CeramiSKIN
Biophilic Topological Potentials for Microscopic and Macroscopic Data in Ceramic Cladding

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Abstract:
CeramiSKIN is an inter-disciplinary investigation examining recursive patterns found in organic matter. Through the use of digital capture and translation techniques, these biophilic systems may serve as topological generators for structural and ornamental consequences well-suited to mass-customizable ceramic cladding systems for architecture. Digital information is acquired through laser scanning and confocal electron microscopy, then deformed using particle physics engines and parametric transformations to create a range of effects promulgated through digital fabrication techniques.

This inquiry is primarily concerned with two questions:

- Is it possible that natural systems may be digitally captured and translated into biophilic structural forms and/or ornamental effects that may foster beneficial responses in humans?
- Since natural orders eschew rigid manifold geometries in favor of compound plastic shapes, is it possible to fabricate mass-customized, large-scale biophilic ceramic cladding from organic digital data?

1. Critical Nature of Nature:
A recent article by Rivka Oxman convincingly argues that Digital Architectural Design (DAD) is substantively different than Computer Aided Design (CAD) due to new ways of design conceptualization and the possibilities inherent in versioning. She summarizes DAD as being comprised of the following models: formation, generative, and performance. ¹

CeramiSKIN is primarily concerned with Oxman’s generative model using biophilic data. Specifically, we are exploring the possibilities inherent in the study of natural systems enabled by increasingly advanced and accurate analysis within the scientific community. This endeavor intends to explore both structural and ornamental effects that can be manipulated in a three dimensional design environment to create digitally fabricated ceramic forms. Data will be gathered at both microscopic and macroscopic levels as generative information for formal systems in architectural cladding.

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 1917². Numerous experiments and structures related to natural forms were explored involving such things as soap bubbles (Matzke, 1945; Lewis, 1949)³, thin shell structures (Pier Luigi Nervi, 1891-1979), and polyhedrons

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(Buckminster Fuller, 1895-1983); however the tools for analysis (compared to today) were somewhat crude and speculative. Among other written works on the topic, Peter Pearce published *Structure in Nature is a Strategy for Design* in 1980, while *Finding Form: Towards an Architecture of the Minimal* was written by the venerable Frei Otto in 1995, suggesting continued relevance for designers. In light of increasingly sophisticated data gathering techniques in the scientific community, as well as the ability to translate this information directly into three-dimensional forms, *natural systems* and *biophilic exploration* offer significant possibilities for a number of aspects of design, from structure to ornament.

![Figure 1. Nassellarian Skeleton, “On Growth and Form”, D Arcy Wentworth Thompson](image)

**1.1. Digital Design—Novelty, Discovery, and Possibility:**

The mediated nature of digital design and the complexity of current formal explorations has generated various positions regarding agency in attempts to categorize, comprehend, and create novel forms. The preoccupation with agency attenuates other meaningful explorations outside of architecture which offer significant opportunities for designers as well as potential benefits for users. Thus, the current emphasis on novelty may be somewhat limiting as it partially veils numerous other inquiries that may offer insight into such aspects as structural optimization, durability, engagement, and possibly even value, to name a few.

For example, the sciences have utilized digital techniques less for purposes of novelty, but rather with a teleological emphasis on analysis and comprehension. Resulting discoveries in the sciences offer an extension of at least a century of architectural and engineering investigations in this area, with far greater knowledge today. Due to the increased clarity of recent scientific analyses and the production of digitally manipulatable data these investigations are worthy of more attention in architectural spheres than they are currently receiving.

Current digital investigations divide themselves into various didactic camps, but in reality these categories resist tidy characterization due to varying degrees of overlap. Thus, they are often employed in a less exclusive fashion than they are portrayed. Oxman’s categories are well-defined, but we respectfully propose alternative labels and one additional category that might more accurately suggest the processes at work:
1) **Willful** (in lieu of *Formation*): Complex shapes enabled by digital tools through conscious parametric manipulation. Highly responsive to cultural trends as commented on by Sylvia Lavin.⁶

2) **Consequential** (in lieu of *Generative*): Includes algorithmic and generative strategies often involving iterative mathematical and logical processes. See Terzides.⁷


4) **Constructive:** (added to Oxman’s categories) Digital fabrication offers opportunities for most digital strategies to be physically produced directly from digital data by computer numerically controlled (CNC) machinery; thus representing a common meeting ground for all forms of digital design. This domain has historically been a significant part of the engineering discipline, but has been largely outside of architectural pedagogical models. This interdisciplinary area resembles and offers significant benefits similar to design/build models inspired by such enterprises as the Jersey Devil⁹ and the Rural Studio,¹⁰ and even the goals of the Bauhaus. Digital fabrication in architecture is explored in-depth through writings and examples by Schodek, Bechthold, et al.,¹¹ Callicott,¹² and Aranda Lasch.¹³ Kieran Timberlake propose that this area will offer significant advantages for those interested in engaging in the opportunities offered by this emergent area.¹⁴

These categories are bounded by current technologies, interests, and fashions; however, as computational power increases and societal trends evolve, others forms of digital creation will propagate. Continued exploration of emergent possibilities benefits designers far more than the institutionalization of boundaries around known strategies.

### 1.2. The Possibilities of Biophilia in the Digital Design Realm:

The Harvard biologist, Edward O. Wilson, commenting on the natural world uses the term *biophilia* to describe “the connections that human beings subconsciously seek with the rest of life.”¹⁵ 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 effects as those in nature,¹⁶ an intriguing idea for those pursuing consequential design explorations.

To date some recent architectural works have incorporated biophilic strategies, such as the 1999 BMW soap bubble pavilion by Bernhard Franken, but most precedent in this area is limited to historical ornamental effects—including non-representational Islamic patterning. Even the ornamental panels of Louis Sullivan feature inspired organic reinterpretation of these non-representational Islamic forms which have translated into ceramics quite well.
The artist Neil Forrest has also explored biophilic patterning in his contemporary work. This strategy of Arabesque patterning features repeating geometric forms that often echo the forms of plants and animals.
2. CeramiSKIN Project Status:

CeramiSKIN was recently accepted by the EKWC (European Ceramics Work Centre) in the Netherlands for an upcoming thirteen week collaborative residency that concludes in the spring of 2009. The intention of the residency is for an artist and architect to collaborate closely throughout the project while exploring new avenues for architectural ceramics. <www.ekwc.nl>

Our work will consist of explorations in porcelain as an architectural cladding system utilizing microscopic and macroscopic digital data to construct mass-customizable structural and ornamental effects. At the time of this writing, the project is in the initial development phase with limited, but promising, findings. The work will feature a variety of scalar studies, as well as a large scale fabrication using ceramic cladding to be exhibited with nineteen other team projects from the past four years.

We’re particularly interested in the rich history of terra cotta and porcelain in architectural cladding systems. The use of 3-d scanning, simulated particle physics deformation, and parametric transformations will create surfaces that both evoke the historical use of ceramics in architecture as well as develop new territory in terms of structural promise, assembly techniques, and complexity of pattern, texture, and ornament. We also intend to explore a range of ceramic surface possibilities including glazing, digitally printed patterning, stained/colored clays, and metallic lusters – adding additional complexity to the ceramic surfaces.

3. Brief Historical Narrative of Ceramic Cladding:
Fired ceramics are certainly the oldest human made architectural cladding material and ceramic tiles have been made for at least 4,000 years. While “Egyptian paste” a technique for creating a glassy surface on ceramic was developed about 7,000 years ago, this surface would have been susceptible to corrosion due its high sodium content and was impossible to form in units larger than a few centimeters. Glaze, as a mixture of silica and fluxes in a fluid suspension applied to a clay object became common in the Han dynasty in China (200BC), but may have developed earlier in Iran (as early as 900BC). Durable glazed brick construction appeared in the Gates of Ishtar in Babylon and the Gates of Persepolis in Iran in the 6th century BC.

The functional advantages of ceramic cladding are its durability and resistance to corrosive forces. The major innovations involved in the use of porcelain were increased durability and a high level of translucency in the glaze due to the interface between the clay and glaze surface. The primary material limitations of ceramics for architectural applications are its weight, its relatively low tensile strength, and its tendency to deform and crack in the forming process. To exploit the material advantages of ceramics while minimizing its structural limitations ceramic tiles tend to be either adhered with mortar to a stone or concrete substrate or hung using a clipping system to a metal structure.

3.1. Ceramic Cladding Hung over Metal Structure.

The New York Skyline—which, without exaggeration, is the most wonderful building district in the world—is more than one half architectural terra-cotta”

— The New York Times, May 14, 1911

The use of architectural terra cotta developed along with the increasingly pervasive use of steel in construction beginning in about 1775 (Thomas Paine’s cast iron bridge—as a monument to the American Revolution—was fabricated and exhibited in England in 1791). Terra-cotta cladding, usually in the form of large blocks hung on a steel clip on the back side, were employed. The functional advantages of terra cotta cladding include: resistance to weathering, oxidation, fire, and lighter weight than stone. Complex
ornamental relief could be carved into the wet clay for a much lower cost in tooling and labor than carving hard stone. Terra cotta was both un glazed and glazed—with a remarkable ability to imitate stone—and are seeing a renewed popularity as cladding by Pei and others.

3.2. Issues involved with the Sectional Assembly of Ceramic Cladding: Functional Necessity, Ornamental Use, and Technical Issues

The size of individual tiles is a function of the weight and structural properties of the material. Larger units have historically been difficult to fabricate as larger pieces of clay tend to deform in the drying and firing process. Tiled surfaces tend to accumulate irregularities due to human error. Grid patterns are the easiest to realize but more complex patterns have been achieved both through clever workarounds in assembly or innovations in high level mathematics. The physicist and Harvard graduate student, Peter Lu, has described a conceptual breakthrough that occurred around 1200CE when tile patterns were “re-conceived as tessellations of a special set of equilateral polygons”. This allowed for near perfect repeating patterns to be developed over large surfaces.

In the construction of the Sydney Opera House several models were tested for adhering the glazed tiles to the surface of the ferroconcrete shell. Finally the concrete sections were cast into beds of ceramic tile and the complete sections were raised into place. In both of these scenarios the underlying problem deals with minimizing conditions which contribute to irregularity due to human error in the application of repeated units over large and complex surfaces. The problem is compounded when working with complex curved surfaces, problems that digital design and digital fabrication may more readily solve.

3.3. CeramiSKIN Tectonics:

There are significant advantages to working with tile units that are hung with mechanical connections rather than adhesive mortar. Assembly involves less possibility of human error—the connection points in the metal framework determine the absolute location of each tile. Broken or cracked units can be replaced easily over the life of the building, and “floating” units permit greater degrees of expansion and contraction.

CeramiSKIN intends to develop a system through which grouped sections of tiles are joined together with flexible mechanical and adhesive connections to form larger units which are than attached to a metal framework with mechanical connections. This method provides the working advantages of firing smaller individual tiles that are inherently less susceptible to deformation in the firing process, combined with the on-site assembly advantages of larger units, and thus fewer total units to assemble on-site.

Typically ceramic cladding systems using mechanical connections have only been developed for flat planar surfaces with tile units arranged in a simple grid. Digital modeling can accurately map connection points between metal structure and cladding units allowing for the development of complexity in the overall curvature of surfaces and in the variation and patterning of tile units.

4. Ceramic Cladding: Forming Techniques and Technology:

A few basic forming techniques—with minor variations—have persisted throughout the history of architectural ceramics. The majority of ceramic tiles have been formed in a gypsum based (plaster) mold. Plastic clay is pressed into the mold, which wicks moisture from the contact surface of the clay, drying it slightly and allowing the clay to shrink slightly and release from the mold. The clay dries as water evaporates, resulting in shrinkage of up to 15%.

Clay contains two types of water: non-chemical, which will evaporate through drying; and chemical which is only driven off during the firing process at about 1000°F. During the firing process molecules in the clay
reorient themselves resulting in increased density, durability and (at temperatures above 2200°F) the formation of a glass. Irregularities in the forming process are often invisible in the unfired clay but result in major structural defects in the fired piece. Contemporary industrially-produced tiles are typically made using a “dry pressing” technique in which clay containing only its chemical water is compacted into a mold at extremely high pressure. This allows for very low water content, even density, and very little shrinkage and deformation and shrinkage in the firing process. However molds for dry pressing are expensive to produce and can consist of a maximum of only two parts meaning the pressed forms can’t be very complex.

4.1. CeramiSKIN Production:

The European Ceramic Work Center has developed as a “hands-on”, highly experimental ceramic production facility. Very little of the production process has been standardized in order to allow for a highly customized approach to the realization of each project. For our project this provides significant advantages over a traditional factory, in which mechanized processes limit the range of possible forms. The EKWC has developed innovative methods for reducing shrinkage and deformation of clay that do not require an investment complex and expensive molds. Additions of fired and ground clays and fiber binders reduce shrinkage and increase strength in the unfired clay.

It is important for us to be able to produce more complex multi-part molds quickly and inexpensively. More complex molds will allow us to create more detailed and higher relief, as well as create tile units that fit more precisely together. The tiles will create interlocking systems not only as a surface of two-dimensional polygons but will also fit precisely on the “Z axis” as three-dimensional polyhedrons. Because of the cost and highly skilled labor involved in producing each mold using traditional processes a relatively small number of molds have been typically used to create a corresponding number of units repeated over a surface. We’re interested in using digital fabrication as a way of making more complex molds and larger numbers of unique molds. This is made possible by direct 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. The additions of binders and fillers in the plastic clay make high pressure forming and additional investment in mechanical jigging unnecessary.

5. Surface Treatments and Printing Technology:

Our focus is on glazed surfaces fired between 2100°F - 2200°F. Glazing on tiles allows for a wide range of saturated colors and a surface that is highly resistant to corrosion/oxidation/discoloration and permits easy cleaning. This temperature range takes advantage of both a strong fit between the clay and glaze surface—minimizing the possibility of surface defects that become visible over time—and reduces additional stresses and deformation in the fired units that may only appear at higher firing temperatures. In addition to this high temperature glazed surface we’ll also employ a new technique using digitally printed ceramic glazes that are fired at a lower temperature on top of the glazes. This allows for additional layers of ornamental and graphic complexity in the cladding surface.

5.1 CeramiSKIN Glazing and Patterning:

Recent innovations in ceramic printing technology make possible direct printing of ceramic decals using inkjet printers retrofitted with ceramic inks (http://www.easyceramicdecals.com/). These were previously produced using screen printing which involved a large investment in tooling. By using direct-printed decals we’ll be able to experiment with a large range of possible surfaces and effects quickly and with a small investment in tooling and a greater degree of freedom to create mass-customized effects.

In addition to printed decals we’ll also develop surfaces using patterns composed of screen printed metallic luster whose constituent materials and processes have evolved from Persian luster painted ceramics.
6. Technologies and Work in Progress:
We intend to utilize the following technologies to explore an expansive range of transformative design solutions for ceramic skins in architectural cladding systems.

**Software:**  Geomagic, RealFlow, Maya, Blender

**Hardware:**  Laser scanning, MRI, Confocal Electron Microscope, ZCorp/Dimension Rapid Prototyping, CNC milling.

6.1 Laserscanning:
Laserscanning allows for accurate and complex form capture which may be manipulated into generative digital material. Organic forms will be explored at a scale of 1:1 for ornament.

![Figure 6: Torso laserscan. Konica Minolta Vivid 700. Celento](image)

6.2 Confocal Electron Microscope:
Electron microscopes permit magnification of up to 2 million times with a resolution of .2 nanometers and generate digital data. Such data will permit investigation of organic material and orders that are entirely unfamiliar in daily life.

![Figure 7: Confocal Microscopic scan of Lily (PSU) Figure 8: Conversion to vector information (Flash)](images)
6.3 RealFlow:
Software particle physics permit complex alterations based upon fields that define characteristics such as flow, gravity, mass, etc., useful for sophisticated ornamental deformations.
6.5 Maya:
Maya software enables complex form generation and parametric deformations through scripting of data permitting exploration of complex transformative designs.

7. Conclusion:
At this early stage in the process the technical challenges of data translation have been largely reconciled and final form generation is in progress. The results thus far suggest that a biophilic strategy for form-generation is entirely realizable and offers significant opportunities. Next steps will involve translation of data to CNC formwork and ceramics casting, first at smaller scales for testing, then larger scalar studies at the EKWC in the summer of 2008. Final results from this study will be presented at an EKWC exhibition in the summer of 2009.
8. Endnotes:


DAD models may be summarized as:

1) Formation - topological studies resulting from animation and parametric design directed by the author.

2) Generative - rule based (and generally parametric) computational mechanisms that produce topological results—similar to prior “paper based” architectural pursuits of natural orders and shape grammars.

3) Performance - potentials for going beyond simulation, analysis, and evaluation (as in Building Information Modeling - BIM) which Oxman suggests will eventually create dynamically modifiable results.


8 see Eastman, C., Lee, G., Sacks, R., “Specifying parametric building object behavior (BOB) for a building information modeling system”, *Automation in Construction* Volume 15, Issue 6, November 2006, Pages 758-776


15 see Wilson, E. O., *Biophilia*, Harvard University Press, 1984
