From texture to volume an investigation in quasi-crystalline systems

Daniel Baerlecken
Visiting Assistant Professor, Dipl. Ing. (hons)
College of Architecture, Georgia Institute of Technology, 247 4th St./Atlanta, GA 30332-0155, Daniel.Baerlecken@coa.gatech.edu

Gernot Riether
Assistant Professor, Dipl. Ing. MS
College of Architecture, Georgia Institute of Technology, 247 4th St./Atlanta, GA 30332-0155, Gernot.Riether@coa.gatech.edu

***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. Only the ornamentation adds pulcritudo to the raw structure and massing. Rather than starting with a volume and applying texture afterwards, the Digital Girih project started with textural operations that informed the overall volume later. The stereometric, top-down methodology is questioned through the bottom-up methodology of the Girih project. Girih lines of traditional Islamic patterns were used as a starting point. The aspect of 3-dimensionality was developed analogue as well as digital, using the deformability of different materials at various scales and digital construction techniques as parameters. The flexibility within the Girih rules allowed the system to adapt to different tasks and situations and to react to different conditions between 2- and 3- dimensionality. The project in that way explored a bottom-up process of form generation. This paper will describe the process of the project and explain the necessity of digital tools, such as Grasshopper and Rhino, and fabrication tools, such as laser cutter and CNC fabrication technology, that were essential for this process.*

***Keywords.** Generative Design, Parametric Design, Tessellation, Form Finding, Scripting.*

massing-structure-texture vs. texture-structure-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. In this way modern architecture's mass production is replaced with mass customization. Thus digital architecture can continue where Art Deco left off a hundred years ago.

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, within some kind of predefined boundary. Therefore, patternmaking is dependent on a given structure. E. Gombrich calls this principle "graded complication", where one boundary after another gets increasing definition and more complexity in a step-by-step procedure.

Rather than using the decorator's approach of a progressive filling in of a pattern into a given boundary, the Digital Girih project was based on the use of a pattern system that is capable of generating form and defining its own boundaries according to its own rules. After researching aperiodic 2-dimensional patterns in Islamic architecture, and Girih patterns in particular, a set of rules was implemented to enable the 2-dimensional system to become 3-dimensional. This was achieved by diverging from the original rules and introducing a new shape or gap throughout the pattern, which was able to transform a flat pattern into a three-dimensional geometry by closing the gaps of the surface. Depending on the location of these gaps, which resulted from the matching rules used for the pattern generation, different formal behaviours could be achieved. The Girih pattern was used as a "Dynamei", Aristotle's concept of potentiality. Through execution of the 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.

Islamic Girih Patterns:

Investigating in pattern formations that can be broken down in geometric principles the preliminary research focused on Islamic patterns. For that project Girih patterns were investigated further due to their transformative behaviour. Patterns in Islamic architecture, designed for ornate tiled surfaces had become extraordinarily complex by the 15th century. These non-periodic and a-periodic patterns of lines on the tiled surfaces are often referred to as Girih lines and have challenged mathematicians and scientists in the 19th and 20th century. 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 aperiodic. Previous studies in aperiodic 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.

Peter J. Lu of Harvard University and Paul J. Steinhardt of Princeton University are suggesting an entirely different way to conceptualize aperiodic patterns in Islamic architecture. As cosmologists looking for quasi-crystals in nature, they found examples of quasi-crystalline Islamic tiling in medieval Islamic buildings (figure 1). Quasi-crystal tiling systems were introduced to the western world in the 70s by Roger Penrose. 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. Peter J. Lu and Paul J. Steinhardt were the first, who made a connection between quasi-crystalline tiling systems and Islamic architecture. They suggest, that Girih patterns in Islamic architecture were produced by using a small set of decorated polygonal tiles, which they call "Girih tiles." Girih pattern systems are generated by a set of five tiles: a bowtie shape, a rhombus, a pentagon, an elongated hexagon and a decagon. In a paper published in “Science” 2007 Lu and Steinhardt prove, that these line patterns were constructed as decorated tessellations using a set of these five tile types, which they call “Girih tiles” (figure 1) . The Digital Girih project was built on Peter J. Lu’s and Paul J. Steinhardt’s research and findings on aperiodic patterns in medieval Islamic Architecture, published in “Science” 2007 (1).

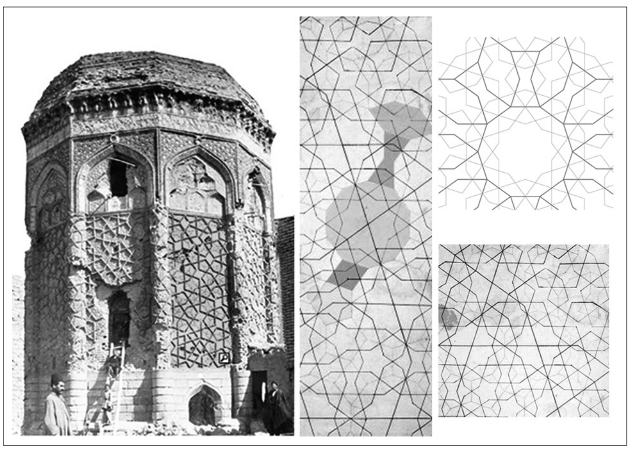

Figure 1. Girih pattern , Maragha, Iran (c. 1197 AD).

Design Process:

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 moleculces in its pursuit of the mechanisms of life. 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 behaviour. “The same concept of emergent behaviour applies to quasi-crystalline growth such as that attempted by the Girih tiling.

Laser cutting the five polygonal Girih tiles allowed us to start experimenting with different matching rules to generate different aperiodic and periodic 2-dimensional Girih patterns. This strategy was first used to reconstruct existing Islamic patterns and then to generate new pattern variations of periodic and aperiodic patterns (figure 1). A matching rule was developed, that introduced a sixth polygonal shape in the form of an acute rhombus, which acted like a crack in the pattern. These cracks, 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. The rule allowed prediction of the location and density of the cracks. By closing all the cracks in the 2-dimentional pattern, a 3-dimensional undulating surface pattern was generated.

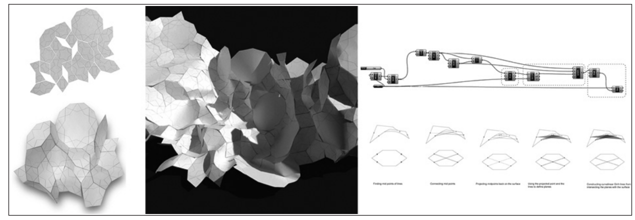

Figure 2: Paper models and script.

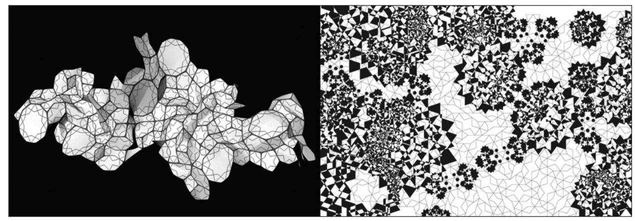

Figure 3: digital model and secondary pattern.

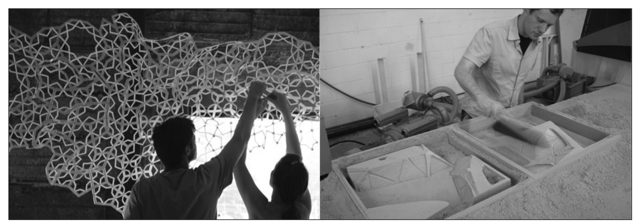

Figure 4: laser cut model and prototype.

The Digital Girih project has the potentiality of realizing many actual conditions from 2d over 2.5d to a multitude of 3d forms. Flatness can be achieved 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 constantly switches its state through its five parts. Closing the gaps introduced 3-dimensional deformation to this system (figure 2).

Paper was preliminarily used as a material for the tiles. Closing or taping the edges of the tiles allowed the surface and joints to bend. The physical model- made of paper - was scanned and digitally reconstructed. Every intersection point of the physical model was digitized. In order to keep track of the individual points each of the five shape types were scanned separately and organized on different layers within the digital file. The outline of the individual shapes were grouped in sets of 4 lines and then lofted to create curved 3-dimensional surfaces. This digital representation of the physical model was used as a scaffolding to reconstruct the Girih pattern digitally (figure 2).

Grasshopper software was used to generate a precise model by creating a script for the Girih pattern (figure 2). 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 3).

Similar to Islamic patterns the Girih lines can be used as a substructure for secondary patterns. In this example the different distances between the Girih tiles that were used as input for a function to size dodecagons that populated all points of all decagon and pentagon Girih tile shapes of the surface.

The final step of the project was the challenge of developing a prototype for a surface at the scale of spatial enclosure. To materialize the surface effects at a larger scale the Girih lines were in the first attempt laser cut from polypropylene (figure 4).

To develop a self-supporting enclosure the surface was in a second attempt milled from MDF boards. The entire surface was tiled in rectangular modules that responded to the size of the MDF boards. Each module was built by laminating layers of MDF boards that were then milled to the surface curvature of the digital model. 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 (figure 4).

Conclusion:

The Girih tiling system, a medieval pattern making technique, has been utilized and transformed in order to demonstrate the potential of aperiodic patterns to create 3-dimensional forms on its own that are as infinite and complex as the original pattern itself. Recognizing this potential an inversion of the classical process in architecture from Massing-Structure-Texture to Texture-Structure-Massing has been suggested as a consequence.

Credits

Project Team: Emily Finau, Josef Fischer, James Ford, Azzam Issa and Laura Wagner

References

Alberti, Leon Battista. De re aedificatoria, On the art of building in ten books. (translated by Joseph Rykwert, Neil Leach, and Robert Tavernor), Cambridge, Mass.: MIT Press, 1988

Langton G. Christopher, Artificial Life. In Christopher G. Langton ed. Artificial Life, Addison Wesley, 1988)

Gombrich Ernst, The sense of order – A study in the psychology of decorative art, Phaidon Press Limited, London, 1979

v. Goethe Johann W., Goethes Morphologische Schriften. Ausgewählt und eingeleitet von W. Troll., Diederichs Verlag, Jena

Kai, Strehlke and Russell, Loverridge , The Redefinition of Ornament, Computer Aided Architectural Design Futures 2005 [Proceedings of the 11th International Conference on Computer Aided Architectural Design Futures] Vienna (Austria) 20–22 June 2005, pp. 373-382, 2005

Lu, J. Peter, Steinhardt, J. Paul, Decagonal and Quasi-Crystalline, Tilings in Medieval Islamic Architecture, VOL 315 Science, p. 1106 – 1110, 2007