Digital Making: 3D printing and artisanal glass production

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Abstract

Direct digital design and additive manufacturing are enabling new pathways for the design, development and distribution of material goods – radically redefining existing sites for knowledge exchange and our core assumptions of what makes a contemporary material practice. In the era of open source, democratized production, the relationships between an object, how it is made, what it is made of, where it is made, by whom and when, are directed by the maker. For the last forty years, 3D printing has been used as an ideation tool to model what could be. The steady emergence of Direct Digital Manufacturing (Singer P. et al. 2011) has enabled us to manipulate true-life materials to directly achieve the final object. This paper will focus on emergent modes of making using legacy materials, leveraging work done in foundry and ceramics into glass, and how 3D printing provides room for innovation not only with these materials, but also with the requisite digital processes in terms of software, hardware, and workflow opportunities. This design-led creative research looks at opportunities for innovation in material practice and also seeks out the affinities and opportunities, which arise when design methodologies are implemented alongside an artisanal, craft-based approach to making.

Introduction

This paper examines intersections between digital technologies and glass production at a Canadian Art and Design University. We will outline our current research and development efforts driven by and related to small-scale, craft and artisanal production. Open source communities may have enabled 3D printing in a variety of materials, however glass remains an emergent topic in additive manufacturing processes (Marchelli et al., 2011). Our areas of inquiry are 3D printing directly in glass and 3D printing kiln cast tooling for glass production.

Our work developing printing methods in glass builds on the research initiated at the Solheim lab at the University of Washington and the Open3DP resource, which has published examples of binder/powder printing directly in glass. Our aim was to carry forward this work born of engineering research to creative research in art, design, and craft production.

First steps: Recipe #1 was 100:10:10 Spectrum clear powdered glass: Powdered sugar: Maltodextrin, hand mixed and sifted through a 400 mesh, used in a ZCorp 510 powder printer with a distilled water and isopropyl binder with a ratio of 10:1. Shell and fill saturation levels were tested at both 100% and 33%, with the latter giving greater detail and similar green strength. Recipe #2 was 100:8:8 Spectrum powdered glass: Powdered sugar: Maltodextrin, and models were printed at 33% binder saturation with no discernable difference. Model shrinkage post-firing was between 20-30%, with no noticeable shrinkage difference between the two recipes.

3D printed models were placed on a kiln shelf and fired without any support material (2.5D firing), or were packed in silica sand or alumina hydrate for support (3D firing). The firing schedule included three stages: low temperature hold (Binder burn-off), anneal temperature hold (soak), and ramp to melt temperature (fuse). The soak hold served as a pre-fuse step to ensure all organic materials had burned off, which usually happens in the range of 200-500°C (Johnston, 2005). For 2.5D firings, depending on model size, low temperature hold was 30-60m at 150°C, soak was 30-60m at 590°C, and fuse was 25-50°C/hr ramp from 590C to 680-800C for 5-30m. No anneal cycle was used due to the scale of the models.

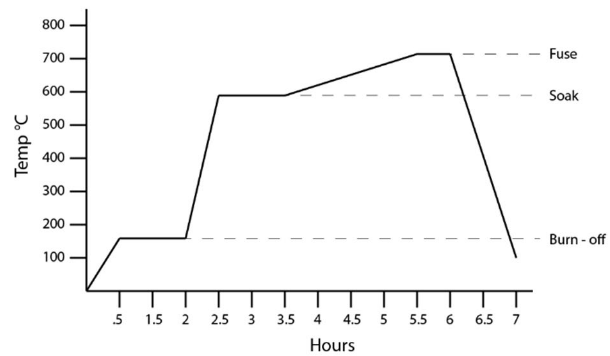

***Figure 1:** Our typical firing program for 3DP glass*

3DP Glass: Translucency + Detail

As the fusing reaches a temperature where the model begins to take on the characteristics commonly associated with glass (translucency, rigidity) the detail from the original model is diminished. Figure 2 illustrates the issues with firing, mainly shrinkage and loss of detail. The model has a Z-height of 5.75mm and is shown in its both its green state and fired to 690°C for 10m with a ramp from anneal temp of 50°C/hr. Figure 3 shows the same model fired to 720°C for 10m with a ramp from anneal temperature of 50°C/hr.

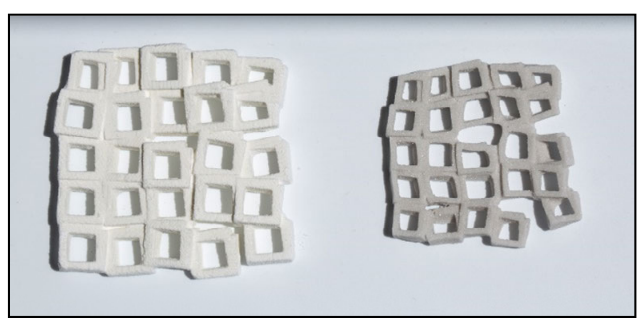

***Figure 2:** Left, unfired 3DP glass Right, fired to 690°C for 10m*

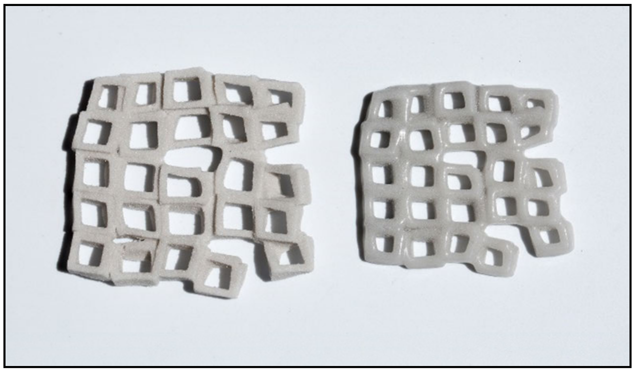

***Figure 3:** Loss of detail as transparency is achieved*

Both fired models exhibit the rigidity of solid glass, however the higher fired model is translucent while the lower fired one is opaque. Two models were created to explore the optical qualities of 3DP glass fired to a translucent state. A model was created with a 2mm sheet base and a 1mm grid relief directly on top, for a total Z height of 3mm. A firing program of full ramp from anneal temperature to 715°C held for 40m resulted in a fully fused, opaque and glossy model, which also retained about .5mm, or one half, of the original 1mm relief. The same model with a fusing step of 715C held for 1h resulted in a translucent model, the 1mm relief fully fused into the base layer (Figure 4). The resulting contrast in depth of fused material displayed an opportunity for fusing 3DP glass into multi-layered sheet, and the next models examined this opportunity for an accurate control of light through the depth of printed material.

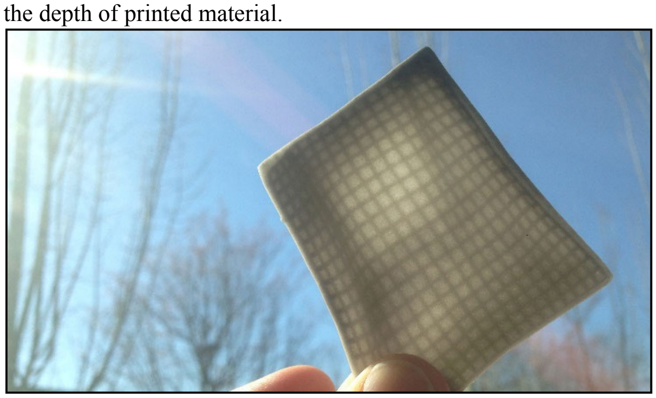

***Figure 4:** 3mm model shows translucent quality of 3DP glass*

Figure 5 shows a model built from a series of connected wedges each gradating from 4mm to 1mm on a 2mm base for a total Z height of 6mm, Y 220mm, X 150mm. The first attempt resulted in a badly torn model after firing, due to the shrinkage of the material at fuse over such a large model in combination with a drag on the surface directly in contact with the kiln support shelf. The complexity and issues of working with this recipe at larger scales became apparent. Different kiln releases were tried to aid in the movement at fusing stage: dry alumina hydrate, dry fine silica, and a wet alumina hydate based kiln wash. While the models show promise for patterning and controlling light, and hints of future applications, the tearing issue was not resolved in full.

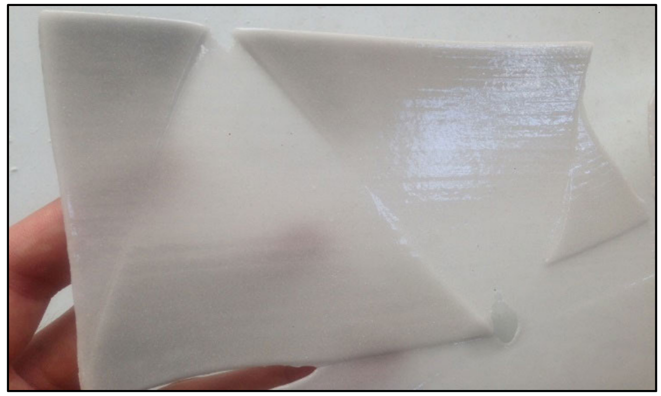

***Figure 5:** Larger 3DP sheet with gradated depth*

Next steps: Two spheres were created to further explore the possibilities of 3DP forms in glass, one closed and one open with polygonal frames. Both models were placed in a dry fine silica sand support and fired to 805°C for 1h. The fired models displayed 25% shrinkage, with an unfired diameter of 40mm and a fired diameter of 30mm. An opaque surface was evident due to contact with silica at melt temperature. An unexpected result of this firing was that the closed sphere acquired a sealed surface at fuse temperature, and as a result, the interior volume of air expanded with heat and self-inflated the model.

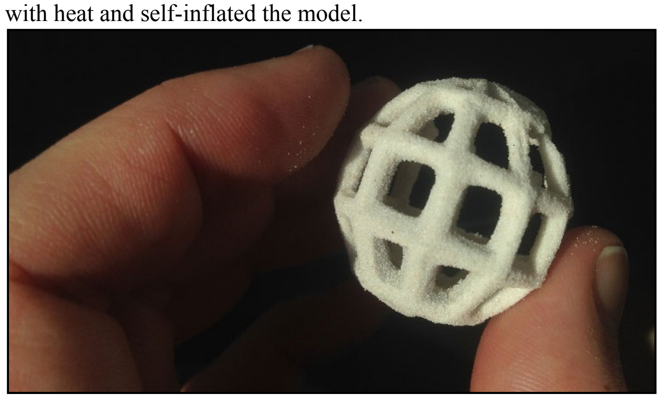

***Figure 6:** 3DP glass sphere fired in support material*

Last: The final models created were a series of woven structures, the largest with a Z height of 8mm, Y 240mm, X 240mm (Figure 7). The open nature of these models allowed for shrinkage to occur with less tearing than the solid sheet model, and while the fired models exhibited a reduction in scale, it was a uniform reduction without significant variation from the green model. Figure 8 was brought from anneal temperature to 680°C with a ramp of 25°C/hr and held for 1h, encased in dry alumina hydrate for support. Figure 9 was brought from anneal temperature to 670°C with a ramp of 25°C/hr and held for 30m.

This material research into 3DP glass has focused on new opportunities in form, and control over optics in a zero waste additive process. The combination of these technologies with established glassforming techniques (blowing, casting, fusing) has the potential to lead to innovative and sustainable small-scale/artisanal practice.

Figure 7: *Unfired 3DP glass, open woven form*

Figure 8: *3DP fired glass, open woven form*

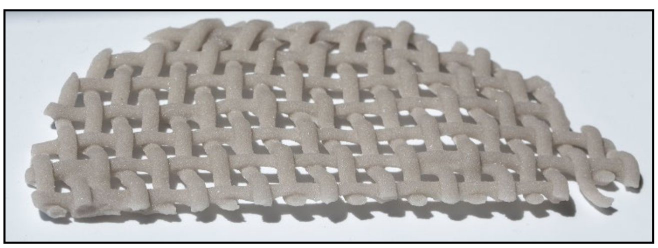

Figure 9: *Fired, translucent 3DP glass*

3DP Glass Casting Moulds

Concurrent with this powdered glass fusing research we have been examining the capabilities of our low cost, open source, 3D printing powder and its applicability to the glass casting process. Building on research initiated at the Solheim Lab at the University of Washington, we have developed an extremely low cost, 3d printable powder that enables to output of 3D forms at a 20X reduction in cost - in comparison to commercial 3D printable consumables. This development has previously led to multiple streams of inquiry based on bronze metal casting (figure 10) and ceramic slip casting (Figure 11), and most recently, glass casting.

The refractory capabilities of our powder formulation are based on its primary constituent, Hydroperm, a commercially available plaster used in the fabrication of hand made refractory moulds for metal casting. 3d printed moulds produced with this material have the capacity to withstand the intense thermal shock of metal casting (typically a moulds transitions from ambient temperature to 1000°C and back to ambient in less than 1 hour) however, glass casting has a casting cycle of multiple 10's of hours with the need to hold high temperatures for multiple hours while the glass is melting and annealing. Initially our explorations were conducted to determine if a 3D printed mould could withstand a glass casting cycle and what level of surface details would survive the process.

Figure 10: *Printed mould and cast aluminum*

Figure 11: *Printed mould and slip cast ceramic*

This 3D printing moulds for glass kiln casting project is in collaboration with Gayle Matthias, Senior Lecturer, Contemporary Crafts and Tavs Jorgensen, Research Fellow in 3D Digital Production, both of the Autonomatic Research Group at the University of Falmouth. They are currently exploring parallel glass casting capabilities in commercial materials in relation to the medical industry, and their original mould file was our starting point. This form had the desirable characteristics of a complex surface, difficult to model and mould by hand via traditional methods, but did not contain excessive surface details making it difficult to de-powder (Figure 12). One characteristic of our powder is that it exhibits a level of "stickiness" between the printed object and the surrounding unprinted powder. Unprinted powder wants to cling to the surface of a printed mould creating the necessity of a mould's surface needing to be cleaned manually. As a mould's surface need to be accessible for this process, we split Falmouth's digital model into two pieces along a relatively simple, straight seamline.

The moulds were then printed, de-powdered, cured with water (to set the plaster), dried and bound together with wire in preparation for casting. The typical glass casting procedure entails using ceramic flowerpots to act as crucible for the glass, containing it while a cool solid and a hot liquid, and directing the molten glass into the aperture of the mould below. This was the procedure for these digital moulds (Figure 13).

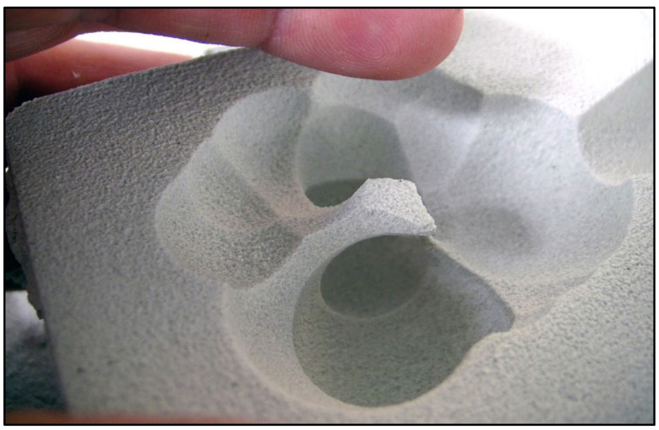

Figure 12: *Detail of mould surface*

The moulds were fired over a 25 hour casting cycle, being held for 4 hours at a peak temperature of 830°C while the glass was molten allowing the glass to flow completely into the mould. At the completion of the casting cycle the glass had melted successfully, being deposited into the mould below by the flowerpot/crucibles above (Figure 14). The mould on it's exterior appeared to have survived the casting process enough to contain the molten glass and had re-calcined during the firing, becoming extremely fragile.

The mould, as a result of the re-calcination of the plaster, is extremely easy to remove from the cast glass object. Additionally, surface detail from the mould readily transferred to the glass; however, the result is not a smooth surface (Figure 15). The cast glass takes on the slightly "pebbly" surface of the mould; this surface is a result of the mould water curing process. When the 3D printed mould is first removed from the printer it is de-powdered then the relatively delicate surface is misted with water to create a much more durable shell. This misting process appears to slightly dissolve the sugar within the printable powder leaving the texture visible in Figure 12 and Figure 16. The success of this material in the glass casting process has created multiple avenues for further development.

Figure 13: *Glass casting setup, pre-firing*

Figure 14: *Detail of full glass cast*

Figure 15: *Glass casting setup, post-firing*

Our current investigations are examining the multiple questions raised by this hybridized digital/analogue process. There is a particular efficiency in creating digital originals as they streamline a traditional workflow (no physical original need be made, undercuts are a greatly minimized issue, physical skill is not as acutely required in the creation of moulds) and create multiple formal opportunities (geometric complexity, repeatability, scalability). We are exploring issues within geometric complexity, the digital versatility afforded by 3D modeling software, and how the Maker remains is apparent in this digitally mediated process (Figure 16). We are investigating parallel formulations of printable materials to refine the depowdering process and refine surface characteristics.

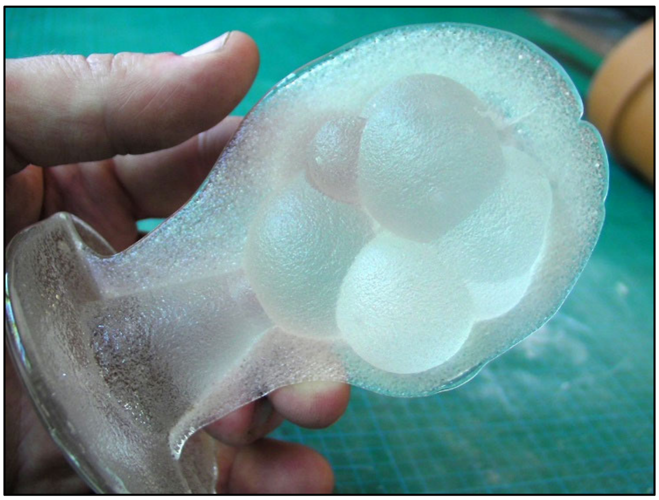

Figure 16: *Surface detail, form and seam flashing, post-casting*

This research in design and making is placed within the current paradigm of open source knowledge and horizontal manufacturing, furthering research within the open source community and enabling individual makers. Material production is actively being redefined, warping our conventional thinking on how something is made, what our relationships to objects are and how production is defined. Within a craft and design context, we continue to research opportunities for digital technologies to increase efficiencies and expand the vocabulary of traditional materials. Research at this intersection of traditional material practices and digital making play an increasingly important role, acting as a catalyst for cross-disciplinary dialogue (Howes P. et al. 2012).

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Keywords: 3DP, material practice, open source, contemporary craft, ceramics, glass

Biography

Aaron Oussoren is a 2016 MDES candidate at Emily Carr University of Art + D0esign. He graduated from Sheridan's Craft + Design program (2004-2008), and was an artist-in-residence at Harbourfront Centre glass studio (2008-2012). Aaron has shown his work extensively in the Toronto area, and has shown in and traveled to the U.S, Belgium, and Germany. He has taught courses in both glassblowing and 3d technology for craft artists. Research funding from the Toronto Arts Council, Ontario Arts Council and the Ontario Crafts Council have enabled Aaron to develop work incorporating 3D scanning with glass, 3D printing with glass, and CNC milling for glass moulds. He is currently involved in material research at the intersection of contemporary craft practice and design with the Material Matters group at Emily Carr in Vancouver, B.C.

Philip Robbins holds an M.A. from the Royal College of Art in London, a B.A. from The Emily Carr University of Art and Design and a B.ed from the University of British Columbia. Philip's is a founding member of Material Matters a research center within Emily Carr University's, Intersections Digital Studios. Philip's practice explores a wide spectrum of materials, media and technology in a career that spans props production for film and television, public artwork and education. Since 2000 Philip has taught across a wide range of disciplines with an emphasis on material practice, 3D software and digital output technologies.

Keith Doyle is an Assistant Professor at Emily Carr University of Art + Design. He is a Lead/co-lead Investigator on a few Emily Carr research initiatives including, the DnA project, cloTHING(s) as conversation, and a founding faculty member of Material Matters, a pragmatic material research cluster within the Intersections Digital Studios at Emily Carr University of Art + Design. Keith holds both a BFA and an MFA in Sculpture. He maintains an active material practice and is a recent Resident Artist at the ACME Studios International Artists Residency Programme situated in London, UK, a Banff New Media Institute alum, 2006-2007 as well as, a NYC Dance Theater Workshop Artist's Research Medialab fellow.