Passive Energy Devices in Ceramics

A study in slip casting toward sweaty, scaly buildings

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Abstract. Buildings with scales, buildings that sweat: this paper proposes two strategies for a materially grounded, performance-based architecture which leverages the strengths of computation and CNC fabrication against the basic properties of traditional ceramics.

Keywords. Building performance, CNC tooling, computer aided manufacture, ceramics, passive energy design

TWO APPROACHES
Two prototypes for passive, energy saving devices involve the use of ceramics to create high performance building envelopes. One strategy uses the tendency of porous ceramic materials such as clay to wick moisture to the exterior of a building causing it to “sweat” and thus to cool itself passively in dry climates. A second strategy uses bi-colored ceramic “scales” to create an array of solar collector/diffusers which can be used to shuttle heat energy either into or out of a building. Both strategies take a cue from systems in nature to leverage a material-based strategy for thermoregulation in buildings. These devices are the result of computer modelling and CNC fabrication to mill positive forms for two types of plaster mold making for ceramic slip casting. One technique is industrial, using pressurized multi-part forms, while the other method uses traditional run-through slip casting molds.

The Sweaty Facade
The built environment as we know it is characterized by constructions which function to keep occupants warm and dry; rainwater is typically displaced from the building footprint and channeled away with gutters, swales, and ultimately retention or detention strategies. Recent popular attention to sustainable building has increased the use of cisterns to collect and reuse water, but these uses remain relegated to watering landscapes and flushing toilets. Biomorphic strategies, however, have been proposed to mimic beneficial cooling effects caused by sweating in mammals (Lilley, et al., 2012). Prototypes are underway for an envisioned “Sweaty Façade” which will use the natural osmotic characteristics of clay to allow buildings to sweat, thus taking advantage of the heat of evaporation of water to passively cool buildings in warm, dry climates. Water collected at the roof can be used to fill façade components which will sweat to save energy.

These intentionally wet façade modules will take forms characterized by highly textured or folding surfaces to create large surface areas for the evaporation of water. Using simple parametric repetition in Rhino/Grasshopper, along with Kangaroo
for shape optimization, prototype forms were then carved from polystyrene on a three-axis CNC router. Such complex objects present a distinct difficulty for traditional casting techniques. The more complex a desired form becomes, the more complex the formwork. Multi part formwork in ceramics is used traditionally to cast parts with large undercuts, or with surface area large enough to create impossible scenarios for demolding due to friction (Reijnders and EKWC, 2005).

The creation of these highly articulated façade prototype units was approached through a traditional mold making technique. A twelve part plaster mold was made by hand, including captured interior pieces held by ties piercing larger parts. The size of the pieces required a so-called “run-through mold” due to the sheer weight of the plaster. In order to empty the mold of liquid clay, a drain is placed at the bottom, which when opened allows remaining clay to drain from the form (Figure 1).

The resultant parts were deliberately designed to maintain the lines left behind by the seams of the mold in order to give clues to the making of the object (Figure 2). The large surface areas exhibited by these complex forms are impossible to accomplish using non-sculptorly techniques. Non-developable surfaces, in other words, must be carved or cast (Duarte, 2004).

A rendering of an architectural corner condition against the sky (Figure 3), shows a sensual façade based on repetitive ceramic elements. These elements are spaced to allow for air flow necessary for evaporative cooling between individual units, while the size and shape of the elements creates maximal surface area. The spacing and shape of the units is designed to minimize “slow” spots in the air flow, but also to provide for diffused daylight to pass through the screen to the building interior beyond.

**Scaly Exteriors**

The “bubble tile is envisioned as a ceramic heat exchange component which has a rough, darkly colored surface on one side, and a smooth reflective surface on the other side (Figure 4). Tiles can be used alone, or in conjunction with a liquid heat transfer system to move heat energy through an array of tiles. In an architectural building façade, heat exchange tiles can be placed in a mechanism which will allow the tiles to reverse front to back. This can allow infrared energy to be either reflected, absorbed, or diffused as necessary for environmental conditions in order to reduce heating and cooling loads on a building. By motorizing each tile, an array of heat exchange tiles can be used as a solar collector, heat exchanger, as a light shelf, or as signage. The technology takes advantage of the thermal properties of ceramics to modulate the heating and cooling loads on buildings in various climates. The function of the façade system is inspired by the Namaqua Chameleon (Benyus, 1997) which changes
color, depending on its needs, to either reflect or absorb the heat of the sun in the harsh and widely varied temperatures of the desert. Following this biomimetic strategy, the façade system will be programmable to alter its orientation to the sun based on material color, climate, and the needs of building occupants.

The creation of the positive forms for the bubble tiles relied on a simple parametric box-morph repetition of pyramidal forms over a simple shape using Rhino/Grasshopper in order to achieve a device with maximal surface area on one side without creating micro shading conditions. The shape of the Bubble Tile poses an interesting problem for slip casting. The scale of the surface articulation is such that traditional mold making techniques become impractical; a multipart mold for this tile would contain many thousands of parts. The bumps on the surface are pyramidal in shape, so designed as to avoid micro shading of the component surface. In terms of the intricacies of mold making, this is the perfect shape for demolding, as it offers no undercuts to impede mold removal. Unfortunately, the bumps create such a massively increased surface area that the force of friction between the part and the mold makes removal of the part impossible. Additionally, large flat, hollow pieces such as this tend to collapse in the mold from the weight of unsupported wet clay. To solve these issues, an industrial slip casting technique was adopted.

In the creation of the four part mold, a manifold of perforated air tubing was embedded in side of the mold corresponding to the highly textured surface of the part to aid in demolding (Figure 5). The mold is also pierced at the end by a plastic tube for pressurizing the interior of the part to stop it from collapsing.

The mold is filled with clay, and after sufficient thickness has developed in the interior of the mold, the remaining liquid clay is emptied. Immediately, the interior of the mold is pressurized through a short tube in the cap of the mold. Air pressure forces
the clay against the sides of the mold allowing the clay to harden without collapsing. As water is slowly absorbed from the clay into the plaster, the part becomes “leather hard” and is able to support itself. At this point, the interior pressure is released. In order to now demold the part, three bars of pressure is pumped into the perforated tube in the plaster. This air is forced through the pores in the plaster mold, causing water absorbed by the plaster to diffuse outward, ultimately creating a molecular mist of water at the exterior surfaces of the mold. This water, extruded at the interior surface of the mold (Figure 6), creates sufficient lubrication against the rough surface of the part to allow smooth part removal without breakage.

On a mockup of an architectural facade, (Figure 7), tiles are arranged horizontally on the southern side of a building, and vertically on the east/west sides of the building. This redering places the concept in a generic glass box facade folly representative of a default retail or office condition suggestive of an energy sensible retrofit to an existing building. Tiles would be operable, allowing for maximization of absorption, reflection, or diffusion of heat energy, and to admit daylight and allow views as desired. The ceramic character of such a facade would allow for the creation of an architectural space reliant on rich materiality, while simultaneously providing a regionally adaptable high performance building.

CONCLUSION
The incredible complexities offered by the possibilities of advanced computation create opportunities for new advances in building performance. These complex forms, however, present unique challenges to traditional forms of manufacture for materials such as clay. A hybrid approach to the creation of complex ceramic parts leverages traditional and industrial techniques to produce manufacturing possibilities suitable for industry. This approach can allow designers to maximize material performance previously inaccessible in traditional materials, while simultaneously tapping into otherwise economically unfeasible material palette which, while firmly rooted in a progressive digital materiality, nevertheless recollects a hand-made past. Furthermore, progressive strategies for performance based design need no longer be the static fixed elements of our design past; instead, using biological models as a platform, architects have the opportunity to create buildings which sweat, change color, or otherwise adapt to their immediate environment with biological precision.

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REFERENCES


Figure 7
“Scaly” Façade over a generic glass retail box. Rendering: Dan Greenberg.