Digital Girih, A Digital Interpretation Of Islamic Architecture

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Abstract

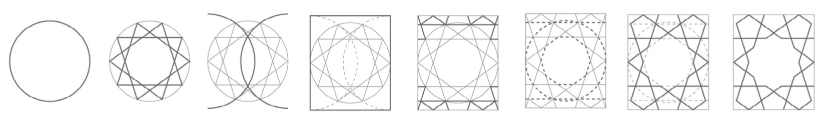
The relation between texture, pattern and massing is a fundamental question in architecture. Classical architecture, as Leon Battista Alberti states in De Re Aedificatoria, Book VI, Chapter 2, is developed through massing and structure first; texture is added afterwards to give the bold massing and structure beauty [1]. This hierarchy has of course been challenged throughout architecture history. This paper will provide a different thinking of the relationship of massing and texture in Islamic Architecture from a digital point of view. An analysis of Islamic patterns challenged this relationship in Islamic architecture. Digital design and fabrication methods for a series of studies and an installation were used to respond to the findings of the analysis.

1. TEXTURE VERUS MASSING

Kai Strehlke and Russell Loveridge underline in "the Redefinition of Ornament" the paradigm shift in the architectural discourse from modern architecture to digital architecture. In modern architecture ornament was eliminated through the replacement of craftsmanship by mass production, whereas today's Computer Aided Architectural Design (CAAD) and Computer Aided Architectural Manufacturing (CAAM) allow the re-introduction of ornamentation and variation [2]. Ernst Gombrich questions the "horror vacui" in *The Sense of Order* as the motivation for the decorator to fill any void space with ornate patterning. Instead he sees this urge as an "amor infiniti," the love of the infinite, which fills void space successively with more complex geometry. This process always works within a frame or some kind of predefined boundary. Therefore, patternmaking is dependent on a given structure. Gombrich calls this principle "graded complication," where one boundary after another gets increasing definition and more complexity in a step-by-step procedure [3]. Rather than using the "decorator's approach" of a progressive filling in of a pattern into a given boundary Islamic architecture suggests a different relationship between texture, structure and massing.

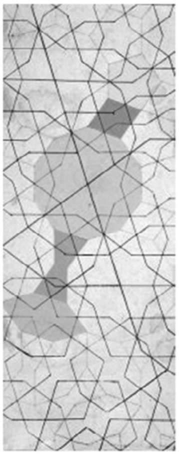
2. ISLAMIC ARCHITECTURE AS NESTED PATTERNS

Most modern literature such as Salma Samar Damluji's book *Islamic Art and Architecture: The System of Geometric Design* argues that Islamic patterns are constructed by using ruler and compass and by repeating rectangular pattern units. The example in Figure 1 shows how one unit is constructed starting with a circle, dividing it, intersecting it and extruding and trimming its secants. The resulting tile can be duplicated over an infinite large plane.



► Figure 1: Islamic pattern constructed using a rectangular tiling system.

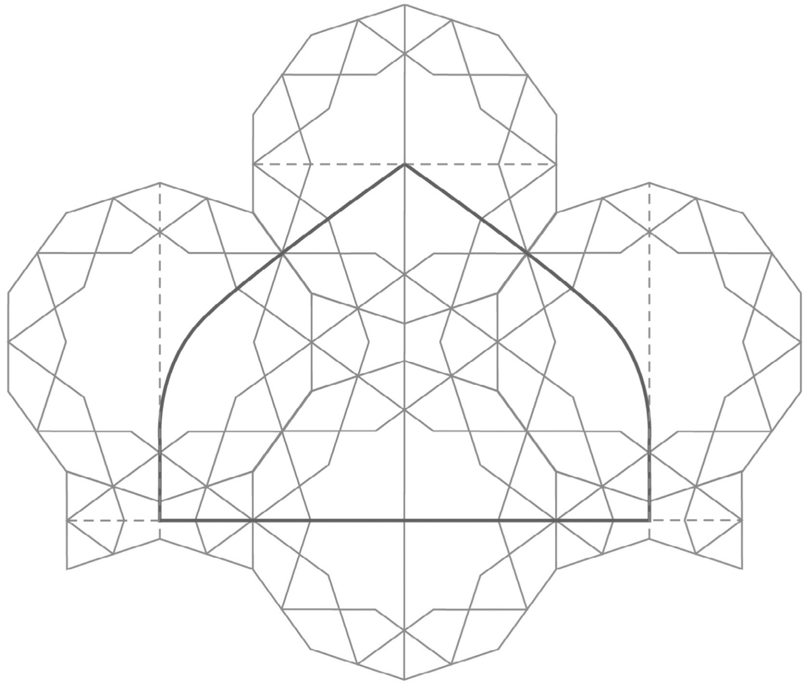
This technique can be used to break down most Islamic patterns except non-periodic and a-periodic patterns. Patterns that do not repeat in any linear direction are called non-periodic. If a non-periodic pattern cannot be rearranged into a periodic pattern it is also a-periodic. Such patterns, as found on the wall surfaces of Gunbad-i Kabud a tomb in Maragha, Iran have challenged mathematicians and scientists in the 19th and 20th century. Most studies in a-periodic patterns in medieval Islamic architecture suggest that they were constructed by drafting a network of zigzagging lines, or strap work, with the use of a compass and straightedge. In 2007 Paul Steinhard and Peter Lu, two physicists from Princeton University discovered a tiling system to construct theses a-periodic patterns. Instead of rectangular tiles Steinhard and Lu are claiming that Islamic patterns were constructed by using a set of tiles of five different shapes, a bowtie shape, a rhombus, a pentagon, an elongated hexagon and a decagon. Figure 2 shows how this set of tiles often referred to as Girih tiles can be used to rationalize the pattern on the wall surfaces of the Gunbad-i Kabud tomb.



◀ Figure 2: Girih pattern at a wall surfaces at the Gunbad-i Kabud in Maragha, Iran (c. 1197 AD) and the five tiles: a bowtie shape, a rhombus, a pentagon, an elongated hexagon and a decagon [4].

The word Girih comes from Persian language and means interlock, suggesting an assembly process of different tiles similar to a jigsaw puzzle. Systems of such extraordinarily mathematical complexity were introduced to the western world much later by Roger Penrose, who discovered Quasi-crystal tiling systems in the 1970s [5]. Patterns in Islamic architecture generated by Girih tiles would suggest that quasi-crystalline systems were already familiar to Islamic architecture in the 15th century. They are tiling systems that grow unpredictably according to a specific set of rules. Quasi-crystal tiling systems are made by fitting a set of units together in a predictable way, but unlike the tiles on a typical floor, the pattern does not regularly repeat. The Girih tiling system can also be nested within itself. This may further suggest that the pattern is not only used in different scale as a texture for a façade, but the outline of the façade itself is a trace of a pattern at a much larger scale. If that was the case, then the pattern might have been first and massing and space was extruded from the pattern. We found that floor plans and elevations can indeed be derived from a pattern logic that was then extruded vertically and horizontally to generate the form and space of the building. It could therefore be claimed that pattern or texture in Islamic architecture was first and massing and structure came after reversing Alberti's hierarchy.

► Figure 3: Analysis and reconstruction of a typical Islamic elevation based on Girih patters.

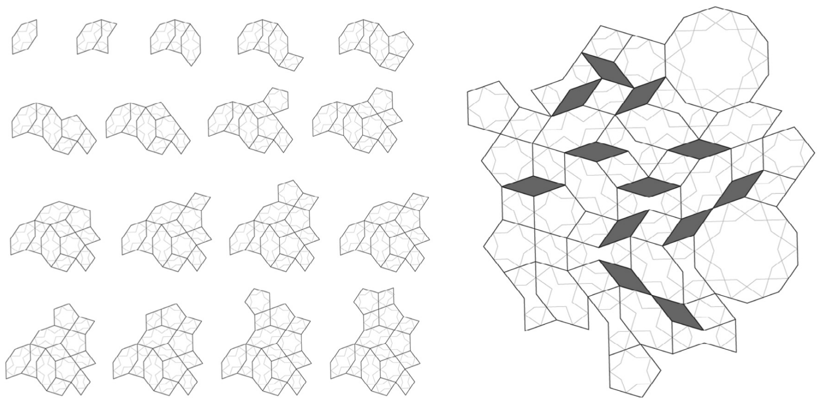


3. A DIGITAL DESIGN APPROACH

The difference between bottom-up and top-down methodologies in biology and Artificial Life is described by Langton as the following: "Biology has traditionally started at the top, viewing a living organism as a complex biochemical machine, and working analytically downwards from there through organs, tissues, cells, organelles, membranes, and finally molecules in its pursuit of the mechanisms of life" [6]. Artificial Life starts at the bottom, viewing an organism as a large population of simple machines, and works upwards synthetically from there, constructing large aggregates of simple, rule governed objects which interact with one another nonlinearly in the support of lifelike, global dynamics. The key concept in Artificial Life is emergent behavior. The same concept of emergent behavior applies to quasi-crystalline growth such as attempted by Girih tiling.

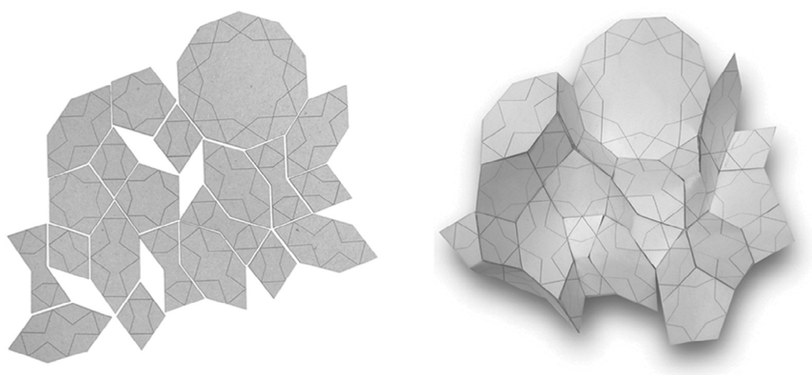
At this point of the project Islamic patterns and its relationship to architectural space were more closely examined. Rather than extruding the geometry from a pattern we were exploring strategies to develop form and space by manipulating the pattern itself. Through a bottom-up methodology the "Digital Girih Project" intends to question a stereo metric, top-down methodology. The intent of this study was to test digital design and fabrication tools to allow for an alternative approach in the generation of form and space from patterns. Such as project would not start with a giving volume but instead be developed through the interaction of parts. The

Digital Girih project started by experimenting and re-writing of rules used for Girih tiling sytems to create a 3dimensional tiling system. Paper models were used to quickly test and approximate this process. Grasshopper was used to create a precise rule based method to develop 3d patterns.



◀ Figure 4: Girih pattern in 2d and manipulated rules in the Girih tiling marked in red.

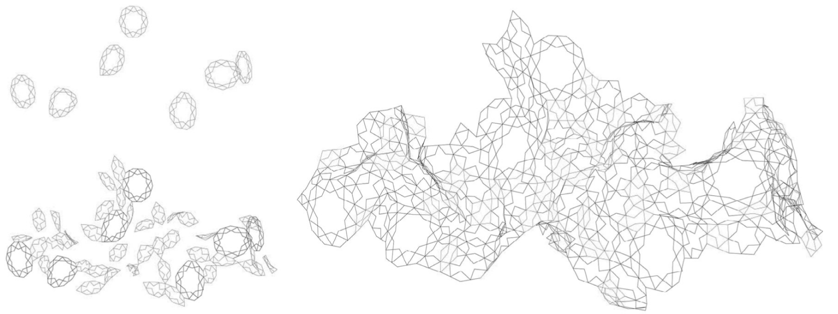
Different strategies were used to reconstruct existing Islamic patterns and then to generate new pattern variations of periodic and a-periodic patterns through analogue model making. A matching rule was developed, that introduced a sixth polygonal shape in the form of an acute rhombus, which created a gap in the pattern that was then closed. The gaps, rhombuses with interior angles of 36° and 144°, emerge in Girih patterns, if no tile meets a matching side with another of its same type. This rule allowed predicting the location and density of gaps. Figure 5 shows how a 3-dimensional undulating surface pattern was generated by closing all the gaps of a 2-dimentional pattern.



◀ Figure 5: Developing a 3d tiling system from a 2d pattern.

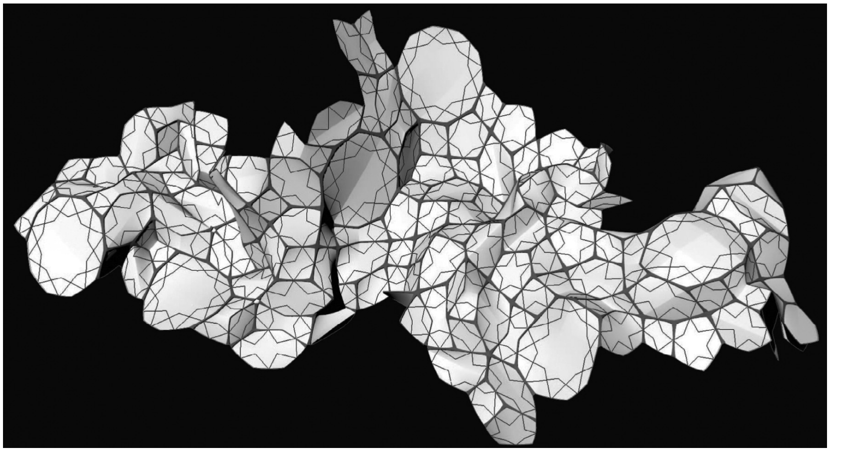
Flatness and curvature can be controlled by closing or pinching the gaps or by filling the gaps with an additional tile, differentiation in shape can be controlled by modifying the use of these matching rules. The Girih system is a transformative system that can switch its state through different combinations of its five parts. Closing the gaps introduced 3-dimensional deformation to this system. The Digital Girih Project shows how the rules of the pattern can be manipulated to generating 2.5d conditions and 3d forms form 2d patterns.

► Figure 6: Scripted Girih lines.

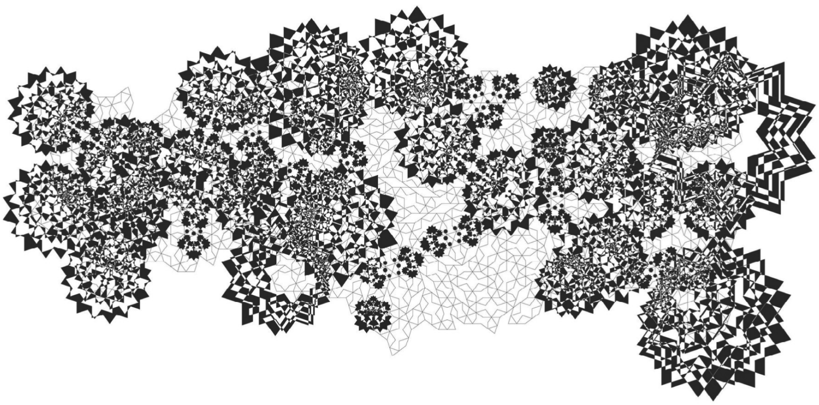


Paper was preliminarily used as a material for the tiles. Closing or taping the edges of the tiles allowed the surface to bend. This model and its properties was the regenerated digitally. Grasshopper software was used to generate a precise model. Figure 6 shows the model that was generated by creating a script for the Girih pattern. A separate script was developed for each of the five different tiles following similar principles. The script first finds the midpoints of all the outlines of the tiles; it then connects all the midpoints and projects the midpoints back on the surface; the projected points and lines are used to define planes that are intersected with the curved tile surface; these intersecting lines are finally extracted as the resultant curvilinear Girih lines. Figure 7 shows a possible configuration of the pattern system that was used as prototype and further studies.

► Figure 7: Digital model that was used for further material explorations.



Similar to Islamic patterns the Girih lines can be used as a substructure for secondary patterns. This potential use of Girih lines as a scaffolding for new patterns was tested in different examples. This process of generating new patterns that are in a parametric relationship to the curvilinear Girih lines is open ended. Figure 8 shows one example. Here the different distances between the Girih tiles were used as input for a function to size dodecagons that populated all points of all decagon and pentagon of Girih tiles defining the surface.

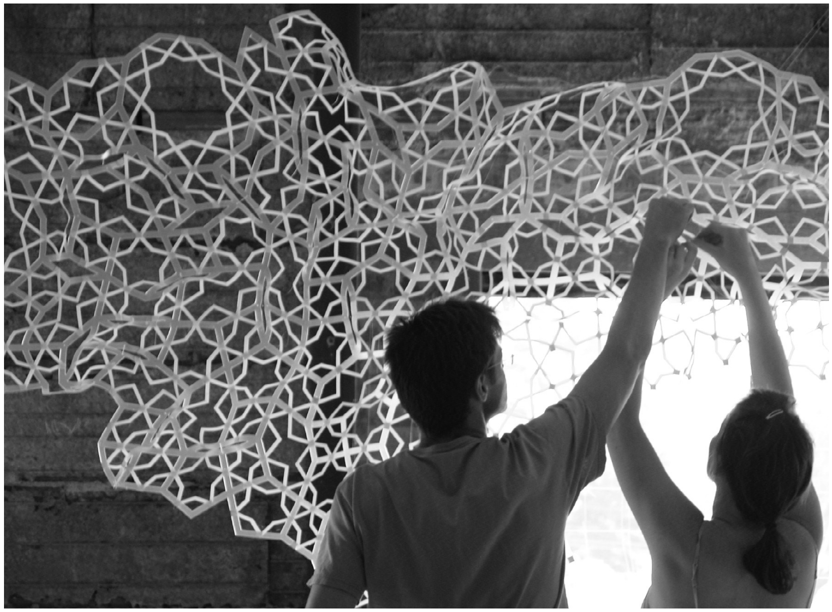


◄ Figure 8: A possible secondary pattern in a parametric relationship to the Girih lines.

4. DIGITAL FABRICATION APPROACH

Different strategies have been explored to manage the complexity of the 3dimensional enclosure from a digital fabrication point of view. Different materials were combined with different digital fabrication methods. The materials explored were: paper, plastics and wood. The fabrication methods explored were: Laser Cutting and CNC. The goal was to develop physical models and prototypes for a self-supporting enclosure. In the first model we constructed the tiles as surfaces that were laser cut from paper. The flexibility of the paper allowed for tiles with single curvature. In a small-scale model the different curved tiles were simply taped together. In real scale application the material might be different, but still bendable. The tape might be translated into flanges that could be glued or bolted together. The advantages of this strategy is a relatively thin material that with increasing complexity of surface transformation leads to structural performance. Picture 9 shows the second investigation. Here the Girih lines and tile borders were constructed as two separate interacting line meshes. The mesh was built from two different types of polyethylene, PETG. A softer PETG was used to construct the tile edges. A more rigid PETG was used to construct the Girih lines. The 2 meshes were first built flat. A nylon string was then used to close the openings, which caused the surface to fall into a

3 dimensional geometry. The more rigid Girih lines transformed the tiles locally, which contributed to the stiffness of the surface. The entire surface measured approximately 14' x 7'.



► Figure 9: Installation using different variations of PETG.

Building the same structure at a much larger scale, the PETG might be replaced by aluminum or metal profiles, flexible but rigid enough to allow for occupy able space. Such a model might also suggest a structure that is cladded after. In a third investigation the tiles were milled from laminating layers of MDF boards. The double curved surfaces were machined with a 1/2" bit first and a 1/4" bit to create the final, more resolute texture of the surface. The Girih lines were added as an additional machine pass that followed the double curved surfaces. With the limitations of a five axes machine the upper side of the tile was machined first. Still connected to an outer frame allowed for the tile to be rotated in order to machine the under side. Using wood as material and milling as technique allowed for a system of tiles that laminated on the edges of the tiles or using bolt connections.

5. CONCLUSION

The Digital Girih project was built based on Peter J. Lu's and Paul J. Steinhardt's research and findings on a-periodic patterns in medieval Islamic Architecture, published in *Science* 2007 [4]. The Girih project points out an intense relationship between texture and massing in Islamic architecture. It recognizes the way space is generated through extrusion as an additional operation necessary to generate space, but alien to the pattern logic. The research is describing a digital design and fabrication process that suggests generated space and enclosure from the pattern logic itself. Such a process is dependent on generative digital design tools such as Grasshopper as well as digital fabrication tools such as CNC fabrication technology.

The process can be seen as a continuation of a philosophy that we found in Islamic architecture that has been enabled through digital and generative tools such as scripting and digital fabrication technology. The Girih Project is a quasi-crystalline system that intensifies the relation of pattern and volume. The volume in this project emerges from changing matching rules within a pattern. In that way it is a bottom-up process. Depending on the matching rules used for the pattern generation, different formal behaviors could be achieved.

The Girih pattern was then used as a "Dynamei," Aristotle's concept of potentiality. Through execution of rules, the surface fell into a 3- dimensional form to reach "Entelecheia," Aristotle's concept of actuality.

Starting with individual parts and a set of pre-defined rules of local configurations, the general design approach can be characterized as a bottom-up process. One might say that the 3-dimensionality of the surface is an emergent property of a bottom-up system. It can also be described with Goethe's distinction between "Gestalt," structured form which refers to something that is already formed and "Bildung," formation which changes structured form in an ongoing process [7].

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References

[1] Alberti, L. B., *De re aedificatoria, On The Art of Building in Ten Books*, (translated by Joseph Rykwert, Neil Leach, and Robert Tavernor), MIT Press, Cambridge, Massachusetts, 1988.

[2] Strehlke K. and Loverridge, R., The Redefinition of Ornament, in Maartens, B. and Brown, A. eds. *Computer Aided Architectural Design Futures 2005 [Proceedings of the 11th International Conference On Computer Aided Architectural Design Futures held at the Vienna University of Technology on June 20-25, 2005]*, Springer, Dordrecht, The Netherlands, 2005, 373-382.

[3] Gombrich E., *The Sense of Order – A Study iIn The Psychology of Decorative Art*, Phaidon Press Limited, London, 1979.

[4] Lu J. P. and Steinhardt, J. P., *Decagonal and Quasi-Crystalline, Tilings in Medieval Islamic Architecture*, Science, 2007, 23, 1106-1110.

[5] Penrose R, *Set of Tiles for Covering a Surface*, US Patent 4133152, 1976.

[6] Langton G. C., *Artificial Life*, MIT Press, Cambridge, Massachusetts, 1997.

[7] Goethe J. W., *Goethes Morphologische Schriften, (Ausgewählt und eingeleitet von W. Troll)*, Diederichs Verlag, Jena, 1926.

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