Demonstrating New Materials, Software, and Hardware from the Hand and Machine Lab

Fiona Bell*
fbell1@unm.edu
Department of Computer Science
University of New Mexico
USA

Camila Friedman-Gerlicz*
cfriedmangerlicz@gmail.com
Department of Computer Science
University of New Mexico
USA

Jaime Gould
egould@unm.edu
Department of Computer Science
University of New Mexico
USA

Erin McClure
emcclure@unm.edu
Department of Computer Science
University of New Mexico
USA

Deanna Gelosi
dege9758@colorado.edu
ATLAS Institute
University of Colorado Boulder
USA

Alyshia Bustos
abustos2436@unm.edu
Department of Computer Science
University of New Mexico
USA

Monica Silva Lovato
monicasilvalovato@gmail.com
Independent Artist
San Felipe Pueblo, New Mexico
USA

Jeff Suina
jeffsuinaart@gmail.com
Independent Artist
Cochiti Pueblo, New Mexico
USA

Leah Buechley
buechley@unm.edu
Department of Computer Science
University of New Mexico
USA

Figure 1: We develop new materials, software, and hardware for small-scale, low-cost Direct Write (DW) 3D printing.

ABSTRACT

There has been a surge of recent interest in new materials and tools for digital fabrication. In this work, we introduce a range of materials that we have developed for use in Direct Write (DW) 3D printers. These materials include play-dough, clay-dough, bronze clay, glass paste, and eggshell paste. Many of our materials exhibit unique properties, so to support and extend the capabilities of printing with these materials, we develop new slicer software and hardware components. For example, we designed new CAM software for successfully printing dramatic overhangs in clay and for printing rheologically non-linear materials by generating toolpaths with

*Both authors contributed equally to this research.

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little to no travel movements. We also created hardware such as custom heaters that improve the structural stability of prints. By presenting an overview of all these works in one demonstration, we call attention to how the development of new materials, software, and hardware are interconnected in digital fabrication.

CCS CONCEPTS

• **Human-centered computing → Interactive systems and tools**; • **Applied computing → Computer-aided design**.

KEYWORDS

Clay 3D Printing, Slicer Software, 3D Printing Hardware, Ceramics, Metal Clay, Glass, Biomaterials, Materiality, Digital Fabrication

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1 BACKGROUND

Digital fabrication (especially 3D printing) has been a continual topic of interest within HCI [19]. In this demonstration, we present new materials, software, and hardware that we have recently developed in our lab to extend the possibilities for Direct Write (DW) 3D printing. DW printers are used to extrude paste-like materials to build forms [9]. Our DW printers are small-scale low-cost printers that were designed for use with clay. They are widely available and easily accessible pieces of digital fabrication equipment. 3D printing in clay has been explored by researchers and artists alike for sculpture [21, 26, 27], data physicalization [11, 12], architecture [2, 23], and material science [17]. Beyond clay, other paste-like materials have been developed for DW printers including spent coffee grounds [1, 24], olive pomace [3], mussel shells [18], mica [13], and cookie dough [20]. We extend this existing library of materials for DW printing by developing the following new materials: ***play-dough*** [8], ***clay-dough*** [4], ***bronze clay*** [7], ***glass paste***, and ***eggshell paste***.

Beyond material development, we are also focused on creating new slicing software to support some of the unique properties these new materials afford. Our software includes ***WeaveSlicer*** [15], which expands the range of printable geometries in clay and paste-like materials, and ***TRAvel Slicer*** [7], which generates continuous extrusion toolpaths to cleanly print our rheologically nonlinear pastes. These tools are situated in a landscape of other tools for .gcode generation and 3D printing including CoilCam, which generates toolpaths for 3D printing complex forms and surface textures in clay [6], and Vespidae, which develops custom toolpaths and visualizations for multiple materials and fabrication machines on a single design [14]. Lastly, we also design new pieces of hardware that can be added to modify the commercially available DW 3D printers that we utilize in our lab, such as a ***custom heater*** [8] that improves the structural stability of our prints.

By presenting these materials—alongside new software and hardware that was developed to support their use in DW 3D printing—we contribute to the ongoing discourse on materiality in HCI and design [5, 16, 25, 28]. Moreover, we highlight the entangled nature of materials, software, and hardware, thus illustrating the advantages of developing these three technological areas in tandem. Through this demonstration (shown in Figure 1), we hope to introduce the CHI community to a wide range of new materials and tools for 3D printing in a hands-on manner, ultimately showcasing the potential research, design, and artistic opportunities that arise from our lab's work in digital fabrication.

2 MATERIALS

The following section presents six materials we commonly use with our 3D printers: clay, play-dough, clay-dough, bronze clay, glass paste, and eggshell paste (demonstrated in Figure 2). Other than clay, we developed each material recipe specifically for DW 3D printing.

Clay. We use a variety of different clay bodies in our lab such as various mid-range stonewares, mid-range porcelain, low-fire earthenware, and a low-fire sculpture body. The mid-range clay bodies reach full vitrification at cone 6 (2232°), and the low-fire bodies reach full vitrification at cone 04 (1940°). The sculpture bodies have larger particles (grog) mixed in with the finer clay particles and are well-suited for printers with larger nozzles. They are more robust and shrink less. The porcelain clay is completely smooth and more prone to collapse in its wet state [10].

Play-Dough. Play-dough is a brightly-colored, easy-to-make, and familiar material made from corn and wheat flour mixed with several different binding ingredients. We developed and tested custom play-dough recipes that can be used in 3D printers that are typically used to print clay. We have explored the design potential of play-dough as a sustainable fabrication material, highlighting its recyclability, compostability, and repairability [8].

Clay-Dough. We arrived at clay-dough by combining different ratios of clay with play-dough. While not sustainable like the play-dough, clay-dough exhibits unique shrinkage behavior when dried and fired in a kiln. This dramatic shrinkage is caused by the play-dough burning away when fired. Thus, we explore clay dough as a tunable, shape-changing material for 4D printing, where we 3D print an initial form that shrinks into new forms based on the ratios of clay-to-play-dough we utilize and how we load the clay-dough materials into the printer [4].

Bronze Clay. Bronze clay is a paste-like material often used in jewelry practices made from bronze powder and several binder ingredients. Once fired at high temperatures, the bronze clay sinters to become solid bronze. Unlike other types of metal 3D printing that are expensive and require specialized equipment, our approach uses commercially available bronze clay for jewelry and small, low-cost DW 3D printers, which makes 3D printing metal significantly more cost-efficient and accessible [7].

Glass Paste. Our glass paste material is made up of glass frit (crushed up sheet glass) mixed with several binder ingredients to arrive at a printable material. Once printed and dried, the objects are fired to a temperature that sinters the glass particles to form a glass object. Like metal, existing glass 3D printing methods are expensive

Figure 2: We 3D print a variety of clay-like materials that vary drastically in their properties, aesthetics, and affordances.

and require specialized equipment. Our approach to printing our glass paste with low-cost, DW 3D printers and then firing the printed glass paste to arrive at solid glass pieces is significantly more accessible.

Eggshell Paste. Inspired by the sustainability of the play-dough, we developed a 3D printable Eggshell Paste that is made from discarded eggshells that are ground into a powder and combined with the same bio-based binder ingredients used for the Bronze Clay and Glass Paste. Our Eggshell Paste has a ceramic-like quality once it dries due to the high mineral content present within eggshells. Unlike clay, however, eggshell paste artifacts biodegrade rapidly in soil environments when disposed of. The eggshell paste also promotes other sustainable practices such as reusing waste materials and recycling.

3 SOFTWARE

Like many digital fabrication machines, clay 3D printers read .gcode files. These files can be generated with commercial slicers like Cura or Simplify3D, or they can be generated by writing code directly [22]. Our lab has found that we like the control and customization we can achieve when we write our own gcode. We mostly use Grasshopper and Python to write this code, which allows us to expand the capabilities of 3D printing in clay and support printing in some of our more unique materials like bronze and glass.

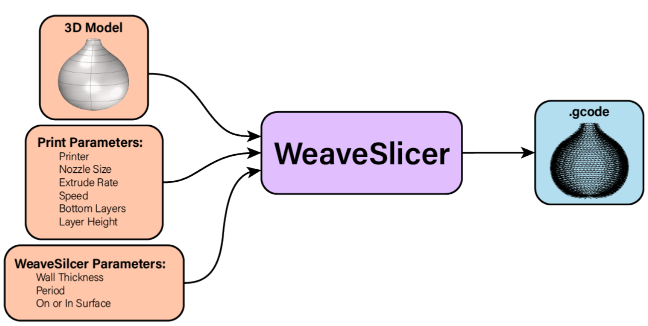

Figure 3: We developed Weaveslicer to extend the range of printable geometries in clay-like materials by maintaining constant wall thickness throughout the form.

WeaveSlicer for Expanding Printable Geometries. Only a narrow range of geometries is 3D printable with clay if one is employing commercially available slicing software. WeaveSlicer is a slicer software that expands the range of printable geometries for 3D printing in clay by maintaining constant wall thickness throughout the form. We achieve constant wall thickness by generating an oscillating path where the amplitude of the oscillation is determined by the form's overhang angle. WeaveSlicer works like many other slicers, where the user inputs a 3D model and chooses various parameters. WeaveSlicer then produces a .gcode file that can be used on various clay 3D printers (see figure 3). Traditional slices maintain a constant layer thickness throughout the print, but this results in a thinner wall where there is a steeper overhang. WeaveSlicer prompts the user to pick a wall thickness and produces a sinusoidal curve whose amplitude will vary to maintain the same wall thickness throughout. Using WeaveSlicer allowed us to successfully print clay sculptures that initially failed to print during an artist residency program in our lab. Beyond clay, we have used this software with our other materials to achieve dramatic geometries that would typically collapse if sliced with traditional software [15].

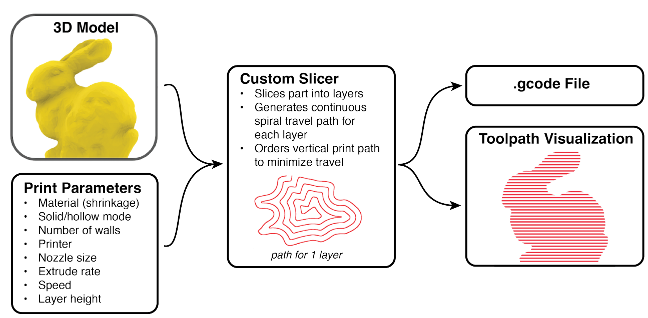

Figure 4: We developed TRAvel Slicer to print continuous extrusion toolpaths using fermat spiraling for rheologically non-linear materials like bronze clay and glass paste.

TRAvel Slicer for Continuous Extrusion Toolpaths. Many of our materials like the bronze clay and glass paste have a non-linear rheology, which makes them particularly challenging to work with because they have significant delays between when a start or stop extrude action is executed by the printer and when the material reflects this action are common. To support printing with the materials, we employ a custom slicing software that takes an imported 3D model and constructs a continuous spiraling path for the 3D printer to follow based on the contour paths of the model using Fermat spirals (see figure 4). It further employs nontraditional vertical ordering of isolated regions to minimize travel paths and produce cleaner prints [7].

4 HARDWARE

Beyond materials and software, we have begun to develop new hardware components that can be added to modify our commercially available DW 3D printers.

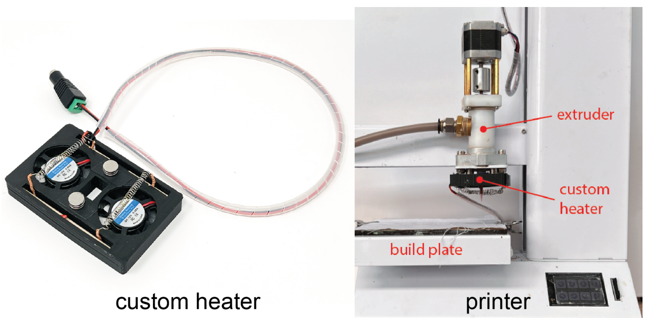

Figure 5: We develop new hardware that can be added to commercially available clay 3D printers. One example is a custom heater that fits around the extruder to dry the materials as they are printed to improve the structural stability of the print.

Custom Heater. To improve the print quality of our materials (especially the quality of the play-dough, bronze clay, glass paste, and eggshell paste), we modify our printer with a custom heater (see Figure 5). The heater is made from two fans and two nichrome wire heating elements that sit within a custom case. The case fits around the extruder and is attached to the metal frame of the extruder with magnets for easy attachment and removal. The fans and heating coils are positioned on either side of the extruder to dry out layers of material as they are printed, thus improving the overall structural stability of prints [8].

5 CONCLUSION

We present a collection of materials that we can print using low-cost, commercially available, desktop, DW 3D printers including clay (such as stonewares, porcelain, and earthenwares), play-dough (a flour-based dough that is recyclable and compostable), clay-dough (a mixture of clay and play-dough that exhibits dramatic shrinkage behavior), bronze clay (a paste made from bronze powder that sinters into solid bronze when fired), glass paste (a paste made from glass frit that sinters into solid glass when fired), and eggshell paste (a paste that is made from ground eggshells that rapidly biodegrades). Working with these materials can be incredibly challenging given that clay printing technologies are relatively new and that each material presents different properties and behaviors. Accordingly, we design new software like WeaveSlicer (for expanding the range of printable geometries) and TRAvel Slicer (for generating continuous extrusion toolpaths), as well as new hardware (like custom heaters) to support and extending the capabilities of 3D printing with our materials. Developing our materials, software, and hardware was often an entangled and interdependent process. Accordingly, we underscore how material, software, and hardware technologies overlap and converge in 3D printing, which we find opens up new opportunities and directions for digital fabrication in general.

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