, 3: 98-115.

AYATOLLAHI, H. 2003. *Book of Iran: The History of Iranian Art*. Iran, Tehran: The Ministry of Culture and Islamic Guidance.

BLAIR, S.S., and J. M. BLOOM. 1995. *The Art and Architecture of Islam*. New Haven: Yale University Press.

BOSWORTH, C. E. 1996. *The New Islamic Dynasties*. New York: Columbia University Press.

BYRON, R. 1982. *The Road to Oxiana*. New York: Oxford University Press.

CRESWELL, K. A. C. 1958. *A Short account of the Early Muslim Architecture II*. Oxford: Claren Don Press. (p. 83-87)

GODARD, A. 1965. *The Art of Iran*. Michael Heron, trans. New York, Washington: Frederick A. Praeger.

GOLOMBEK, L., and D. WILBER. 1988. *The Timurid Architecture of Iran and Turan*. New Jersey: Princeton University Press.

GRABAR, O. 1963. The Islamic dome: Some considerations. *Journal of the Society of Architectural Historians* **22**, 4: 191-198.

———. 2006. *Islamic Art and Beyond: Constructing the Study of Islamic Art*, Vol. 3. Aldershot, UK: Ashgate Publishers.

HATIM, G. A. 2000. *Mimari-i Islami-i Iran dar dawrah-i Saljuqian* (Islamic Architecture of Iran during the Seljuks). Tehran: Muassasah-i Intisharat-i Jihad-i Danishgahi . (In Persian.)
HEJAZI, M. M. 1997. *Historical Buildings of Iran: Their architecture and Structure*. Southampton: Computational Mechanics Publications.
HILLENBRAND, R. 1994. *Islamic Architecture: Form, Function, and Meaning*. New York: Columbia University Press.
HILLENBRAND, R. 1999. *Islamic Art and Architecture: The Ilkhanids and Timurids*. London: Thames and Hudson. (p. 196- 202)
HOAG, J. D. 1987. *History of World Architecture: Islamic Architecture*. New York: Rizzoli.
HUERTA, S. 2006. Galileo was Wrong: The Geometrical Design of Masonry Arches. *Nexus Network Journal* **8**, 2: 25-52.
MEMARIAN, G. H. 1988. *Statics of Arched Structures* (*Nîyâresh-e Sâzehâye Tâghi*), Vol. 1. Tehran: University of Science and Technology Press. (In Persian)
MICHELL, G., ed. 1978. *Architecture of the Islamic World: Its History and Social Meaning*. New York: Thames and Hudson.
O'KANE, B. 1998. Dome in Iranian Architecture, Iranian Art and Architecture, [Retrieved November, 21, 2010, On-line, http://www.cais-soas.com/CAIS/Architecture/dome.htm].
PETERSEN, A. 1999. *Dictionary of Islamic Architecture*. London: Routledge Press (Reprint edition).
PIRNIA, M., and Q. Memarian. 2003. *Recognition of Persian Architectural Styles*. Tehran: Pazhoohandeh. (In Persian)
POPE, A. U. 1965. *Persian Architecture*. London: Thames and Hudson Press.
———. 1976. Introducing Persian Architecture. Pp. 52-68 in *A Survey of Persian Art*, J. Gluck, A. U. Pope and P. Ackerman (eds.). Tehran: Soroush Press.
SAOUD, R. 2003. Muslim Architecture under Seljuk Patronage (1038-1327). Foundation for Science, Technology, and Civilization (FSTC). http://www.muslimheritage.com/features/default.cfm?ArticleID=347. Last accessed 25 March 2012.
SEHERR-THOSS, S. P. and H. C. SEHERR-THOSS 1968. *Design and Color in Islamic Architecture: Afghanistan, Iran, Turkey*. Washington. D.C.: Smithsonian Institution Press.
SMITH, E. B. 1971. *The Dome: A Study in the History of Ideas*. New Jersey: Princeton Press.
STIERLIN, H. 2002. *Islamic art and Architecture: From Isfahan to the Taj Mahal*. London: Thames and Hudson.
SYKES, S.P. 2003. *History of Persia* (3rd ed.). London: Routledge Publisher.
WILBER, D. N. 1969. *The Architecture of Islamic Iran: The Il-Khanid Period*. New York: Greenwood Press.

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