CeramiSKIN

Aperiodic Tiling using Biophilic Data in Ceramic Cladding Systems

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Abstract. ceramiSKIN is the result of an inter-disciplinary investigation between an architect and a ceramics artist. We are exploring natural orders as generators for aperiodic (non-repeating) tiling systems in architectural ceramic cladding systems. Of particular interest are the possibilities offered by digital imaging of organic materials [at various scales from 1:1 to 1:1 nanometer] as a means of form generation. After scanning, shapes are computationally deformed to create a range of biophilic effects promulgated through unique large scale ceramic cladding systems constructed using digital fabrication techniques.

Keywords: Ceramic cladding systems: biophilia in architecture; digital design; digital fabrication; mass-customization.

Biophilic Inquiry

Edward O. Wilson, the renowned Harvard biologist, commenting on the natural world uses the term biophilia to describe “the connections that human beings subconsciously seek with the rest of life.” (1984, 1993). Renewed inquiry in this area by Stephen Kellert, Judith Heerwagen, and Martin Mador (2008) identifies early research supporting health benefits resulting from biophilic environments. Going beyond this observation is James Wise, an environmental psychologist from Washington State University, who suggests that it is the fractal patterns in nature that are primarily responsible for beneficial human responses. Further, Wise believes that these natural patterns can be mathematically reproduced with the same beneficial affects as those in nature. (2006). These observations provoked two questions:

a. Since natural orders eschew rigid manifold geometries in favor of plastic shapes with compound curvature, is it possible to combine analytical data with digital fabrication techniques to produce mass-customized ceramics?
b. If biophilic forms do indeed foster beneficial responses in humans, might large-scale ceramic cladding be suitable for communicating both structural and ornamental effects?

A Century of Biophilia

Natural structures received much attention in architectural and engineering circles during the past century following publication of ‘On Growth and Form’,
by D’Arcy Wentworth Thompson in 1917. Numerous experiments and structures related to natural forms were explored involving such things as soap bubbles (Matzke, 1945; Lewis, 1949), thin shell structures (Pier Luigi Nervi, 1891-1979), and polyhedrons (Buckminster Fuller, 1895-1983); however the tools for analysis then, as compared to today, were somewhat crude and speculative. More recent works on the topic are found by Peter Pearce (1980) who published Structure in Nature is a Strategy for Design. The venerable Frei Otto (1995) wrote Finding Form: Towards an Architecture of the Minimal, suggesting continued relevance of organic matter to designers.

In light of increasingly sophisticated data gathering techniques in the scientific community, and improved ability to translate this information directly into three-dimensions through digital modeling and digital fabrication techniques, continued exploration of biophilic systems offers significant possibilities for designers.

**ceramiSKIN Initiative**

Biophilic matter in architectural ceramic cladding suggests large numbers of similar, but not identical pieces. This presents a challenge to traditional methods for making ceramics, since molds are often used to create multiple units which are then aggregated in a ‘kit of parts’ fashion. Our interest is in exploring the possibility of making entirely unique parts in a mass-customized fashion, using digital visualization and digital fabrication strategies.

Regarding form generation we have focused upon capturing existing natural matter and computationally generated fluids models. We have utilized several different data gathering techniques (laser-scaning, particle physics generation, and electron microscopy) combined with various ceramic construction techniques (extrusion, slip-casting, and hand-moulding). At this stage the work is intentionally wide-ranging and of various scales favoring breadth to better inform future efforts regarding
At the time of writing, we are engaged in the first four-week phase of a juried thirteen-week residency pertaining to architectural ceramics at the European Ceramic Work Center in The Netherlands. The mission of the EKWC is to provide a highly experimental ceramic research facility with very little standardization. This allows participants to undertake highly customized work providing significant advantages over a traditional factory, in which mechanized processes often limit the range of possible forms. The EKWC has also developed innovative methods using fired and ground clays, as well as fiber binders to reduce shrinkage and deformation, as well as increase strength and stability. (Reijnders, 2005).

Due to the uniqueness of each of our pieces, it is important for us to be able to produce complex multi-part molds quickly and inexpensively that are capable of providing detail and relief, as well as permitting precision fitting of tile units. Point cloud data from lasercanning or particle physics generation permit the creation of interlocking tile systems not only as a surface of two-dimensional polygons but also as three-dimensional polyhedrons. One promising solution for creating a large number of unique molds for slip casting is using CNC milling of mother molds—a mold of a mold. The sections of a mold can be made quickly by pouring plaster into the negative form of a mold section directly CNC milled out of a foam block.

**Lasercanning of Lily Petal and Slip Casting**

Our first experiment was to lasercan a lily petal and produce units using the slip casting process (wherein a porcelain slurry is poured into a plaster mold) which then ‘congeals’ onto the walls of the mold through moisture migration. These pieces are bisqued (fired to create strength) then glazed. The lasercan data was manipulated in Geomagic (a surface analysis tool used in the aerospace industry) to reduce the surface curvature to two percent of the original in order to create a surface description comprised of facetted shapes. It is worth noting that this
faceting process was done solely for formal intent and was not necessary for the process to be successful. The digital model was then sliced into sections in Maya, with foam molds CNC milled in sections, then cast in plaster to permit slip casting of smaller elements. Glazing experiments followed. The entire assembly was about three feet long, with each slip cast unit about one foot long. A question that was raised is whether plaster molds may be directly CNC milled, thus replacing foam milling, then plaster casting.

Benefits: A high degree of surface relief due to the homogeneity of the mixture, smooth glazing effects, and fairly precise fit between units.

Challenges: Relatively low strength of thin-walled porcelain, small unit size, time spent creating plaster casts for molds that may be used only once.

**Digital Fluid Simulation and Hand Moulding**

Our second experiment (currently in progress) is based upon the particle physics engine RealFlow used to create fluid effects in the film industry. We created a shape, then converted the point cloud data into flat triangular planes in Rhinoceros, offsetting side-walls to create hexagonal units. The data was digitally unfolded, plotted, then used for templates to build plywood molds with each cell measuring almost three feet across. A very stiff mixture of clay was rolled into flat sheets one and a half centimeters thick, then hand pressed into the molds. The units
may be bolted together to serve as a free-standing structure, or fastened to a wall to create a waterproof membrane if grout is installed between units.

Benefits: Strength of assembly, ability to serve as cladding and freestanding sculptural object, ability to fasten together and to sub-assemblies.

Challenges: The primary challenge was an unexpected consequence of the offsetting process in Rhino which created twisted planes in the sidewalls. Triangulating these sidewalls will correct this, but doubles the effort to construct them. Other consequences include: residual seaming between clay sheets and a rough texture. These attributes we found desirable, but others may not share this preference.

Penrose Patterning and Extrusion Process

Our third experiment (which we are in the very early stages of) is based upon the use of Penrose geometries inspired by the research by physicist and Harvard doctoral student Peter Lu into Girih tiles. He has described a conceptual breakthrough that occurred around 1200CE when tile patterns were ‘re-conceived as tessellations of a special set of equilateral polygons’ in Islamic architecture. This allowed for precise patterns to be developed over large surfaces using aperiodic Penrose patterning.

Using this pattern, our intention is to construct extruded clay forms using these five different geometries to create aperiodic stacking of units to construct screen walls for arid climates. Similar to traditional techniques, these walls would permit shading, light filtration; however, because the units
are spaced apart water could be introduced into the interstitial spaces to enhance passive cooling effects. Steel dies for the extrusion machine (‘pug mill’) will be lasercut, then clay will be extruded through them to form the desired shapes. The Penrose geometries will be intersected with the lily petal scan, then using an unfolding process in paper, the ends will be trimmed to replicate the curvature of the lily petal scan. As such, when the units are aggregated, the surface of the lily petal will be evident at the open ends of the extrusions. Additionally, the interiors may be glazed for color effect and light diffusion, while the unglazed exterior will permit absorption and retention of water for cooling.

Projected Benefits: Small units easily transported and assembled, light filtration and cooling, variety of patterns capable.

Projected Challenges: Surface effects may be too subtle. Orthogonal side and corner conditions will require modifications prior to firing. Interstitial tabs need to be protected until firing.

Collaboration: Design versus Art

While sculpture and architecture may be viewed by those outside of these fields as similar disciplines, each area contains very different embedded logics. Collaboration between these fields raises various questions regarding issues related to: craft, scale, function, meaning, value, and decision-making to name but a few. In The Sciences of the Artificial, Herb Simon (1969) writes, “Design is defined as any action that transforms an existing condition into a preferred one.” Compare this attitude with that of
Joseph Beuys’ comment, “To make people free is the aim of art, therefore art for me is the science of freedom.” The variance in these statements underscores the range of deviation between these two creative disciplines. We have found that mediating these attitudes (when possible) offers potential to define new territory in both fields; suggesting results that are less normative to either discipline, but ‘hybridized’ to some degree offering potential for new insights regarding form, function, and methodology.

**Figure 17**
Girih tile analysis (from Lu, 2007)

**Figure 18**
Gurbad-i Kabud, Maragha, Iran (from Lu, 2007)

**Figure 19**
Penrose extrusions: by shape

**Figure 20**
Penrose extrusions: aggregated

**Summary**

The natural sciences have utilized digital techniques less for purposes of novelty, but rather with a teleological emphasis on analysis and comprehension. Recent discoveries in the sciences offer potential to further extend at least a century of architectural and engineering investigations in the area of natural forms, with far greater specificity. Due to the increased clarity of recent scientific analyses—and resulting data which is often usable in design software
environments—natural investigations seem worthy of more attention in design spheres than they are currently receiving.

The somewhat autocratic nature of design has generated various positions regarding agency in attempts to categorize, comprehend, and create novel forms. This preoccupation with agency among theorists attenuates other meaningful explorations outside of architecture which may offer significant opportunities and benefits for designers and users alike—such as biophilic inquiry. Natural forms in the design milieu may offer insight into many areas, such as structural optimization, complexity, value, and perhaps even offer health benefits. Further, our research into ceramic cladding systems suggests promise for digital processes in fabrication to better enable mass-customized solutions that explore biophilic concerns.

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**References**


