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The revival of the historic Islamic geometric pattern on the gate of The Al-Sharabeya School in Wasit City using the Grasshopper program

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ABSTRACT

There is a lack of knowledge that is required for using computer programs (parametric computing) to generate and derive new Islamic geometric patterns locally. This study focuses on the application of parametric modeling using the Rhinoceros 6 Grasshopper program on an Islamic geometric historical pattern, which decorated the gate of the School in Wasit, where the search imposes a spatial approach. This program is applied with the help of the algorithmic parameters used by the parametric design technique to generate and derive new Islamic geometric patterns from an extinct reference pattern used in contemporary urbanism. The goal is to enhance and impart an attribute of cultural inclusion and architectural originality to the local architecture of cities. The results demonstrate that the program was able to generate a new Islamic geometric pattern that did not previously exist, by finding the associative relationships and a hidden network between the tessellations of the Islamic geometric pattern, through algorithmic relationships, which was not visible. Therefore, the Rhinoceros 6 Grasshopper program can be used by architects and urbanites to devise distinctive design alternatives based on historical patterns and heritage models that can be applied in the future design of urban areas and cities that belong to the Islamic civilization.

Keywords: Grasshopper, Islamic geometric pattern, Revival, tessellation. Parametric design

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1. Introduction

Islamic Geometric Patterns (IGPs) can be observed with regularity traits, in both, artificial and natural structures [1]. The Alhambra palace that has distinct Islamic geometrical patterns [2], demonstrated the relationship between Islamic geometrical patterns and the Islamic architecture that appears in several types of building elements [3] such as, tiles or tessellates made of space-filling shapes produced by repetitive cells in two directions, these tiles contain complex polygons formed by the intersection of a group of circles [3]. IGPs are a set of patterns that appear on interior surfaces such as walls, ceilings, doors, and other surfaces [4]. The development of Islamic architecture has constantly changed with the progress of time [5]. However, the architecture in the Islamic world has been largely inclusive of the values and the culture of Islam, where the architecture plays an important role as evidence of the cultural identity of Islam [5]. The study of Emami N & Giles H/2016, concurs with previous studies and classified Islamic art, on calligraphy, floral ornamentation, and Islamic geometric ornaments or patterns [6]. The presence of IGPs greatly affects the design and the construction of buildings and structures [5], which allows for the identification of architectural movements, regional styles, and building elements in Islamic architecture [5]. The importance of the past can be expressed by defining heritage revival (synonymous with heritage revolution, the ascent of history, etc.) [7], as a priority in architecture. This means that the connection between heritage revival and the development of designs related to

new projects, by referring to traditional buildings and architecture (Sherine S. et al./2011), in the three-dimensional modeling of architectural elements that fulfill historical, artistic, and constructive aspects, is based on the usage of programs for heritage development [8]**.** (Zheliazkova M. et al.\2015) argued the importance of the creation of as-built heritage buildings, which takes place in three phases: data collection, data processing, and the production of the final model [9]. Masdar City, which was designed by Foster and Partners, revived heritage by using IGPs in the building design, the façade, the skins, and the screens [10]. According to (Bosma K./2014), the term heritage revival involves the selection and the revival of man-made structures or buildings from the past elements. Some of these elements receive more emphasis based on their importance [11]. The researcher, (Tolina L./2006), demonstrated the ability to make a visual abstraction of the past elements to deal with them with a photographic sense [12]. IGPs in Masdar is a good example of the visual abstraction treatments for a hot humid environment, which preserves the traditions and the heritage of the site [10]. The IGPs shown in the book by (Bonner J.\ 2017) (Islamic Geometric Patterns: Their Historical Development and Traditional Methods of Construction), demonstrated the historical development of Islamic patterns and highlighted the importance of computer software programs to draw IGPs by translating them into an algorithm for use in ornamental designs or the reproduction of real-world artifacts [13]. (Toorabally/2016) implied the importance of external factors that influence various styles of building elements and defined Islamic patterns in general, as a set of patterns that appear in three forms of exterior design, represented by domes, pointed arches, and ornaments or motifs [5]. (Aldulaimi\2009) classified Islamic patterns into three types (geometrical, floral, Arabic script patterns, and star polygon patterns), as seen in figure (1). Floral patterns were inspired by nature using samples such as tree leaves. Arabic script patterns record sentences from the Quraan and Prophet Mohammad's speeches. The Islamic patterns follow several rules such as balance, symmetry, isolation, and repetition [14]. (Abdullahi and Bin Embi\2013) sorted the types of Islamic geometrical patterns according to their historical emergence, into Umayyad, Abbasids, Fatimid, Mamluk, Ottoman, Safavid, Mughal, and Spanish architecture, and to the shape of pattern related to its era into eight forms. The rosette star of 8 to 12 points, and the muqarnas decoration appear in the Abbasid palace, the Al-Firdaws and the Al-Mustansiriyah school in Baghdad (Abdullahi, Y. et al., 2013). In the architecture of IGPs, H. Sobh and H. A. Samy compare digital technology with traditional methods in the architectural terms of IGPs such as formation, generation, and performance [15]. Some of these terms showed that an original and transformed pattern moves from design to construction to performance to practice [16] in the design phase, represented by algorithm design programs, laws, computing, and mathematical and parametric design theories [17][18]. Digital machines were developed for implementation, shortening the time and the cost of implementation and increasing the accuracy [19][20][21], which allowed for work with new materials that were highly efficient and effective [22][23]. This study focuses on a historic Islamic geometric pattern on the gate of the Al-Sharabeya School in Wasit City, analyzed by parametric design techniques using the Rhinoceros 6 Grasshopper program, to discover the possibilities that are provided by the Grasshopper parameters to generate new IGPs. Therefore, these subjects were taken into consideration in the methodology of the study.

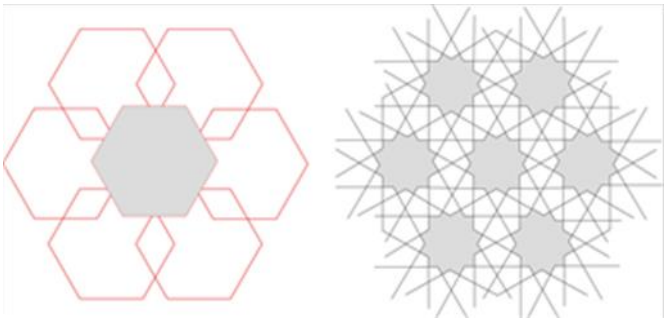

Figure 1. Grid pattern made of closed polygons (Autocad 2020 drawing)

2. Materials and method

IGPs are considered to be artistic compositions and are observed to be generated from the repetition and the overlap of squares and circles [5]. The compositional structure consists of the repeated unit (RU), which is the minimal boundary of the basic shape, the repetition structure is formed by repetitive units, and lastly, the fundamental unit is the smallest composition that is not subjected to symmetry. Tiles tessellate, and repetitive units from Islamic patterns [24]. This study articulates the relationships among Islamic pattern’s stars in the

pilot study and applies these relationships to study new possibilities to create derivative patterns using parametric modeling software (Rhinoceros 6 Grasshopper). The following sections show the methodology of the study.

2.1. Islamic patterns tessellation

Islamic patterns vary in appearance, depending on several aspects, and are subject to mathematical relationships. Islamic patterns were classified into two and three-dimensional patterns by (Sehnaz and Cagdas\2006). The two-dimensional Islamic patterns consisted of closed polygons, and the three-dimensional patterns were represented by floral patterns. Geometrical ornaments were related to geometrical rules, such as isometric transformations and Boolean operations.

Tessellation is defined as the tiling of polygons in two, three, and n dimensions. The repetition of the shapes creates ornaments, which necessitate a grid system made of triangles, circles, and squares (Sehnaz. Gulen, 2006). (Mohamad M. et al./2016) studied the six-point star of the IGPs parametrically. He first studied the compositional elements of the IGPs represented by the fundamental unit and the cells and then made parametric variations of the shapes and colours and considered these variations as metamorphosis operations. The researcher generated new geometric possibilities considering the cell as a basic unit, and the fundamental unit as a set of geometric shapes which cannot be obtained by repetition. Several steps were taken to achieve the generation process using the Grasshopper/Rhinoceros software: step 1 is ensuring no point overlapping, step 2 is ensuring no line overlapping, step 3 is making intersections, and step 4 includes points within the fundamental region as shown in figure (2). (Zahra S. et al./2015) classified IGPs to three categories according to the construction method. First is the strap work, second is the modular system, and third are the polygons in contact.

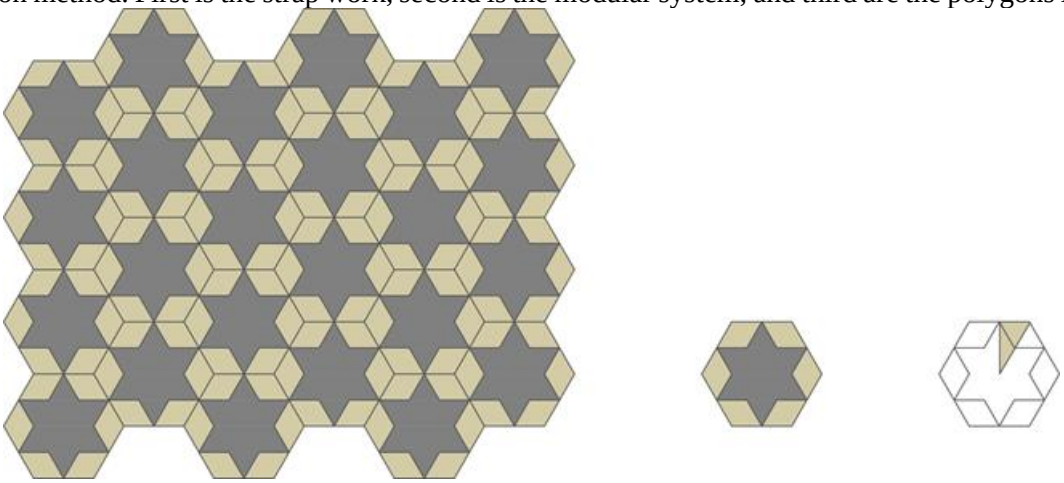

Figure 2. The (IGP) with cell and fundamental unit (Autocad 2020 drawing)

Constructing the IGPs using the strapwork method requires the use of hand tools such as a ruler and a pair of compasses. The ruler is used to draw straight lines and the compass is used to draw circles and the projected IGP is the result of the overlapping shapes produced, such as triangles, circles, squares, and polygons by creating new shapes, stars, and tessellates [25]. The IGPs drawn using modular systems are based on picking smaller modules or units and repeating them periodically to create a shape tessellation. This tessellation is made of squares and rectangles and this method can effectively produce many IGPs. The polygons in the contact method describe the IGPs as two layers of geometric grids, where one is the original layer of IGPs and the other is a polygonal grid. This method of construction is called the Hankins method. The polygonal grid is formed by connecting the edges of polygons and by applying regular and irregular tiling polygonal networks. A new possibility is generated by changing the polygonal angle, as seen in figure (3) [1]. (Khamjane A. & Benslimane R./2017) sorted Islamic patterns generally to floral designs, calligraphy, and Islamic geometric patterns, and considered the Islamic star patterns as a distinctive character of IGPs. Islamic star patterns are the result of repeating symmetric star or rosette shapes. To draw a rosette Islamic pattern the following parameters must be satisfied [26]:

N: the rosette order.

R: the rosette radius.

è: the angle between the segment, DG, and the side of the boundary polygon.

S: a set of intersections of each edge of the rosette with the others.

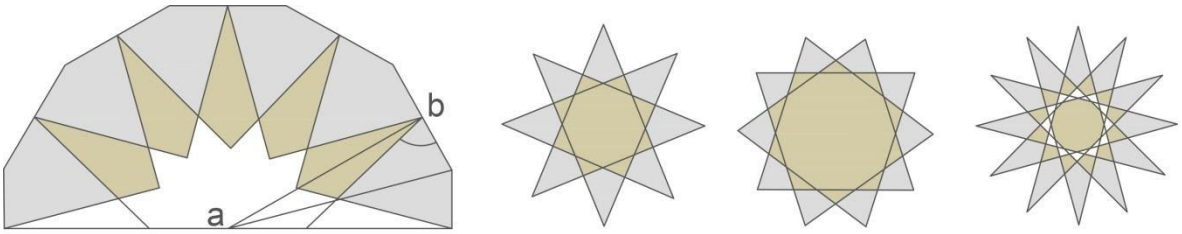

Figure 3. The Rosette changing angle that changes the final shape (Autocad 2020 drawing)

The n architecture IGPs appeared in religious buildings, tombs, and traditional dwelling units. The researchers explained four possibilities of creating the IGPs. The first is by selecting a single shape and repeating it and obtaining variation by changing the angles or by removing or making shape holes. The second possibility is recombining shapes or stored tiles to create a more complicated pattern. The third possibility is using a geometrical construction with simple shapes such as squares. The final possibility is creating a grid and then applying polygons or circles regularly with adding points on the boundaries of the shapes to project the final pattern and then removing the construction lines as shown in figure (4) [6].

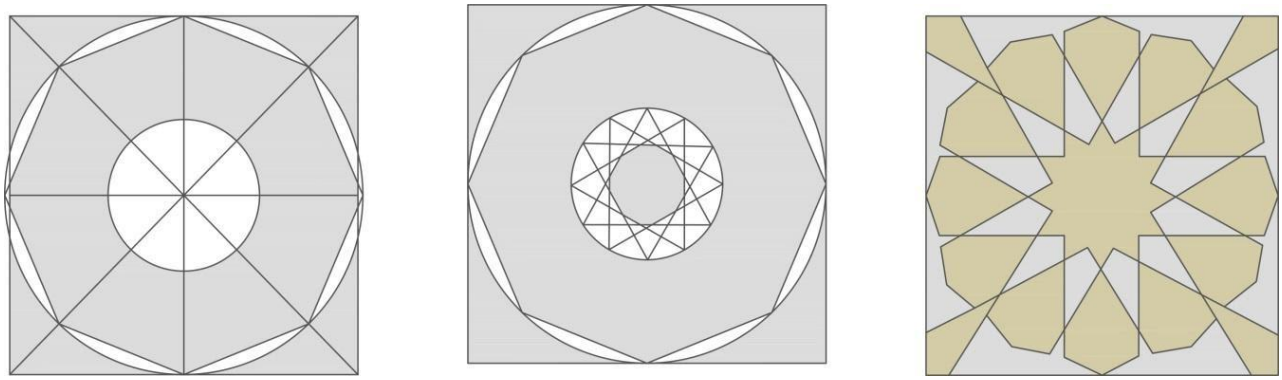

Figure 4. Shows the final possibility or the concealed grid method (Autocad 2020 drawing)

2.2. Parametric design

There are various definitions of parametric design. According to (Holzer D. et al/2007), a parametric model is defined by the relations of its components, these relations are subjected to various rules and design constraints that allow the designer to manipulate parameters without deforming the design principles. Parametric design is used to create design solutions and alternatives using several software programs such as Archicad, Autodesk Revit, CATIA, etc. (Jowers I. et al./2010) studied the generative methods of IGPs, The creation of these patterns starts with simple shapes like squares, triangles, and stars then follows the rules of symmetry, scalability, and movement. According to previous studies, there are three generation methods of IGPs: the compass and ruler method, the set-based method, and the motif-based method. The compass and ruler method is an old technique that uses grids, squares, stencils, and other parameters. The set-based method is influenced by the tile work of Islamic architecture and is composed of simple repetitive polygons or repetitive units, as seen in figure (5). The motif-based method depends on applying a set of rules called shape grammars. Shape grammar is the use of shape rules to define a certain geometric pattern. These rules are used to analyze existing styles and generate new or existing patterns [27]. New methods to create patterns depend on encompassing parametric values as a way of building geometrical inputs through associative values and relations [28]. Parametric design is defined as a computational method capable of producing analytical and generative models to take advantage of the design process and the design exploration. This study describes the relationship between parametric design and algorithms or algorithmic systems and highlighted the role of 3D software programs like Grasshopper3D plug-in for Rhinoceros and Generative Components [29]. (Monedero J./2000) defines parametric design as a restricted term to form parameters and the relations that define these parameters using the modeling technique [30]. The parametric design includes techniques dealing with parameters or algorithms to produce associative geometric structures using software programs that promote architecture by creating new designs or reviving buildings.

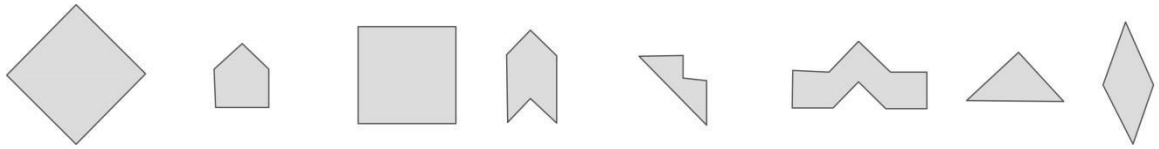

Figure 5. Furman different forms (Autocad 2020 drawing)

Sobh H. & Heba S./2018) explained the generation of IGPs starting with the creation of geometric shapes that construct a system of closed triangles, squares, and hexagons, and used this system to build free forms or generate new proposals [15]

3. Framework

The revival of the damaged parts of Islamic building patterns is carried out with the help of computer programs. (Sampaio et al.\ 2010) highlighted the importance of building models during the revival process for a better understanding of the building approach. The following sections demonstrate the parametric modeling technique using Rhinoceros 6 Grasshopper.

3.1. Parametric design techniques

Parametric design has been observed in previous architectural compositions that depended on mathematics in their relationships, such as the Sagrada Familia Basilica [31]. (Oxman\2006) defined parametric design techniques, as a provider of associative geometry, which has changing parameters to control topological surfaces. These techniques include modeling using architectural three-dimensional programs, and motion-based geometry or animation (Oxman, R., 2006). (Beesley et al.\ 2006) reported parametric modeling, tool building, and form-finding tools in architecture and engineering as parameters of the design representation in software programs. Parametric design techniques for (Mario\2013), are represented by modeling, form-finding tools, and animation (Carpo, M., 2013). According to previous literature, the parametric design includes three techniques: modeling, form-finding, and animation. The modeling technique is demonstrated in the framework

3.2. Modelling

Previous studies have shown that for the Islamic patterns of two and three-dimensional types, the modeling technique is effective for creating complicated forms such as the muqarnas, depending on the quality of the plans [32]. (Milena S. et al.\2013) defined the relationship between modeling and scale, and defined scale modeling as a discipline of building models that have a specific scale or related proportions. Scale modeling has several purposes such as exploring and presenting forms and details [33]. To build a parametric model with a level of complexity that represents the various forms of Islamic patterns, a methodology that considers the produced geometry as a set of mathematical functions to describe surfaces, curves, and solids are used [34].

3.3. Grasshopper for Rhinoceros 6

Grasshopper is a graphical programming environment that works as a plug-in within Rhinoceros three-dimensional modeling software. Grasshopper allows architects to link existing project components and create new ones [35], using methods of simulation, modeling and generation [36]. It provides the ability to change parameters and understand how variations control the outcomes [37]. (Airbus A.\2017) used Grasshopper in his study (Teaching Design by Coding in Architecture Undergraduate Education), which enrolled students of architecture to produce IGPs based on previous knowledge of the rules controlling the pattern [38]. The Grasshopper software can produce the IGP parametric variations [36], due to which, it was used by (Salam M et al.\2019) in a study (Fractal Dimension of Islamic Architecture: The case of the Mameluke Madrasas: Al-Sultan Hassan Madrasa), highlighting the importance of mathematical understanding of Islamic architecture as a set of rules then applying these rules using Grasshopper [39], generating several IGPs according to the fundamental region [36].

3.4. Measurement

The measurement starts with the building of a grid of polygons according to the type of pattern, when the number of sides of the polygon is equal to the pattern's folds. It is implemented by using Grasshopper for Rhinoceros 6 software owing to its ability to build a parametric model and the flexibility in analyzing the resulting geometry. (Aghabayli A.\2016), in his book (Geometric Patterns in Islamic Decoration), argued the possibility to produce

infinite IGPs based on a set of rules of creation using Grasshopper which enabled the researcher to find a universal code for patterns [40].

3.5. Case study

The pilot study involves the revival of Islamic patterns appearing on the gate of the Al-Sharabeya School in Wasit owing to the historic values, the rare Islamic pattern, and the lack of previous studies based on this architectural monument. The Wasit Governorate is located in Iraq, near the Iraq-Iran border, bounded by the Hamrin hills in the east, the Wadi Galas in the north, and the Hor Al Shiwach in the east and the south.[41]
The Al-Sharabeya school belongs to the Abbasid period and was built in the eastern part of the city by Sharaf Al-Din Al-Sharabey in 632 A.H. The gate consists of two minarets where, the right one was restored by the rehabilitation process in 1965 A.D, which did not target the diminished Islamic pattern of the gate. Figure (6) and figure (7) show Al-Sharabeya school's gate and the selected IGP [42].

Figure 6. Al-Sharabeya school after rehabilitation of 1965 A.D.

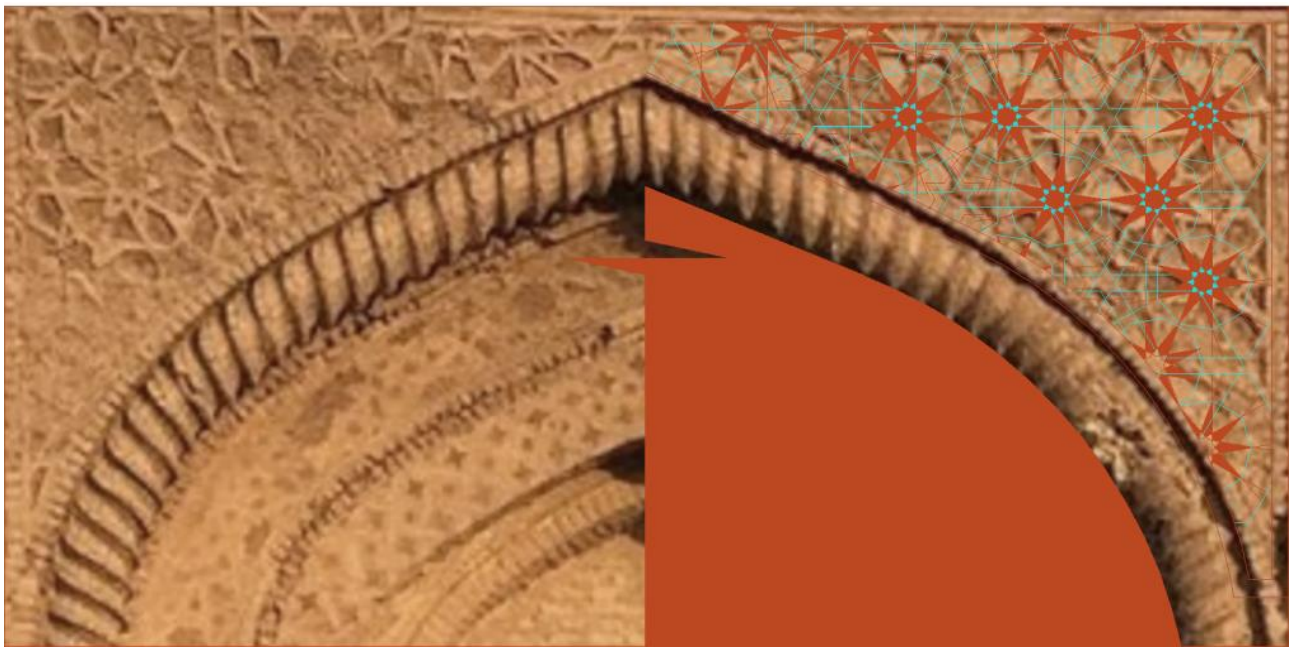

Figure 7. Selected IGP of the Al-Sharabeya school

The gate's Islamic pattern assessment shows that the pattern in the upper part of the gate has deteriorated, but the remaining parts of the Islamic pattern are well preserved. The Islamic pattern on the left minaret is symmetric with that of the right minaret. The analysis of the remaining parts shows that there are two types of stars: the six-fold pattern and the nine-fold pattern, with figure (8) describing the nine-fold pattern. These two types of stars are derived from the three-fold or the triangular pattern unit. The hexagonal grid guides the Islamic pattern's tessellation. The stars are controlled by a hidden grid of nine-sided and six-sided polygons and figure

(9) shows the hidden grid. Parametric modeling of the Islamic pattern is built using the Autodesk-Autocad 2020 version and the Rhinoceros 6 Grasshopper software, starting with the tessellation and the hidden grid as seen in figure (10).

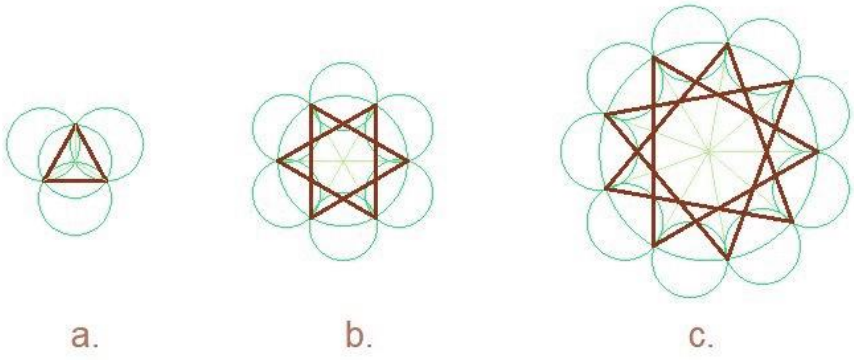

Figure 8. shows a. three-fold, b. six-fold and c. nine-fold (IGPs)

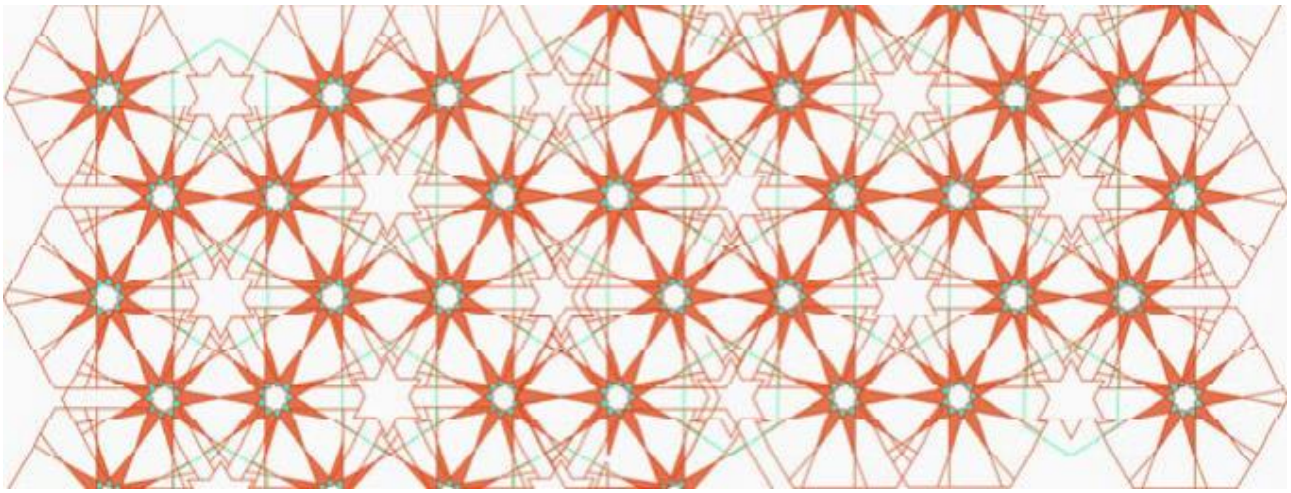

Figure 9. Hexagonal grid tessellation (Autocad 2019 drawing)

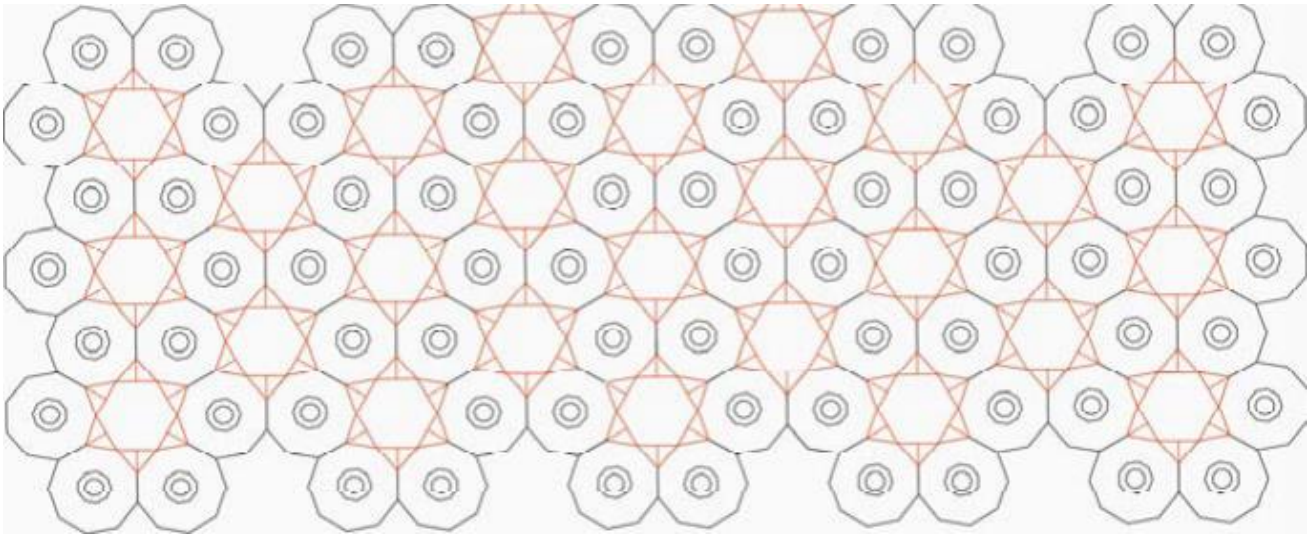

Figure 10. The hidden grid (Rhinoceros 6 drawing)

4. Findings

Building a tessellation of the IGPs requires analysis of the existing pattern. The analysis begins with determining the number of starting circle segments or sections that divide it and create the pattern as shown in figure (11). Four sections of the circle provide a four-fold pattern, five sections of the circle provide a five-fold pattern, and so on. Twelve-fold and ten-fold patterns belong to the six-fold and the five-fold pattern families respectively, while seven-fold, nine-fold, and eleven-fold patterns are rare. Tessellating patterns make a composition consisting of a hidden grid of squares, hexagons, or both squares and hexagons, which form the pattern [6].

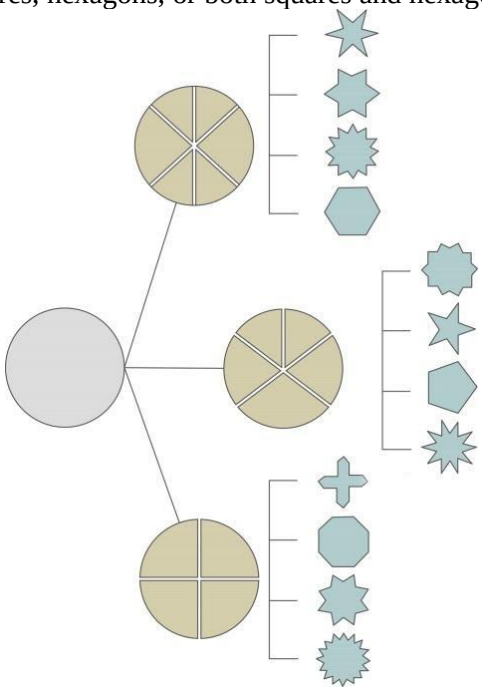

Figure 11. The segmentation of circles to create various patterns (Autocad 2020 drawing)

The findings reveal the relationship between the six-fold and the nine-fold star patterns, with the help of the controlling parameters of the hidden grid using Grasshopper version 6 (obtained after purchasing the program license on Aug. 31, 2020), as seen in figure (12). The changing parameters provide various Islamic pattern derivations, corresponding to the stability of the hidden grid of the reference pattern represented by the stars on the gate of the Al-Sharabeya school. Figures (13) and (14) illustrate the ability to provide derivations from a reference pattern. A nine-fold star pattern is initially drawn as an individual unit composed of a center and a perimeter, and this unit is then repeated so that the linking points can meet and finally form an interactive grid that can endlessly generate IGPs by changing the angles.

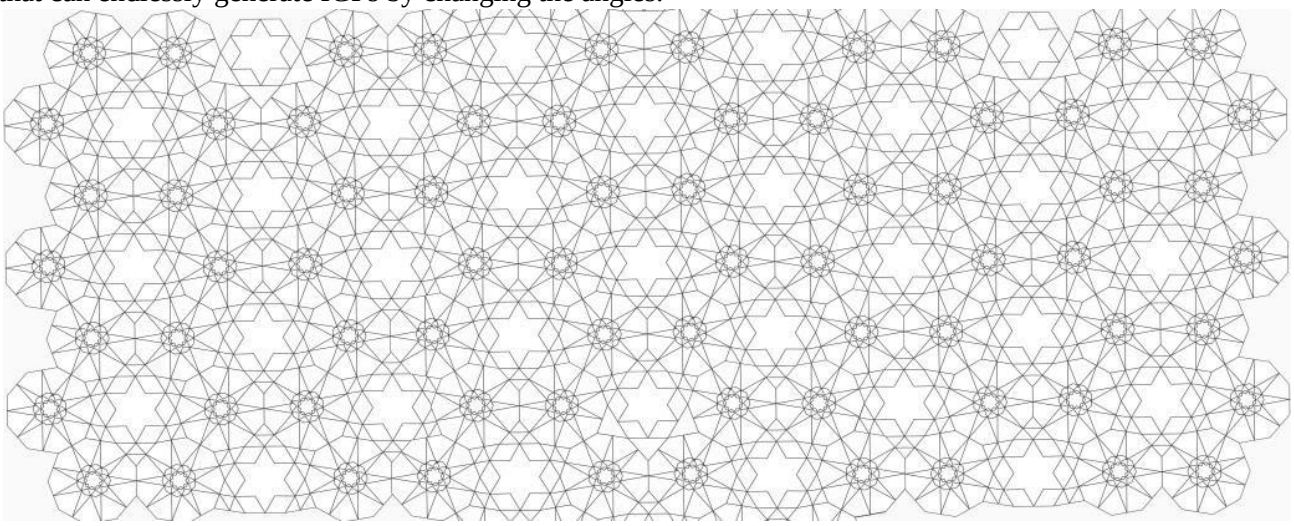

Figure 12. The whole grid of (IGPs) that contains the nine-fold pattern and the hexagonal grid (Rhinoceros 6 drawing)

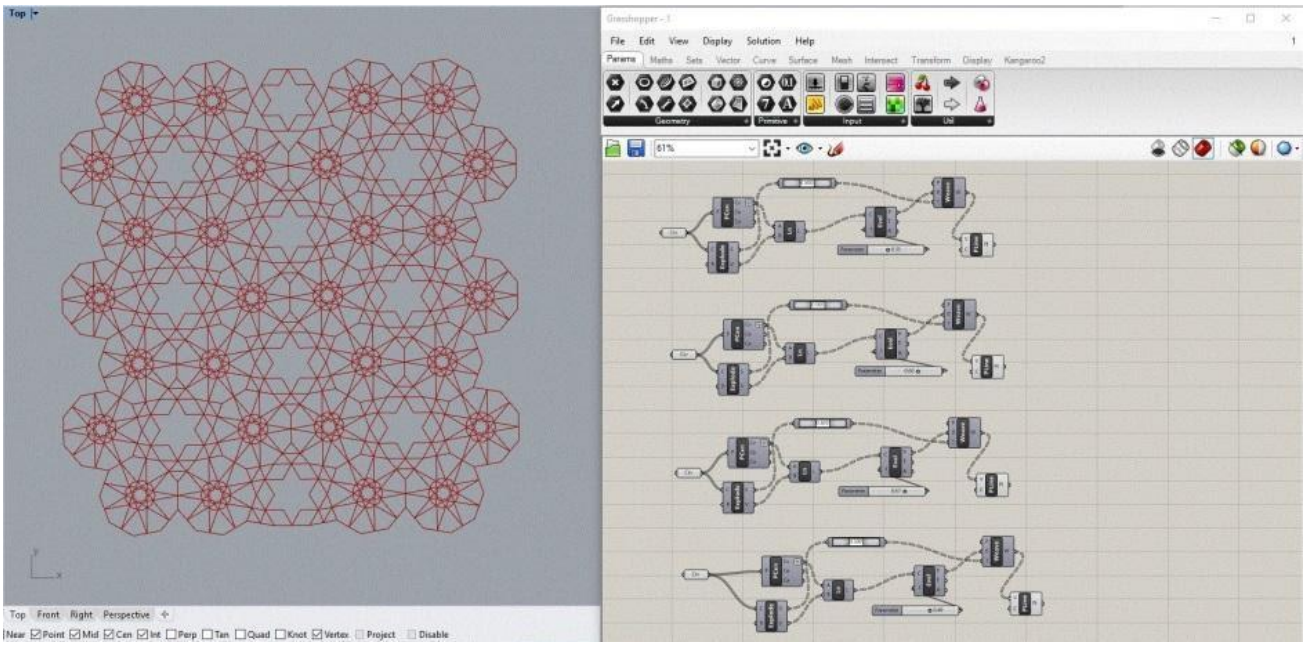

Figure 13. Al-Sharabeya school Islamic pattern no. 1 related to changing angles that provide endless (IGPs) (Grasshopper of Rhinoceros 6 drawing)

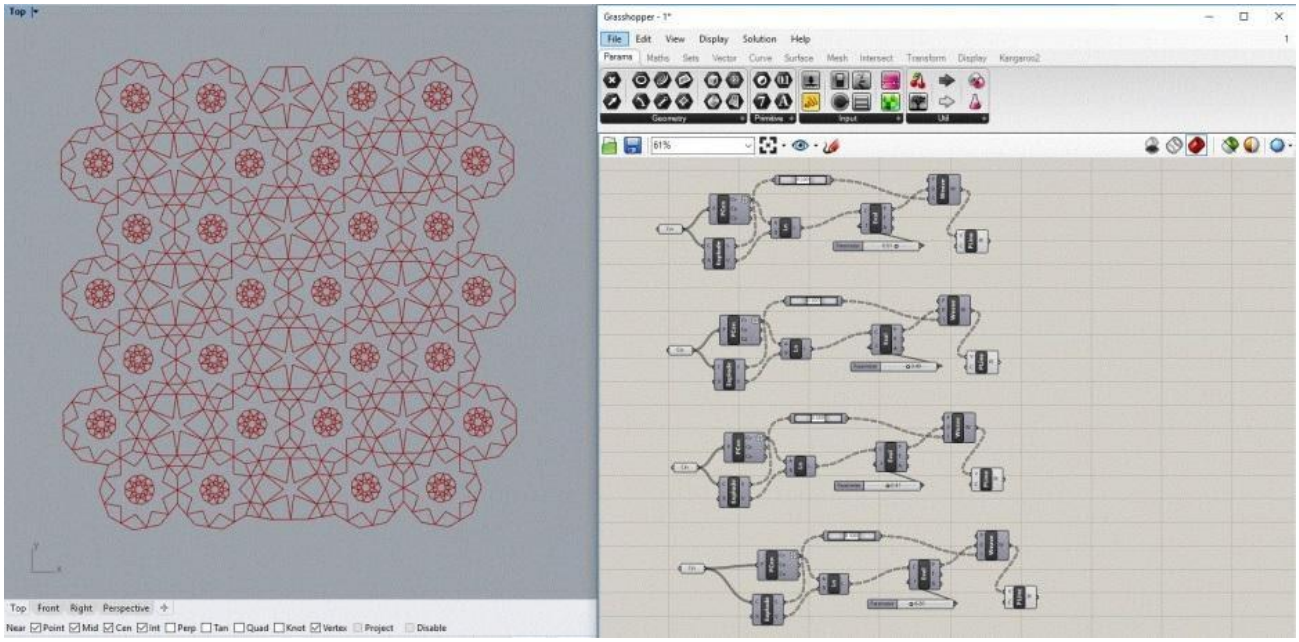

Figure 14. Al-Sharabeya school Islamic pattern no. 2 related to changing angles that provide endless (IGPs) (Grasshopper of Rhinoceros 6 drawing)

5. Conclusions and recommendation

- The revival of deteriorated Islamic patterns depends on understanding the origins of the pattern. Islamic patterns are subject to mathematical relationships or changing parameters, called parametric design.
- Parametric modeling is a technique used to build Islamic pattern-associated relationships that could result in various patterns, derived from the architecture of the Islamic era. The derivative patterns can serve new design alternatives that simulate certain styles of Islamic architecture. Parametric modeling involves analyzing a reference Islamic pattern, establishing a hidden grid, and tessellation.
- Grasshopper plug-in for Rhinoceros is an effective software program that enables architects to study existing historic patterns and generate new ones by understanding the pattern's generation process.

- The revival of deteriorated Islamic patterns is achieved by studying the style related to a certain period of history, understanding the components and the drawing of the pattern, and lastly, using the available tools to generate the pattern.
- Materials and weathering factors influence the Islamic patterns that can be employed in the future.
- Form finding and animation are techniques related to three-dimensional patterns and are applied with the help of particular three-dimensional software.
- The Grasshopper plug-in is effective in the study of Islamic architecture and IGPs, in terms of rule-based design as Islamic architecture follows a set of strict rules.
- IGPs have mathematical relationships and are recommended to be added to the study of architecture.

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