Creating a parametric muqarnas utilizing algorithmic software

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Abstract
Muqarnas is one of the most beautiful elements of Persian architecture which was used to cover the great height of entrance spaces or domes in old mosques or religious schools. Although rapid growth of digital design software brought lots of innovations and ease of use to the world of architecture, this specific vernacular art reached the state of abandonment. This article focuses on modelling Persian patterns by using Grasshopper3D, a Rhinoceros plug-in and by demonstrating the process it hopes to create a basis for a full 3d parametric muqarnas application. Utilizing such software, it is probable to generate desired patterns with the help of today’s algorithmic technology and revitalize muqarnas and other Persian patterns and define them as contemporary architectural elements of Persian architecture.

Keywords: Muqarnas, Parametric Architecture, Persian Patterns, Persian Contemporary Architecture

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**Introduction**

Modular geometric patterns play an important role in Islamic architecture. Among all, Muqarnas (or Stalactite Vaults) is somehow the principle characterizing element of the Islamic architectural style. They are generally, with rare exceptions, based on an octagonal symmetry, though pentagonal symmetry is very common in the Persian style. [The Muqarnas Dome of the Hall of the Two Sisters in the Alhambra in Granada, JEAN-MARC CASTERA. P102]

Muqarnas is defined as an original Islamic design involving various combinations of three-dimensional shapes, corbeling, and other pieces. [Dictionary of Architecture and Construction 4th Edition, Cyril M. Harris p.650].

This decorative element with its complex 3D geometry was used by 7th century architects to cover the great heights of entrance spaces or domes in religious buildings such as mosques and schools.

CAD software helps architects to draw complex shapes and contemporary digital tools such as grasshopper3d have become an important asset in creating modular forms hence they are called algorithmic software.

Recently, the use of the term “parametric design” has been widely expanded in the architectural work, mainly associated to the use of advanced digital technologies in complex projects (Meredith et al., 2008; Woodbury, 2010).

According to Gero (Gero, 1994), there are two main areas in the development of computer aided design: “the representation and production of the geometry and topology of designed objects” and “the representation and use of knowledge to support or carry the synthesis of designs”. While the first category relates to the general use off-the-shelf CAD tools that aim to increase the efficiency or aim to automate design and drafting activities, the second has given birth to novel generative approaches that regard computation as an aid to the design process and to explore design ideas. Generative design systems allow the formation of complex compositions, both formal and conceptual, through the implementation of a simple set of operations and parameters. This new understanding marks the emergence of innovative modes of design thinking. [CREATIVE DESIGN EXPLORATION BY PARAMETRIC GENERATIVE SYSTEMS IN ARCHITECTURE, İpek GÜRSEL DİNO]

**Algorithmic Software**

There are numbers of software available which support algorithmic modelling such as; CATIA, Autodesk 3ds MAX, Autodesk Revit, Autodesk Dynamo, Bentley's Generative Components and Grasshopper engine which is a plug-in for Rhinoceros. In this paper Grasshopper engine is used as a testbed for designing a parametric Muqarnas utilizing algorithmic procedures. Grasshopper is a free plugin for Rhino3d developed by David Rutten at McNeel Associates which allows architects to do dataflow modelling. With the Grasshopper approach to dataflow modelling, complex parametric models can be created by defining relationships between entities in design model or specifying procedures and implementing algorithms in its scripting components (the C# Component and the VB Component), easily.

**Research History**

Muqarnas is a critical element that denotes Persian architecture that was common in the domes and entrance spaces of mosques and to some extent residential buildings. Although current century has witnessed rapid growth in the field of digital design, performed works on muqarnas remains largely at virtual modelling, therefore, a parametric model has not yet been created (Dold-Samplonius, 1992). The star models in these decorations embody a huge mathematical mystery. The decorations utilized 2D plans projected on the ground. The Muqarnas resembles a staircase with more than one facet made on a flat roof. The facets intersect and can be viewed as standing on a plane that is parallel to the horizon (Kaplan, 2000). Virtual modelling, unlike the parametric one, entails creation of models for simulation and virtual reality (Gherardini & Leali, 2007). The virtual modelling of Muqarnas has been used widely in history as evidenced by the studies related to understanding basic tools used for construction. In most cases, the Islamic designs are mostly in 2D with the placement of patterns superimposed on each other (Gangopadhyay, 2013). They are inspired by vegetal patterns which acts as a contrasting background for main the model. Geometric ornamentation in Muqarnas reveals a great degree of freedom. Nevertheless, Islamic art is defined by the numinous quality of the patterns envisaged in a sense of sublime tranquility. In particular, there is a huge connection between geometry and contemplative state used in the aspects of virtual modelling.

The unique patterns of deformation in Islamic art have been explained well using the virtual
modelling in terms of elucidation of the design. The Muqarnas is a 3D architectural decoration comprising of the niche-like elements that have been arranged in tiers (Metropolitan Museum of Art (New York), 2004). The use of computers and the virtual modelling has played an immense role in the understanding the 3D structure of the vault in real time. This would enable the architects to reconstruct the vault in situations where it has collapsed (Taani, 2013). Therefore it can be employed interactively when it comes to deciphering the structure of the Muqarnas. The mesmerizing element of this architecture is intricate geometry. For instance, virtual models of the Muqarnas are important in understanding the star patterns of the decorations where the single design originates from the use of the multiple tilings (Kaplan & Salesin, 2004). Historically, the patterns include the spatial transitions. Some of these transitions helped in establishing the segue between the shapes.

Historical influence of the Muqarnas comes from the Ashkanid dynasty that ruled Iran. The equivocality of the Islamic arts makes it difficult for one to note the resemblances and other dissimilarities (Henry, 2007). The use of computer models to understand art would reveal the element of statics and aesthetics as the main entities. Islamic Architecture reveals that the artisans-architectures in early Islamic civilization were not only the masters of their craft but also possessed theoretical qualities (Harmsen, Jungblut, & Krömker, 2007). The immediate outcome of the effort was creation of the infinite compositions with sophisticated configurations that ended up decorating the Islamic Architecture.

In conclusion, the construction of the Islamic patterns demonstrated the need for separate invocations using the reference algorithm. The virtual modelling has been used historically to understand the decorations. Despite the fact that some of the historical patterns in the decoration have been deciphered, others are still elusive. In light of this fact, historical studies of the pattern should make use of the technological dispensation to understand the missing links (Tabbaa, 1985).

**Geometry**

Briefly, the main geometrical patterns which are used in Iranian architecture include Gereh, Rasmi, Yazdy and muqarnas which all have a linear trend; however, they have more geometric complications respectively. Whereas Gereh is merely constructed in 2D designs among the aforementioned group, the other patterns are constructed in 3D formats. The most significant point in drawing a geometrical plan is that it has a determined length-width ratio (mostly the same span dimensions that the plan is implemented in them), and we could not disturb the proportion of an Iranian geometrical plan. This leads to the disturbance of the plan’s form and destruction of its beauty.

![Figure 1 Samples of Persian Patterns: a- Gereh, b- Rasmi, c- Yazdy, d- Muqarnas](image)

Rasmi is a 3D design constructed for covering the ceiling of vaults, iwans and domes for decorative or structure purposes. It seems that Rasmi is actually the basic form of constructing a complex muqarnas, i.e. it could be considered as the simplest form of a muqarnas. Finding the virtual modelling method of Rasmi paves the way for creating more complicated muqarnas models.

**Parametric Modelling**

In order to have a precise modelling of a muqarnas, the knowledge about the methods of fundamental drawing forms of Iranian architecture is necessary. Primarily, the geometrical method of drawing 2D plans is examined in this research in order to realize better the drawing procedure of the muqarnas. Afterwards, a 2D parametric modelling is performed by the software.

As mentioned above, it is the span’s length which determines the width for construction of a muqarnas. As it could be observed subsequently, the method of width finding begins with dividing an arc (circle) into equal parts and choosing a desirable radius for its central part as in all other Iranian designs.

In our case, an eight-division is used which caused the selected Rasmi to be called “Rasmi-8”. The traditional drawing of the 2D Rasmi-8 briefly includes the following steps, and in the following parts of the research, it is comparable by drawing via the software.
2D Modelling

All the following information is usable in order to draw a Rasmi-8 plan for a determined span with the length of AB. In addition, a half plan which is appropriate for an Iwan’s ceiling is presented in order to have a better realization of the matter. In order to draw a Rasmi plan, it is sufficient to make the plan symmetric in proportion to the horizontal axis.

Initially, we start by drawing a semi-circle with a desirable radius at the center of point “O” (midpoint of line AB) and we divide it into 8 equal parts. Then we connect point O to the third point of the division by a straight line and extend this line until it intersects with the perpendicular extension line derived from point B at point C. Accordingly the width of BC span is obtained and the framework for drawing the Rasmi-8 is prepared (figure 2).

Now we choose a desired distance on the 6th division line (OE) and we draw CE line (Figure 3). The position of point E determines the shape of the plan’s central star which is called “Shamseh”. The longer OE becomes, the larger Shamseh will be produced.

According to (Figure 4), we draw three arcs with the radii OE, OF and OG at the center point O. It is worth mentioning that these are the arcs to which we give a height in our 3D modelling, and obtain different alternatives from Rasmi-8.

Afterwards, we connect the points to each other as shown in (Figure 5). The set of points E, F, G and C lie on a straight line and this also applies to points G, K, H and points M, K and L as well as any other similar group of points.
By omitting the extra lines, the fundamental figure of the Rasmi-8 plan is clearly visible in (Figure 6) including Iranian names of every section.

Parameter 2D Modelling

In order to implement the parametric Rasmi-8 in Grasshopper3D software, some simple components including move, mirror and intersection are used. The difference between this method and the traditional drawing method is that first, a point is selected as the origin, and then, the main points of the plan are located in their exact position by the help of move and rotate components. Regarding various methods which were tested in the provision of this file, it seems that our method is the most efficient Grasshopper3D definition concerning RAM load and simplicity.

A figure related to Grasshopper3D definition in Rhino 5 can be seen below.

The changeable parameters in this code are the width of span and the radius of Shamseh, which enable the user to create many alternatives and choose the appropriate ones (Figure 8).

Parameter 3D Modelling

As obtained in 2D drawing of Rasmi-8, it is appropriate to raise or lower the heights of points on arcs in order to create a 3D Rasmi-8. Consequently, no special new component is applied compared to 2D modelling. The following figure is the relevant Grasshopper definition of 3D Rasmi-8 modelling in which 9 changeable parameters are embedded.

These parameters come in three main categories. The first set consists of two parameters, one is related to the length adjustment (and consequently, width) of the framework and the other one is the radius of Shamseh. The second group is used to change the arcs’ (circles’) heights from the ground,
and the third one is related to changing the height of the vertices of the elements of Rasmi-8.

![Grasshopper3d Console](image)

**Figure 10. Parameters in Grasshopper3d Console**

By changing each of the aforementioned parameters, we could create various alternatives of Rasmi-8, select the best alternative regarding the circumstances of the design and then, present it as a design solution.

![Rasmi-8 Alternatives](image)

**Figure 11. Rasmi-8 Alternatives**

**Conclusion**

In the traditional method, Iranian architects were restricted in terms of having pre-sketched alternatives for making decisions about their intended design. However, using software such as Grasshopper3d enriches the ability to virtually display various alternatives and designs to architects. There are three significant visions, including being parametric, high performance (speed) and precision in the creation of virtual models.

A parametric model allows architects to compare and produce various outputs in a short time by controlling desirable parameters and without mere need to imagine them. Needless to say, the speed of virtual modelling is more than creating a physical model by far, and on the other hand, the virtual model is generated with precise details and dimensions.

Besides, having access to parametric virtual modelling gives the possibility of analysis and various realizations of virtual modelling to architectural professionals. A virtual model can be examined and analyzed regarding structure, sound, shadow or energy as well as dynamic calculations for robotic modelling.

None of the abovementioned opportunities could be achieved without utilizing algorithmic software, and perhaps the main reason for the insignificance of this beautiful element in Iranian architecture is the lack of adequate skills for applying digital architectural technologies.

Despite all other attempts on the production of a virtual muqarnas, it could be stated that our approach can be considered as the first parametric virtual model of a muqarnas.

**References**


