Hybridizing Emergent Digital Methodologies Across Legacy Creation Ecosystems

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Abstract

Material Matters – a research cluster within the Intersections Digital Studios of Emily Carr University – is exploring new digital technologies as an analogue to traditional methods and materials. As technologies become less expensive, more powerful and more pervasive they diffuse into a wider range of opportunities. As new means of creative production emerge, they intersect with established practice. Material Matters examines these points of contact.

3D printing is an emergent digital technology experiencing explosive growth; a proliferation of applications and technologies is multiplying across a very broad spectrum of activity. As the technology matures and disseminates, the 3D printing ecosystem grows and diversifies, and avenues for innovation proliferate.

Material Matters is examining a diversity of conceptually interlinked inquiries framed by this new production platform. We are developing alternate pathways to object making that conflates the new digital opportunity with the inherent strength of legacy process.

Conceived as symbiotic methods, rather than discreet, self-contained systems, we are examining how new technological means can interconnect and carry forward legacy process rather than simply supplanting it.

Keywords: *Cost, 3D printing, legacy process, tacit knowledge, metal casting, slip casting.*

Background

Recent years have witnessed a strong consolidation of technology and service with wide commercial market speculation on this potentially revolutionary wave of manufacturing or DDM (Direct Digital Manufacturing) (Singer, et al., 2011). Consolidation of the commercial market is made doubly evident by the recent mergers of the major North American commercial 3D print technology manufacturers and suppliers; 3DSystems and Z-Corp, and most recently; Stratasys and Objet (Hurst, 2013). These companies previously defined the main pillars of the North American commercial market's share of 3D print service, technology and material systems.

Concurrent to this market based consolidation, open source additive manufacturing technologies, which are built upon an extremely fluid digital infrastructure allowing an unprecedented level of public participation and interaction are developing at a rapid pace. Powerful computer systems, affordable, full-featured 3D modeling programs, and high-speed communications networks allow for the design, production, sharing and refinement of any aspect of 3D printing's architecture. As a result, an open-source community is driving the demand, development and distribution of a broad spectrum of inexpensive, high-resolution 3D printing technology.

Easily slotting into a home workshop, a studio, an office or emergent make-space, 3D printers have equipped the eager, engaged practitioner with a diversity of means for 3D form production. Further, Open-Source Appropriate Technology (OSAT) (Pearce, et al., 2012, pp. 17-29) and the widespread search for increasing economy in material cost, selection and ecological impact are rapidly re-defining what it means to have a sustainable, small-scale, personal production platform.

This proliferation of 3D printing technologies is leveraged by the inherent simplicity of its underlying premise: (1.) the processing of virtual, 3D, digital objects into *slices* and (2.) the accurate, sequential printing of these slices. Objects of nearly any complexity are recreated physically, layer-by-layer, utilizing FDM (Fused Deposition Modeling- plastic filament), SLS (Selective Laser Sintering-laser melted powdered substrates), SLA (Stereolithography – UV curable resins), LOM (Laminate Object Manufacturing – thin foils and papers) and 3DP (3D printing – powders set with printed binders). Each of these genres of printing have been championed by various commercial entities, and though built upon the original simple premise of slicing and outputting, commercial machines have come to represent the pinnacle of accuracy, reliability and resolution, but at a cost.

To date, commercial machines have ranged from expensive to extraordinarily expensive. Commercial machines have tended to target large, and well funded, industrial market segments such as the automotive industry, aerospace, architecture and industrial design. Furthermore, 3D printing consumables (the materials that actually comprise the 3D print) have typically cost hundreds of dollars per pound/gallon regardless of the printer type. This cost structure has acted as a significant impediment for a broad spectrum of potential users as the capabilities of the technology are directly impacted by the overall expense of the printed object. The more expensive an object is to output it becomes less likely to be created.

The first research objectives this papers seeks to illustrate, explore the ways of capitalizing on the strengths of the previously mentioned communities: the burgeoning open source with its hands-on, egalitarian and highly accessible developments, and the parallel advancements within the high quality, closed source, for profit, commercial sector, combining them to produce accessible, high quality results at the lowest cost.

The initial objective of this research sought to replicate commercial 3D printable consumables for powder and binder based printing (3DP), utilizing a relatively inexpensive, and somewhat obsolete, Zcorp 310 printer (the 310 offers the identical mechanical functionality of higher end 3DP machines but with a comparatively limited feature set), and materials that are readily available at low cost. The primary advantage of hacking 3DP is that it utilizes some of the most straightforward printing materials available and does not require the complex production of specialized filaments (FDM), exotic photo-polymers (SLA) or difficult to manufacture powdered metals and plastics (SLS).

The second objective of this research is to explore the new methodological pathways created as the cost barriers inherent to 3D printing are reduced. Inexpensive, plaster based, printed objects not only allows for the creation of more or larger scale editions but also enables the production of objects of very different function – objects that begin to interact with existing ways of making.

Objective One: Reformulate commercial consumables to drastically reduce cost

Through an inference of the constituents of commercial powder-based consumables (gypsum based, hygroscopic [moisture attracting], easily screed-able, strong green strength, high resolution output) a test regime was initiated to systematically replicate these characteristics. Initially, a baseline printable material was examined to investigate the viability of US Gypsum's 'Hydroperm' plaster. This initial work builds on the pioneering research by Dr. Mark Ganter at the Open3DP lad at the University of Washington. Hydroperm has a number of desirable characteristics: it is readily available at a relatively low cost; it is a plaster based material that replicates the fundamental characteristics of commercial 3DP materials; and it is has both absorbent and refractory characteristics.

By itself, Hydroperm, though printable, produces less than satisfactory results. A fundamental characteristic of 3DP printing is the systematic, predictable transportation and deposition of a thin, flat layer of powdered material from a supply reservoir to a build reservoir via a rotating spreader bar. Hydroperm can be mechanically transported from one of these reservoirs to the other, but with random inconsistencies. Periodically, as material is collected in the supply reservoir and pushed to the build reservoir, it interacts with the previously deposited layers beneath it, dragging them out of position. This dragging may be repaired by a subsequent pass of the spreader bar or may recur in the same or other locations(s), producing objects with incomplete edges and unsatisfactory surfaces. Despite these inconsistencies, initial results did show that it is possible to print *off the shelf* materials directly, with no prior reformulation, but not to a standard that matches the surface resolution or reliability of commercial materials.

This issue of *spreadability* is partially the result of plaster's cohesive characteristics as plaster, in its powdered state, wants to aggregate or clump to some degree. A solution to this *clumpyness* was found within the food processing industry. Many dry, fine-grained foodstuffs tend to stick to themselves during processing, creating difficulties for material handling. Calcium carbonate is employed as a food grade anti-caking agent to improve flow characteristics. Fortuitously for Emily Carr, as an Art and Design institution, it is also used extensively within a multitude of ceramics processes as an important and inexpensive constituent in clays and glazes. The addition of calcium carbonate to Hydroperm produces

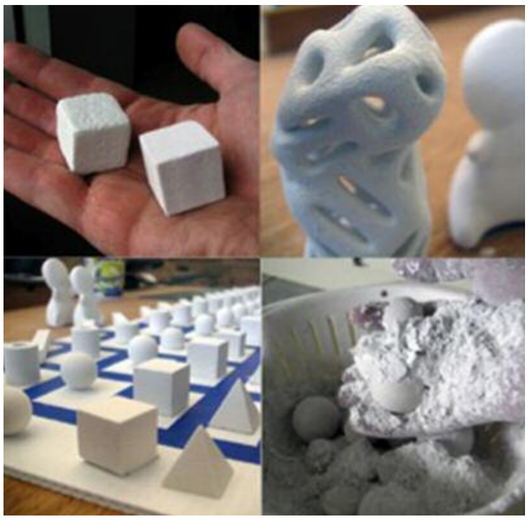

Image 1

Image 1.
Clockwise from top left:
Initial comparative tests, (left) basic powder formulation (right) commercial powder.
First *proof of concept* print with new powder formulation.
Ball-mill processing of powder for uniform consistency.
Selection of iterative tests – closest objects, commercial material, and next closest, best formulation of *off the shelf* powder.

a more predictable, free-flowing transportation and deposition of the powder.

Objects printed with a combination of Hydroperm and calcium carbonate produce outputs with predictable spread characteristics and relatively high surface qualities, but with relatively low green strength (the robustness of an object after printing but before final infiltration with waxes or adhesives). A solution also came from a food grade material – Maltodextrin.

Maltodextrin, a fine-grained sugar used in the brewing industry, adds considerably to green strength and resolution. Maltodextrin's small particle size allow it to evenly diffuse through the hydroperm/calcium carbonate powder, creating three positive, interrelated scenarios:

1. Sugar is highly hygroscopic and readily accepts the printed binder as it is being applied.
2. Sugar liquefies and gels relatively quickly, thus holding the binder in place, and preventing excessive wicking into adjacent material.
3. As sugar dries it recrystallizes, forming a relatively firm matrix within and between printed layers allowing for strong green strength to develop.

The combination of these three constituents – Hydroperm, calcium carbonate and maltodextrin – produced a workable material with good spreadability, relatively high resolution and good green strength. At this point a test regime was initiated to determine an optimal ratio of constituents.

Through a series of 75 iterations a powder formulation was devised that closely replicates commercial powder's characteristics but at a considerable reduction in cost. Commercial materials for 3DP based printing typically cost in the range of $50 a pound, this reformulated material, using readily available and inexpensive constituents, costs in the range of .50¢ a pound. This 20X reduction in cost has enabled the production of cost effective objects much more readily and at a much larger scale than was previously financially feasible and enabled the examination of an entirely different class of objects that explore questions of complementary production methods and hybridized digital workflows.

Objective Two: Integration with legacy process

The second trajectory of this research examines how the disruptive capacity of inexpensive object printing can be harnessed as a way to interconnect new digital methods with legacy processes (ceramic slip casting andnon-ferrous metal casting).

Relatively large moulds for casting can now be printed affordably, creating a new type of digital workflow that jumps directly from the virtual (the digital model) to the actual (the cast-able mould) with no intervening steps. The moulds printed with this new powder formulation display two distinct and important characteristics: they are hygroscopic (they want to absorb moisture) and they are refractory (they can

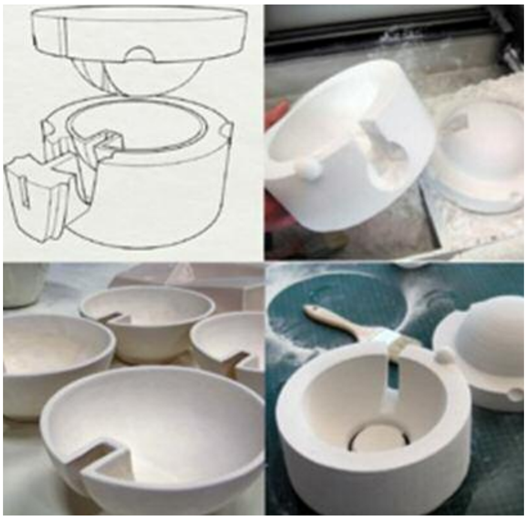

Image 2

Image 2.
Ceramic slip casting, *clockwise from top left:* Digital mould design; printed mould being removed from printer; mould components prepped for slip-casting; ceramic object slip cast from digital moulds.

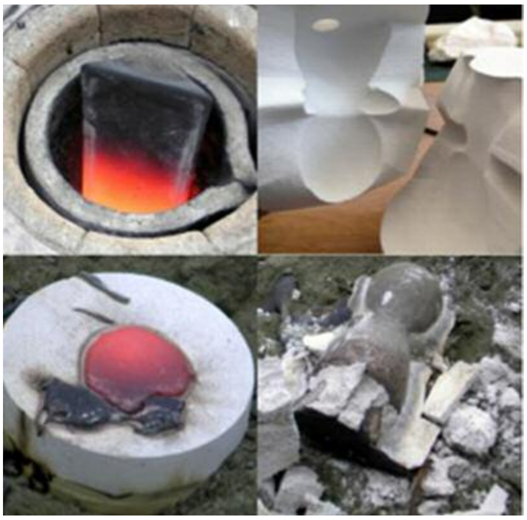

Image 3

Image 3.
Non-ferrous metal casting, *clockwise from top left:* Bronze ingot being melted in induction furnace; mould components printed and ready for casting; removal of mould to reveal cast metal object; mould soon after being filled with moulten bronze.

withstand high heat). These characteristics have allowed two streams of inquiry to emerge.

Ceramic Slip Casting

Ceramic slip casting is an artisanal and industrial process with a long history which is still very much in evidence within contemporary ceramic production. At its most fundamental, slip casting involves the introduction of liquid clay (slip) into a dry plaster mould such that the dry plaster pulls excess moisture from the slip until it has solidified enough to be removed from the mould and remain self supporting in preparation for final drying and initial firing. Mould-making has traditionally been a complex and time-consuming process involving multiple steps tied to the time sensitive application of tools and materials. Digital mould-making considerably shifts this workflow.

Within this digital process, the original and the mould are entirely designed on the computer; there is no physical master model. All the required geometry that enables the slip to flow into and out of the mold, that allows the mould to release properly from the casting and that allows to mould pieces to fit together accurately, are created in one closely interrelated,

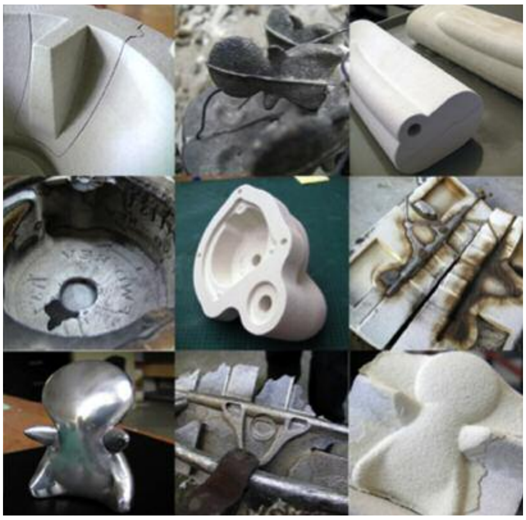

Image 4

Image 4.
Top row, left to right: Detail of slip cast, showing the mould's complexity [mechanical fit]; miniaturized and multiplied objects from the original full size file; detail of metal casting mould interior, highlighting heat resistance.
Middle row, left to right: Complexity of mould geometry; finished aluminum cast from printed mould; detail of cast skateboard truck immediately after casting (note fin flashing).
Bottom row, left to right: Multiple copies of skateboard truck mould prior to casting; detail of ceramic slip cast on initial mould opening.

continuous process. The mould is then simply printed, de-powdered, set with water and dried in preparation for casting.

Non-ferrous Metal Casting
Metal casting is an ancient process that involves the introduction of liquid metals at high temperatures into a plaster based mould; traditionally it is a highly complex and labour intensive process with multiple critically interconnected steps. The creation of cast metal objects typically entails:

1. The making of an original form.
2. The creation of a mould of this original object.
3. The production of wax copy(s) from this mould.
4. The preparation of the wax object for casting (sprueing up).
5. The *investing* of the wax in a plaster/sand matrix.
6. The burning out of the wax from the plaster investment.
7. The casting of the metal into the void created by the burnt out wax.

The creation of cast-able, digitally printed moulds enables the reduction of the above seven steps down to two. In the digital metal casting workflow, the object, the mould, the channels for the molten metal to flow through and the channels for expanding gasses to escape, are all created in one digitally mediated process. There is no need for a physical original, wax copies or burning out. Once the digital content is created the mould is simply printed, de-powdered and cast.

Conclusion
Digital moulds have multiple specific characteristics: they can display complex geometries that are difficult or impossible to create manually; they can be scaled, distorted, multiplied and edited at will; they can be used for extremely different types of cast-able materials (metal, ceramic); and moulds need no longer be physically stored as they can be easily recreated on demand, and are now inexpensive to produce.

Importantly, these developments help create the conditions that invite the hybridization of the traditional with the digital. Combining methodologies enables 3D printing to transition away from outputting expensive facsimiles (plastic or plasters prototypes) to producing cost effective *end of line* objects in *true life* materials. Furthermore, this shift creates a framework for the reevaluation of the relationship between tacit *making knowledge* and digitally mediated processes.

3D printing, in its typical manifestation, can be a somewhat hermetic experience. There is a distinct separation between the maker and what is being made. Objects can display wildly complex geometries but:

> *[T]he 3D printing process involves laying down material in a new way that bears little relation to the processes that have in the past been used to create artifacts in a familiar manner.* (Hoskins, 2014)

As a result, 3D printed objects can display more evidence of the capability of the underlying technology than the nuances of the maker. Tacit material knowledge is redundant in a process that is completely separated from it, but the result can be objects that:

> *[A]t best look as though they are using a very specific technology in itself and not a means of communicating an idea through an appropriate tool.* (ibid.)

By inserting the tool of 3D printing within existing method, an interactive relationship is established between legacy process, personal experience and the digital technology.

This relationship between emergent digital capabilities, tacit material knowledge and traditional ways of making, was initially presented at the 'All Makers Now?' conference at Falmouth University, examining craft values in 21st century production. As historic practice increasingly interacts with new methods and materials, new forms of making are emerging. Indeed the very term *maker* has become a signifier of the blurring boundaries between disciplines, materials and technologies. As we move into what has been called the *post-digital* age, as objects increasingly become extractions from the virtual into the physical, knowledge of material production, digital know-how and the distinctions between disciplines are developing increasingly permeable boundaries.

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Philip Robbins *holds an MA from the Royal College of Art in London, a BA from The Emily Carr University of Art and Design and a B.ed from the University of British Columbia. As a founding partner in Polyglot Design, 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 within Visual Arts & Material Practice, Design & Dynamic Media and Continuing Studies, with an emphasis on material practice, 3D software and digital output technologies. As a co-conspirator within Material Matters, Philip has the great pleasure of partnering in a range of cross disciplinary research objectives, exploring that creatively productive space where ideas, materials and process overlap.*

Keith Doyle *is an Adjunct Research Associate in Applied Arts at Emily Carr University of Art & Design. He has taught in both the Visual Arts & Material Practice as well as the Design & Dynamic Media faculties. Currently, Keith is a faculty coordinator for AD-NODE a GRAND NCE affiliated research project situated in Art and Design institutions. 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 is a co-founder of Intelligent Forms Design Incorporated as well as one of five co-creators of ContainR, a public work of design, consisting of two repurposed used shipping containers. ContainR featured 48 films from around the world, including five commissioned films made specifically for ContainR and broadcast on Bravo!FACT / CTV. www.containr.com. Keith holds both a BFA and an MFA in Sculpture. He 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. IcarusCar, a five channel video and sculpture installation co-developed while in residence at the Banff New Media Institute has been exhibited internationally and western Canada wide.*

Hélène Day Fraser *holds a MAA in Design from Emily Carr University and a BAA in Fashion Design from Ryerson University, Toronto. Her fashion-based work in both Canada and France has moved in recent years to encompass critical design: exploring sustainable consumption and textile form interfaces with technology. Between 2006 and 2011 Hélène was a cofounder of the Vancouver based Intelligent Forms Design Inc. (iF) and a member of the UBC based Visual Voice research team that developed DIgital Ventriloquized Actors (DIVAs). Currently, she is a Lead investigator on several Emily Carr University research projects: DnA, cloTHING(S) as conversation. She is also Lead Investigator in the international Local Wisdom research network, a member of the ECU Material Matters group and the Operations manager for the Emily Carr DESIS Lab. Hélène's work consistently re-imagines textile product possibilities and explores art/design-based collaborations.*