Shape Grammar of Geometric Islamic Ornaments

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Shape grammars are the algorithmic systems used to analyze existing designs or create new ones. In spite of using text or symbols to express abstract representations, shape grammars aid to create novel designs through computational effort with shapes and rules. Many probabilities of rule selections and applications of these rules may generate emergent design solutions or create new design objectives. This paper aims to present the characteristics, shape grammar rules and historical background of geometrical ornaments in Islamic culture and to point out the possibilities of mathematics of symmetry. The knowledge presented in this paper can be used to generate new depictions and to gain new application areas like typography, wallpaper, landscape, façade design, tiling, jewelry, and textile designs. Even, these types of shape grammar studies can be used to open a novel approach as in Jean Nouvel's "Arab World Institute" in Paris. The role of shape grammar analysis of geometrical Islamic ornaments explained in this paper is to increase the efficiency of architectural design education by facilitating the formal understanding of historical patterns. Novel use of shape grammars in education can enrich the designer's ability to generate original designs. In this paper variants of Islamic ornaments are created with a CAAD program. A selected geometrical bezeme (ornament) from Islamic ornamental design is generated by encoding with a computer programming language. According to the generated bezeme, interaction scenario is as follows: Computer has the main control over grammar application. Only, some of the rules can be selected by the user. Varieties of this ornament are generated randomly through their line weight, line colors, filling types and filling colors. The shape grammar rules outlined in this paper are simple, but the resulting figures can be very inspiring. Furthermore, the endless potential for future design innovations is unlimited.

Keywords: *Computer-generated geometrical design; shape grammar rules; geometrical Islamic ornaments; Islamic patterns.*

Introduction

After Turks accepted Islam religion, they developed completely original and new art. It was first begin with Karahanlis. Karahanlis are the first Turk Islam nation (Aslanapa, 1997). Muhammed Farabi was one of the famous Turkish philosophers and he was developed Islam philosophy on the base of old Greek ideas with works of Aristoteles (Aslanapa, 1997). The octagonal interlacing patterns had important role in Karahanli architectural ornaments and after that, in Gazneli, Big Seljuk, Anatolian Seljuk and Ottoman culture these patterns had always been evaluated with novel ideas. Nasr Bin Ali was one of the most important monarchs of Karahanli. Border of the portal of his tomb has interlacing semi-octagonal brick patterns created quad knots and stellar ornaments. These ornaments were important because of their pioneering and later on, they were improved and used in several ways in both Turkish Islamic art and architecture.

Shape grammars in the art and architecture include Chinese lattice designs (Stiny, 1977), window designs of Frank Lloyd Wright (Rollo, 1995), traditional Turkish houses (Cagdas, 1996), ornaments on ancient Greek potteries (Knight, 1986), chair designs of Hepplewhite (Knight, 1980) and paintings of Richard Diebenkorn (Kirsch and Kirsch, 1986), Georges Vantongerloo (Knight, 1989) and Fritz Glarner (Knight, 1989). Ranges of these examples indicate that shape grammars can be used to generate new models on the basis of historical styles. There are many important studies related to Islamic ornamentation and geometric origins of Islamic patterns such as a computer program based on Arabic calligraphy (Moustapha, 2001 and 2004), a computer program called "Taprat" based on Islamic star patterns (Kaplan, 2000), and studies about conceptual design by means of Islamic geometric patterns within a CAAD environment (Ozsariyildiz, 1991), and an analytical and cosmological approach to Islamic patterns (Critchlow, 1976).

Roots of Islamic ornamental design patterns are differentiate in time, according to historic periods and cultures. Two and three-dimensional artistic expressions can be seen in Islamic culture. Geometrical and floral patterns are the most important ornamental design components in Islam, because any depictions of human and human related subjects are forbidden. Art and need of expression lead people to another solution, which is based on geometry and mathematics. Although the main aim of these symmetric geometrical or floral patterns is decoration, they depict a variety of Euclidean rules and geometrical structures. In Islamic culture, ornamental design patterns are used on different kind of materials such as tiling, glass, paper, wood, plaster, metal, stone and brick. Generally, Islamic ornamental designs are seen on some places like *mihrap* (niche in a mosque wall indicating the direction of Mecca), minbar, window and door shutters, *hünkar mahfili* (sultan's lodge), fountain fences, tile, stalactites (muqarnas), *rahle* (reading desk), ceiling and walls.

Seljuk ornaments are different from Ottoman ornaments. Seljuk preferred to apply ornamental designs especially on portal façades. These ornaments are constructed mostly in stone and brick, in this way they specialized at stonework. Also, Seljuk draw both geometrical and animal based ornamental designs on the façades. On the other hand, in the Ottoman culture there are no animal figures. Also, Ottomans preferred to let the façades plain. They mostly decorate inside of their buildings. Especially Classical Period is climax point for Ottoman Architecture. Ottoman decoration items are tile, carving, engraving for ceilings and walls, relief and stalactite.

Islamic art has three main objectives which are Arabic calligraphy, floral ornaments and geometrical ornaments. Mostly, combinations of these elements are used on the same object. This study focused on geometrical ornaments in Turkish Islamic art and architecture.

Geometric Islamic patterns

Shape grammars are the algorithmic systems used to analyze existing designs or create new ones. In spite of using text or symbols to express abstract

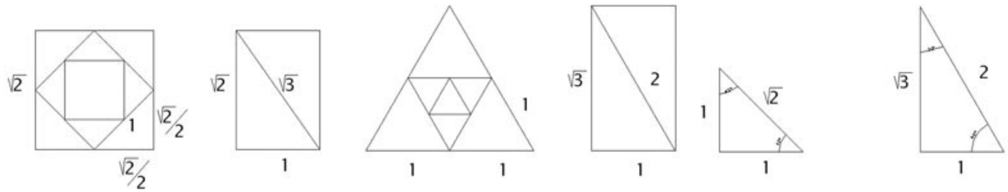

Figure 1
Proportions of a square generates octagon and hexadecagon (hexakaidecagon), proportions of an equilateral triangle generates hexagon and dodecagon, right triangles (isosceles right triangle and 30-60-90° triangle) are used for the rules of symmetry and proportion (Uluengin, 2000).

representations, shape grammars aid to create novel designs through computational effort with shapes and rules. Shape grammar applications guide the designer towards emergent design possibilities. Many probabilities of rule selections and applications of these rules may generate emergent design solutions or create new design objectives. This paper aims to present the characteristics, shape grammar rules and historical background of geometrical ornaments in Islamic culture and to point out the possibilities of mathematics of symmetry.

The works of Euclid and Pythagoras were among the first to be translated into Arabic[1]. Therefore, Islamic art was derived from Greek math that based on pure geometry (Figure 1). According to Pythagoras, everything in the universe can be defined by mathematics. Each number has certain meanings. Cube and square represent world, pyramid and triangle represent fire, and dodecahedron represents the universe. Two-dimensional geometrical patterns in Islamic art are compositions of closed polygons. Geometrical and floral ornaments are generated by certain geometry rules. These basic rules are classified as two groups. These are isometric transformations and Boolean operations. Translation, rotation, reflection, repetition are the isometric transformations, and they are also called as Euclidean transformations. Second group is Boolean operations that consist of operations such as union, intersection, and differentiation.

A regular tiling of polygons (in two dimensions), polyhedra (three dimensions), or polytopes (n dimensions) is called a tessellation[2]. If adequate sided polygons are combined to create a composition, then a "tessellation" will be generated. Equilateral triangle, square and hexagon are the best shapes to generate these tessellations. In geometry, a polyhedron is simply a three-dimensional solid which consists of a collection of polygons, usually joined at their edges.[3]. However, in this study two-dimensional figures are analyzed, polyhedra and polytopes are not included in the study.

"Repetition" is the most effective and important theme for geometrical patterns. There can be one or two basic shapes in an Islamic ornament, but interlocking design of these basic patterns generate different and complex patterns at the end. Ornamental designs are generally generated by the repetition of square and triangle shapes. These geometrical shapes are generated by repetition; therefore they need a grid system. These grid systems can be obtained by square and triangles. Together with square and triangle; pentagon, hexagon and decagon are also having important roles in generating geometrical shapes. Octagonal and hexadecagonal forms can be generated by a grid consists of squares. A grid created with equilateral triangles can generate hexagonal and dodecagonal forms. Circle generates three fundamental forms that are triangle, square and hexagon. Also star is another important figure in Islamic art. Every arm of a star has equal distance from its centre. Because of circle has neither starting point nor ending point, in every culture it represents eternity. In Islamic art, circle and the center of circle represent the creator (*Allah*) and also represent Mecca, the center of Islam. Therefore, circle is one of the most important figures in Islamic ornaments.

Another important operation is "symmetry". It is the key factor in derivation of both geometrical and

1 http://www.islamicarchitecture.org/art/index.html:May06
2 http://mathworld.wolfram.com/Tessellation.html:May06
3 http://mathworld.wolfram.com/Polyhedron.html: May06

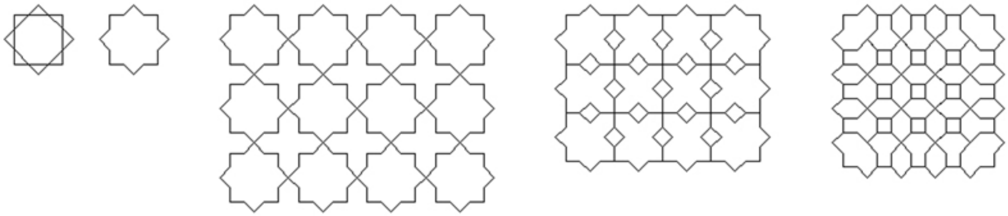

Figure 2
Rectangular array was applied to the pattern.

floral patterns. Symmetry in human body is called bilateral symmetry (Mitchell, 1990). In bilateral symmetry, figure is mirrored through vertical axis. This is the most important rule in generating the compositions. Stylized rose figure, which is called as *gülçe* (rosette) and star shaped patterns (stellar) are the most common Islamic figures and they are generated by these simple rules.

Figure-background relationship is another important aspect in Islamic art. Different parts of the figures can be dominated by figure-background relationship. Especially, in tiling and engraving, color usage is important for figure-background relationship and visual perception of ornaments. If colored area is changed, ornament will also be changed. Sometimes, material type can be differentiated for perception. Ornaments in wooden material can be combined with silver, *bağa* (tortoise shell), ivory and nacre to increase visual perception.

Generation of geometric Islamic patterns

This paper is focused on ornaments generated by one of the basic figures in Islamic ornamentation, eight-pointed star, but patterns derived from triangle and pentagon are also examined in the study. Different rule-sets are applied to the figures. These generative rules are based on shape grammar and fractal geometries. Drawing software has been used for the exploration and generation of basic figures in Islamic ornamentation to create new forms. Some of the generated patterns are colored in a picture editing software (Figure 11). These patterns are seen in religious buildings as interior or exterior ornaments but most of the patterns in this study are generated for the first time. Different geometrical Islamic ornaments can be used to generate new emergent shapes.

Patterns derived from rectangle

In drawing software, rectangular array (figure 2) and polar array (Figures 3-11) are applied to the eight-pointed star. Total numbers of items are 8, 16, 24 and 32. Angle to fill is 180° in some examples (figure 10); in most of them is 360° (Figures 3-11).

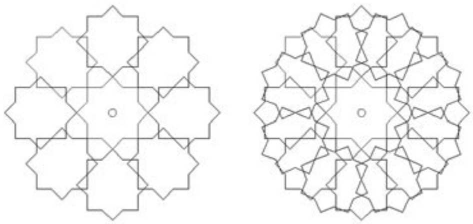

Figure 3
Polar array was applied to the pattern, total number of items: 8, 16, angle to fill: 360°, rotate items as copied, center point of array: marked at the origin.

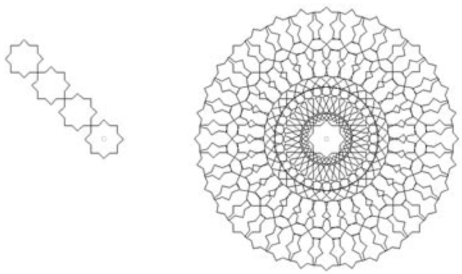

Figure 4
Polar array was applied to the pattern, total number of items: 32, angle to fill: 360°, rotate items as copied, center point of array: marked at the origin.

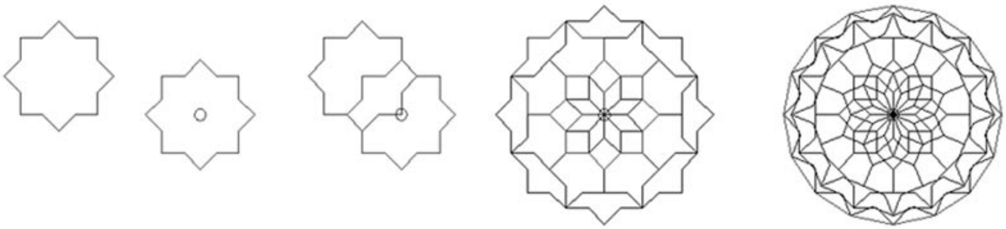

Figure 5
New rule-set and polar array application to the pattern, total number of items: 8 and 16, angle to fill: 360°, rotate items as copied, centre point of array: marked at the origin.

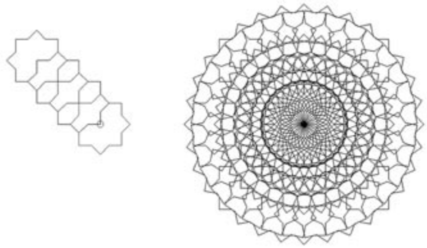

Figure 6
Initial shape consists of four eight-pointed stars, total number of items: 32.

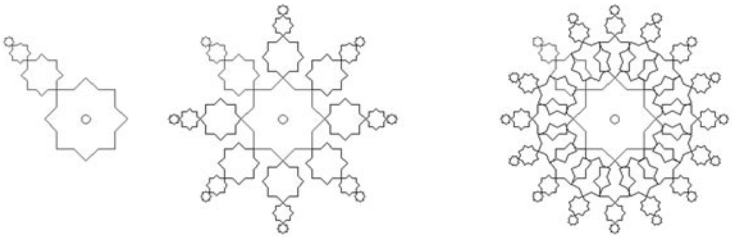

Figure 7
Rule-set of snowflake pattern, pattern scaled 3 times with ratio of 1/2, total number of items: 8 and 16, multiplication point: upper left corner of the pattern, centre point of array: marked at the origin.

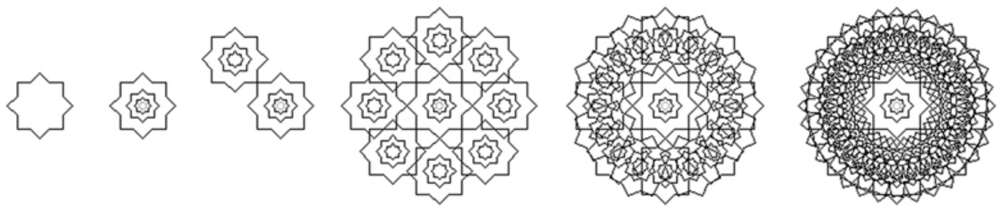

Figure 8
Polar array was applied to the pattern, total number of items: 8, 16 and 32, angle to fill: 360°, rotate items as copied, center point of array: marked at the origin.

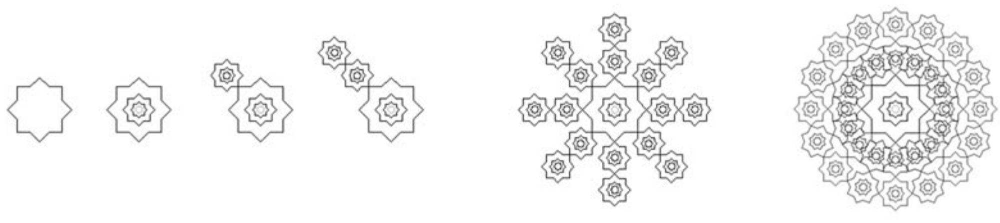

Figure 9
Pattern scaled 2 times with ratio of 1/2 into the pattern itself, total number of items: 8 and 16, multiplication point: upper left corner of the pattern, center point of array: marked at the origin, angle to fill: 360°.

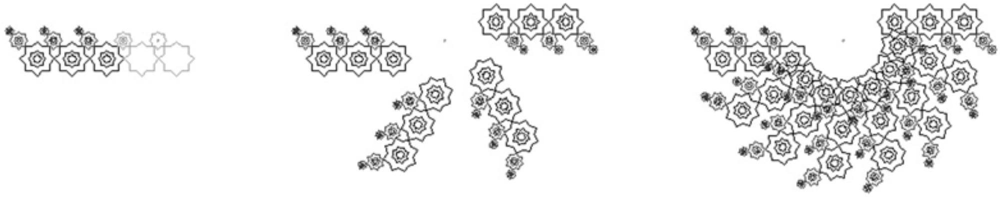

Figure 10
Pattern scaled 2 times with ratio of 1/2 into the pattern itself, multiplication point: upper left corner of the pattern and left arm of the star, centre point of array: marked at the origin, angle to fill: 180°.

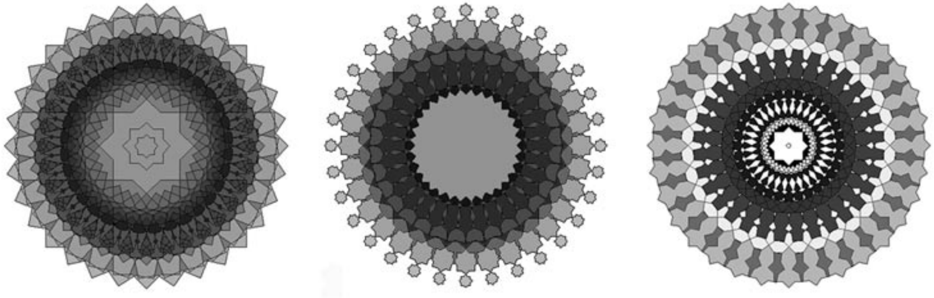

Figure 11
Coloured illustrations of the generated patterns, total number of items: 32, angle to fill: 360°, rotate items as copied, center point of array: marked at the origin.

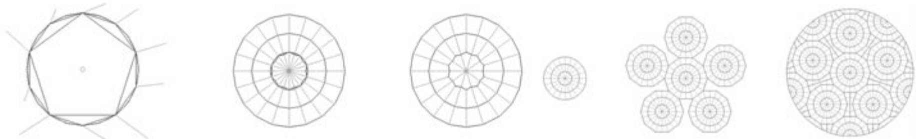

Figure 12
Generation of icosagon from pentagon and icosagonal rosette.

Patterns derived from pentagon

Pentagon is an important form because golden ratio can be obtained from pentagon. Decagon and icosagon can be generated by pentagon (Figure 12). Icosagon is the only form that can be closed in 3 dimensions, so sphere can be generated by icosagon.

Patterns derived from triangle

A selected geometrical *bezeme* (ornament) from Islamic ornamental design is generated by encoding with a computer programming language (Figure 13, 14). According to the generated *bezeme*, interaction scenario is as follows: Computer has the main

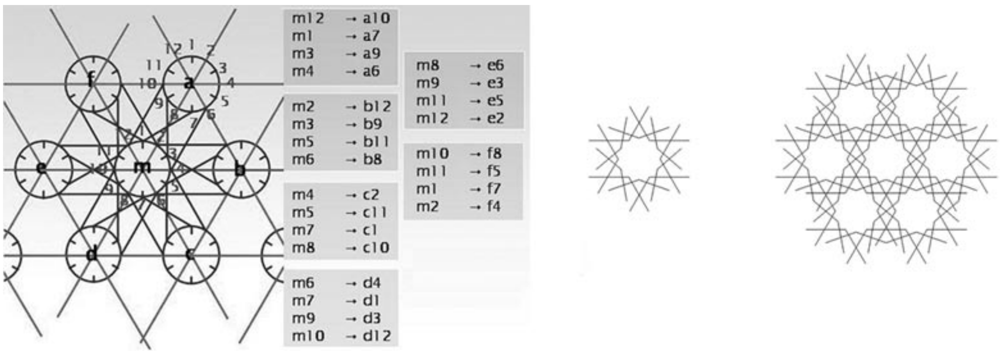

Figure 13
Generation process of the pattern.

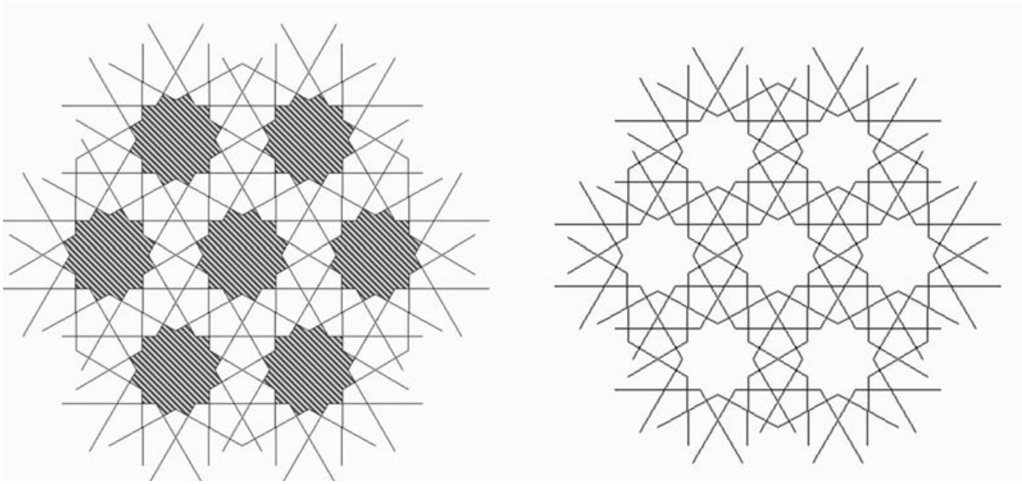

Figure 14
Variations of generated pattern.

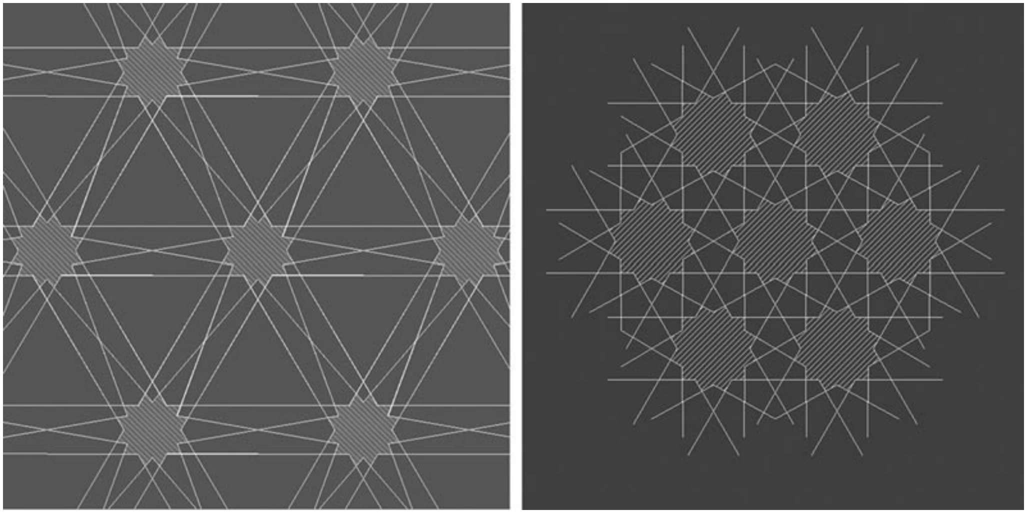

Figure 15
Deformed pattern and variation of generated pattern.

control over grammar application. Only, some of the rules can be selected by the user. Varieties of this ornament are generated randomly through their line weight, line colors, filling types and filling colors (Figure 15-18).

Conclusion

Although there are both floral and geometrical ornaments in Islamic art, in this paper, shape grammar of geometric Islamic ornaments is studied and geometric patterns are grouped as patterns derived from triangle, rectangle and pentagon. All the patterns shown are linear forms. These geometrical shapes are the origin of Islamic art. The stylistic features are related to the structural framework and that the structural framework comes from social, material and personal constraints (Ozkar and Lefford, 2006). However, the most important point of these patterns is the artisans generated them. Formerly, measurement knowledge did not exist. They used simple tools such as straightedge without numbers, triangle and compass. In the contrary, we have CAD programs help us to explore new design possibilities from the domain of Islamic ornamentation to innovative design features. Generated patterns can be used in jewelry designs, interior and textile designs (carpet, wallpaper, curtain, fabric for clothes, furniture), landscape design, façade screens, ceramics, tiling, typography and logo designs. Architecture can be united with art, and these studies help to create buildings like Herzog & de Meuron's "Eberswalde Library" and "De Young Museum" or Jean Nouvel's "Arab World Institute". The applications in this study are appropriate for capturing a novel design approach as Art Nouveau movement in art and architecture. This study is one of the starting points in the field of shape emergence which is also one of the features of shape grammars. The shape grammar rules outlined in this paper are simple, but the resulting figures can be very inspiring. Furthermore, the endless potential for future design innovations is unlimited.

Acknowledgements

I would like to thank Professor Gulen Cagdas (Istanbul Technical University) and Professor Bulent Uluengin (Mimar Sinan Fine Arts University) for their valuable contribution to this study with their guidance and lecture notes.

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