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DECODING GEOMETRIC PROPERTIES OF MUQARNAS BASED ON ARCHITECTURAL SCROLL

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ABSTRACT

Understanding the mystery of muqarnas geometry and its complexity needs to have knowledge about the designing thought and designing methods of these geometrical decorative elements. This topic tries to reveal the architectural scrolls, geometrical properties of muqarnas,what we should know and how to researchtechnologies of creation of the muqarnases. Furthermore, in order to understand the structure of muqarnas, we going to study muqarnas structure in both two-dimensional plane projection which is a substitute for the muqarnas design, and three-dimensional muqarnas compositions and the way that are constructed as a volume. In this regard, all information is based on scroll and knowledge of traditional masters of Uzbekistan, Iran, Turkey, and so on.

KEYWORDS: *Muqarnas, Karbandi, Rasmi bandi, Yazdi bandi, Kaseh sazi, stalactite,shamseh, toranj, taseh, parak, shaparak, tee, espar, takhts, scroll.*

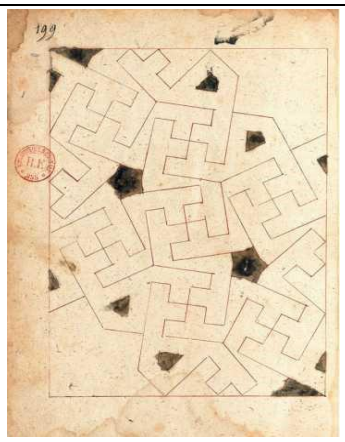
INTRODUCTION

Because of Islamic belief, architects and artisans started to use singly or combined motifs of geometric patterns instead of living creature figures in their architectural decoration. Such as adorning the surfaces or using complex arrangements.

According to the survey that is presented by The Metropolitan Museum of Art (2000), the first samples of geometric ornamentation already existed in late antiquity in the Byzantine and Sasanian empires. Islamic architects mostly tried to lay emphasis on unity, logic, and order in architectural decoration. Geometric patterns in Islamic world developed by mathematicians, astronomers, and other scientists, whose ideas reflected in works as *Abū al-Wafā Būzhjānī*, *Ghiyāth al-Dīn Jamshīd Masʿūd al-Kāshī***]** and so on*(Fig. 1).* Compasses and Ruler were the first tools to draw these geometries and circle was the first geometric form of Islamic patterns.

According to Necipoglu and Al-Asad (1995**)[20],** the most interesting fact about Muqarnas is its geometry and the mystery behind it. Most of the scientists and architects, from *Ghiyāth al-Dīn Jamshīd Masʿūd al-Kāshī (or al-Kāshānī)* in the nineteenth to contemporary researchers, like Notkin**[22,22],** have tried to analyze it. Understanding the mystery of Muqarnas geometry and its

complexity because of their mathematical relations is too much complicated so that researchers must have not only the mathematical knowledge but also has to analyze them as an artisan.



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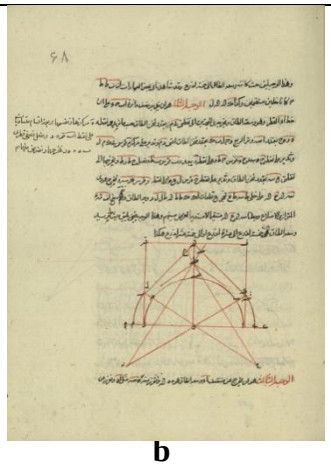

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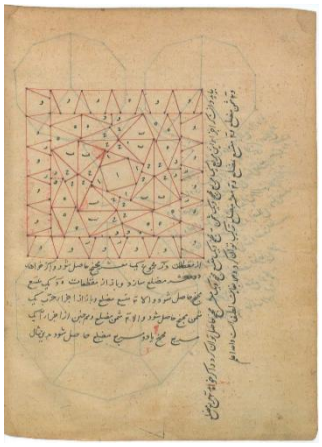

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Fig 1.

a – Folio from Abū al-Wafā Būzhjānī's appendix, eleventh -thirteenth century, Bibliotheque Nationale de France.

b – A page of Ghiyāth al-Dīn Jamshīd Masʿūd al-Kāshī's book, IV Manuscripts. Memarian. (1988).

c – A "dividing and assembling" construction in two stages, showing the transformation of a pentagonal star and two congruent decagons into a larger decagon containing a central pentagonal star. From the Anonymous Compendium. Paris, Bibliothèque nationale de France, Ms. Persan 169, fol. ı8or ***[1].*** *(Photo: Bibliothèque nationale de France)*

d – Fol. ı8ov ***[2].*** *Anonymous Persian Manuscript, Fi tadakhul al-ashkal al-mutashabiha aw mutawafiqa. Bibliothèque nationale de France, Ms. Persan 169, fols. 180r-199r. Nasta'lîq script, folio dim.190x270mm.Construction with parallel and rotating concentric squares, subdivided into trian-gular or trapezoidal pieces to be reassembled into polygons and star polygons.*

Dadkhah, Safaeipour, and Memarian [5] state that one of the common methods of decoding a Muqarnas composition to its basic elements is the projection method, which is a Two-

dimensional representation of the complex three-dimensional Muqarnas. This method presents us two fixed rules that are valid for all Muqarnas compositions:

1. Using simple and uncompounded geometric elements in every Muqarnas projection.

2. Determining a geometric system for connecting muqarnas elements.

They are also refer to the definition that is expressed by the fifteenth century mathematician *Ghiyāth al-Dīn Jamshīd Masʿūd al-Kāshī* and note that the first category consists of two main geometry groups: its basic building blocks that are called cells and the primary elements or intermediate elements that are used between the cells to complete the geometric network *(Fig.2).*

Fig.2 Architecture details of muqarnas Shodi Mulk Oko Mausoleum at the Shah-i-Zinda, Samarkand, Uzbekistan. Photo and geometric analysis of Shakhboz Mustafoev.

Architectural Scrolls. Based on available resources, no architectural drawing survives in the Muslim world, predating the Mongol era, yet occasionally mention is made of patterns that were drawn on the ground*(Fig. 3* This stucco plate shows one-quarter of a muqarnas pattern of a vault. Parts of the actual muqarnas were also unearthed from the ruins where the plate was found. The elements of the muqarnas seem to be pre-fabricated and then mounted on the wall. **(Ghazarian & Ousterhout, 2001[11]; Harb, 1978[14]; Dold-Samplonius & Harmsen, 2005[8]; Harmsen, 2006[15]; Hoeven & Veen, 2010[17]).**

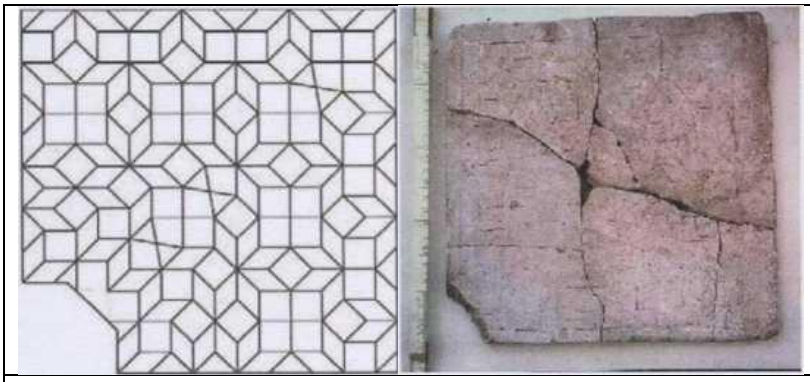

Fig.3. The oldest found example of a muqarnas pattern is the 13th century plaster tablet found in Takht-i Sulaiman, Nishapur, West Azarbaijan, Iran.(Harb, Ulrich. 1978.).

The *Topkapi Scroll* (16th century) and *Mirza Akbar Scrolls* (19th Century) are other samples in which two-dimensional pattern plans of muqarnas can be found**.[20]** The Topkapi Scroll contains

a collection of 114 muqarnas patterns as documented in 1986. The valuable scroll is kept at the Topkapi Palace Museum, in Istanbul, it is the oldest available scroll of its kind which was discovered intact**.[17]**

Necipoglu is of the opinion that the plans of the Topkapi Scroll, as shown in *(Fig.4.a.)*, are composed of radial orders adorned by intertwined stars and polygons in angular arrangements. She further explains that the patterns are drawn on the basis of the radial lines projecting from the comer of the design. In the drawings, black, red, and dotted lines are used to facilitate the reading of the plan by the builders. Further, as illustrated in *(Fig.4.b.)*, elements such as *toranj***[Error! Reference source not found.],** *shaparak***[Error! Reference source not found.]** and *parak***[Error! Reference source not found.]** are colored to distinguish them from other filling components, in addition to a clear distinction of the tiers.

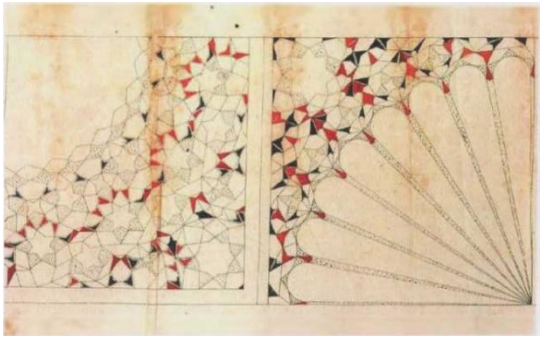

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Fig. 4.a. Topkapi scroll, radial design (Necipoglu, 1995).

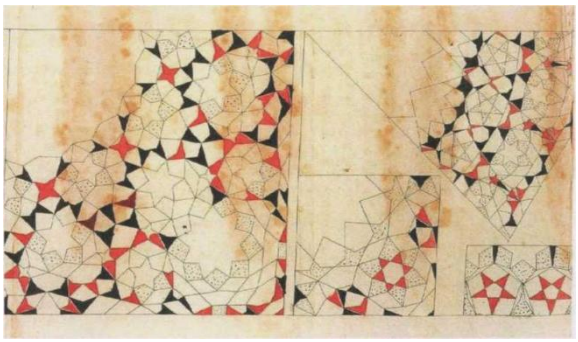

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Fig.4.b.Topkapi scroll, coloured elements (Necipoglu, 1995).

The distinction of the elemental contours and tiers with different colors in the plans resemble very closely the designs of the *Tashkent scroll*, *Bukhara scroll* and *Mirza Akbar scroll*, and the drawings of *El-Bouri*. The other common factor among all of these scrolls and drawings is that they represent direct or inverted ceiling plans with all of the tiers present *(Fig.5***.).[20]**

Fig.5. Tashkent scroll 2.1. (Photo by Shakhboz

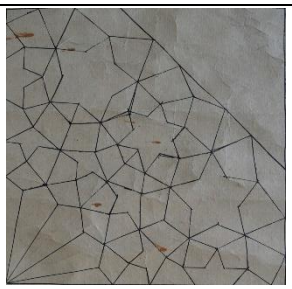


Fig.5.Bukhara scroll 4429-16. Fig. 40.(Photo by

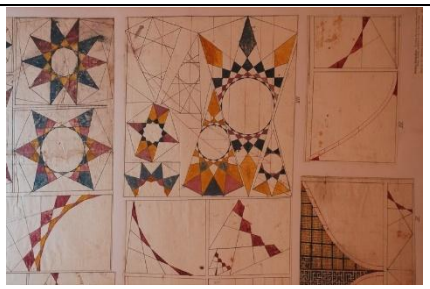


Fig.5.Mirza Akbar Scroll, coloured elements (Source:

Mustafoev.)	*Shakhboz Mustafoev.)*	*Patteminislamicart.com).*

Christie describes the drawings found in the Mirza Akbar scrolls, as shown in *(Fig.5.)*, as a set of stars and polygons intertwined by concentric circles and dissected by radiant lines, turning them into a complex system of radial symmetries**.[3]** This method in the latter's opinion enabled Muslim designers to redefine the pre-existing geometrical forms with their own inventive rules. The scholar considers this discovery as the greatest achievement of Muslim ornamentation, with yet limited effects on Western decorative traditions. From this, Christie surmises that as the designers overcame the complexities of the designs, each pattern would degenerate into a repetitive module and passed around until the likes of scrolls in Mirza Akbar's possession would become indispensable tools at every significant work site.

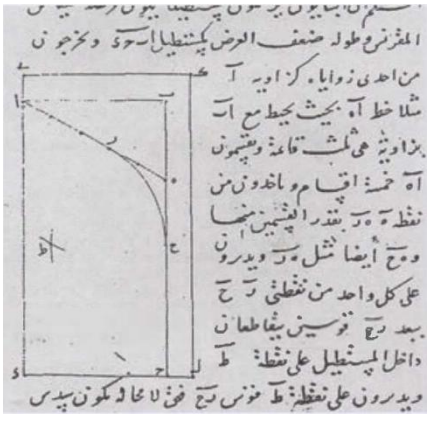
Referring to the similarities between 2DPPs of muqarnas and Arabesque knot work or interlace patterns, known as gerehs, Behrens-Abuseif writes:

"It is not clear whether the development of the mukarnas in Persia started from the planar into the three-dimensional, or vice versa, or that it developed in parallel directions. Since the excavations in Takht-i Sulaiman, the ornamental rather than the structural origin [for muqarnas] is being favored."

*Behrens-Abuseif (1993***).[1]**

In addition, Bulatov believes that the direct interchange of patterns between the two dimensional gereh and the three-dimensional muqarnas has enriched the Islamic architecture of Iran and Central Asia, with a congruity that unites the symmetrical order of the plans, walls, and vaulted ceilings**.[2]**

Al-Kashi's Method of Drawing Muqarnas. The proposed method of drawing a simple muqarnas by Al-Kashi is very significant since all other extant drawings pertaining to muqarnas comprise of plans only, but this drawing comes with an explanation on how builders decide the curve of the arch. *(Fig.6.a.).*



a *b*

Fig.6. Al-Kashi illustrates the pertinent instructions as they appear in the manuscript.Hand-drawing (Dold-Samplonius, 1992).

With reference to *(Fig.6.b.)* builders draw a rectangle (ABDG) to the width of the elemental profile and a height twice the width. From point A they draw a -30° angle. Then they divide AH into five, and mark the second division from H, hence R. Using a compasses they determine E on

the vertical line BG, where HE=HR. using points R and E as the centers and RE as radius, they draw two curves to intersect at point T. now placing the needle of the compass on T, and with the same radius, they draw a curve to connect AR to GE.

Next, they extend DA and DG to the desired lengths at points I and L, constructing IKLGA. This profile will be used for a mold to reproduce as many similar shapes as needed by the plan. They will then install each of these plaster profiles on the sides of an element at the workplace. It must be added that the height to width ratio is flexible since the depth of the muqarnas elements is not constant at all points. However, the height of the elements will be equal since the distances between the tiers are uniform**.[Error! Reference source not found.]**

Construction Characteristics. Clarke has been one of the earliest eyewitnesses to record the traditional method of constructing muqarnas in 1893. According to Clarke, the construction of a muqarnas vault commences with the execution of the plan on the actual scale on a flatbed of plaster poured onto the ground that is leveled with a layer of ash. Builders would then imprint the lines carving them into the plaster, lubricating the surface with lard, out of which they produce a plaster template roughly half an inch thick. They repeat this procedure for all of the tiers in the plan, after which they install them into place on the designated site. It noted that because Eastern muqarnas contain straight edges, manual construction is not very difficult (**Clarke, 1893[4].** See also Notkin, 1961**[22].**). Forty-three years later, Myron Smith speaks of a trip to Isfahan in 1936, wherein he observes the construction of a muqarnas vault using basic tools like straight edges, strings, and needle compasses. At the site, as Smith explains,

"The builders had laid the real scale plan carved on a plaster bed using a pick."

Smith, 1947.[**25]**

This statement means that the techniques had not changed since Clarke's observation in the 19th century. In addition, Snelling speaks of a similar experience in 1995 in Turkey:

"I watched a local builder decorating the interior of a cafe and he made 30mm slabs of shaped Plaster of Paris "stucco" on a glass sheet bounded by wooden battens and with fresh plaster, he could both stuck slabs together and then onto walls."

*Snelling, 1995***.[26]**

In fact, the spatial organization of muqarnas in a building and its pertaining construction technique depends on the location of the decorations in the building. This location is determined by the intersection either of two non-coplanar surfaces (i.e. cornices, corbels, and capitals) or at the transition zone between the rectangular quarter and the spherical vault (i.e. pendentives, squinches, portals, and ceilings**).[10]**

Wheeler Thackeston describes the methods applied by masons and craftsmen in constructing muqarnas, by using inverted plans. He illustrates how builders apply a vertical rectangle with a width equal to the projection of the muqarnas element, and a height twice the width, to construct the decoration. After explaining the method by which the vertical profile of the *taseh* is determined, he moves on to analyze the technique by which each muqarnas tier is laid out on a plasterboard and adjusted to the pertinent vault. Komaroff also believes that Al-Kashi wrote his treatises for a scientific audience rather than for artisans. She points to the fact that the scholar reiterates the otherwise alternative terms used by craftsmen for the mathematical phenomena he

discusses, which indirectly hints to the fact that he is discussing this with and for a group of scholars**.[18]**

Necipoglu speaks of practical training by which builders would decipher the most complex plans of multi-layered stalactites for construction. In this craft, the masons would develop three-dimensional views of the relevant elements, eliminating the need for elevation drawings, by which they would project the working plans onto the actual surfaces, as well relying on their practical expertise**.[25]** Pugachenkova posits that in the construction of complex vaults and arches, the old technique of drawing the plan on the floor in real scale, and without the need for elevations is still in practice. The elements of the muqarnas are constructed on the ground first and then, hung and attached to the structure by means of ribs**.[24]**

Sha'rbaf, who is a famous expert traditional architect in Iran, also mentions that in constructing a muqarnas suspended layer technique is used over the vault.[**Error! Reference source not found.**] For a better understanding of the building process of muqarnas, as illustrated in *(Fig.7.),* he always equips his muqarnas plans with line projections onto the elevations of the pertinent vaults.[**Error! Reference source not found.**] Al-Asad posits that the most important factor in the execution of the muqarnas plan is the equal division of the height into the number of component tiers. Each tier represents a set of elements with uniform height and contains a number of *shaparaks*. On the elevation, each set of *shaparak* elements is accompanied by a tier devoid of *shaparak*. Unlike other tetragonal elements, the *shaparaks* get narrower as they recede, and this lack of uniformity disables the formation of a rectangular row**.[20]**

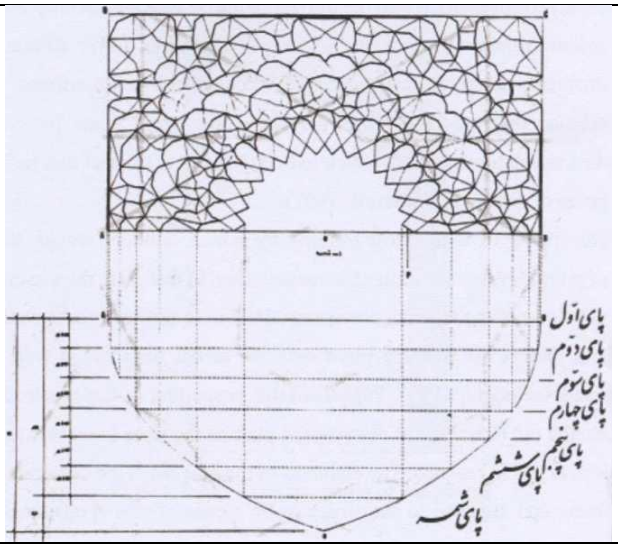


Fig.7. Sha'rbaf drawing, including projection lines (Sha'rbaf, 1996).

Constituent Elements of Muqarnas. Different approaches were taken to describe the constituent elements muqarnas. Many scholars rely on Al-Kashi's definition of muqarnas elements **(Dold-Samplonius, 1996[7]; Dold-Samplonius, [9], 2002; Hamekasi, 2011[12]; Harmsen, 2007[15]; Hoeven & Veen, 2010[17]; Kromker, 2007[19]),** while some other professionals define the constituent elements of their own (Yaghan, 2001[28]). Al-Kashi's explains muqarnas to be comprised of tiers that are in turn divided into cells, in round stair-like arrangements on the vault, where each cell connects to the next with a predetermined angle. In addition, there are

intermediate elements that connect the roofs of adjacent cells to each other. **[Error! Reference source not found.]**

The two-dimensional plans of Al-Kashi's described muqarnas cells are basically simple geometrical forms like *square*, *half-square* (right-angled triangle), *rhombus*, *half-rhombus* (isosceles triangle or equilateral triangle), *almond* (deltoid), *jug* (one-quarter of an octagon), *large biped* (complement to a jug), *small biped* (complement to an almond) and sometimes *rectangles*.**[6]** Since the Ilkhanid period, the above-mentioned elements are used for constructing muqarnas without any change. Although more advanced forms of muqarnas with four- to seven-pointed star elements were erected during the Ilkhanid period as well*(Fig.8. a.).*

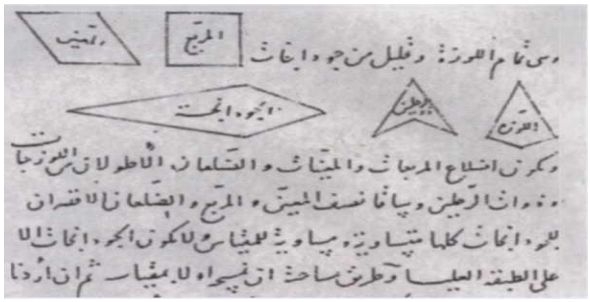


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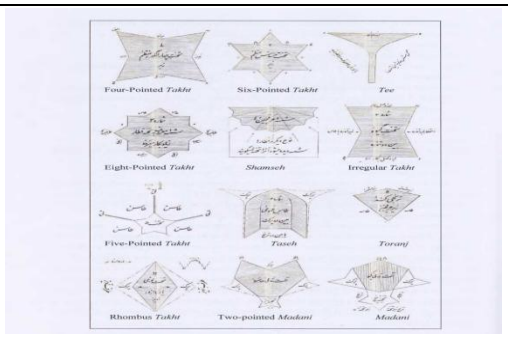
Fig.8.a. Constituent elements of muqarnas as introduced by Al-Kashi (Dold-Samplonius,1992).



b

Fig.8.b. Constituent elements of muqarnas, from Lorzadeh's point of view (Source: adapted by Hamidreza Kazempour from (Lorzadeh, 1981)).

Vincenza Garofalo simply compares the constituent elements muqarnas to portions of vaults ranging from a few centimeters in Moroccan muqarnas to meters in Jame' Mosque of Isfahan, in dimension. She adds that material is one of the important factors that influence the size of the muqarnas. Big muqarnas can be made of stone, while the small ones can be made of wood. In addition to material, the historical periods can also affect the dimensional aspects**.[10]**

Among Iranian masters and scholars, Ustah Lorzadeh introduces a set of constituent elements for muqarnas, comprising of eleven elements that are explained below and shown in *(Fig.8. b. see also Table 1.):*

TABLE 1.

1.	*Shaparak.*	A three-sided element, responsible for connecting the tiers and units together.
2.	*Takht.*	The regular horizontal star-shaped element maybe four-, five-, six- or more pointed.
3.	*Irregular Takht.*	A horizontal element that has an irregular shape.
4.	*Shamseh*	The medallion on the apex of vaults or iwans, responsible for finishing the ornament.
5.	*Toranj*	The element that comes immediately after shamseh, as well as under regular Takhts.
6.	*Taseh*	A famous element that always appears between shaparaks, and sometimes

		between two Toranjes.
7.	*Tee*	A narrow element that appears between Tasehs.
8.	*Madani*	An element that fills the space between two Takhts from two different tiers.
9.	*Double-Madani*	This element is a Madani that has two legs instead of one.
10.	*Lozi*	Equivalent to Darvazeh, meaning gate. A curved rhomboid is responsible for creating hanging components.
11.	*Susan*	A small Taseh, that looks like an isosceles triangle (Lorzadeh, 1981).

Sha'rbaf, on the other hand, adds two more elements to the collection, namely pabarik, and tanoureh**,[Error! Reference source not found.]** while Pirnia adds ahou-pa too and posits ahou-pa as the hanging portion of the muqarnas**.[Error! Reference source not found.]** In this collection, tanoureh is identical to Lorzadeh's madani element and pabarik is in fact an elongated toranj.

CONCLUSION

In spite of the vast amount of researches focusing on the subject of muqarnas over the past few decades, only a portion of the existing gap in the knowledge is filled. To obtain a comprehensive chronology of muqarnas, its origin, evolution and maturation process, its design and construction methods, as well as its meaning, reliance on the available information is still not enough and further investigation on the subject is demanded.

To overcome these shortcomings, not only do we need to survey, record, and document the extant samples of ancient works, but we also need to pay attention to what may be found in poems and literary works of the past, which has less attracted the attention of the architectural historians of the Muslim world. Only through these kinds of interdisciplinary research is it possible for a scientific investigation to come out of pure speculations and get closer to the truth. We could see increasing desire between the scholars to discover the beauties behind the most complex decoration of traditional architecture, which is now a signature decorative element of Islamic architecture ***(Fig.9.)***.[13]

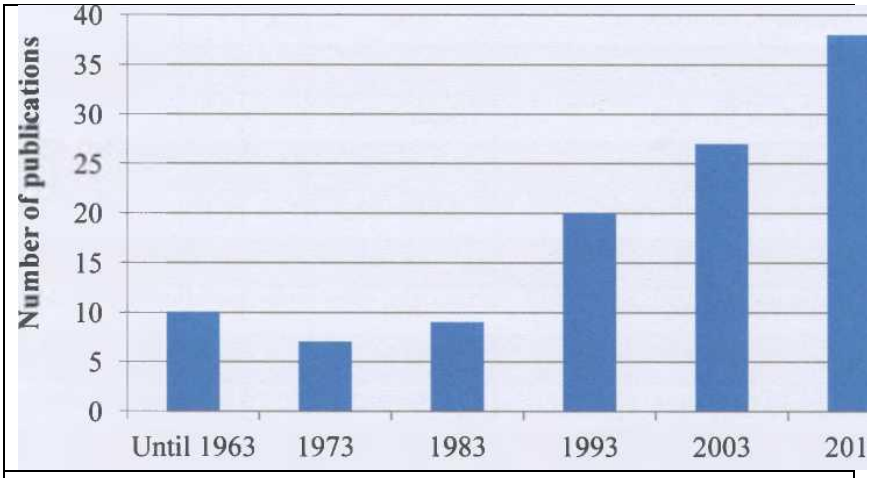


Fig.9. Number of publications about muqarnas, in each decade (Source: Hamidreza Kazempour, 2016.).

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