FROM SURFACE TO VOLUME
AN APPROACH TO POCHÉ
WITH COMPOSITES

ABSTRACT
While the digital era has brought with it a vast assortment of tools from which we can generate form and geometry, often the result is a tendency to focus primarily on either surfaces or solids as a means of modeling for representation or fabrication. Consequently, this impacts the various fabrication and construction techniques deployed in order to realize such digital models. In certain academic environments, this has led to a divide between discussions and methodologies surrounding surface, and those surrounding solids or volume. And while the desire to implement new methods and materials into both research and practice grows, such a divide may only hinder the potential for speculative material exploration. This paper presents an approach to coalesce generative techniques of surface generation via computational tools, and fabrication strategies for constructing volumetric elements through a process of backfilling. The paper will highlight current research through an ongoing project, which aims to merge strategies for mass-customized mold making via robotic hot-knife cutting, composite materials, and hybrid design and fabrication methodologies.
INTRODUCTION

In recent years, the increasing presence of industrial robotic arms in architecture has spawned various techniques for fabrication through highly customized hardware and software platforms. Utilizing such technologies affords architects the ability to engage with design more directly through the processes of making. This project utilizes previously developed methods for multi-axis robotic hot-knife cutting of expanded polystyrene (EPS) foam in order to rapidly produce molds with zero waste (Clifford, Ekmekjian, Manto, Little 2014). Custom tooling, specifically a hot-knife with an external power supply, was designed and developed to allow for more efficient material removal while also presenting the opportunity to control the profile of the cut itself (Figure 2). The blade is made from nichrome, a non-magnetic alloy typically used as a resistor in standard electrical applications. It is available in the form of 1/32” thick by 3/16” wide flat stock, which can then be shaped into any desired profile. The tool itself is then mounted onto a six-axis KUKA Agilus industrial robotic arm (Figure 3). Future versions of this hot knife tool, which are currently in development, will incorporate low-level electronics to allow for a dynamic blade profile, varying the shape of the blade throughout the duration of the cut itself.

STRUCTURAL SURFACE PATTERNS (TOOL PATHS MEET LOAD PATHS)

This project aims to shift one’s attention away from the role of tool paths typically noted for their aesthetic qualities resulting from fabrication processes, and instead, proposes a new reading into their performative capabilities. The scale of the hot-knife blade profile used in this project is remarkably larger than that of any standard CNC machining end mill (4” vs. ½” in diameter). When swept along a path through a block of EPS foam, the result is the formation of a new surface rather than what would be simply the trace, or the mark left behind by that of a standard end mill. Thus, the resulting new surface now plays a much more important role in the overall formation of a larger geometry or topology.

In the case of EPS foam molds, this becomes especially relevant when considering the scale and thickness of the composite materials which are then cast into them. Depending on the scale of the sweep, the final surface can take on drastically different qualities, both visually and structurally. Larger sweeps allow for deeper concave surfaces in the mold, which result in more bulbous convex parts; while smaller sweeps produce more shallow conditions, resulting in less pronounced surface features (Figure 4). No longer is the tool path a consequence or aftereffect of the machine process, or a texture on a surface, but instead is a communication protocol embedded within the shaping logics of the surface geometry itself (Figure 5).
Taking advantage of this, the project explores the idea of synthesizing tool paths with load paths, generating patterns of smaller surface geometries implemented throughout a more global form, which pronounce the underlying structural diagrams of certain conditions. Currently, the work is operating in the realm of bilaterally symmetrical structures, specifically columns whose tops fan out toward other columns, producing formal conditions akin to gothic fan vaults (Figure 7). This is due to the efficiencies afforded by working with identical parts produced from a single mold. This is not, however, the intention for future design propositions. The simplicity of the column grid easily demonstrates the structural diagram, with the diagonal ribs aligning in their respective axes (Figures 8 and Figure 9). These are in turn the directions for the deeper concavities from the surface of the mold to align toward, resulting in more pronounced creasing in the outer composite surface (Figure 6). This suggests a new reading of the relationship between global form and more localized surface deformations.

**MATERIALS**

Work in progress prototypes fabricated for this project currently utilize various composite materials and vacuum bagging in order to produce lightweight, doubly curved, rigid surfaces (Figure 11). Currently, the preferred inexpensive analog to carbon fiber or cloth is burlap, however infused with the same high-grade epoxy resin hardener in professional applications, manufactured by US Composites. The surfaces are produced through a “wet lay-up” process where multiple layers of burlap are sandwiched between a layer of release film and a bleeder film, as well as a breather layer to absorb any excess resin (Figure 12). In addition to the burlap composite surfaces, the process of backfilling calls for the use of
expandable polyurethane foam, a liquid two-part system whereby the mixing of both parts results in an expanding solution, which eventually hardens into a solid. The expansion rate of such foams varies; however, most standard industrial products may go up to 1:30 times by volume. This is extremely advantageous as it allows for the production of volumetric elements from surfaces, which may have hard-to-reach areas to fill often inaccessible otherwise using standard, non-expansive materials like plaster for instance. When used correctly, expandable polyurethane foam also has considerable adhesive capabilities, allowing fusion between multiple composite surfaces, in turn improving structural capabilities. The result is a lightweight, rigid, insulated part which has the ability to take compressive loads while span potentially long distances.

CONCLUSION

When producing objects of volume, the frequently used technique of casting carries with it issues of accuracy and fidelity, despite it’s often cited economic efficiency (Carpo 2012). And while it’s commonly accepted that molds generally produce identical parts (to some degree), the issue remains that the parts themselves are only as accurate as the mold from which they were cast. This generally leads to more time and money being spent on producing more accurate molds, but more problematically reduces the tolerances of a given part such that there is almost no room for adjustment once it has been made. Perhaps where these prototypes proved to be most promising was in their ability to address these issues commonly attributed to the making of volumetric elements solely through means of casting. Where a single solid part would have no ability to conform to its adjacent boundaries, the flexibility of the burlap surface would allow for a degree of adjustability,
which may be necessary to achieve tighter seams for instance. This, of course, would need to happen prior to backfilling any cavities with the expandable urethane foam. Thus, one could suggest an alternate reading of the “surface element” as not only a finished rigid surface, but also as a secondary mold in and of itself, one that is capable of satisfying specific on-site conditions unique to each architectural project.

The first sets of prototypes were intended to understand the nature of the materials and how they might interact with one another (Figure 13). The burlap that had been rigidized in a vacuum sealed bag was found to typically have two different surface qualities to it. The outer surface (facing away from the core) would tend to have a smooth finish, while the inner surface (that which the core adheres to) would tend to be much rougher. This proved to be extremely convenient during the process of backfilling as the rough texture of the rigid burlap surface provided a desirable condition for the expandable urethane foam to adhere to. More problematically however, the final rigid burlap surfaces contained extremely small holes, which ultimately led to some of the expanding urethane foam to seep through while in its earliest and most volatile expanding stages (Figure 17). This also occurs when pouring the foam prematurely and not allowing it to thicken to a more stable state. Future experiments will address these issues in various ways.

It’s also worth noting that while the “surface element” of the final part was a rigid composite material, it still showed some flexibility overall. However, when adhered to a secondary surface through the urethane backfill, the rigidity of the overall part increased significantly, producing a tremendously rigid volumetric element capable of withstanding up to 200 lbs of weight in its horizontal span. Future prototypes are intended to be subject to load testing as one avenue of development and interest. As mentioned before, the goal of this research is to develop new hybrid design and fabrication methodologies to ultimately better understand the relationship between free form surface modeling and volumetric object making.
One area in particular that requires more attention and research is in the generation of structural data and how it directly informs the surface geometry. Currently, the approach is more intuitive due to simplified symmetric forms, but ideally this information would be generated from a structural analysis model capable of solving for more complex geometries.

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Figure 7. Ekmekjian, Nazareth (2014) Elevation and Sectional Diagram.
Figure 8. Ekmekjian, Nazareth (2014) Stereolithography Study Model.
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Figure 14. Ekmekjian, Nazareth (2014) Backfill Sequence.
Figure 15. Ekmekjian, Nazareth (2014) Large Prototype.
Figure 16. Ekmekjian, Nazareth (2014) Poche’.
Figure 17. Ekmekjian, Nazareth (2104) Large Prototype, Close-up.

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