Glass + Digital Making
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Abstract

Since the mid-1970s, 3D printing has been used as an ideation tool by industry. Recently, broad access to 3D printers and other digital manufacturing technologies has delivered these tools to artists, designers, crafters, and makers, enabling us to expand, develop, and challenge our concepts of approaches to cultural production. This design study looks at new production paradigms emerging from access to digital manufacturing, and explores approaches to creating in the digital manufacturing context.

This study focuses on emergent modes of creation using glass, in particular how 3D printing not only provides room for innovation with material production, but also extends the poetics of materials. The bases for these conclusions are founded in a practice-led study, which developed workflows that incorporate both 3D printing and traditional glass working techniques. This practice-led study led into a course-led study which used the previously gained material knowledge to develop a new approach to digital manufacturing, taught in a third-year design course at Emily Carr University of Art and Design. A reflective practice throughout these studies served to inform the codification of an emergent method and approach to glassmaking within the context of digital manufacturing.

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Cultural Production in a Digitized Creative Environment

Neil Postman (1998) discusses the impacts of technology as ecological rather than additive using an analogy – if we add a drop of red dye to clear water, do we then have water plus a drop of dye? Obviously not. We have a new colouration of every drop of water. After the invention of the printing press in the 1440s, we did not have Europe plus the printing press, we had a new Europe. After the introduction of television in the 1940s, we did not have America plus television, we had a new America (p. 2). Technological change is not additive, it is ecological. In the spirit of Postman, our recently gained, broad access to digital manufacturing technologies – machines which encompass all methods of computer controlled additive and subtractive machine production, such as 3D printing and CNC machining – is altering our creative ecosystem.

In our altered ecosystem of production, the roles, sites (of production and knowledge exchange) and visual language of creative production are being re-negotiated. In the midst of new access to digital manufacturing, we are re-framing how these roles, sites, and objects interact. As we collectively shift our ideas about how something is made, by whom, and where, our theories associated with creative practice are evolving.

The work presented in this paper is an exploration into the emergence of a creative practice that incorporates both digital manufacturing and material-based methods. An in-depth discussion focused on definitions of different creative practices is beyond the scope of this paper. Discussions of craft and design are presented here within a contemporary context that includes digital manufacturing – the intention is not to define the terms *craft* and *design*, but to explore how elements of these creative approaches may align with a contemporary creative practice that combines analogue and digital tools and methods.

Creative Background

My studies at Sheridan College's School of Craft and Design (2004-2008), and as an Artist in Residence at Harbourfront Centre's Craft Studios (2008-2012) in Toronto, Canada, have given me a base of knowledge in traditional and contemporary craft practices. Project funding from the Ontario and Toronto Arts Councils (2011, 2012), the Ontario Crafts Council (2013), and collaborations with industry have encouraged my education in digital manufacturing. Over this ten-year period, my practice consisted of an exploratory approach in glassblowing, glass casting, kiln casting, fusing and slumping, and architectural and public art projects.

My studio practice in recent years has increasingly blurred the line between analogue and digital glasswork, conceptualized digital manufacturing (3D printing, CNC milling, CAD) as a craft material, and intuitively explored this new material and the perspectives it may offer craft practitioners. The opportunity to combine a material-based approach with digital manufacturing motivated my enrolment in the Master of Design program at Emily Carr, with the goal of furthering and codifying my explorations in this area.

Contextual Overview: The Introduction of Digital Manufacturing into Craft Traditions

Since the mid-1970s, 3D printing – an additive digital manufacturing process, in which an automated machine builds up an object from stock material according to a digital model – has been used as an ideation tool mainly in industrial design, as a tool to envision what could be. The steady emergence of direct digital manufacturing through 3D printers that can inexpensively produce high-quality objects now enables us to manipulate craft materials to directly achieve final objects (Schuette & Singer, 2011). How these technologies are employed in contemporary creative practice has the potential to expand and enrich our material culture. Worldwide, arts institutions and funding bodies are directing their energies towards the integration of digital manufacturing into creative practices. Canada's largest funding bodies and cultural centres increasingly devote resources to digital manufacturing (Anisef, 2010). Critical discussion in this area is needed to uncover the disconnects and affinities between traditional creative practices and new paradigms of digital production.

Contentious Creative Terms

As a society, we know that many of our patterns of production and consumption are socially and environmentally unsustainable. Since the Industrial Revolution, craft production has been an empowering response to this unsustainability, with craft practitioners protesting against divisions of labour, standardized designs, and unethical production methods (Ruskin, 1892; Morris, 1898). Often cited as defining the philosophy of the Arts and Crafts movement as an ethical movement in response to the First Industrial Revolution, Ruskin (1892) forecast some of the implications that mechanized production would have on the culture of his day. These ideas have not lost their import a century and a half later. In his view, the danger inherent in a mechanistic approach to labour is that conceptions of *wealth* and *pleasure* shift; people no longer find pleasure in work itself, and instead look to the wealth that they might gain in exchange for labour as a source of pleasure (Ruskin, 1892, p. 179). After mechanization of production removed the need for craftspeople to produce everyday objects, craft became a pursuit of individuals who strove to find pleasure in labour itself. This broad conception of craft, not as a discrete set of techniques but as a way of being within society *(*Alfoldy, 2012, p. 89), is an approach which separates craft from an association with any specific production method – handmade, small batch, local; rather, this conception relates craft to a way of being in the world.

The word *maker* has entered the mainstream lexicon following an increased ease of access to emergent personal production platforms (Troxler, 2013). In this thesis, the term refers exclusively to creators who work within the context of the maker movement. How do we speak about *making* in 2016? If we parrot the popular notion that now everyone is a maker, the catchphrase of Anderson's (2012) third industrial revolution, we may naively mistake a willingness to try with gaining in-depth knowledge.

Anderson (2012) describes the following chain of events, which sets the stage for his definition of a maker:

> Transformative change happens when industries democratize, when they're ripped from the sole domain of companies, governments, and other institutions and handed over to regular folks. We've seen this picture before: it's what happens just before monolithic industries fragment in the face of countless small entrants, from the music industry to newspapers. Lower the barriers to entry and the crowd pours in… The Internet democratized publishing, broadcasting, and communications, and the consequence was a massive increase in the range of both participation and participants in everything digital… Now the same is happening to manufacturing. (p. 63)

This democratization manifests in the maker movement as "open source appropriate technologies" (Pearce, 2012) and "commons based peer production" (Benkler, 2006), where individuals work to subvert mainstream manufacturing models by developing open source production devices and accompanying software. This new production ecosystem shifts our notions of access and proprietary knowledge related to objects and manufacture, just as torrents and YouTube shifted our notions of cost and copyright associated with entertainment.

The phenomena of the maker movement and maker fairs has built community, spread knowledge, and in general has educated people on a large-scale who would otherwise not consider how things are made, but when seen through the lens of contemporary craft and design, the maker movement does not actually seem to be about making things. As Wark (2013) describes: "the stuff has already been made, you put it together. Like Ikea furniture, but, you know, fun"(p. 297). Wark's (2013) comments point to a re-framing of the maker movement as a movement of assemblage, concerned mainly with a broad education in modes of fabrication.

As the word *maker* has entered the mainstream lexicon, *craft* has emerged in the mainstream as a marketing fad, wherein the word is used to its full anachronistic potential – *craft-washing* places the word back in its pre-industrial production light, an action out of time and place. To speak about craft in this sense is to speak about a different concept than the craft which has foundational philosophies, studio movements, and redefinition as an approach and philosophical mechanism – dialogues which all make up a material practice relevant in this time and place.

Both terms – *maker* and *craft* – are provocative and carry different meanings depending on the contexts they are used in. There is a common connection between them, in that both movements claim to see the creation of goods as a political action. The idea of making as a disruption of mainstream manufacture and as an empowering activity aligns with the ethos of the Arts and Crafts Movement as a response to the First Industrial Revolution and the mechanization of hand labour. In hacklabs, fablabs, makerspaces, garages and libraries, a new wave of makers builds on open source resources and social platforms in response to a contemporary alienation from production.

Aims

This study looks at a new production paradigm that is emerging from access to digital manufacturing, and explores the roles of craft and design in the digital manufacturing context. My line of inquiry addresses the emerging visual language, inherent efficiencies and complexities, and meanings that might be found in digital manufacturing and its products. The objectives of this inquiry are:

- To connect the material specific practitioner and their tacit knowledge to digital manufacturing

- To develop novel workflows that incorporate digital manufacturing while expanding its inherently linear, certain nature

- To locate transferable skills and sites of knowledge transfer when craft and digital manufacturing are combined

Outcomes of this work include expanded glassforming workflows using digital processes, an updated approach to craft and design education, and a furthering of the discourse on our emerging collective ecosystem of production.

The design study presented here encompasses three main aspects. These include:

- Material research, developing workflows that include 3D printing and traditional glass working techniques;

- A course-led study, in the form of a third-year design course at Emily Carr;

- And a reflective practice throughout these activities, which serves to inform a mixed craft/design methodology and approach.

This study is founded on theories of creating and knowledge, the key concepts of which are introduced in the following section. These concepts and my remarks are interrelated, and serve to mark the conceptual boundaries within which this project is framed.

Materiality and Virtual Space

A creative's practice encompasses varying aspects depending on their goals, disposition and skill sets. The term can describe individuals who draw on varied approaches to craft and design, including digital manufacturing. Their practice may be driven by anything from a rich interest in historical technique, to an ethos of responsible production, or perhaps a philosophical search for meaning through objects in an age of uniformity. It may be the route to making a critical comment, might be driven by social engagement, or reflect a desire for autonomy in work and in life. Wherever the work locates itself, the practitioner's relationship with materials is a central focus. The understanding that the ideas which arise through materials and processes are as valid as the ideas that the creative brings to the project is vital to a material-centric practice.

As material production is increasingly informed by digital manufacturing, defining materiality and how a creative can bring this approach into their work in virtual space becomes relevant. Seelig (2009) describes a relationship with materials, saying:

> To make form that responds only to a material's physical properties – to what it can do rather that what it encourages us to do – more often produces results that are predictable and familiar. The artist's ability to discover qualities in materials that go beyond their scientific properties will provoke form with a far more convincing sense of expression… materials contain clues that allow us to discover our own personal sense of reality through a subconscious process, an intuitive, creative process in which material is an active partner. (p. 55)

Seelig's (2009) idea of responding to materials in terms of "what they encourage us to do" (p. 55) refers to the experimental dialogue that practitioners enter into with materials. This concept can be a challenge for practitioners arriving at their materials from within an outcome-driven culture and mentality. Creating for ideation, producing a design slowly, and reflectively moving through production processes are methods that generate a specific type of knowledge.

Knowledge of materials refers to an understanding of the physical characteristics of the material, and also the meanings that that material carries. To be with a material through as many stages of its transformation as possible gives a practitioner insight into how a material may take on meanings through its origins and processes. For example, a glass artwork may be made from the raw materials of sand, soda and lime, mixed and melted by the craftsperson, or it may be made from re-melting discarded florescent tubes. Each of these material origins may allow a different type of discourse through the produced object. A 3D printed object may be made using a filament derived from petroleum extracted at Fort McMurray, Albert or a corn-based filament extracted from corn fibre, using the same machine and resulting in a dimensionally similar 3D printed object. The origin of the material used, however, allows for a different set of meanings to be ascribed to the objects produced.

In a similar way, practitioners may gain insight through the processes that their materials go through. In the above example, consider the practitioner being with the material from its raw state, as it is prepared as a stock material, to its use in production processes. At each of these stages of transmutation, there is the opportunity for a more expansive understanding of material. In her essay "'Reading' the Language of Objects," Fariello (2005) points to transmutation – the transformation of material via process – as part of an *expansive making* methodology that gives creatives the potential to "lead in an infinite number of directions" (p. 154).

The knowledge of how materials take on meanings through their origins and processes gives practitioners an intuition about their materials that is essential to a design process, consequently giving them a stronger visual language to draw upon. Pye (1968) lauds the value inherent in a deep understanding of material practice, asserting, "there is in the man-made world a whole domain of quality which is not the result of design… the designer is deep in its debt, for every card in his hand was put there originally by the workman" (p. 2); this knowledge is especially valuable when a creative is acting as both designer and craftsperson.

This *expansive making* methodology, central to building the resources from which to design, is a creative approach which at first glance does not seem well suited to the linearity of the virtual spaces of computer-aided design (CAD) or computer-aided manufacturing (CAM). Materiality is what we touch, feel, and break; it is tangible, something offering haptic feedback, texture, and temperature. Virtual space is limitless and infinitely replicable, existing in a perfectly theoretical space without any of the direct physicality of material. The words *virtual material* seem an obvious oxymoron. In her disertation, "Integrating Digital Design and Fabrication and Craft Production," Kamath (2009) contends that craft thrives on physical phenomena that are computationally unpredictable. Where are the knots, the cracks, the loose threads in a 3D printed object? When a creative is engaged with a traditional material, they are working in the realm of risk and error; in their response to error, the creative discovers and learns. It can be hard to see where risk and error might be found when working in virtual space.

Pye (1968) presents his view of risk and certainty related to craft making in the context of mechanized production in *The Nature and Art of Workmanship*. Pye describes two types of workmanship – the workmanship of certainty and the workmanship of risk. *Workmanship of certainty* refers to industrial production and industrial design, the goal being to design, prototype and test repeatedly until results are 100% predictable – a traditional industrial design fabrication method. Pye describes *workmanship of risk* as a realm where individuals, not entire industrial systems, hold the key to success (as cited in Malins, Press & McKillop, 2004). In this production system, any mistake on the part of the creative at any point in the process could ruin the final object. In the hands of the practitioner, the work could be destroyed, or improved, through their direct actions. In this space of risk and potential error, is the possibility of responding to any error and thereby gaining information about process and material.

With our recent, broad access to digital manufacturing, we may apply Fariello's (2005) approach of expansive making with traditional materials to virtual space by using process for idea generation, and employing the workmanship of risk to gain information about our virtual material, just as we might with traditional materials. We may also seek to expand our understanding of and the poetics of traditional materials. These considerations can guide us to use approaches that are fruitful in traditional spaces in virtual spaces as well, creating opportunities for expansive making using virtual materials.

Shifting Meanings in Virtual Space

How do our associations of value, and the creation of meaning, shift as we begin to work creatively using machines which allow infinitely replicable, yet easily customizable objects? In this section, I consider perspectives on the creation of value and meaning in objects in the context of digital manufacturing. Chikszentmihalyi's (1991) exploration into quantifying the creation of value, "Design and Order in Everyday Life," considers how possessions create meaning for an individual. He concludes that objects create meaning and order in our lives when they symbolize our values. To the owner, an object in the home may reflect the socio-economic conditions in which it was produced, reflect considerations of environmental impact and product life-cycle, or symbolize a relationship to a giver (if it was a gift) or to a memory (as in an heirloom). While Chikszentmihalyi addresses the creation of meaning through symbolic representation imposed by an owner onto an object, he does not touch upon the information that a creative embeds into an object. This information, which might include design affordances, aesthetic choices or historical references, for example, can be embedded by a creative and can become points of access for a viewer to reflect their own values.

This relationship between what a creative has to say through an object and how a viewer reads an object can be further described in terms of information and meaning. In *Why We Make Things and Why it Matters*, Korn (2015) defines the difference between information and meaning in the context of objects, saying

> Information is intrinsic and permanent. It resides in the object's physical characteristics, which are an unchanging record of thousands of decisions made by its maker during its creation. Meaning, on the other hand, is extrinsic and subjective. It resides in the minds of respondents, and will differ among them, just as two readers may arrive at widely divergent interpretations of the same text. (p. 65)

The values of the creative are expressed through that embedded information and made accessible to the viewer, providing points of access for the creation of meaning by the viewer. These values are often the starting point of the practice itself, informing not only what the practitioner wants to make, but who they want to be, in a philosophical sense. Korn (2015) explains, "My own values became clear when I eventually realized that the words I used to describe my aesthetic goals as a furniture maker – integrity, simplicity, and grace – also described the person I sought to grow into through the practice of craftsmanship" (p. 102). In this way, a link is established between a creative's mode of being and the values they seek in their life, and what they make. These values become the embodied values of the object, and are made accessible to viewers in a physical way.

This conversation through objects is made possible through a creative's relationship to materials as described in the previous section; that relationship is a direct result of engaging with materials and their affordances. This association is also often an abstraction of the material processes, as the centering of clay to a potter may be broadened into a philosophy of life. This abstraction is an important part of the creation of meaning – it allows a creative to relate to the world through a new lens, and share that view with others through objects. As we begin to work in virtual space, where is the opportunity to express the values and meanings we find in materials? Moving into virtual space, how does the creative retain their link to what is made when the process is digitally mediated?

Massumi (2002) suggests a starting point for understanding how creatives and viewers can find meaning in digitally mediated products, by turning to a familiar example:

> All of the possible combinations of letters are enveloped in the zeroes and ones of ASCII code. You could say that entire language systems are numerically enveloped in it. But what is processed inside the computer is code, not words. The words appear on screen, in being read. Reading is the qualitative transformation of alphabetical figures into figures of speech and thought. This is an analog process. Outside its appearance, the digital is electronic nothingness, pure systemic possibility. Its appearance from electronic limbo is one with its analog transformation. (p.138)

Drawing on word-processing for this example, Massumi alludes to digital space as a site of infinite possibility, but one wherein potential can only be realized when an idea is translated or connected to the analogue. This translation, or transition, from one state to another is analogous to the transmutation of material for a material-centric practitioner. To carry the analogy further, in the context of a relationship with materials, a creative can find opportunities in knowing the virtual material, or its grain, intrinsic qualities, and embedded metaphors. In this sense, a connection to the creative may arise from their interaction with virtual space, and be extracted by them into analogue space. Without this relationship to the virtual materials, the practitioner risks making what Lunenfeld (2001) describes as "artefacts of digital culture whose appeal is essentially their perceived novelty. They attract less for what they mean than for the fact that they are" (p. 173). Without consciously forming a relationship to virtual space, employing the workmanship of risk in this realm of certainty, and pursuing an individual line of inquiry, objects made using digital manufacturing run the risk of expressing only technological enchantment.

New production paradigms open up space for creatives where considerations of materiality and meaning are shared between digital and analogue processes. How we respond, consider, and look at this shared digital/analogue space allows us to make the best use of our new access to these technologies. We can respond to virtual space in terms of what it encourages us to do, much in the same way that we can respond to how traditional materials encourage us to work in certain ways. We can consider the whole process of production in virtual space, from CAD to CAM to output, as points in an expansive making methodology, similar to Fariello's (2005) discussion of points of transmutation with traditional materials. We can look for points of risk, as described by Pye (1968), and consider how to subvert the predetermined nature of digital manufacturing processes. These considerations of materiality, meaning and abstraction, shared between digital and analogue processes, fortify links back to the creative, as the creative forms relationships with digitally mediated processes.

Creative Design Study: Practicing and Teaching Creation in a Digital Environment

I synthesized my motivations and the theories outlined above over the span of two years, as a two-tiered study. My ongoing, practice-led study into the development of novel workflows incorporating 3D printing and glasswork informed my approach to digital manufacturing and this aspect of my creative practice. The study is presented here in two sections: Practice-led and Course-led.

Practice-led Study: Digital Methods and Traditional Glassworking

My practice-led study focused on innovative techniques associated with glass tools and processes. In parallel with this practice, I documented reflections on both artifacts and processes through journaling. This reflective practice attended to both the formal considerations of structure and form and the nature of phenomena and materials. The resulting documentation includes discussions on:

- Making information visual using symbols and mapping
- Conversations regarding outcomes with participants and collaborators
- Comparisons of different works to discover similarities and differences
- Analogy and metaphor to abstract the work
- Sorting information into a creative framework, i.e. a mock exhibition with a theoretical statement
- Insights from both a micro view and a macro view

These were valuable lenses through which to consider and synthesize the outcomes of my practice-led study. The study itself is concerned with the building-up of information, and the artifacts that I produced are the result of a consistent investigative process. A discussion of the practice-led work is presented here. Technical details referring to the development of the process of 3D printing glass and moulds for glass casting are attached as the Appendix.

Optic Tableware and *Rise*

My approach for this project was to use the digital prototyping resources at Emily Carr in an intuitive way, with my previous knowledge of glass as a guide. I created two works, *Optic Tableware* and *Rise*, using novel workflows enabled by digital manufacturing, though still based in traditional glassworking methods. By *workflow*, I mean a methodical process of fabrication wherein a set series of actions produces a predictable result. A traditional workflow for glassworking includes melting material, forming, annealing, and cutting and polishing. My novel workflows incorporated digital manufacturing into a traditional workflow.

Optic Tableware draws on glassblowing and CNC milling – a subtractive digital manufacturing process, in which an automated machine cuts away from stock material according to a digital model. In this case, I machine cut plates of brass according to a digital model, and then hand rolled them into a form suitable for a glassblowing mould. A shift from traditional moulds used to create uniform texture in glass, this mould accentuates the seam and handmade variation, while referencing machined production. The seam became an important focus, as it broke the monotony of the machined pattern, and led me to further exploration. In all, I made three moulds in this series, each building on the successes of the previous.

My considerations for this work were historical reference (the traditional optic mould in glassblowing), the ontological decoration of virtual space (i.e. its intrinsic aesthetic), and an overt reference to handmade production (the seam). I wanted the work to use the efficiencies of CNC milling, yet retain a connection to a mode of handmade production. What I ended up creating was read either as handmade, or machine-made. Dormer (1997) asks us to consider the Turing Test[1] as it applies to craft and digital manufacturing – what does it mean that the line between handwork and machine made becomes nearly indistinguishable when using digital manufacturing?

Dormer's question became increasingly intriguing to me, as viewers mistook my blown glass tableware for 3D printed glass. There is an assumption by most viewers that most objects in the prototyping lab that my work was displayed in are 3D printed, however this was also indicative of a broader assumption within the general population that 3D printing is capable of anything. To me, the hand/machine aesthetic was a subtle reference to the broader question of how a craftsperson might approach digital manufacturing. According to Korn's (2015) definition (p. 9), this was information I was placing in the object. To others, of course, this aesthetic presented different meanings, and because it

[1] In artificial intelligence, the Turing Test is a method for determining whether or not a computer is capable of thinking like a human. According to this kind of test, a computer is deemed to have artificial intelligence if it can mimic human responses under specific conditions. In Turing's test, if the human being conducting the test is unable to consistently determine whether an answer has been given by a computer or by another human being, then the computer is considered to have "passed" the test (Dormer, 1997).

was necessary to look closely at the objects to catch the clues that they were in fact handmade, about half of viewers assumed they were completely machine fabricated.

Observing how people engaged with *Optic Tableware* deepened my understanding of the digital process, what it produces, and how those results are received. It is difficult to break away from what Adamson has refered to as the determinate language of digital fabrication (2010). That language is related to things that computers do well: repetition, scale, skewing, distorting. But is this a negative point? Does not every process and material have, in some sense, a predetermined visual language?

Within both digital fabrication and traditional craft processes, form and surface may follow the cue of the materials and processes. In architecture, this is referred to as ontological decoration – an example of this is in laid brickwork, which forms patterns through its application "and nothing more" (Brett, 2005, p. 220). Reflecting on *Optic Tableware,* and considering this perspective of a visual language predetermined by digital fabrication, I re-directed my approach. I wanted to look more closely at what computers do well, in the same way that a craftsperson would look closely at their material and take cues from what it does well. This is the inquiry that led me forward in my practice-led study, through work which I called *Rise*.

Rise was made in three media – animation, print, and glass. Using an animation program that has the ability to simulate natural forces such as wind, turbulence, and gravity, I animated bubbles rising through water. In virtual space, these rising bubbles were dynamic, three dimensional forms. When the animation was paused, it was possible to export the animated forms as three-dimensional objects. I then used these exported objects as positives, and made a 3D printed mould from them. In this way, I extracted the mould from the paused animation.

Rise was an opportunity for my relationship with traditional glassworking to extend into digital space. I think my previous work in glass has been strongest when I have followed the cues of the material, allowing heat and gravity and the forces working on the material to guide my decisions. In these cases, I have avoided overly interfering with the material, guiding it as it moves in its liquid state, and choosing the moment to pause and let it solidify. I think of this less as glassblowing, and more as creating compositions of the subtle forces that act on the material. Relating to the material in this way led me to see myself, and the people around me, in the same way – as compositions of the subtle forces at play in our lives. This is the way I relate to creating in glass, which is a result of working with glass over a period of time. *Rise* gave me the opportunity to take my conception of glass, developed through material practice, and extend this abstracted notion of material into digital space.

If this type of glassworking embodies Pye's (1968) *workmanship of risk,* where is the parallel in virtual space? I searched for this as an algorithmic risk involving virtual forces of gravity, wind and turbulence. However, this risk needed to be balanced with the pragmatics of casting glass. Here, material knowledge had to be balanced with the digital process; I chose a composition that would work well as a glass mould, where glass would flow into the chosen form. I used a 3D printer to make the mould from plaster (technical details in the Appendix); the ability to 3D print plaster moulds was received with enthusiasm within my creative community. While making *Rise*, I dedicated a significant amount of energy into the refinement of 3D printing plaster moulds for glass casting. I realized that moulds could be printed directly from animated forms, and in the animation a risk could be realized which had parallels to handwork.

After feedback and discussion, I showed the cast glass piece alongside the animation from which it was made, as well as a two-dimensional drawing of the animation. This composition of three media allowed viewers to engage with the work through video, print, or object. The effect of this juxtaposition was that as their gaze shifted from one piece to the next, viewers realized that each piece was an expression of the same digital data. To encourage viewers to engage with the work, I created a subtle experience, to be felt and easily entered into, allowing space for viewers to draw their own connections.

Rise allowed me to take cues from the digital platform; following those cues led to a new workflow for glass casting. Creating a form using simulations of forces such as wind and gravity resulted in a more dynamic composition for *Rise* than with *Optic Tableware,* and presented my response to the notion of a predetermined visual language of digital manufacturing. I brought my material knowledge into digital manufacturing through the pragmatics of the mould design and my abstraction of glass as a material, both of which are a result of my previous, more traditional glassworking experience. In this way, I used my tacit knowledge of the material in the development of the forms and tooling using digital manufacturing, and the outcomes are the result of both the knowledge of material and the affordances of the digital process.

Throughout this practice-led study, workflow opportunities were quickly revealed at each stage, from 3D model, to 3D print, to cast glass. In terms of expressive potential and fabrication methods, the 3D printing process makes new forms possible which were previously impossible. My work has successfully extended to include the use of 3D printed moulds for glassblowing, with the efficiency of the printing process compared to traditional plaster work, along with the opportunity for extended expressions with glass, continuing to motivate my practice.

Course-Led Study: Engaging Students with CAD and Glasswork

Digital Making and Glass was offered as a course to students at Emily Carr in both the Design and Visual Arts streams. My intention for the course was to give students guidance in both digital and analogue learning spaces, and to discover the dialogues and actions that occurred when the class occupied this space. Sixteen students took part in the course, which consisted of seven classes in the hot glass studio at Terminal City Glass Co-op in Vancouver, and seven in computer and prototyping labs at Emily Carr. Moving back and forth between material explorations and digital design, students physically and mentally occupied a mixed analogue and digital space. All of the students' projects incorporated new digital manufacturing methods along with traditional glass-forming studio work. Most students had little or no knowledge of working with digital manufacturing or with glass. They were guided through the glass portion and the digital portion by Phillip Robbins, prototyping lab technician at Emily Carr, and myself.

The design of this course, and its theoretical approach to production, was directed by the definition of a contemporary creative practitioner as empowered by both localized/tacit and explicit/distributed knowledge. Dormer (1997) describes two types of knowledge, *personal knowledge* and *distributed knowledge*, with personal knowledge being very similar to tacit knowledge - highly individual, and arising from personal experience. Dormer's conception of distributed knowledge relies on two core concepts: first, that in our current age any object that is made requires many different knowledges to bring it into being, and second, that many products combine and embody many other people's knowledge.

I designed the course in two modules, with each module focused on a unique aspect of glassworking and a corresponding digital manufacturing technology. The modules were sequenced to build both tacit skill and explicit knowledge in parallel as the course progressed. Module one served as an introduction to working with hot glass, working in a glass studio, using a prototyping lab and 3D printing, using Adobe Illustrator, and using a CNC machine. Students designed a tool in Illustrator, and then used the CNC machine to make the tool in brass. Students were introduced to glass in its molten state, and after gaining some basic skills, challenged to experiment with their brass tool. In order to encourage experimentation and ideation, and discourage infatuation and attachment to any specific object, all work that students produced was in clear glass, which was later recycled. We informed students at the beginning of the course that everything they produced would be re-melted in the furnace, and that they would keep only the few pieces needed for their final project.

This strategy enabled some students to go deeply into ideation through the material. Others were more interested in producing what they had originally designed. The course pushed students to enter into an experimental headspace of ideation through material – to take the material as it was. Students gained tacit knowledge, learning how to react physically to questions they had about the material. How does it move when it is a liquid? Where does it fracture? How does it flow into a mould? Challenging the students to enter this type of headspace was an important element of the course, so they could experience the immediacy of the material, and then bring that same approach into a digital space in the other component of the class.

The first module overlapped with a research project in which students chose a topic related to either an aspect of traditional glassworking methods or innovative use of glass and technology. At the completion of module one and the research project, students had gained a level of understanding of both the physical material and aspects of its historic and contemporary context, laying the foundation for the final project in module two. Module two challenged the students, working in groups, to incorporate glassblowing, 3D printing, Rhino (a CAD program), and traditional mould making to realize a series of glass objects.

Working creatively in CAD is a challenge. Students were eager to learn, but were challenged by the steep learning curve of CAD. When students were able to broaden their scope, however, and conceive of the whole process from CAD, to 3D print output, to glassblowing mould, they were better able to work creatively in digital space. By linking CAD to material outputs, students were able to conceive of each step as an equal opportunity for creativity. For example, if some found CAD to be creatively narrow, they could view the 3D printed object or the mould making steps as better suited for creative expression. When this broader approach was taken, the digital space became less intimidating, and the conception of it less prescriptive.

The course placed students in a liminal space, challenging them to combine analogue and digital processes. My practice-led study guided me in developing this course-led study, giving me the experience and tools to design and sequence a learning experience for students. While my own interest in the course was to better understand how material and digital approaches might intersect, there were significant learning outcomes for students: a first hand understanding of glass and its contemporary context, as well as CAD and 3D printing knowledge. Robbins and I designed the course taking into consideration how and when students undertook which activities and challenges. After the course, it became apparent how this method might be refined, insights which are useful in an educational sense, and may also extend more broadly to the craft practitioner. Further consideration of these experiences, whether in the context of course development or exploration of studio workflows, will be an avenue for future study.

Insights

Conditions of production are rapidly shifting, due to broadening access to digital manufacturing devices; inquiries into this area guide our approach and help us understand the impact of this paradigm shift for our material culture. Both the practice-led and course-led studies presented in this paper illuminate a need for novel methods with which to approach digital manufacturing. The emergent approach to digital manufacturing described in this study considers the appropriate strengths of both digital and analogue spaces, in the interest of identifying emerging opportunities in material expression.

Emergent Production Paradigm

In my experience, I found the necessity of front-loading much of the creative decision making when working with digital manufacturing to be at odds with a traditional material approach of ideation through material interaction. I began to see this differentiation manifest in the distinction between tacit/localized and explicit/distributed knowledge. This observation was affirmed in the course-led study, where students engaged with these two different approaches, gaining two different types of knowledge – a poetic, personal ideation through material, and an understanding of digital tools and their embodied distributed knowledge through their virtual work.

Both the practice-led and course-led studies demonstrated that access to digital manufacturing has opened up a new creative space. This space is difficult to define, as it is an emerging space. I have the sense that this creative space cannot be defined by a practice, such as digital craft practitioner, or creative CAD designer. Rather, this emerging creative space is more appropriately conceived of as a catalyst – a space that in and of itself does not offer anything specific, but that encourages reactions to occur. In my view, our emerging production paradigm, enabled by access to digital manufacturing, does not need to be defined by a new practice or practitioner. Our best use of our new access to digital manufacturing is to let it be the catalyst – a place where creatives work using the approaches they deem appropriate, a place where different disciplines come into tension, react, and ignite each other.

Emergent Method

Sustained efforts are needed for inquiries into the meanings, emerging modes of expression, and visual language offered by digital manufacturing. In both the practice-led and course-led studies, I noted that a challenge when working in this space is to identify and navigate the pre-determined, linear, and potentially monotonous nature of working with CAD and in virtual spaces. Furniture maker Baier (2011) comments that if practitioners do not push and pervert digital technologies, their role of author or composer is downgraded to performer; I observed this in the course-led study as a distinction in the way that students approached creating in virtual space. Students tended to conceive of virtual space as either a creative, personal, poetic ideation space, or as a tool for executing their idea – the former group being composers, and the latter being performers. When students moved towards the performer role, faculty interventions encouraged them to move away from established systems of design and prescribed results, and toward experiments that had the possibility of encouraging access to new paradigms of production. When students moved towards the composer role in virtual space, they became motivated by process, and a personal, deeper expression was made possible in their work.

During and after the course-led study, I began to develop principles to guide approaches to digital space. Without a conscious method of approach, creatives can find digital space restrictive, and quickly downgrade their role from author to performer. The practice-led and course-led studies both aimed to access elements of risk in a realm of certainty, to explore the poetics and materiality of virtual space, and to promote a critique of the digital/analogue dichotomy. Existing in this liminal space, this study begins to open the door on an emerging method that connects material knowledge and digital manufacturing.

Balancing a material approach and digital manufacturing, this emerging method contends that the methodical steps of ideation, divergent and convergent thinking, and iterative prototyping need to occur in both the material space and the digital space. The balance of where and when these steps occur is determined by the affordances and restrictions offered by the digital and analogue spaces that the creative is working within. The analogue approach generates knowledge from which to design in the digital realm; ideation through traditional materials, however, often requires more time and reflection than digital ideation. Digital ideation can be quick and effective, but on the other hand, if used uncritically, may lack the abstraction and potential poetics found in working directly with materials. The benefits of digital design, such as its effectiveness at iterative prototyping, can be put to good use, however, when combined with a material practice that looks for happy accidents. These concepts may inform a method and approach to combining digital and analogue production such that both offer a space for imaginative creation. In essence, they offer a balance of tacit knowledge learned through craft practices, and broadly sourced knowledge found in digital manufacturing devices.

Closing: Hybridizing our Creation Knowledge and Spaces

At a recent symposium, Tina Aufiero, education director at Pilchuck Glass School, commented: "Pilchuck has been open-source since the 70s… although we haven't been calling it that". There are several significant suggestions in Aufiero's comment. First, while Pilchuck, and more broadly the material-based community, has not historically called their open knowledge sharing *open-source*, they are now. That is, they are actively engaging with the language of digital production, alongside digital processes, and are acknowledging the connections being made. The comment also acknowledges the importance of open information to Pilchuck, and by inference the material-based community, which has developed based on the open sharing of information. This information might include where to source materials, ideal temperatures for glass melting, recipes for colour, and furnace designs. But there is often also a hidden layer of information – references to canonical works, indications of traditional or experimental processes or materials, cues that point to or expound on contemporary issues – that is also shared. Works in traditional materials have a strong catalogue of this hidden information, and endless precedent to refer to. What is the hidden information in an object produced through digital methods, when a sketch becomes a scan, then a digital render, and finally a digital output? As we celebrate the concept of open-source and the inclusion of digital processes, creatives must work to develop rich layers of meaning in these processes, or risk becoming performers of the digital process, making enchanting, but vacant objects.

As we hybridize knowledge bases that creative practices are built on, we also somewhat align this hidden information of objects. Over the course of this study, I saw the subtexts of combined analogue and digital objects allow for a richer, sublime expression in the things we make. One student project, for example, used abstracted satellite data to generate a digital form, and glass as a material to express stratification. The form generated from satellite data spoke to a new interpretation of our environment, while the layered glass referenced the layering of information and an analogue history. The students were able to abstract the objects and processes in both the analogue and digital spaces, expanding the visual language of the objects they produced. This understanding of the expressive potential of the abstracted digital object could not be similarly gained were the steps in the making process segregated.

In our current era of broad access to digital tools, we are able for the first time to use these tools in a creative way, to engage with digital processes from ideation to output. We are afforded individual expression by using digital processes through our entire production process, an expression that would not come about if the digital and analogue processes were segregated. Using digital processes fully, we can allow our intuition to develop and use these processes to find new meanings and expressions in how we relate to the world through what we make. Seelig (2009) conceived of material such as glass, ceramics, wood, and metals, as an active partner in production. In the spirit of Seelig, digital processes may also become an active partner, as we re-imagine our relationship to digital production.

At the close of this study are the beginnings of new inquiry. This new inquiry relates to the ethos that we may adopt as we develop these new material pathways to making objects. It questions notions of efficiency that are assumed inherent in digital production. It considers that an efficient and customizable production process like 3D printing still produces objects which may be discarded prematurely in our throw-away culture. This new inquiry is centred on longevity in the things we make, and asks where the affordances are in a mixed analogue/digital practice that support longevity in goods. It is related to the ethos of the first Arts and Crafts movement, but prioritizes the ecological impact of production. Its aim is to use our new tools and methods related to the production of goods, some of which have been discussed in this paper, and mobilize them to address issues relevant in this time and place.

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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.

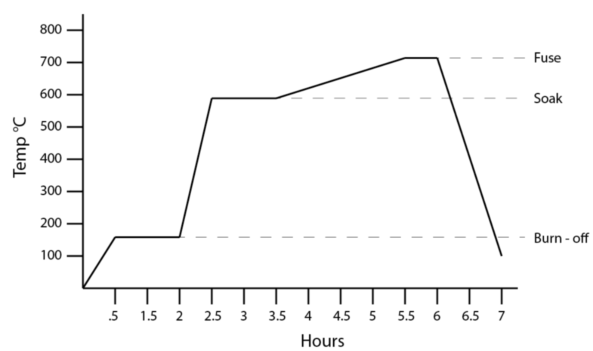

Figure 1: *Our typical firing program for 3DP glass*

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.

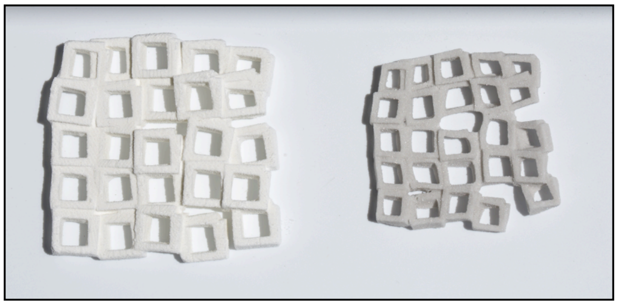

Figure 2: *Left, unfired 3DP glass Right, fired to 690°C for 10m*

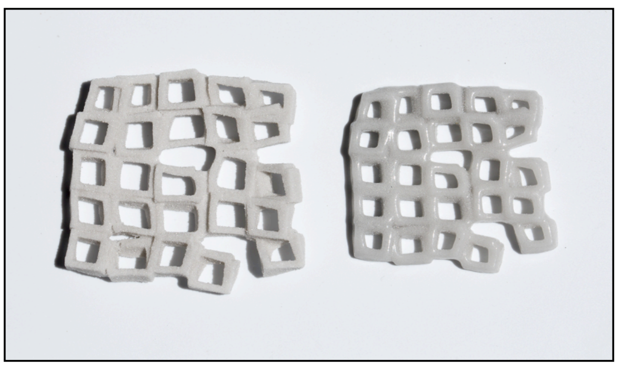

Figure 3: *Loss of detail as transparency is achieved*

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.

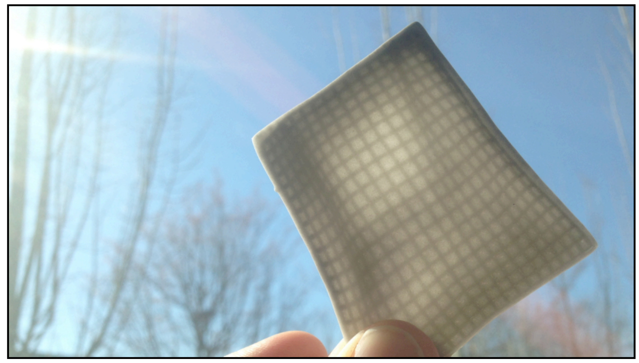

Figure 4: *3mm model shows translucent quality of 3DP glass*

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.

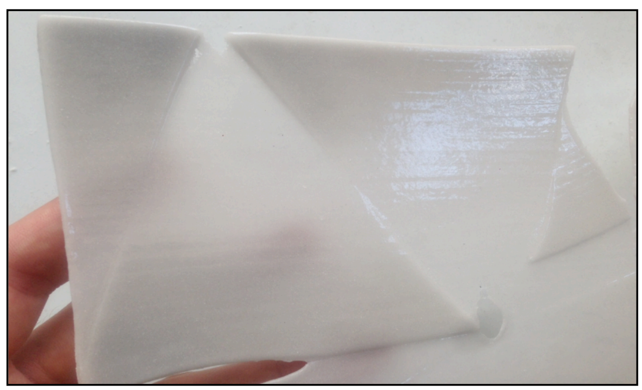

Figure 5: *Larger 3DP sheet with gradated depth*

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.

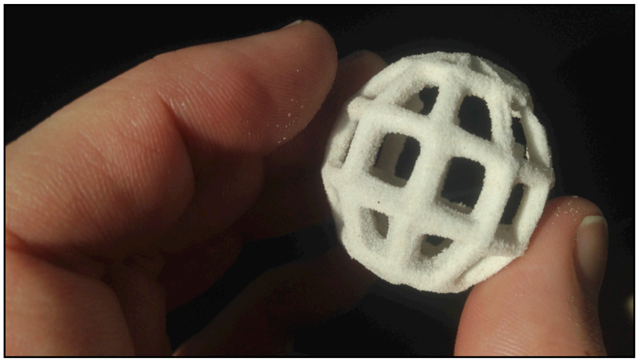

Figure 6: *3DP glass sphere fired in support material*

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.

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

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

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.

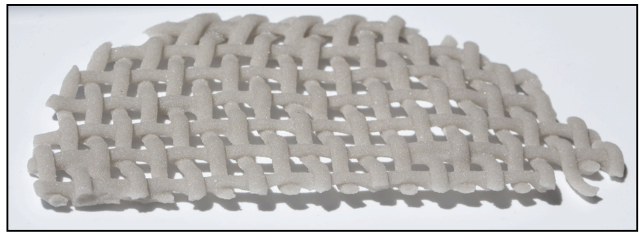

Figure 9: *Fired, translucent 3DP glass*

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.

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

Figure 14: *Detail of full glass cast*

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 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.

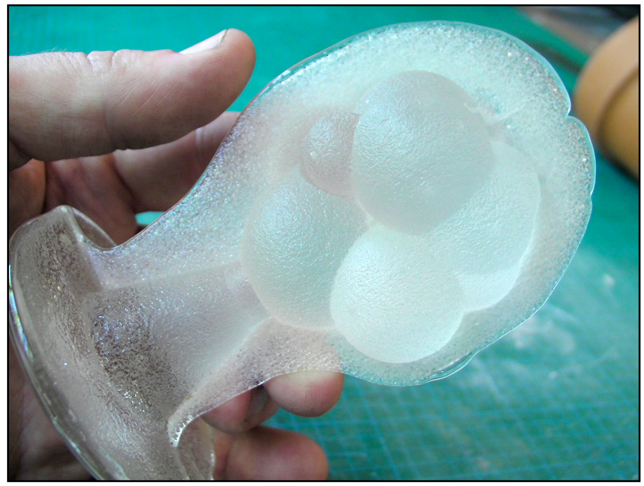

Figure 16: *Surface detail, form and seam flashing, post-casting*

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.