J. King Saud Univ., Vol. 10, *Arch. & Planning*, pp. 17-52 (A.H. 1418/1998)

Structural Genuine-Muqarnas Dome: Type Definition, Unit Analysis and Computer Generation System

Mohammad-Ali Jalal Yaghan
Graduate School, Tsukuba University, Tsukuba Shi, Ibaraki Ken 305, Japan

(Received on 28/6/1417 H.; accepted for publication on 29/8/1417 H.)

Abstract. One way to understand the muqarnas phenomenon is by establishing types according to some attribute values, analysis of which, as well as those found common to the type, in relation to other similar studies would later explain issues of form evolution, origin, etc. This paper represents one such study. It is divided into three parts. The first defines "Structural Genuine-Muqarnas Dome" as a distinct type, that has been included along with other types under "muqarnas dome". The second analyzes this type's unit system. The third presents an algorithm of a computer generation system for this type, its advantages, and some outputs of a test program.

Keywords: Muqarnas, Islamic architecture, Islamic art, Computer generating system, Types.

Introduction

One way to deepen the understanding of the phenomenon of muqarnas and the relation between its different forms is by establishing types according to certain attribute values[1] that are under consideration, then to analyze any other attribute values that are common to all members of such type. The results obtained from each study will provide a group of information whose relation to results of other studies would eventually explain many unsolved issues of muqarnas like form evolution by time, origin, etc. A complementary study would then be done to present the common attribute values of the type in hand in a generic way and accordingly create a computer generation system that can produce forms belonging to this type. Some of these would resemble its existing

members, while others might represent some forms that once existed or totally new forms. Out of these outputs, and the abstract mathematical analysis used to create them, links to other muqarnas forms and their evolution process could be established. This paper represents one step along this course.

1. Type Definition

The type that will be defined here is one that has been looked at only from the perspective of the "muqarnas dome" type, thus its structural quality, which is one of its defining attribute values, has never been studied in depth for the reason that the majority of the members of "muqarnas dome" type are purely decorative. That is the reason why this part will start with a discussion of these two issues.

The term "muqarnas dome" has been assigned to all domes associated with muqarnas in one way or another, and it was referred to in many scholarly works as a "type" of muqarnas[2]. Only one attribute was considered when establishing this type. It is "the form in which muqarnas was applied." Two of its members were thus the muqarnas over the mausoleum of Imam Dur in Iraq and that of al-Qarawiyyen mosque in Tunisia. Although all other attribute values of these two forms are different as seen in Table 1[3], this single-attribute type was considered as a standard class and conclusions of different issues were generalized to include all its members, including these two. An obvious misleading consequence can be seen in the issue of the origin of muqarnas domes, where the categorization of these two specific examples as one type, led some recent researchers to conclude that the origin of the muqarnas dome is Iraq as the older case is found there, and to refute the earlier theory of multiple origins[4]. Another consequence was the association of one meaning to these two and all other members of this type.

Table 1. Comparison between Al-Qarawiyyin mosque's Muqarnas dome and Imam Dur's

	Al-Qarawiyyin mosque	Mausoleum of Imam Dur
Date	1142	1090
Location	Tunisia	Iraq
Function	Mosque	Mausoleum
Plan	Rectangular, no distinction between the dome and its tranzitional zone	Circular, with a clear distinction between the dome and its transitional zone
Layout	Major orthogonal grid composition	Radial, star composition
Focal points	Main and multiple minor focal points	Single focal points
General profile	No profile of a certain type of dome but a formation of many units eventually culminating in the central point	Overall conical profile both internally and externally
Units	Many small units of different forms	Big Units different in size but similar in form
Architectural hanged role	Units are added or to the structure, themselves are decorative	Units compose the structure with a layer of intricate decoration added uniternally

can be cleared out by considering the section of the part of the dome that is continuous around its vertical axis, which could be arrived at by considering different vertical and horizontal sections of the dome and taking the common part between all of them. Within the boundaries of such section, if another section of any continuous type of domes (e.g. conical or round) is found with acceptable visual proportions through which loads would transfer, then an argument can be raised that muqarnas is like a cladding for some type of a continuous-surface dome (such conceptual section can be seen in Fig.1-a); if not, then it could be concluded that such muqarnas plays a definite role in load transfer (Fig.1-b)[8].

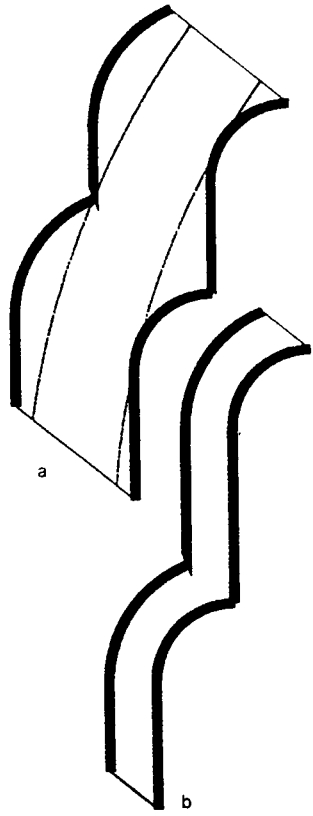


Fig. 1. Conceptual sections of the parts continuous around the vertical access.

This domain would clearly classify its muqarnas instances as "structural" because muqarnas parts are the only media through which loads could transfer down, and as genuine because it is visible internally and externally. Thus, the term "Structural Genuine-Muqarnas Dome" will be adopted, from now on, as a title for this type.

The first case study of this paper that satisfies these values is the dome over the mausoleum of Imam Dur on the Tigris, Iraq. Dated 1085-1090[9] it represents the earliest known example of this type and of any muqarnas dome at all[10]. The most comprehensive set of drawings was produced by Herzfeld[11]. Figure 2 shows new roof plan and plan and two vertical sections, of only the dome, based on Herzfeld's[12].

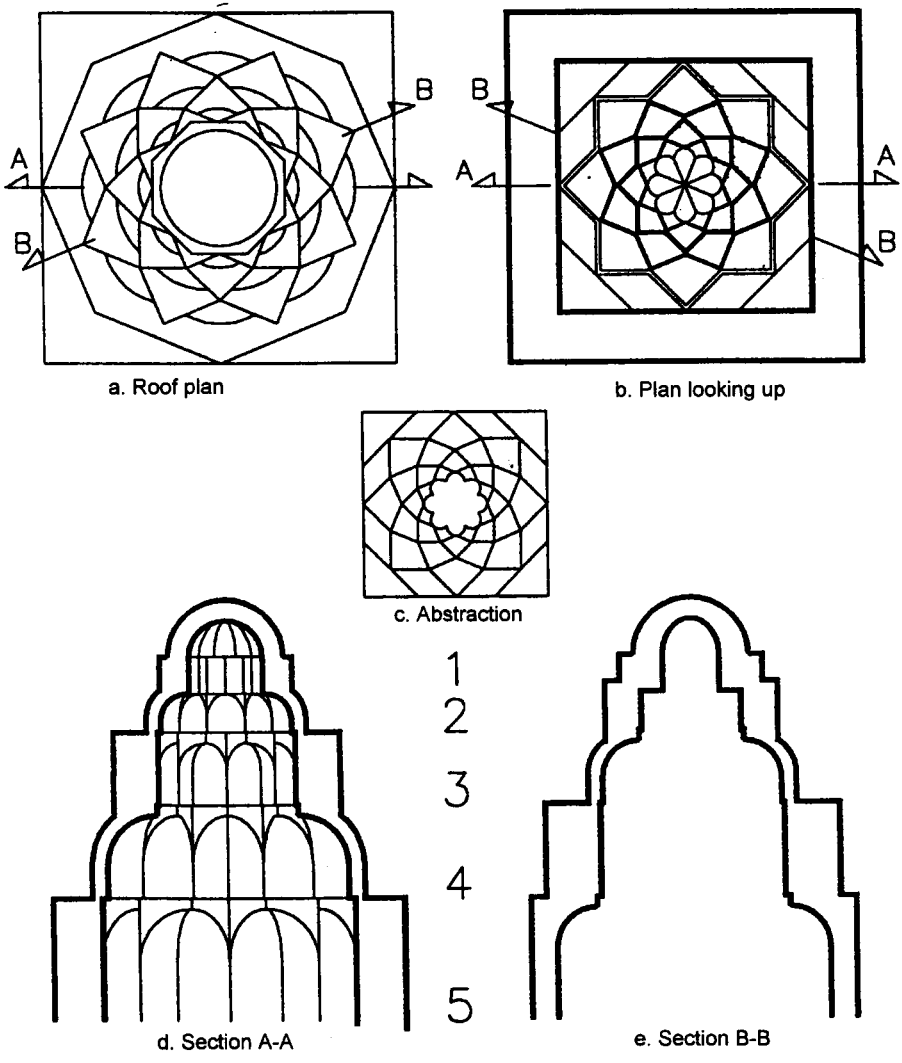


Fig. 2. The dome over the Mausoleum of Imam Dur.

This is a single shell dome composed of muqarnas units that, apart from obvious

intricate decorative cladding superimposed on the interior and which do not change the general appearance of the muqarnas, echoes its interior in the exterior. The section clearly shows that muqarnas parts are the media for load transfer. In Fig.3 the load transfer lines are shown for each tier, the whole structure, and a single unit (for ease of reading the drawing only half of the dome is drawn).

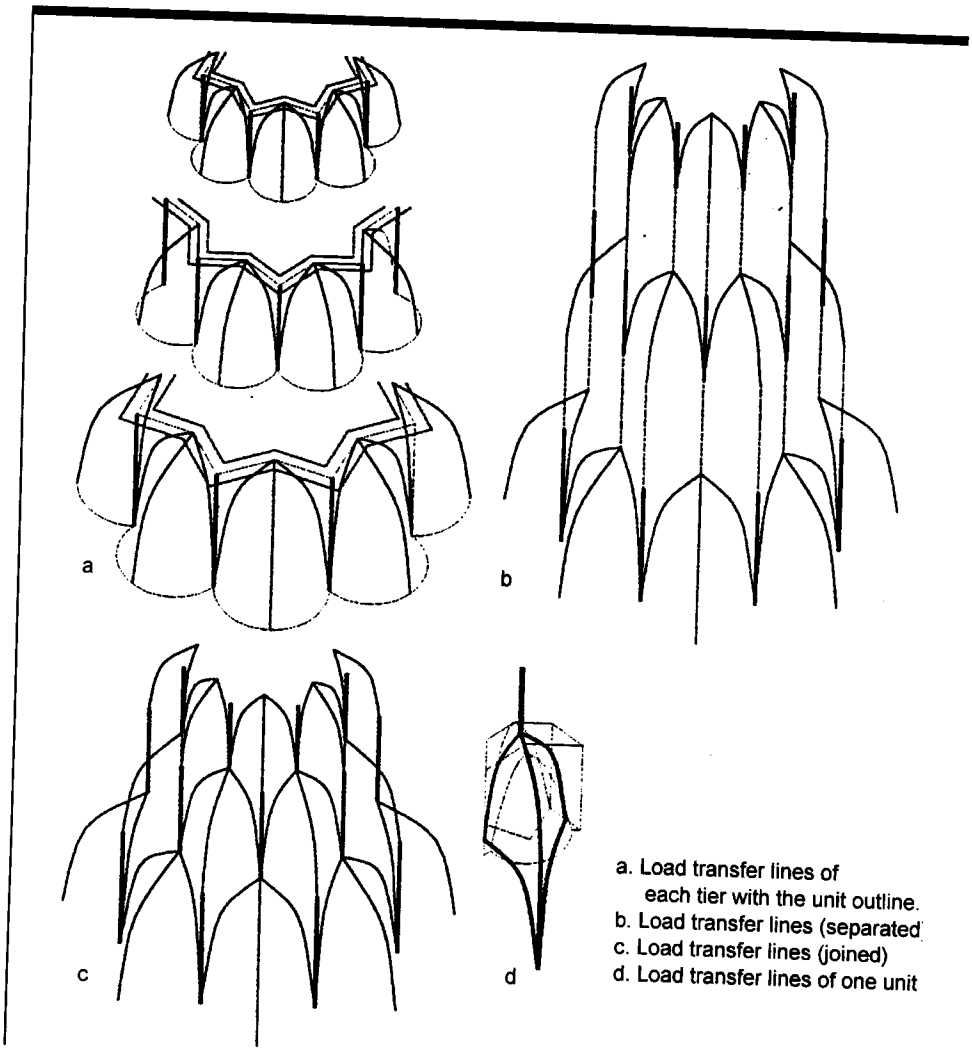


Fig. 3. Lines of load transfer in Imam Dur's Muqarnas.

The second case is the muqarnas dome over the tomb of Zumurrud Khatun , also

known as Sitt Zubaida[13]. It represents the best example of its "type" according to many researchers[14]. It belongs to the late twelfth or early thirteenth century (around 1200)[15], almost a century and a half after that of Imam Dur. During this period of time, the maturity of form reached its peak. Again, a complete set of orthogonal drawings, which includes a roof plan, a plan, an elevation, and a section, was produced by Herzfeld[16]. Upon reviewing these drawings, and cross examining the data provided within, it appears that Herzfeld made an approximation in portraying the external boundaries of the section he provided from tier 8 up to 1[17]. This can be seen when superimposing the section on the elevation and reading data from the roof plan. To a degree this is understandable, and maybe acceptable for general purpose studies, but for this research's issue of assigning the "structural" quality for the muqarnas in hand, a more accurate section was needed. That is why the drawings were reproduced on the computer based on Herzfeld drawings, verbal descriptions of different researchers[18], and photographs, as an actual survey was out of hand. Figure 4 shows the plan, roof plan, and two sections, one taken longitudinally re-portraying that of Herzfeld's, the other taken along the center of the dome and rotated at 11°15' from the first one, and passes proper through all tiers of muqarnas unlike the first one whose cutting plane is not aligned to tiers 1-3. Three points made these drawings an acceptable reference for further analysis of this case, they are:

1. The assumption that other drawings have a good level of accuracy and are reliable, being produced by a researcher with such reputation and credibility in the field of Islamic architecture throughout his lifetime.

2. The fact that the issue of this study that depends on actual accurate data of the case, is determining whether its muqarnas is structural or not, which conclusion can be drawn from the parts of the section with no approximations (as will be shown later), and supported by the new group of drawings.

3. As for the purpose of arriving at a generic unit for creating this type of muqarnas form, the analysis of the form and its units seeks its descriptive qualities rather than its quantitative values. Consider a star composing edges of a unit; the issue would be the number of its points, the way they are connected, and what relation the star has with other shapes rather than its actual dimensions. In this aspect the descriptive qualities within the drawings are reliable as supported by external and internal photographs of the building, as well as verbal descriptions.

This dome itself is a single shell dome, composed of muqarnas units whose interior echoes its exterior. Taking 10 horizontal and two vertical sections in tiers 10 and 9 would end with the section shown in Fig.5-c which is the one circumventing the central vertical axis of the dome, and which, in reference to discussion of Fig.1-b, shows that the only media for the loads to transfer is through the jaggy form of the muqarnas units. Also superimposing the two sections of the whole dome will give a rough section of the continuous part of the whole dome around its vertical axis, which supports the

conclusion of structural role (Fig.5-d). The reason for doing this in two steps is the approximation in Herzfeld's drawings mentioned above. The first step involved the two tiers with no approximation, and as long as they are the lower ones, loads from above have to pass through them (i.e. are structural). According to this and to the second step of superimposing the new sections, the structural quality can be assigned to this muqarnas dome.

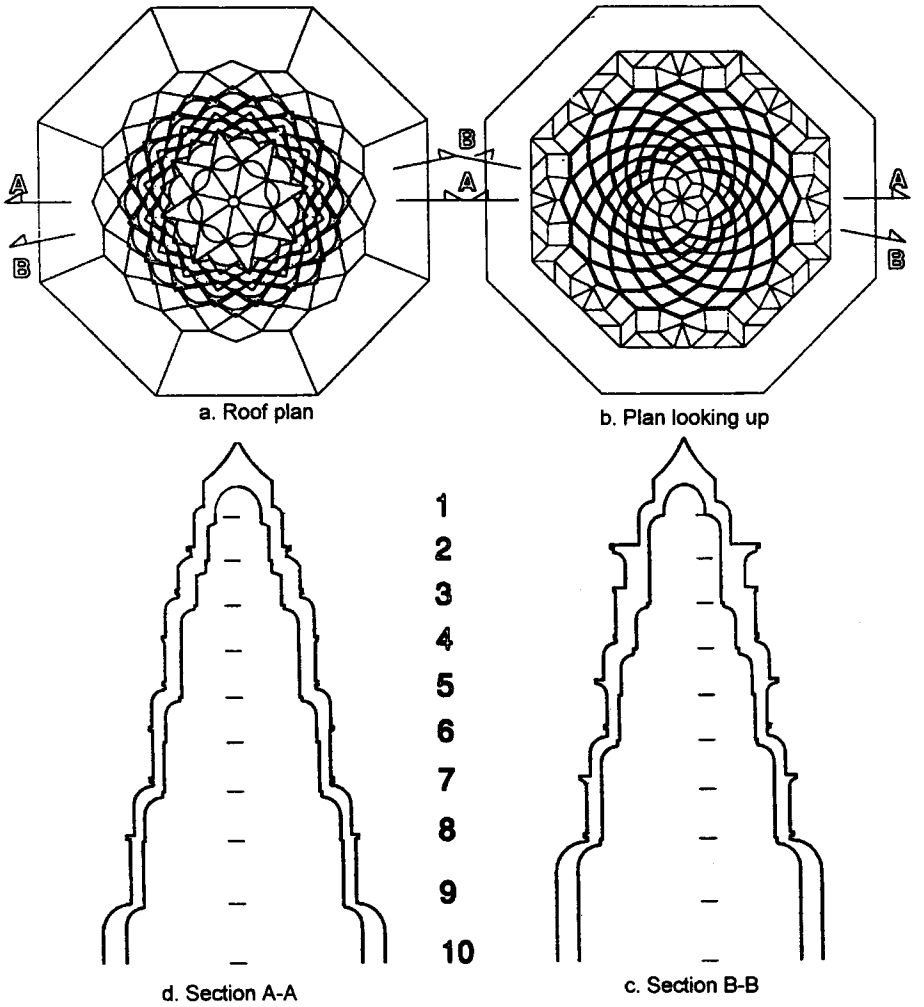
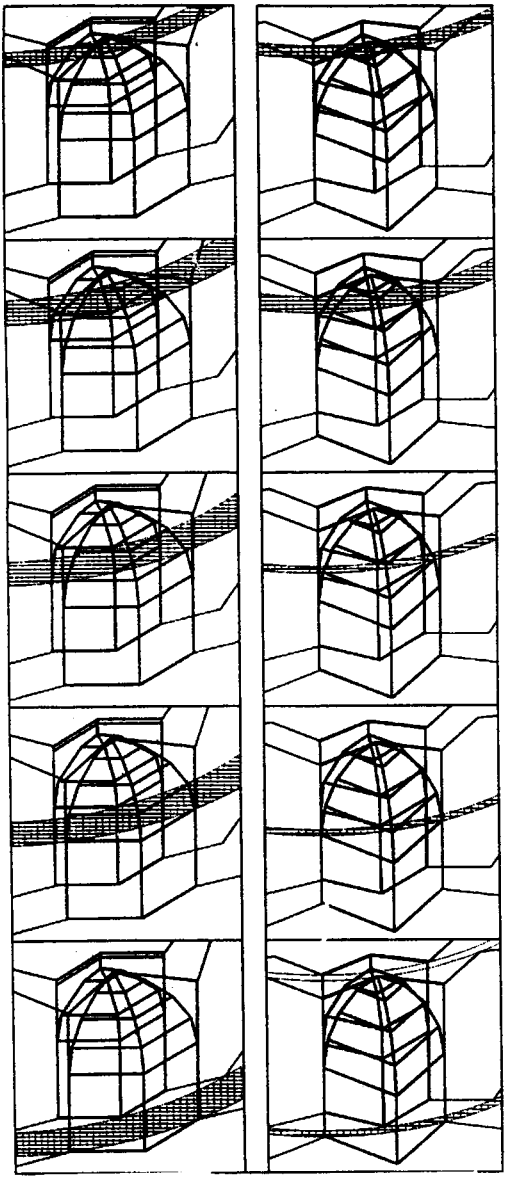
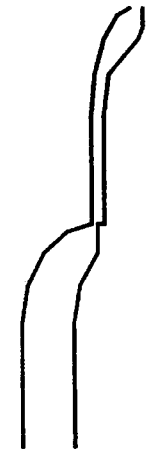


Fig. 4. The dome over the tomb of Zumurrud Khatun.

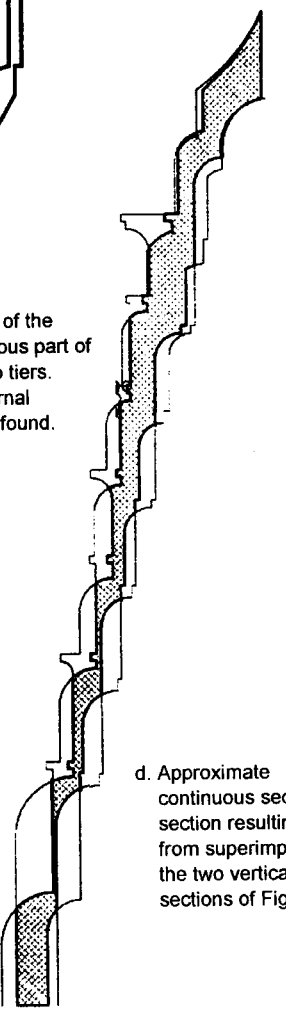


a. Tier 10 b. Tier 9

Horizontal sections of the continuous part of tiers 9-10.



c. Section of the continuous part of the two tiers. No internal shell is found.



d. Approximate continuous section section resulting from superimposing the two vertical sections of Fig. 4.

Fig. 5. Structural quality of Zumurrud Khatun Muqarnas.

There are 13 tiers of muqarnas, only ten compose the dome, the other three work as a buffer between the dome and the octagonal building base.

These two cases were chosen because one represents the earliest prototype and the other a highly mature model of the type. The other examples shown in Table 2 seem also to be members of this type. Although a further study to confirm their structural quality has yet to be conducted, all other similarities (shown in the table) make it justifiable to consider them as members, at least till any further study proves the contrary.

Table 2. Potential members of the S.G.M.D. type

Building	Date	Function	Materials	Location	No. of tiers **	Low stars No. of points	Changing points tier
Mausoleum of Al-Shaikh* Al-Sahrawardi	1235	Mausoleum	(?)	Iraq: Baghdad	12	16	5
Mausoleum of Al-Shaikh Hadid	1st quarter 13th century	Mausoleum	Stone and stucco	Iraq: Haditha	10	163	
Mashhad Ashshams	1st quarter 13th century	Mausoleum (?)	Baked brick	Iraq: Al-Hallah	14	24	6
Mausoleum of Imam Al-Baqir	1st half 13th century	Mausoleum	(?)	Iraq: Daquq	13	16	non
Tomb of Zumurrud Khatun	1200	Mausoleum	Baked brick and stucco	Iraq: Bghdad	10	16	4
Mausoleum of Imam Dur	1090	Mausoleum	Baked brick	Iraq: Dur	5	8	non

* Currently this dome is of two shells but the internal one is a later addition. Atta Al-Hadithi and Hana A. Khaliq. Conical domes: 41.

** Tiers counted are only those visible from outside.

Another attribute value that is found common to all members of this type is the plan layout. It could be seen as a type definer[19]. The plan of each member is a radial composition of concentric stars, with every other one rotated so that its external points will coincide with the internal points of the previous one. Consequently, the number of points of all the stars are either equal, or some inner stars will have their number of

points equal to half that of the outer ones by means of extending some lines of one star (which is refereed to as "changing points tier" (Table 2). Further analysis of this attribute value lead to the unit analysis of this type which will be introduced in the second part of this paper.

As a summary to this part, the following is a definition of the "Structural Genuine-Muqarnas Dome".

"A type of muqarnas that is structural, reflecting its interior to the exterior, and whose formation is based on a plan of radial composition of concentric stars[20].

2. Unit Analysis

One of the most important characteristics of any muqarnas form is that it is composed of units[21]. The study of the unit system of different types of muqarnas would shed light on the issue of form evolution. The purpose of this current study is to provide the raw materials of structural genuine-muqarnas dome unit system for such further studies. Before attempting this, a clear distinction between the "geometrical unit" and the "erecting unit" must be drawn.

Geometrical units are deducted when only geometrical qualities are considered and accounted for. They might or might not be the units used to actually build up and erect muqarnas (whether decorative or structural), which are here referred to as "erecting units". Geometrical units are not the same for all types of muqarnas, each type, some times each case, has its own set of units. In terms of form and size they can be categorised into many groups[22]. Three patterns of relation between geometrical and erecting units can be seen: The first where they are identical, as seen in some faience muqarnas as in the entrance portal of masjid-i Shaykh Lutfallah in Isfahan; the second where the geometrical unit is composed of many erecting units, as seen where bricks were used as erection units of muqarnas; the third is where the structural unit would contain more than one geometrical unit (some times parts of geometrical units) as clearly seen in the stone muqarnas portals of Anatolia and Syria where the erecting stone units are larger than the geometrical units which are carved and contained within. This is applicable for any type of muqarnas whether decorative (where cells or carvings are prepared and used) or structural (where the geometrical unit's form is structurally active).This study will consider only the structural genuine-muqarnas dome's geometrical unit, as the issues of form and form creation are sought.

2.1. Unit analysis of Imam Dur case

The horizontal sections in Fig.6 all have sixteen axes of symmetry. Accordingly the first approach in arriving at the basic geometrical unit will be considering the parts contained within two of the sixteen axis of symmetry as one unit. This will end up with a

two-units-based system each being a mirror image of the other. If one-unit system is sought, then the parts contained within two of eight-axes of symmetry should be considered as one unit. Such a unit is the combination of the previous two. Two combinations are found. Figure 7-a shows the two-units-based system, (b) shows their first possible combination in one-unit system, and (c) the other. Any of these possibilities can be considered as the geometrical unit(s) for the structural genuine-muqarnas dome because they would work the same in dome load transfer. Nevertheless, in this paper the second combination in the one-unit system (c) in adopted. The reason for this is the consideration of the single unit qualities in addition to its function within the dome system of load transfer. These qualities include unit stability and form unity or continuation. For unit stability, the one unit system in (c) is preferred to the other two because it provides a wider base area, for the centroid's (most probably in this case it coincides with the center of gravity) base-projection to fall in, in relation to the volume. In terms of form unity or continuation, the adopted unit (c) has one continuous curved surface with clear edges, while (a) and (b) have half curved surfaces , thus (c) would imply one united, continuous form.

The unit has a plane top, base, and sides, as they are its media of contact with neighboring units. When eight units of the same size are assembled as one tier via their sides, the radius inscribed within the top of this tier is smaller than that within its base, and is equal to the circle inscribed within the base of the next tier. By piling the tiers of the three different sizes of units on top of one another, the top inscribed circle grows smaller until it is finally covered with a small (cap) dome. This technique of covering the area under such dome can be clearly seen in the abstraction of the internal plan[23] (Fig.2-c), which shows four eight-pointed stars embedded within each other, and every second star being rotated at 22°30` so that its outer points would coincide with the inner points of the previous star. The unit's internal side is composed at the base of two outwardly-directed edges of one star, and at the top of the corresponding two inwardly-directed sides of the next star. Thus it works as the media of transfer between the two stars in the plan as well as in the third dimension. The connecting surfaces between the two edges are two curved surfaces joining the two base lines to the middle point on top and two vertical planes joining each of the two top lines and the corresponding end point on the base, complementing the curves. The external side's top edges correspond to those of the internal and are parallel to them, while the base edges are replaced by a curve converting the total external base shape to a flower rather the a plane star. This, along with the fact that the endpoints of this curve do not start exactly from the points the star replaced by this curve would have started, but leave a small distance (most probably for practical building reasons), gives an overall richness to the form, and makes the task of perceiving and understanding the form even more difficult.

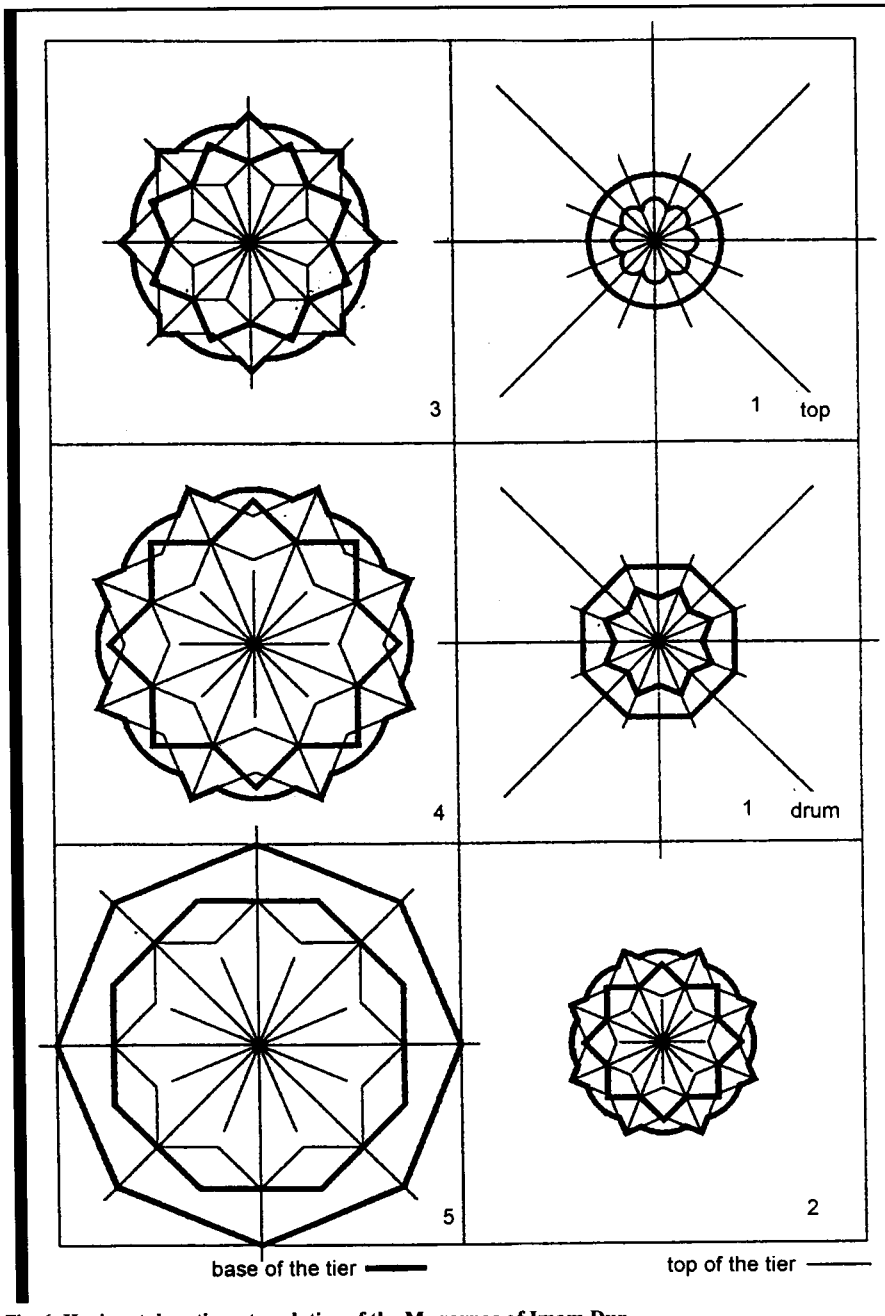


Fig. 6. Horizontal section at each tier of the Muqarnas of Imam Dur.

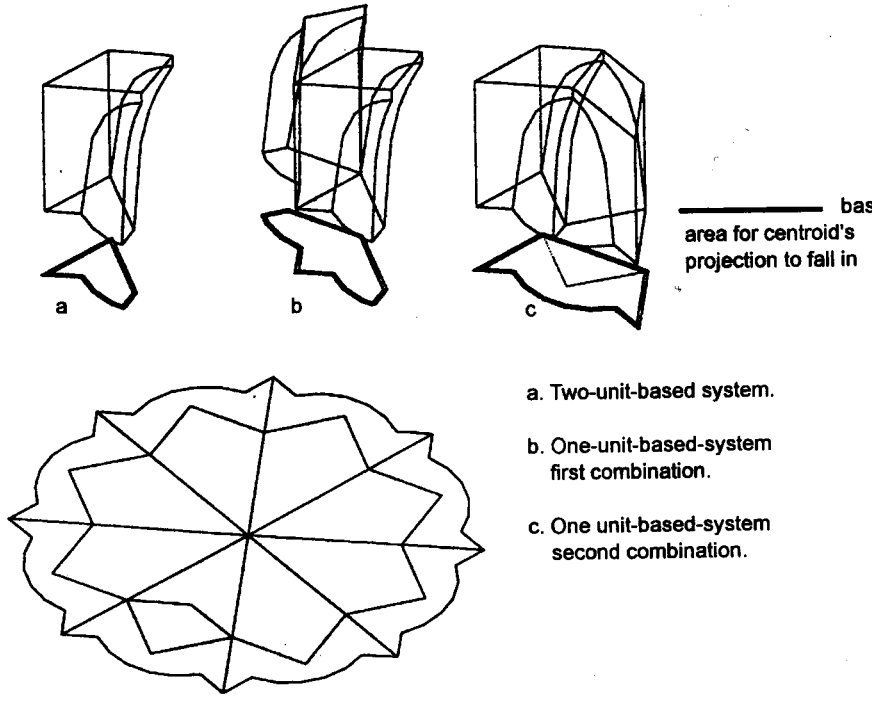


Fig. 7. The unit systems.

2.2. Unit analysis of Zumurrud Khatun case

The plans of tiers (5-10) are of 32-axes of symmetry, the rest are of 16-axes of symmetry. In order to arrive at a one unit based system only 16 and 8 axis of symmetry are to be considered; the same approach adopted in Imam Dur's case. Figure 8 shows a table of the units of each tier composing the dome. The following are some observations on this table.

2.2.1. Units of tiers 10-5 are based on 16-pointed stars, while those of 4-2 are based on 8-pointed stars.

2.2.2. The top front[24] edges of the units are not necessarily parallel to the rear ones, thus they belong to stars of different joining systems. This can be seen in tiers 10, 8, 6,and 3.

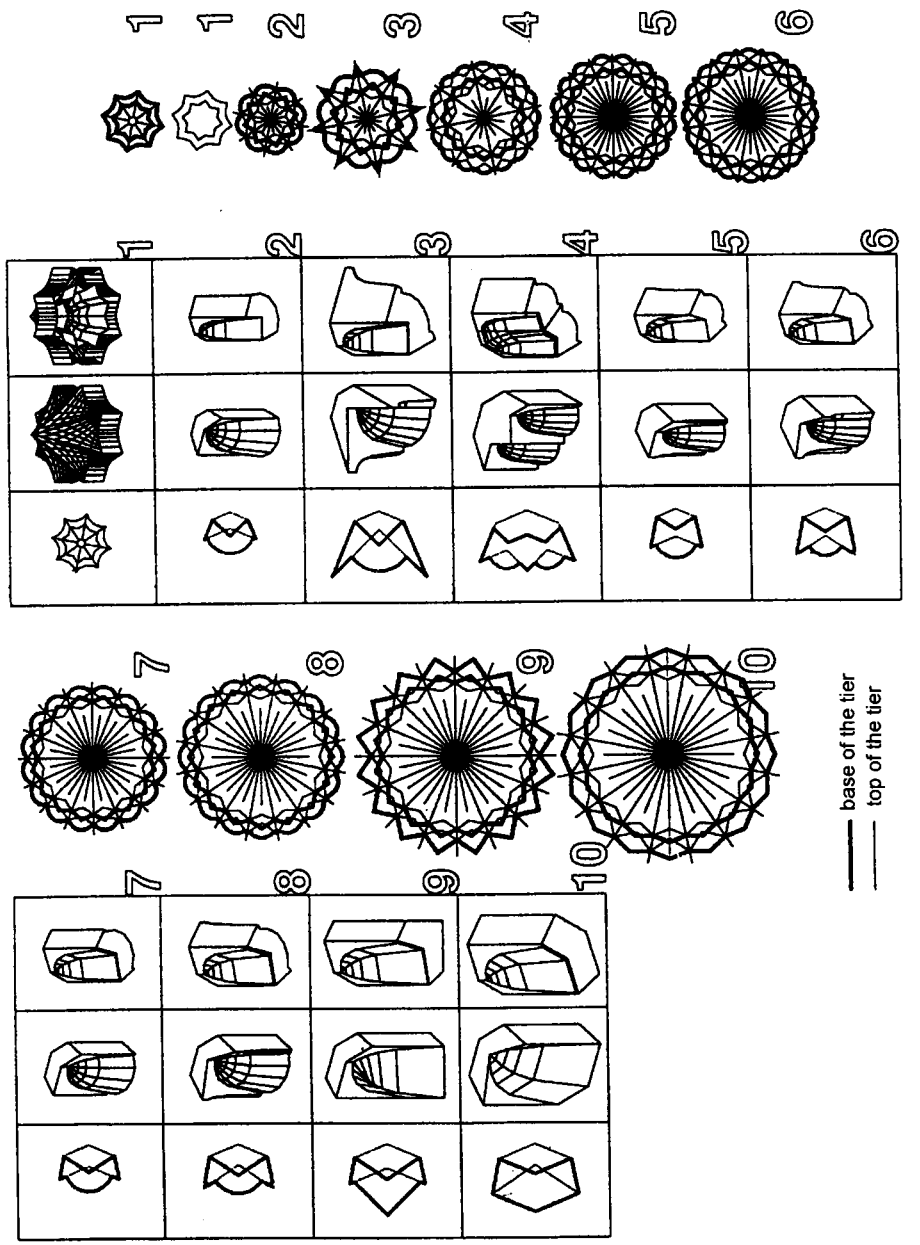


Fig. 8. The unit of each tier of those composing the dome over the tomb of Zumurrud Khatun, along with the plan of each tier.

2.2.3. An additional feature is added in some units, which is slicing the rear wedges of the unit with a curved cut that is perpendicular to the side edge, so that the two sliced surfaces of two units will constitute one continuous surface when assembled beside each other (Tiers 8, 6, 5, and 3).

2.2.4. Units of tiers 10 and 9 have their rear curves replaced by two lines, it could be perceived in a similar way by representing a circle with a polygon in computer graphics.

2.2.5. In units of tiers 10, 9,and 2 there is no distance left between the end points of the rear curve and the rear points.

2.2.6. The unit of tier 4 has its base based on 16-pointed star while its top on 8-pointed stars, reducing the number of points in half. It appears to be as if composed of two units of a 16-pointed star base along with a small internal unit that fills their in-between angle, and projects forward in alignment with the front lines of the two units, thus when assembled with the other 7 units an 8-pointed star will be composed.

2.2.7. A sort of a ring that is star shaped is found between each two tiers of the dome. Its shape is identical to the interior and exterior of the dome in the position it is placed, but projecting outwardly in the exterior. It can be also viewed as a ribbon surrounding the base of each tier[25].

2.2.8. Finally, a small ribbed cap dome covers the top (tier 1).

2.3. Structural Genuine-Muqarnas Dome's Unit types

The muqarnas dome of this type is usually built on or corbeled over another transitional form (e.g. squinch or even some other type of muqarnas). This study is concerned with the muqarnas of the dome and not with the transitional zone bellow.

The units of this muqarnas type can be classified into three basic generic units. They will be referred to from here on as "Basic Unit", "Reduction Unit", and "Top Cap Unit". Each will be discussed separately.

2.3.1. *Basic Unit*

This is the essential unit for this type of muqarnas, encountered in all of its members. That is why reference to it was made as "basic". Its top, base, and sides are flat as they are the media of contact with neighboring units. A certain arrangement of stars centred at the center line of the dome at different heights determine the shapes of its front and rear faces. In addition to the number of points of those stars, the unit has many variables, which values can be altered widely. Accordingly the actual end units can vary endlessly.

In terms of the three dimensional form, the "basic unit" can be broken down, for analysis, into four simple elements, two of which are solids (or mathematically have positive values), and the other two are voids (negative values). The unit is thus looked upon as being composed by adding the first two forms together, and carving out the other two. Nevertheless, the existence of all four elements is not necessary for creating the "basic unit", as two are optional and examples can be seen with the absence of one or both. They will be referred to as element A, B, C, and D. They are shown in Fig.9 along with their combination into one form (i.e. a "basic unit").

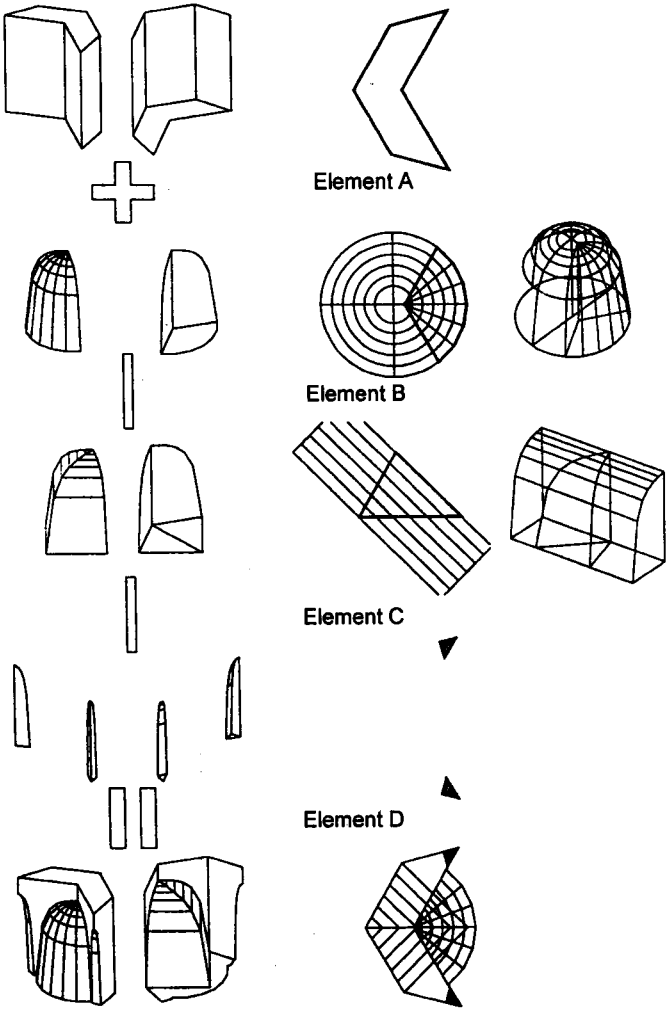


Fig. 9. Basic unit composing elements.

2.3.1.1. *Element A*: A solid vertical prism. Its plan looks like a chevron whose two side edges are not parallel, but directed towards one point, which is the center of the dome. Its front and rear edges belong to two different stars with the same number of points. These stars can be similar (i.e. created by skipping the same number of points)[26], thus the rear and front edges of the chevron will be parallel, as in the case of all Imam Dur's units; else the edges will not be parallel, as in units of tiers 10, 8, 6, and 3 of Zumurrud Khatun. As a polygon is a star created by skipping 0 points when joining them, the rear edges of the chevron thus might appear as one straight line (which is the edge of a polygon that is of same number of points the dome is composed of at that tier). The unit of the fifth tier of Imam Dur's case, where the rear edges belong to an octagon, belongs to this type.

Element A is an essential element of the basic unit, its different values can vary, but it cannot be absent.

2.3.1.2. *Element B*: A solid created by the revolution of a curve around a vertical axis positioned at any point along the center line of element A, and bounded by the rear "V" sides of its prismatic chevron. Its lower base edges can be equal to the rear edges of the chevron plan in A, as seen in the units of tiers 10, 9 and 2 of Zumurrud Khatun; or smaller in size as in the rest of the units. As a curve can be represented by a number of straight lines, some units can be produced with the curve replaced by two edges as in the units of tiers 10 and 9 of Zumurrud Khatun.

Element B is not essential for creating the basic unit, as seen in the case of the unit of the fifth tier in Imam Dur's case.

2.3.1.3. *Element C*: A void composed of two parts, each being a mirror image of the other. They can be visualised as sections of half vaults cut by two vertical intersecting planes in the acute angle area.

In the plan, element C is a rhombus or a barley kernel shape. Its front base edges coincide with those of element A, but at some times are smaller in size, while its rear edges belong to another star with the same number of points, rotated at an angle equals to (180^{o} / number of points), thus its inner points would coincide with the outer points of the star composing the front edges.

The two parts mentioned earlier will be mirrored along the center line of element A. The half vault section will be taken by placing the base edge of the vault along the rear edge of the element's plan, while the front edge of the corresponding part of element A along with the mirror plane will be its cutting surfaces.

This is an essential element for creating the basic unit.

2.3.1.4. *Element D*: A void which resembles slicing a piece out of the rear corner edges of the chevron in element A. The cutting curved surface is vertical to the sides of the chevron so that when two units are assembled beside each other one continuous surface will be created.

This void is not an essential element of the basic unit. Examples of its existence are the units of tiers 8, 6, 5,and 3 of Zumurrud Khatun.

The relative relations between these four elements creates many variable of the basic unit, which values can be altered to create endless combinations. Figure10 shows two views of an example unit with these variables indicated.

Using this analysis, the seemingly awkward unit of the fifth tier of Imam Dur's case can easily be recognized as a "basic unit". Even the usual squinch, which example can be seen in the transitional zone of Imam Dur, can be interpreted as a basic unit with special variable-values (Fig.11)[27].

2.3.2. Reduction unit

This unit can be visualised to be composed of three elements. The first two, are basic units joined at their sides, the third is an element filling the angle created between their two neighboring front faces. In plan, the third element looks like a barley kernel shape, whose two rear edges being the two neighboring front edges of the first two elements, while its front edges are the extension of the two far front edges of these elements. This third element is composed of five points and five faces. The top four points are those of the plan with an elevation equals to that of the top part of the other two elements, while its fifth point is the rare point of the plan with the elevation of their base. All of the three top front points are connected to the base point via a curve, while a vertical line joins the top and base rear points. Its five faces would thus be: the top, composed by joining the four top points; the two front faces, each bounded by one top front edge and the corresponding two curves; and the two rear faces, which are identical to the two neighboring front faces of the first two elements and the media through which it is joined to them. If the other two elements, which are two basic units in form, have their own A and C elements of different heights; then a vertical prism, with the plan of the third element and a height that is equal to the difference in these heights, is added on top of the third element. Figure12 shows three-dimensional views of a sample reduction unit (a), along with a plan of its three composing elements (b), and a diagram of the reduction concept (c).

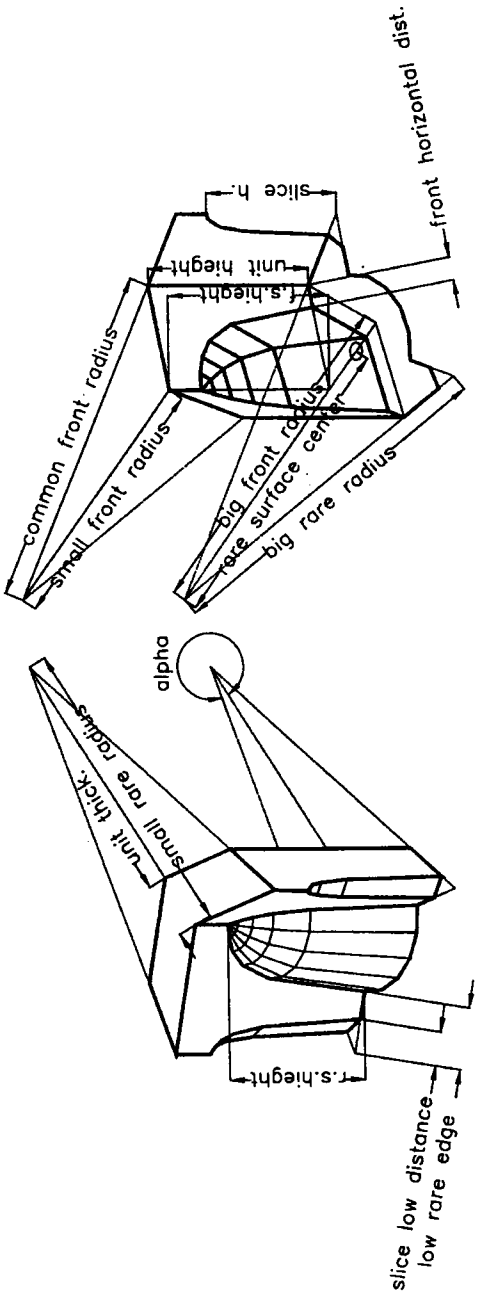


Fig. 10. The variables of a basic unit of SGMD.

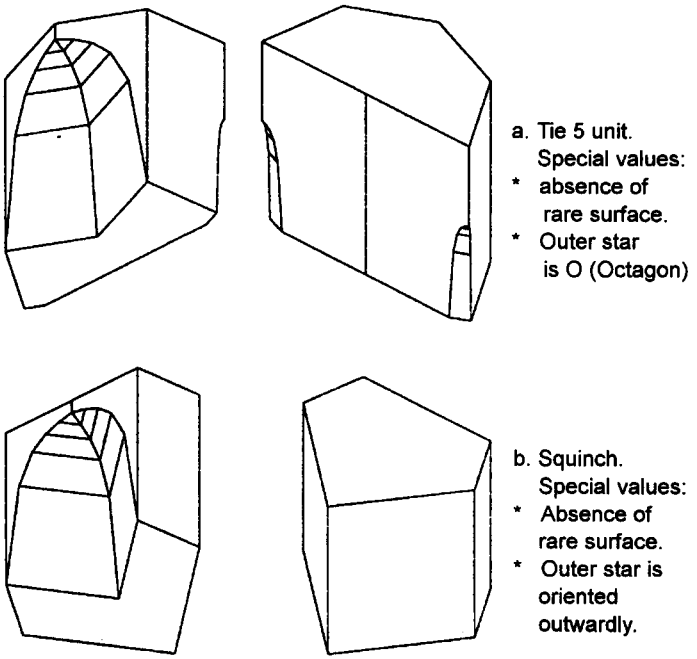


Fig. 11. The squinch and the unit of tier 5 of Imam Dur's dome as Basic units.

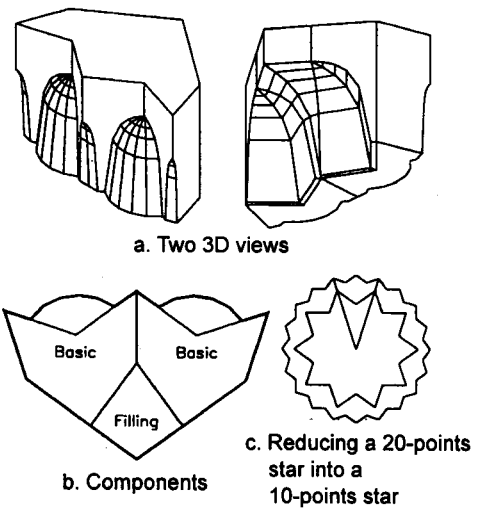


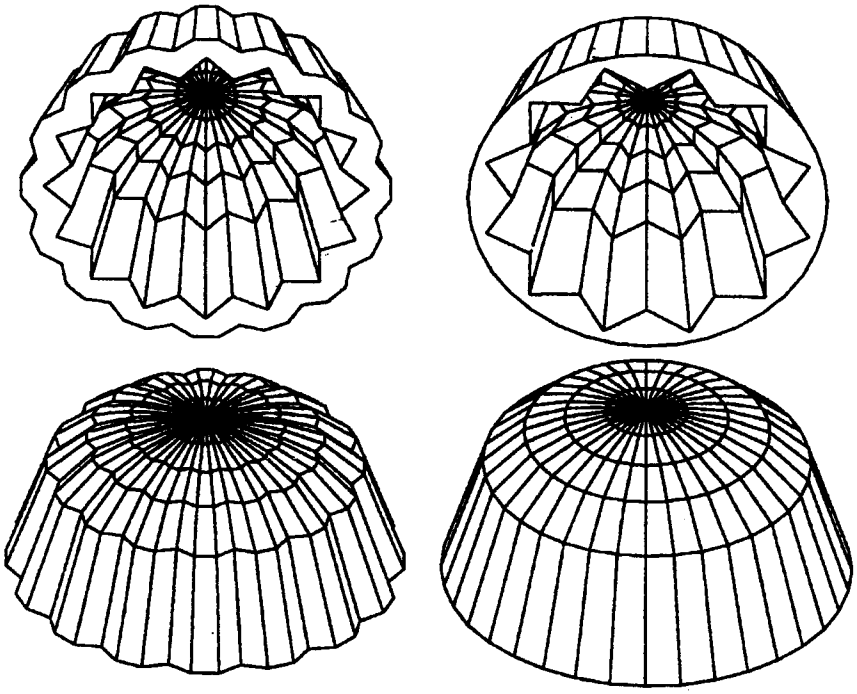
Fig. 12. Example of a reduction unit.

Accordingly the reduction unit has its base belonging to a star of certain number of points, and its top front edges belonging to a star of half that number of points. Needless to say that it would exist only in cases where the base number of points is even[28].

2.3.3. *Top cap unit*

This is an actual small dome, used to cover the opening left within the most-top tier, as no total covering can be achieved by either of the two previous units. The reason for this is that stars embedded within each other, diminish in size according to certain ratio that is never equal to zero, thus an opening is always left.

From inside, the top cap dome takes a sort of a ribbed form whose base matches the star below. From the outside, it can be any sort of dome, ribbed, round, elliptical etc. Accordingly only its interior has a rule of formation, while the exterior is left to the designer. Figure13 shows samples of this unit.



a. Flower-plan unit b. Round-plan unit

3. Computer Generation System

The above analysis demonstrates that the structural genuine muqarnas dome is a type whose members are created according to geometrical relations and clear rules. One of its basic variables is that it is based in plan on concentric stars. Each time the number of points of a star differs, a new member is created. Many other variables also determine the creation of new members like the type of the unit, and the variables of each unit. This muqarnas type, still, has much to offer in terms of the design of new forms. That is why the attempt was made to computerise its design process. This will facilitate the creation of new structural genuine muqarnas domes. Even architects with no knowledge of the rules of its creation will be able to create new designs. This was done using the concept of generation systems.

3.1. The meaning of a generation system

A generation system is an abstract representation of a type that contain many members. It is composed of units, with a lot of alternatives for each, which could, if properly combined, generate all possible members of the type. The concept of a generation system is not new. It was described first by Aristotle in "Politics" and since then applied in many fields[5]. It works as a prototype from which different actual forms can be created.

Computer Aided Design programs prove to be an excellent tool for applying such generation systems. For a certain type of composition the different variables would be stored, along with the rules of their combinations. The user would alter the values of these variables and the program would make the calculations accordingly and produce the forms.

A computer generating system for creating structural genuine muqarnas domes was written. Following is a description of the program.

3.2. The program

The program described in this paper is a computer generation system for producing the Structural Genuine Muqarnas Dome type. The general conceptual structure of this type is constant for all of its members. It is composed of tiers, each of which is composed of units. The units of a single tier belong to one of three types (basic, reduction, top-cap), each unit has many variables and is created according to certain geometrical rules. This system's variables ranges form the number of tiers to the very specific variables of each unit.

The program operates from the single unit level up to the whole structure (simulating the process of building). Its operational system can be summarized in the following steps. (Fig.14 is a flow chart for the program and Fig.15 is a sample run).

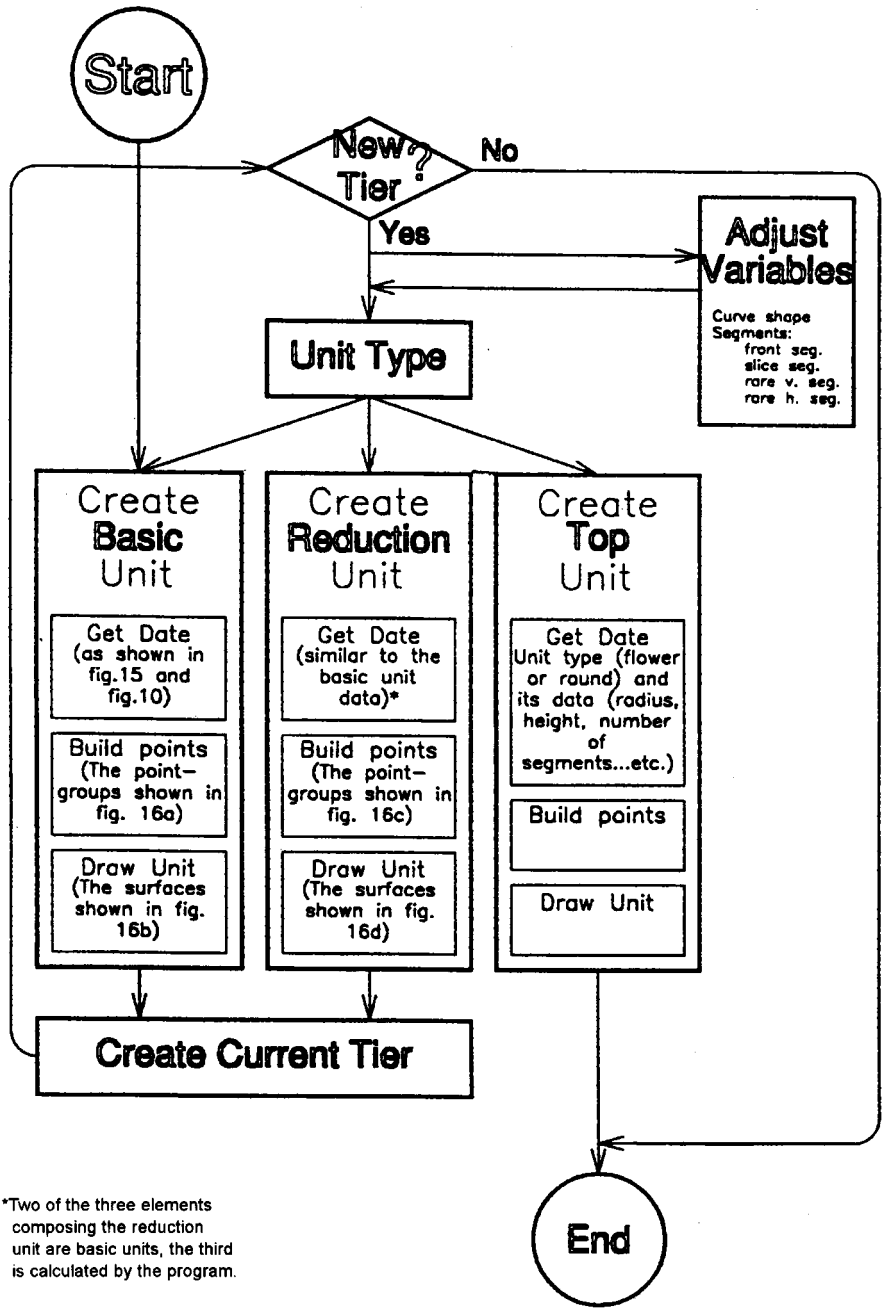


Fig. 14. Flow chart of the structural genuine-muqarnas dome's computer generation system.

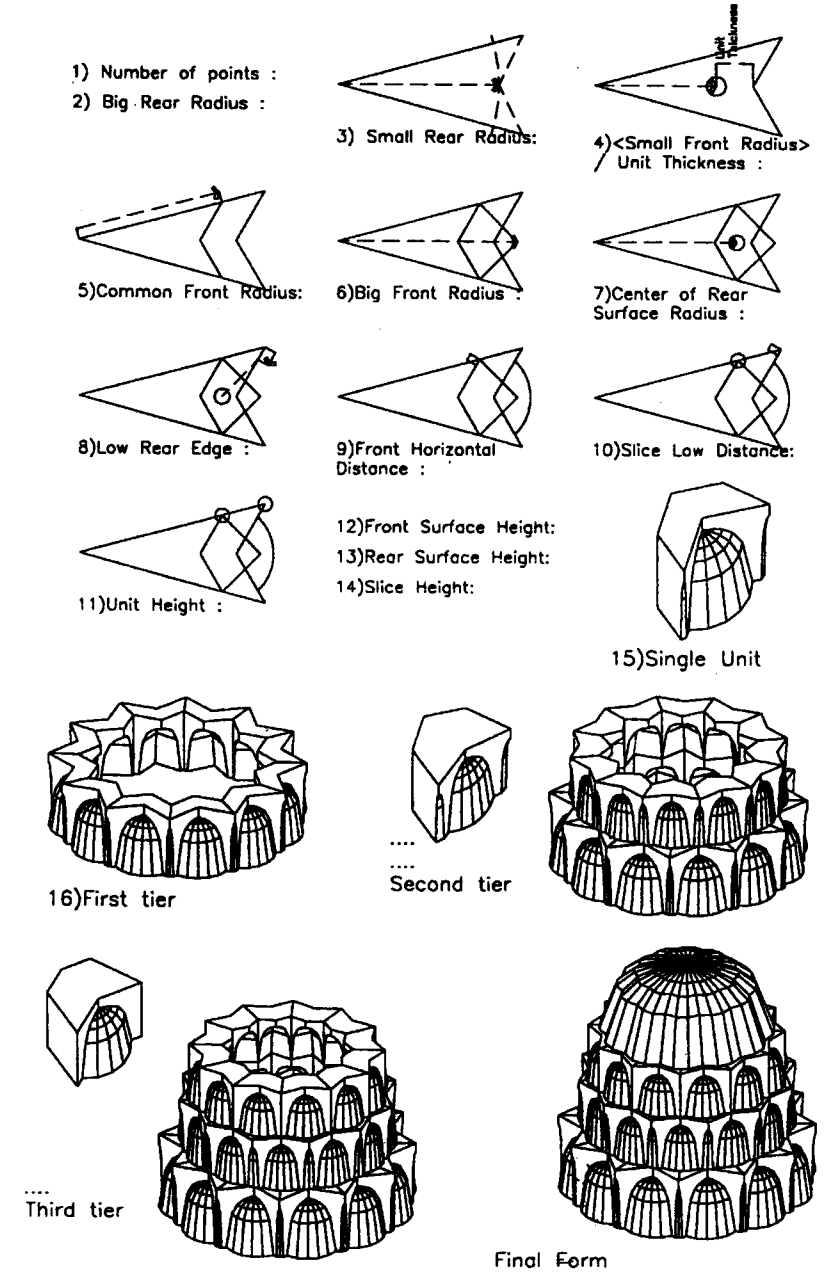


Fig. 15. A "blue print" of the S.G.M.D. of Imam Dur's case.

1. For the first tier the unit type is always a basic unit. The program prompts the user for the number of points of the star he wants to build the dome according to. In the subsequent tiers this will be constant, except when the user decides to use a reduction unit (then the number of points will drop into half).

2. The program prompts the user for the values of the variables of the single unit, like the values of different radii, heights, etc. According to these data, the program carries out the necessary mathematical calculations, and defines different groups of points, and surfaces that describe the geometry of the unit. These groups are shown in Fig.16 for both the basic and the reduction units. According to these data the unit is created.

3. It creates the whole tier by repeating the unit number of times equal to the number of points for that tier.

4. It prompts the user for the type of the unit to be used for the next tier.

The steps (2-4) will be repeated. Each time a tier is designed, it is added on top of the previous ones.

This process will continue until the top-cap unit type is chosen or when the user terminates it at the end of step 4.

The user can enter the different values by means of typing them, pointing them visually on the screen, or choosing form a range provided by the program (which is calculated according to the data in hand). He does not need to be an expert in the system to create such a dome. The data can be entered in any value, and if there was any contradiction between some values the program will ask for modification. The variables of the unit are divided into two parts: global variables, which are almost constant for the whole process, or at least for a group of tiers (like the curve shape and number of segments); and tier local variables, which can be changed for each tier (like radii values, unit height etc.).

The different variables and the interaction mode between the program and user can be seen in the sample run of Fig.15.

The program was written in AutoLisp language, which is a programming language for the AutoCad system, under the Windows environment.

3.3. The advantages of the program

Such a computer program has many advantages, some of which are listed below:

1. It is a tool for producing new structural genuine muqarnas domes for today's

architects. The wide range of different forms that can be designed by the program, indicates that this type has much to offer in terms of form experimentation for toady's architects and designers.

2. It can provide a sort of a "blue print" of form for existing cases. This can be produced according to approximate data and visual observations at early stages of any excavations of this type of muqarnas.

3. Many records of buildings in Islamic architecture are available in written form of historical literature, which is neither complete nor architecturally accurate[6]. In other cases researches arrive at such data from other artistic expressions like miniatures[7], which again are very sketchy. Variables would be supplied according to such data, and historical contexts of the example in hand, unavailable data would be provided in different values; obtaining more than one approximation of such forms.

4. The wide range of outputs along with the related analysis may constitute a step in understanding other types of muqarnas, and drawing the general muqarnas types relation scheme in later studies.

Figures 17 and 18 are two outputs resembling the muqarnas of Imam Dur and that of Zumurrud Khatun.

Figure 19 shows an example where two reduction units are used, reducing the points from 32 to 16 to 8.

Figure 20 illustrates how this type can be related (internally) to other muqarnas forms in the transitional zone of domes[??]. This example is achieved by reducing the number of the points skipped in creating internal stars until the polygon is reached, that where a dome would be placed.

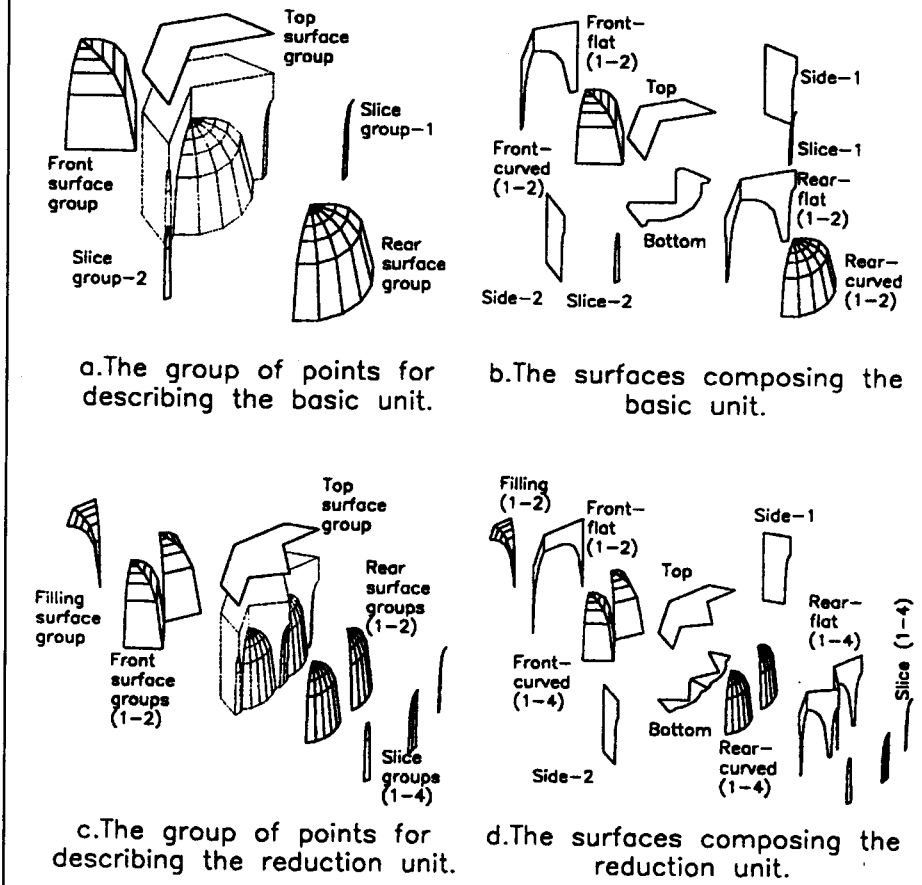
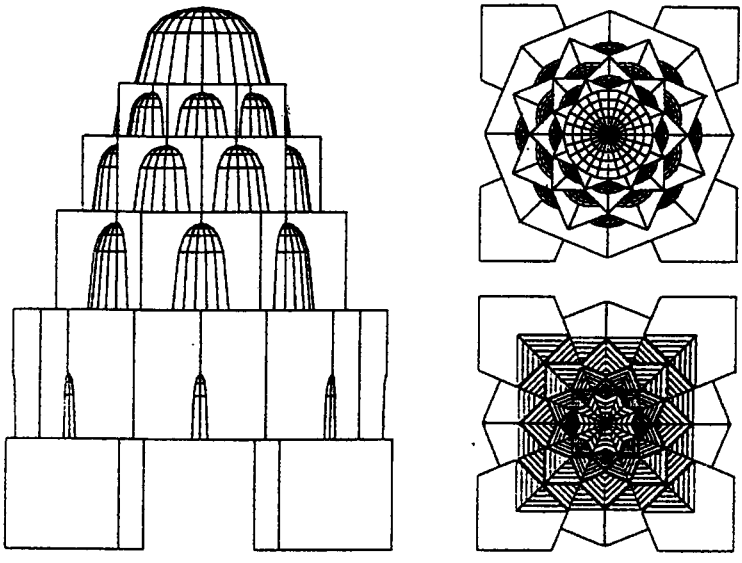
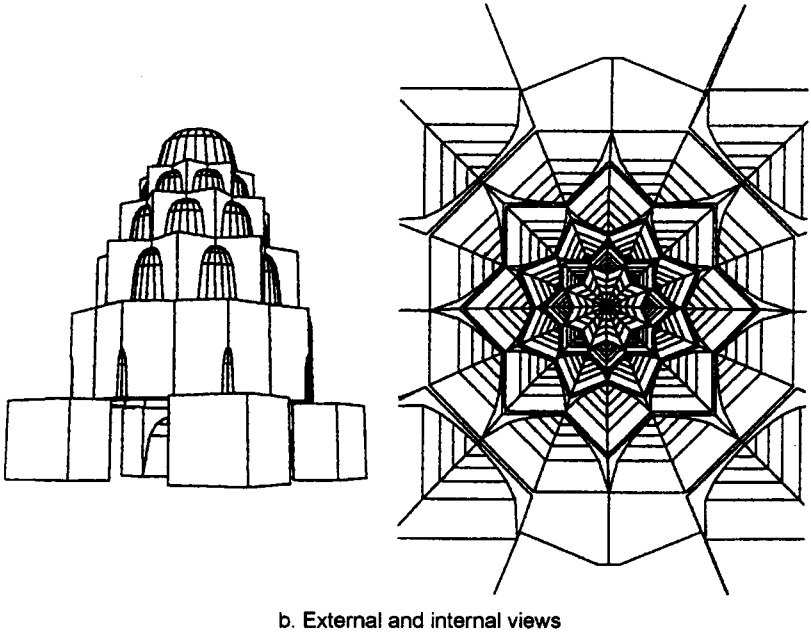


Fig. 16.The point-groups and the surfaces used to describe the unit in the computer database.

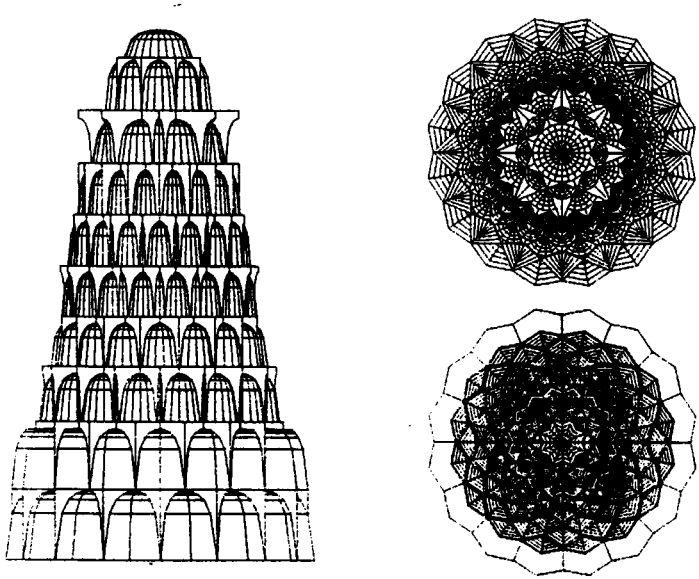


a. Orthogonal drawings

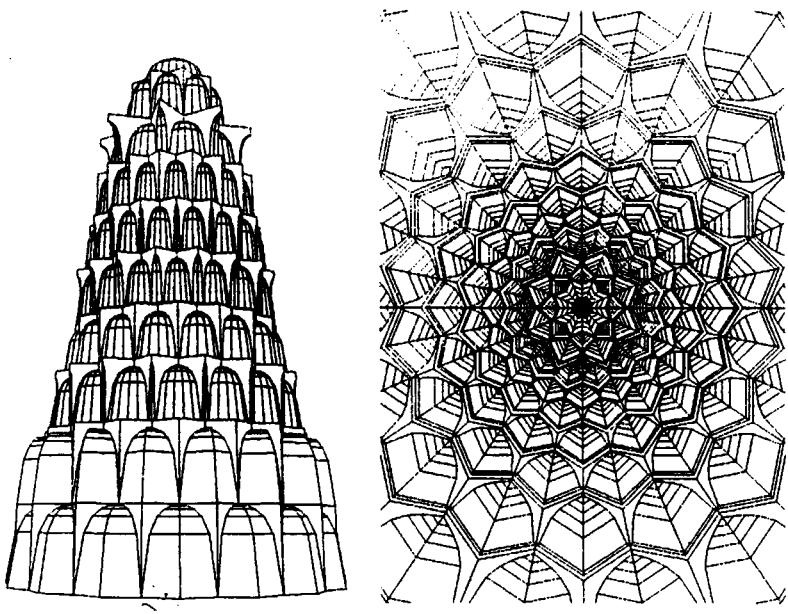


b. External and internal views

Fig. 17. A "blue print" of the S.G.M.D. of Imam Dur's case.

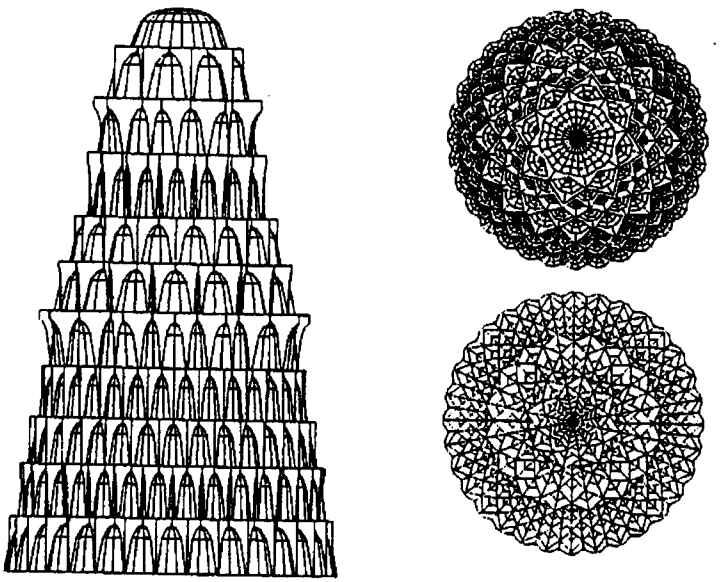


a. Orthogonal drawings

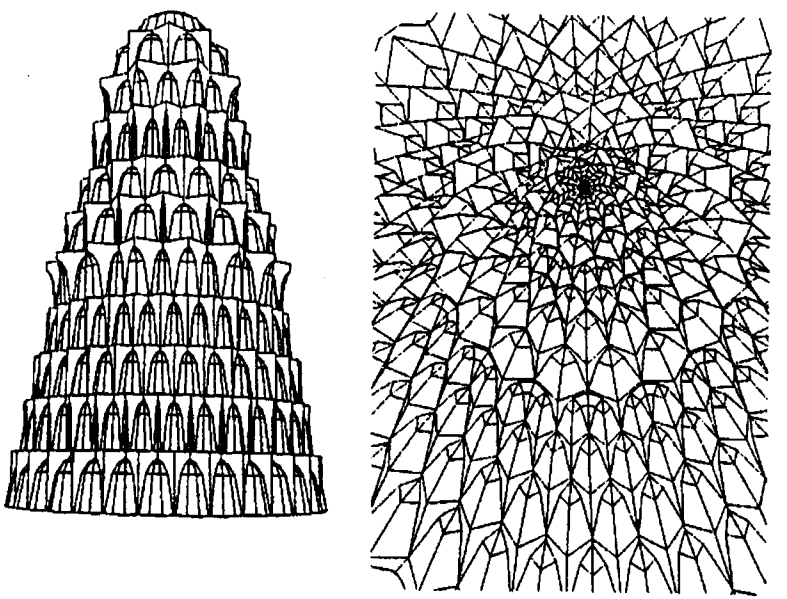


b. External and internal views

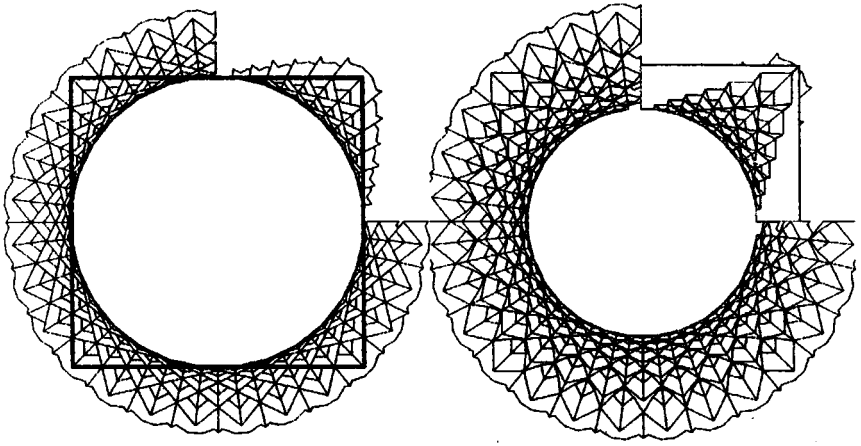
Fig. 18. A "blue print of the S.G.M.D. of Zamurrud Khatun case.



a. Orthoganal drawings

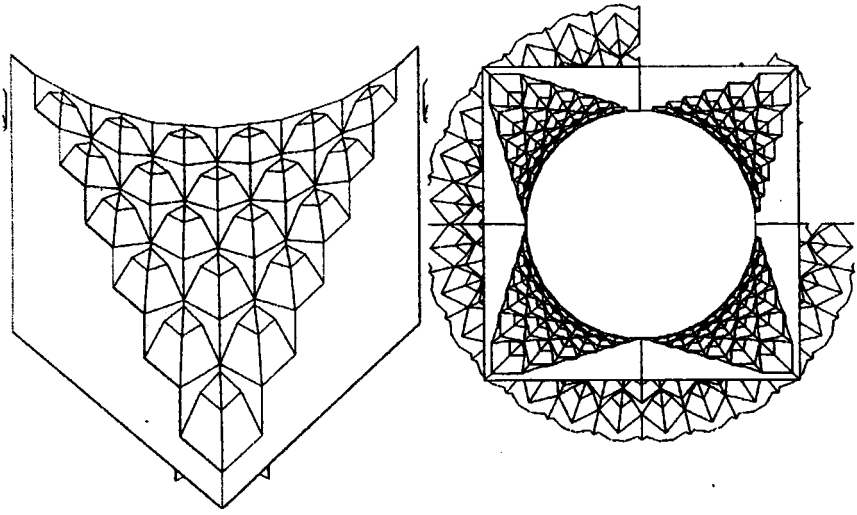


b. External and internal views



a. The part of the interior that composes the transitional zone

b. Perspective showing the relation to one corner



c. The transitional zone

d. Total view of the relation

Fig. 20. Example of relation to another type in the transitional zone of the dome.

Conclusion

This study represents only a part of much greater work that must be conducted before clear and final pictures of muqarnas characteristics and attributes can be drawn. Therefore, it calls for establishing proper typological strategies to be adopted in further studies, and recommends the use of computer generation systems in result-representation, for they can be powerful in revealing different patterns of form relations.

The computer program can also be expanded to include more attributes of this type (historical, geographical, the function of the space, engineering attributes etc.) for the purpose of further analysis in other criterion.

As for the units of this type, it recommends the use of the units deducted here as an actual building unit, with some modifications, for new domes of this type. The computer form manipulation, Cad-Cam, and mass production capabilities might prove that such units, which need no centering, would be a very fast and convenient way for dome erection.

Acknowledgement. I would like to thank Dr. Mitsui Hediki for his supervision and kind support, Dr. Hidaka Kenichiro, and Mr. Timothy Weeks for kindly checking the English text of this paper.

Content Notes

[1]The word "attribute" is used to refer to a quality of muqarnas that can vary in different forms, like "materials" which can be stone, wood, stucco or else; thus the "attribute value" is the value of that attribute in a certain case(s). On the other hand, a constant quality for all muqarnas forms, like being three dimensional or composed of tiers and units, is referred to as a "characteristic" of muqarnas.

[2]Other methods of studying muqarnas ranges form analyzing a single case to attempting the study of a certain issue of muqarnas in general (like the origin) without reference to types. The one adopted here is believed to provide a very well defined range for the study, from which more concrete results can be obtained.

[3]This categorization of so many different domed forms into one category of "muqarnas dome" because they are associated with muqarnas, can be seen to have begun by Herzfeld in his analysis of many domes in Iraq, Iran and Syria, published in [1] and [2].

[4]Compare Fig.2 of this paper and Fig.36a of [3].

[5]There the author refuted an earlier argument by Henri Terrasse that Al-Qarawiyyin mosque's muqarnas is a local development, and gave Imam Dur's as its earlier prototype, on bases that they both belong to the "muqarnas dome" type.

[6]It is not stated that it is a structural necessity though.

[7]The choice of the attribute values for any study is dependent on the purpose of the research and the criterion it intends to investigate.

[8]It should be noted here that if one vertical section of the whole dome contained no continuous shell section within, then there is no need to consider more sections as structural quality would apply.

[9]It is to this range that most researchers date this building. See [2,p. 20],and [7,p. 20].

[10]Although a form with this degree of maturity would imply the existence of earlier models, there are no available data of any.

[11]Most researchers agree that this tomb belongs to the mother of caliph An-Nasir Li-Din Allah; Zumurrud Khatun, died on 1199 AD- 599 H., and the name Zubaida is a deviation of Zumurrud [7,p. 27-28, and 8,p. 41-47].

[12]Although a type was never declared as such, researchers used to refer to this example as the best of "its" type [2,p. 25], and [4,p. 66]. This unconscious acknowledgement of existence of a "type" supports the definition of the "structural genuine-muqarnas dome" type of this paper.

[13]According to [8,p. 41], it was built before 1190 AD (588 H).

[14]Since the transitional zone is out of the scope of this paper, the tiers are numbered from the top downward to avoid starting from numbers other than one.

[15]Whether a type is defined according to the attribute values of its members or according to pre-defined ones is a debatable issue. The approach adopted here is that both are two levels of a study and that they complement each other rather than being contradicting.

[16]Other common attribute values are found, like function and location (see Table 2). These, along with formal similarities, make it acceptable to suggest one origin and common meaning to members of this type, thus those refuted earlier as general to all muqarnas domes [4, p. 62 and p. 69] can be accepted as one interpretation for this type.

[17]This can be supported by the fact that the earliest known article about muqarnas in the 15th century by Al-Kashi, used the units as the factor according to which types of muqarnas were established [9,p. 381-391]. Some other recent works that elaborated the role of units in muqarnas were those by Harb [10] and Andrè [11].

[18]A separate study on units and its groups is being prepared for it is out of the scope of this paper.

[19]A better term would be "plan looking up", but in muqarnas drawings, plan is usually used for convenience, and as muqarnas is usually symmetrical both would be identical. The word plan is thus acceptable.

[20]The adjective "front" is used for internal edges and surfaces facing the center of the dome, while "rear" is used for external ones.

[21]That is why it will not be considered as part of the unit, but a sort of an added decoration, same as the internal decoration added on the interior of Imam Dur's case.

[22]For full discussion of stars as units in two dimensional Islamic patterns, and their geometrical and mathematical aspects see [12].

[23]Thus the squinch can be seen, form wise, as a basic unit of a structural genuine-muqarnas dome type, in a tier composed of 8 units, four of which being discarded, while the remaining four would compose the corners of a square building.

[24]The concept applied in this unit can be extended to create reduction units that reduce the number of points of the base star into its third or fourth ...etc.

[25]For a full description of the generative systems see [12, 13 and 14]. For the relation of typology,

types and prototypes to design and computer aided design see [15] which largely base the knowledge base design systems on these concepts in most of its chapters.

[26]An example of a description of what looks like a structural conical muqarnas dome, can be seen in [8,p. 39], where the author quotes Ibn Jubair describing a dome built by Malikshah in 1086 AD-479 H. Though this description indicates a similar form to that of Imam Dur, researchers might find other descriptions for other forms that can be approximated by the computer program.

[27]Two examples can be seen in plates 4-"Flood of Baghdad"-dated 1468, and 5-"View of Baghdad"-dated 1537, of [4]. Both show Baghdad with many structural conical muqarnas domes.

[28]For such transitional zones analysis see [16 and 17].

References

[1] Sarre, Friedrich and Herzfeld, Ernst. *Archaologische Reise Im Euphrat- Und Tigris-Gebiet* vol.2. Berlin: 1911-1914.

[2] Herzfeld, Ernst. "Damascus: Studies in Architecture, I." *Ars Islamica,* IX (1942), 1-53.

[3] Ecochard, Michel. *Filiation De Monuments Grecs, Byzantins Et Islamiques- Une Question de Geo'metrie.* Paris: Paul Geuthner, 1977.

[4] Tabba, Yaser. "The Muqarnas Dome: Its Origin and Meaning." *Muqarnas: An annual on Islamic Art and Architecture*, 3 (1985), 63-64.

[5] Behrens-Abousief, Doris. "Mukarnas." In: *Encyclopaedia of Islam.* Vol. VII, pp 501-506. Leiden-NewYork: E.J.Brill, 1993.

[6] Hillenbrand, Robert. *Islamic Architecture: Form, Function and Meaning.* Edinburgh: Edinburgh University Press, 1994.

[7] Al-Hadithi, `Atta and Abdel-Khaliq, Hana. *Conical Domes.* Baghdad: Ministry of Information, Directorate General of Antiquities, 1974.

[8] Jawad, Mustafa. "Al-`Amarat Al-Islamiyya Al-`Atiqa fi Baghdad" [Old Islamic Buildings in Baghdad]. *Sumar*, III-I (1947), 38-59.

[9] Al-Kashi, Jamshid. *Miftah Al-Hisab* [Key to Arithmetic]. Nadir Nabulsi (Ed.). Damascus: Damascus University, 1977.

[10] Harb, Ulrich. *IlKhanidisch Stalaktitengewolbe- Beitrage zu Entwurf und Bautechnik Dietrich Reimer Verlag.* Berlin, 1978.

[11] Paccard, Andre`. *Traditional Islamic Craft in Moroccan Architecture*, Marry Guggenheim (Transl.). Vol.1. France: Editions Atlier 74, 1980.

[12] Yaghan, Mohammad Ali. "Islamic Pattern Generation System -Theory and Application." (M.Sc. thesis, University of Strathclyde, 1988).

[13] Mitchell, W.J. *Computer Aided Architectural Design.* New York: Van Nostrand Reinhold, 1977.

[14] Mitchell, W.J. "Formal Representaions: a Foundation for Computer Aided Architectural Design." *Environment and Planning B: Planning and Design*, 13 (1986), 133-162.

[15] Coyne, R.D., M.A. Rosenman, A.D. Rdford, M. Balachandran and J.S. Greo. *Knowledge Based Design Systems.* Tokyo: Addison- Wesley Publishing Company, 1989.

[16] Rosintal, J. *Pendentifs Trompes Et Stalactites Dans L'Architecture Orientale.* Paris: Paul Geuthner, 1928.

[17] Pauty, M. Edmond. "Contribution `A L'etudes Des Stalactites." *Bulletin de l'Institute Francais d'Archeologie Orientale*, XXIX (1929),129-153.

قبة المقرنس الفعلي الانشائية
التعريف والوحدة الاساسية وبرنامج حاسوب

محمد علي جلال ياغان

كلية الدراسات العليا، جامعة تسوكوبا، إباراكي كين ٣٠٥، اليابان

(قُدم للنشر في ١٤١٧/٦/٢٨هـ، وقُبل للنشر في ١٤١٧/٨/٢٩هـ)

ملخص البحث. أحد أساليب دراسة ظاهرة المقرنس هو تعريف نوع ما بناءاً على قيم معيارية محددة مسبقاً وإيجاد أي معايير أخرى مشتركة بين عناصر النوع. نتيجة دراسة ذلك النوع بمعاييره المحددة مسبقاً أو التي يجدها الباحث مشتركة بين عناصره تؤدي بالنهاية مع مثيلاتها من الدراسات إلى فهم واضح لأبعاد ظاهرة المقرنس مثل أصله وتطوره.

هذه الدراسة تمثل إحدى تلك الدراسات. وهي في ثلاثة أجزاء، الأول يُعرف نوعاً من المقرنس "قبة المقرنس الفعلي الإنشائية" الذي يُدرس دائماً تحت عنوان القبة المقرنسية، والثاني يدرس الوحدة الأساسية لهذا النوع، والثالث يعرض برنامج حاسوب عمل لهذا النوع مع الفوائد المرجوة ومجموعة من نتائجه.