M.A.K.E. 3D

Material to Form Curriculum

School of Visual Arts

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Sincerely,

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INTRODUCTION

The increased availability to low-cost additive manufacturing (AM, or 3-D printing) systems has been one of the key catalysts in the democratization and popularization of the maker movement. This movement emphasizes learning through hands-on design and fabrication experience, and capitalizes on sharing, connecting and do-it-yourself tinkering. Inspired by the potential for interdisciplinary learning in these informal educational environments, a team of art and engineering faculty and graduate students from the Pennsylvania State University began working on a project called M.A.K.E. 3D (Mobile Atelier for Kinesthetic Education, 3D).

Funded by the National Science Foundation (NSF), M.A.K.E. 3D is a deployable makerspace exploring making and 3-D printing technologies. Our interdisciplinary approach to design thinking and material science incorporates a comprehensive spectrum of concepts that we call the “Material to Form” curriculum, of which this document is comprised. Our curriculum is structured as six modules that include: Designing Form, Modeling Form, Capturing Form, Extrusion, Process, and Material Variety. The Material to Form curriculum was created to maximize informal learning in making by emphasizing modularity in order for learners to engage with concepts from multiple entry points. This is done through various hands-on activities and exercises that invite participants to engage with design and inquiry-based methodologies as integral components of making.

In the Material to Form curriculum, you will find a variety of materials to support student learning in AM processes and STEAM. Each document type is organized by module and color-coded to signify its suggested purpose. Gold pages represent Lesson Plans, in which learning goals, essential questions, key terms, and suggestions for core standards assessment can be found. Blue pages signify Handouts, which can be used to guide learners through suggested activities that engage with the technologies and processes of each module. Pink pages feature Case Studies, which offer real-world examples of how these technologies are being used today.

In the spirit of the open-source movement which 3-D printing is a part of, we encourage educators to utilize and reinvent this free resource to suit their unique needs.

DESIGNING FORM

Module 1: Lesson Plan

MODULE GOALS

Design drives innovation and can significantly impact the successful production of a new commodity or product. It is an iterative process which can be strategically performed using an approach known as **design thinking**. In this module, students will learn to utilize the stages of **design thinking** in order to cultivate ideas and respond to situations and challenges creatively.

ESSENTIAL QUESTIONS

- How/where do designers find inspiration for their ideas?
- How do designers turn their ideas into usable forms?
- What is **design thinking**, and what makes it an iterative process?
- How can **design thinking** and other iterative design processes be employed when approaching a new creative challenge?
- What role do the **design thinking** steps of empathize, define, ideate, and prototype play in developing a design?

MEANING AND ACQUISITION

- Students will engage in experiential learning through the application of **design thinking**.
- Students will understand strategies for applying material play for open-ended exploration.
- Students will know how to utilize **empathy** in order to help define the parameters of an inquiry.
- Students will know how to utilize **ideation** in order to engage with open-ended exploration of an inquiry.
- Students will know how to utilize **prototyping** as an effective way to try out new design ideas.
- Students will experience the use of "low-fidelity" materials such as clay, paper, and craft items to ideate.
- Students will be proficient at problem-solving with the use of **iterative** design processes.

DESIGNING FORM

Module I: Lesson Plan

FORMATIVE ASSESSMENT STANDARDS

- Students demonstrate active problem-solving skills throughout the development of their design **(Cr2.I.8a).**
- Students know and use fundamental vocabulary relevant to design and the design thinking process **(Cr3.1.1a).**
- Students demonstrate the ability to form and defend judgments about the characteristics of their designs in order to accomplish commercial, personal, communal, or other purposes **(Pr4.I.IIa).**
- Students evaluate the effectiveness of their designs in terms of function reflected in the design thinking process **(Cr3.I.IIa).**
- Students are able to discuss and explain their efforts with consideration of factors surrounding the origin and journey of their design **(Cr3.I.6a).**

SUMMATIVE ASSESSMENT STANDARDS

- Student work delineates a unifying concept through the production of a design that reflects skills in iterative processes and low-fidelity prototyping techniques **(Cr2.1.IIIa).**
- Students describe the origins of specific images and ideas and explain why they are of value in their artwork and in the work of others **(CnII.1.Ia).**
- Student work demonstrates how design can communicate experiences and stories or address a creative challenge **(Cr2.3.7a).**
- Student work exemplifies an effective use of materials, equipment and tools into the production of design forms **(Cr2.1.IIa).**
- Student work demonstrates the conceptualization and use of both traditional and contemporary technologies within the design or product **(Cr3.I.8a).**

DESIGNING FORM

Module I: Lesson Plan

MATERIALS

- Air-dry Modeling Cloy
- Cardboard
- Craft paper
- Pipe Cleaners
- Pencils & erasers
- Scissors
- Tape

KEY TERMS

- **Design thinking -** the idea that a hands-on, user-centric approach to problem solving can lead to innovation, reflected in an iterative process of "understand" (empathize and define), "explore" (ideate and prototype), and "materialize" (test and implement).
- **Empathize -** Conduct research in order to develop knowledge about what people (your neighbors, your school, users of a product) do, say, think, and feel about an issue.
- **Define -** Determine problem(s) to be solved, based on knowledge gained in the 'empathize' phase.
- **Ideate -** Brainstorm a range of creative ideas that the problems/needs identified in the 'define' phase. Give yourself and your team total freedom; no idea is too farfetched and quantity is more important than quality.
- **Prototype -** Build real, tactile representations for some of your ideas. The goal of this phase is to understand what components of your ideas work, and which do not.
- **Test** - Get feedback on your prototype(s). The best feedback comes from the people you are designing for, but fellow designers can also help.
- **Implement -** Put the vision into action! Materialize your solution and address the identified problem(s).
- **Iteration -** Looping back to a previous step in the process, to make changes based on new knowledge

Derived from Gibbons, S. (2016). Design thinking 101. https://www.nngroup.com/articles/design-thinking/

DESIGNING FORM

Module 1: Lesson Plan

PROPOSED ACTIVITY

1. Students will **define** a problem in their world, their community, or in their life by **empathizing** with what people do, say, think, and feel about an issue.
2. Students will **ideate** different material solutions to the problem they defined. Students will sketch their various solutions. In this process, students will:
    - Play with concepts through free association, exploration, chance, and reflection.
    - Look at examples to gain insight, source options, and remix possibilities.
    - Discuss possibilities with others.
3. Students will use cardboard, modeling clay, pipe cleaners, and other "low-fidelity" materials to **prototype** a chosen design from one of their sketches.
4. Students will **test** their prototype by getting feedback from their group, and **iterate** to revise their design.

DESIGNING FORM

Module 1: Case Study 1

REBECCA STRZELEC

Rebecca Strzelec is an artist, designer, and educator at Penn State Altoona, where she has been a faculty member since 2002 (Lippincott, 2016). Strzelec's practice includes the creation of wearable art objects via computer-aided design (CAD) programs and 3D printing. Once she has completed a design, her objects are printed by Rapid Prototyping, which involves various computer-controlled machines that quickly fabricate a scale model of a digital design using CAD data (Strzelec, 2017). Her work is inspired by popular culture iconography as well as the lived experiences of those around her, and it investigates the relationship between the wearable objects that she creates and the surfaces of the body (Lippincott, 2016). Rebecca's work is a unique combination of the utilitarian, the political, and the whimsical, and exemplifies how everyday life can impact product design in unexpected ways.

Figure 1. Red Bracelet, 2008. This figure illustrates one of many projects in which Strzelec appropriated the form of a gas pump.

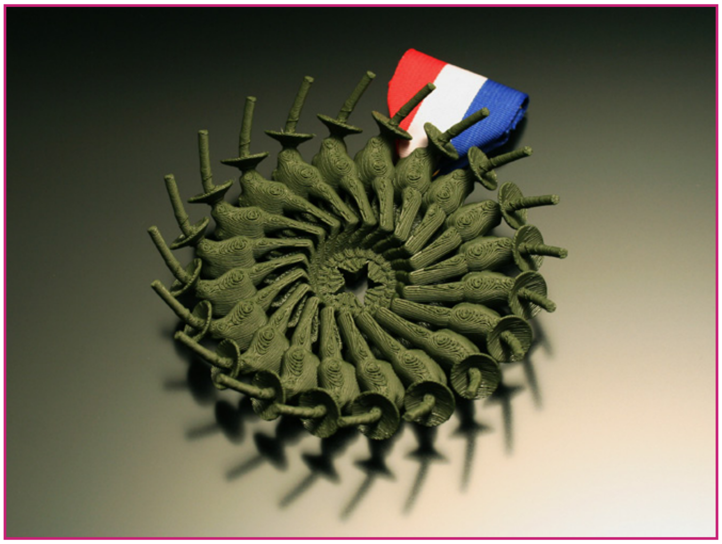

Figure 2. Octane Medal, 2007. In this piece, from Strzelec's "anti-war medals" series, the gas pump comments both on the way petroleum is used to justify war, and its presence in the plastics used for 3D printing.

PROJECT DESCRIPTION

Originally trained as a traditional bench jeweler, Rebecca Strzelec converted her practice to digital methods in 1999 ("Professor of Visual Arts Rebecca Strzelec named 2016-17 Penn State laureate", 2016). Strzelec originally began using digital design and additive manufacturing due to the flexibility it provided to her practice (Strzelec, 2004). At each stage of development, she saves the current **iteration** of her design which provides for and encourages risk-taking at later stages of the object's development (2004). In this sense, her work is inextricably linked to the **design thinking** skills that the making process needs in order to happen in a way that other forms of art practice wouldn't allow for, minimizing the potential consequences of experimentation through the use of rapid **prototyping** (Strzelec, 2004).

Strzelec's pieces have been exhibited throughout the United States and currently reside in multiple private and public collections (2016). Her current practice is driven by the creation of wearable objects via computer aided design and 3D printing, and is an ongoing investigation into the ways wearable objects interact with the surface of the human body (Strzelec, personal communication, May 11, 2017). The objects themselves are built layer by layer using various plastics and photosensitive resins ("Professor of Visual Arts Rebecca Strzelec named 2016-17 Penn State laureate", 2016). Strzelec's pieces find their origins in common or recognizable forms inspired by contemporary society, be it a gas pump, balloon, or a baseball diamond. These shapes are altered and conceptualized through their application as wearable objects ("Rebecca Strzelec: Gallery", 2017).

Wielding the iconography of everyday life, Strzelec's work seeks to create and communicate hybrid histories in new spaces by blurring borders and using cutting-edge technology (Strzelec, personal communication, May 11, 2017). The relationships born from these interactions are meant to promote dialogue and question the status quo of contemporary society ("Rebecca Strzelec: Statement", 2017, para. 8). In her lecture "Hybrid Makers: The Role of Rapid Prototyping in Jewelry and Metalsmithing", Strzelec explains: "It is the duty of the technology driven artist to create work that exceeds the novelty of their process."

DESIGNING FORM

Module I: Case Study I

REFLECTION QUESTIONS

1. Rebecca Strzelec takes the forms and objects that inspire her pieces and turns them, through design, into artworks that are able to convey ideas. What kind of criteria do you think she uses to select and alter those objects in order to explore her ideas? How might **empathizing** with others and **defining** problems play a part in her choice of source material?
2. Strzelec believes that technology driven artists are obligated to make work that "exceeds the novelty of their process." What do you think she means by this? Do you agree or disagree?
3. How does Strzelec utilize **design thinking** in her artistic practice? Does her use of rapid **prototyping** technologies facilitate this process?

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Strzelec, R. (2017). Rebecca Strzelec: Statement. http://www.personal.psu.edu/ras39/Rebecca%20Strzelec_Statement.html

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from http://personal.psu.edu/ras39/red%20bracelet.html

Figure 2. Retrieved from http://personal.psu.edu/ras39/octane.html

JONATHAN KEEP

Artist Jonathan Keep works in Suffolk, United Kingdom, and is a pioneer in synthesizing traditional techniques in ceramics with digital fabrication processes. In his studio, Jonathan describes his process as seeking to explore the use of objects to communicate thoughts and express emotions in a way that goes beyond utilitarian need (Keep, n.d., para. 2). Keep's works ore often inspired by patterns and forms from the environment such as icebergs, petrified wood, and even the sound waves of a bird (Han, 2014, para. 2). His practice reflects upon the aesthetics of the natural world while simultaneously experimenting with process and materiality. The integration of computer-aided design into his process urged Keep to problematize aspects of digital fabrication as they compared to analogue work in his studio (Keep, n.d., para. 3).

Figure 1. Icebergs, porcelain, 2016.

Figure 2. Jonathan Keep pictured with recent work.

DESIGNING FORM

Module I: Case Study II

PROJECT DESCRIPTION

Jonathan Keep has a long history of utilizing computer software to develop new ceramic forms. This practice was developed from his interest in the hidden numerical codes and patterns that occur naturally in the world (Keep, n.d., para. 1). This interest in sequence and order is intimately linked to Keep's design process, whereby the shapes of his vessel formations are written in computer code using Processing (n .d.). Despite there being more visually-oriented design software available, Keep chooses to utilize parametric design to create his forms in a significantly more abstract, code-oriented way (Keep, 2014, para. 1). He says of this process: "It was that 'blind forming' in code that interests me ... 'Form' is my driving fascination . So the question for me is then, assuming we and our psychological make-up has evolved out of the same natural system out there in the wilderness what is the relationship between natural form and artistic form. I was seeing how scientists were gaining a better understanding of us and our world through computational modelling and thought, 'why can't artists be doing the same?' Architects had developed a whole new formal language through computation, so why not potters?"

Keep admits to a fascination with abstraction, favoring it over and above representation (Han, 2014). This visual appreciation combined with a love of instrumental music have intimately informed the forms he creates and the sources of his inspiration (Keep, n.d., para. 4). All these abstract visual ideas turn later into digital objects designed via computer code. After these unique forms are generated, the digital information is then passed on to a DIY studio-based 3D printer which Keep created by adapting a Delta-style 3D printer for clay (Han, 2014). The process concludes with the combination of digital and traditional fabrication techniques, when the forms are glazed and fired as traditional ceramic vessels would be.

REFLECTION QUESTIONS

1. Jonathan Keep uses computer code as an art material, just like he uses clay as an art material. How does thinking about computer code as an art material change how you might use it? If you're not comfortable "writing" code, do you think you could "sculpt" code like clay or "chop" code like wood?
2. Why do you think Keep chose to design his vessels using computer code? How does the code, and the rules Keep programs into it, help the final object communicate his intentions? If he sculpted the same objects by hand, how would that change them?
3. Jonathan's work is made possible by utilizing "open source" software and hardware. Open source means the technology is made free for others to use and change. Jonathan has developed and disseminated his own open source tools. Large 3D printing companies have not shown an interest in 3D printing with clay, so the development of clay printing has been carried out by a loose group of artists, designers, and engineers working and sharing information. What are the perceived benefits and drawbacks of using an entirely open source process? What are the challenges?

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Keep, J. (n.d.). Digital pots. http://www.keep-art.co.uk/

Keep, J. (2014). Studio journal: Sunday, march 2014 [Blog post]. http://www.keep-art.co.uk/journal_4.html

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from http://www.keep-art.co.uk/digital.html

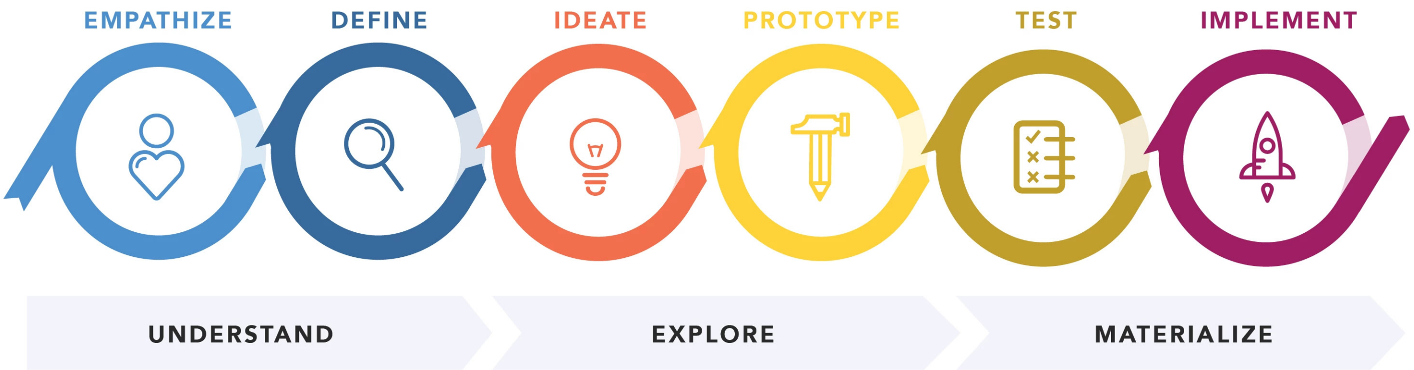
Figure 2. Retrieved from http://www.keep-art.co.uk/digital.html

DESIGNING FORM

Module 1: Handout

DESIGN THINKING PROCESS

Any design process requires creative thinking. It starts with **defining** a problem by **empathizing** with people's needs, **ideating** and **prototyping** possible solutions, and then **testing** them to **iterate** and improve on ideas. (See all those arrows looping back? That's **iteration**!



Source: https://www.nngroup.com/articles/design-thinking/

1. UNDERSTAND

In the spaces below, identify problems faced by you, faced by people you know, and faced by humankind in general. By open-minded about what constitutes a "problem." These problems can be as serious ("global warming") or as frivolous ("my desk at school doesn't serve me ice cream") as you want. These problems could be as real ("economic inequality") or fanciful ("it's hard to eat a cloud") as you want.

Empathize with what people do, say, think, and feel about an issue (maybe interview some people!). Then **define** problems based on that empathy.

Problems I personally face	Problems people I know face	Problems faced by humankind

DESIGNING FORM

Module 1: Handout

2. EXPLORE

Ideate. Choose one of the problems from the previous activity, and sketch (below, or on a separate sheet) at least 4 different possible objects that might address that problem in different ways. No idea is a bad idea at this point - feel free to be as inventive or wild in your concepts as you want!

- Play with concepts through free association, exploration, chance, and reflection.
- Look at examples to gain insight, source options, and remix possibilities.
- Discuss possibilities with others. You can **test** your ideas before **prototyping** them by getting feedback from others on your brainstormed concepts.

3. MATERIALIZE

Prototype. Use the materials provided to build a model of your strongest sketch/idea from part 2, based on your own reflection and feedback. Your model could be functional, or could be a physical "sketch" that represents your idea, even if it doesn't "work" yet.

Test. Share your prototypes with your groupmates. Explain the problem(s) you are trying to solve, and how your design addresses them. Take note of the feedback, and provide thoughtful feedback on your groupmates' designs.

Iterate. Revisit and revise your prototype, based on the feedback.

MODELING FORM

Module II: Lesson Plan

MODULE GOALS

In 3-D printing and **additive manufacturing**, a three-dimensional object is created from a digital model that has been designed on a computer. **Computer-aided design** (CAD) and modeling programs like AutoCAD, Sketch-up, and TinkerCAD are used to create these digital forms that contain the information from which an object is printed. In this module, students will use the TinkerCAD platform to build new digital forms by **remixing** pre-existing digital models. In doing so, they will be able to identify some of the differences between digital and real-world modeling, and learn how to navigate the various applications available through computer-aided design. They will also learn how appropriation and remix as creative tools can play a part in 3-D modeling, as they do in other forms of digital creativity.

ESSENTIAL QUESTIONS

- How do we turn a design idea into a digital model using computer-aided design programs?
- What are the capabilities that TinkerCAD offers as a digital design program? What other design tools are out there?
- What are the advantages and limitations of designing objects digitally versus creating an object in the physical world?
- What possibilities are we presented with through the digital creation of 3-D objects that change the way we produce resources for the public?

MEANING AND ACQUISITION

- Students will have a basic grasp of the tools available in computer-aided design programs and how to use them.
- Students will experience and understand the process of turning an abstract idea into a digital model.
- Students will gain experience in building 3-dimensional objects in a digital space using additive and subtractive modeling techniques.
- Students will understand the role computer-aided design plays in the overall process of additive manufacturing.
- Students will explore the distinct potentials afforded by digital modeling, specifically the ability to remix pre-existing forms.

MODELING FORM

Module II: Lesson Plan

FORMATIVE ASSESSMENT STANDARDS

- Students demonstrate active problem-solving skills throughout the modeling of their design into a functional digital form **(Cr2.1.8a)**.
- Students know and use fundamental vocabulary relevant to CAD and the TinkerCAD platform **(Cr3.1.1a)**.
- Students actively consider the practices, issues, and ethics of appropriation, fair use, and open source as they apply to creating digital designs and 3D-printed objects, and to accessing repositories of publicly-available models and scanned artifacts **(Cr2.2.8a)**.
- Students ore able to discuss and explain CAD processes and techniques to their peers and help facilitate peer-to-peer learning **(CrI.1.II)**.

SUMMATIVE ASSESSMENT STANDARDS

- Student work demonstrates relationships among form, context, and purposes **(Cn10.1.5a)**.
- Student work delineates a unifying concept through the production of a design that reflects skills in iterative processes using traditional and contemporary technologies **(Cr3.1.8a)**.
- Student work exemplifies on effective use of materials, equipment and tools into the production of design forms **(Cr2.1.IIa)**.
- - Student work exemplifies a synthesis between creative and analytical principles and techniques of the visual arts and the sciences **(Cr2.3.IIa)**.

MODELING FORM

Module II: Lesson Plan

MATERIALS

- Laptop/iPad/Chromebook and mouse
- Internet Access
- TinkerCAD (and free accounts set up for student access)
- Projector (for instructor demonstration)

KEY TERMS

- **Additive manufacturing** - Also known as 3-D printing or digital fabrication, additive manufacturing is creating physical objects from digital data, by building up, layer by layer, building material (General Electric, n.d.).
- **Computer-aided design (CAD)** - Also known as computer-aided drafting, CAD tools are software that allow designers to draft construction documents, explore design ideas, visualize concepts, and simulate how a design performs in the real world (Autodesk, n.d.).
- **Additive sculpting** - Sculptural processes where material is added to the sculpture.
- **Subtractive sculpting** - Sculptural processes where material is taken away from the sculpture.
- **Remix** - A remix is a cultural artifact that is made from inventively combining parts of other cultural artifacts. Rooted in music remixes pioneered in 1960s-70s Hip-Hop, remixing is an active creative practice across numerous art mediums. Some artists and scholars argue that all creativity is, on some level, remixing (Navas, 2007).
- **Parametric modeling** - A 3-D modeling process where a shape has geometric parameters that can be changed numerically. For example, a gift-box might have parameters like "number of sides" to make it triangular, square, or hexagonal, as well as parameters for "depth," "width," and "height" to change its size.

Derived from:

Autodesk. (n.d.). What is CAD? https://www.autodesk.com/solutions/cad-software

General Electric. (n.d.). What is additive manufacturing? https://www.ge.com/additive/additive-manufacturing

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MODELING FORM

Module II: Lesson Plan

PROPOSED ACTIVITY

1. Students will participate in a teacher-facilitated demonstration on the basic functions available in TinkerCAD. These applications include:
   - How to utilize the library of available forms, including publicly-released artifacts from the Smithsonian collections, and **parametric** "Shape Generator" forms.
   - How to import designs from other sources for **remixing** and how to determine which file type to upload.
   - How to view your object from different angles.
   - How to change on object's orientation.
   - How to **additively** build forms in TinkerCAD (by "grouping" forms).
   - How to **subtractively** build forms in TinkerCAD (by grouping with "hole" forms).
   - How to change the dimensions and scale of your object.
2. Students will be given free time to experiment and familiarize themselves with the available tools before beginning the activity.
3. Either:
   - Students will use the available tools to remix one or more objects, either selected from the Smithsonian gallery, or imported from an external source. The Modeling Form worksheet below can be used to scaffold this activity.
   - Students will use TinkerCAD software to create a digital "next draft" of the physical prototype the developed in the previous Designing Form unit.
4. A student's design may change as they begin to understand the capabilities and limitations of computer-aided design.
5. Students will export their finished design. **(Export> "Everything in design"> STL)**
6. Students will critically reflect on and discuss the affordances and constraints of designing and building digitally versus physically.
   - If students continued developing their prototypes from the previous module, students will discuss whether and how CAD software offered different possibilities and limitations for their ideas.
   - If students remixed artifacts from Smithsonian or other collections, students will discuss the potentials (and hazards) digital modeling offers for remixing existing culture.

MODELING FORM

Module II: Case Study I

SHIV INTIGER

In 2016, artist Matthew Plummer-Fernandez created on algorithmic "artbot"* in collaboration with Julien Deswoef called Shiv Integer (Hern, 2016). The program appropriates blueprints for 3-D models found on Thingiverse, an online archive of user-mode digital 3-D models. Shiv Intiger randomly selects objects licensed for **remixing** before assembling them into dysfunctional sculptures and uploading them once more onto the Internet as new designs (Newitz, 2016). Since its inception, the artbot has received both appreciative and negative reviews by the makers and designers who hove had their projects repurposed by it (Plummer-Fernandez, n.d.).

*__Algorithmic__ means something that follows a specific procedure, most often a program written in computer code. An **artbot** is an automated, self-directed computer program (a "bot") built for artistic purposes.

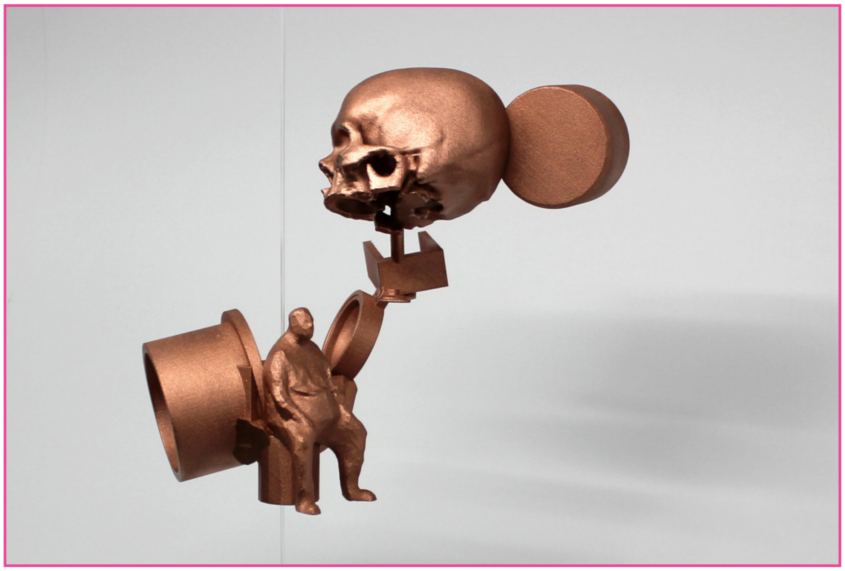

Figure 1. Tlppy PrettyTron by a filter. A 3-D print of a model generated by Shiv Intiger.

Figure 2. Webcom on und Ben. A digital 3-D model generated by Shiv Intiger.

MODELING FORM

Module II: Case Study I

PROJECT DESCRIPTION

Matthew Plummer-Fernandez, a British/Colombian artist working with various forms of sculpture, software, and online interventions, is known for work that reflects on the complexity of contemporary socio-technical relationships (Plummer-Fernandez, n.d.). Shiv Integer is one of Plummer-Fernandez's many projects that explore the possibilities offered by **computer-aided design**, dealing with the everyday entanglements of software automation in humorous and aesthetic ways. Its assemblage process is reminiscent of Dadaist reodymodes and chance art, and was partially inspired by the Japanese video game Katamari Damacy (Hern, 2016).

Shiv Integer is on artbot that makes assemblage digital sculpture for 3-D printers within a **computer-aided design** (CAD) environment. It does so by randomly sourcing previously designed objects from Thingiverse, an online 3D-printing community in which users can upload and share print-ready objects and engineering ports (Plummer-Fernandez, n.d.). Shiv Intiger functions by downloading digitally designed 3-D objects at random, assimilating these entities into a nonfunctional sculptural form, and re-uploading them to Thingiverse as new designs after tagging the original creators of each of the sculpture's constituent ports (Newitz, 2016). It then assigns each new creation a "word-salad" title using a similar algorithmic system (Plummer-Fernandez, n.d.).

According to artists Matthew Plummer-Fernandez and Julien Deswoef, these repurposed sculptures hove hod mixed reviews in the maker community (Hern, 2016). Plummer-Fernandez remarked that prior to the artists publicly claiming the venture, 'The bot ho[d] been ... receiving hundreds of complaints and online harassment from the Thingiverse community, amid a few fans responding with poetry and defending its rights" (Hern, 2016). The project itself simultaneously explores the subject of authorship, appropriation, and fair use in Creative Commons licensing environments, and performs on archiving of internet subculture by orchestrating what ore essentially cross-database snapshots of 3-D print culture via Thingiverse (Hern, 2016).

REFLECTION QUESTIONS

1. Behind Shiv Integer there is a synthesis between scientific practices (the use of programming **algorithms**, for instance) and visual arts concepts (such as **remix**). What new possibilities are opened up through the combination of activities that are traditionally considered "scientific" with ones traditionally thought of as "artistic"? What are the limitations or potential hazards of this partnership?
2. Do you think Thingiverse designers should have the right to decide how their designs are used and remixed? When remixing artifacts scanned and uploaded by museums like the Smithsonian, do you feel cultures whose artifacts might be in those collections, and who might not have agreed to their inclusion, have a right to decide how their artifacts are used and remixed? What are some of the ethical decisions, in terms of appropriation, fair use, and open source, that you believe are involved in remix exercises such as Shiv Integer? Can an "artbot" make those decisions? Who should take responsibility for the choices it makes, if they end up breaking the law, or harming or upsetting someone?
3. Are the sculptures produced using Shiv Intiger Plummer-Fernandez and Deswoef's artwork, or Shiv Intiger's artwork? How do you justify your answer? When human artists use human assistants to produce their artworks, should those assistants be credited? Should Shiv Intiger be credited?

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Plummer-Fernandez, M. (n.d.). Works. http://www.plummerfernandez.com/

Shiv Intiger. (2016). Designs. Thingiverse. Retrieved from https://www.thingiverse.com/thing:1811207

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from https://www.plummerfernandez.com/shiv-integer/

Figure 2. Retrieved from https://www.thingiverse.com/thing:1877380

MODELING FORM

Module II: Case Study II

MASS CUSTOMIZATION OF CERAMIC TABLEWARE

Grasshopper is a program which allows for mass customization of ceramic tableware. It is a generative design process that generates geometric shapes in a **CAD**-like environment. It uses **parametric modeling**, which allow users to customize various traits, or parameters, of their tableware digitally before buying it.

These systems enable designers to create customizable tableware collections with ease and efficiency. End users (i.e. customers) can customize their final design solution through a user-centered interface that utilizes everyday language and commands. The customized digital 3-D model can then be manufactured via a production system supported by **digital fabrication**, such as a special 3-D printer that uses ceramic clay instead of plastic.

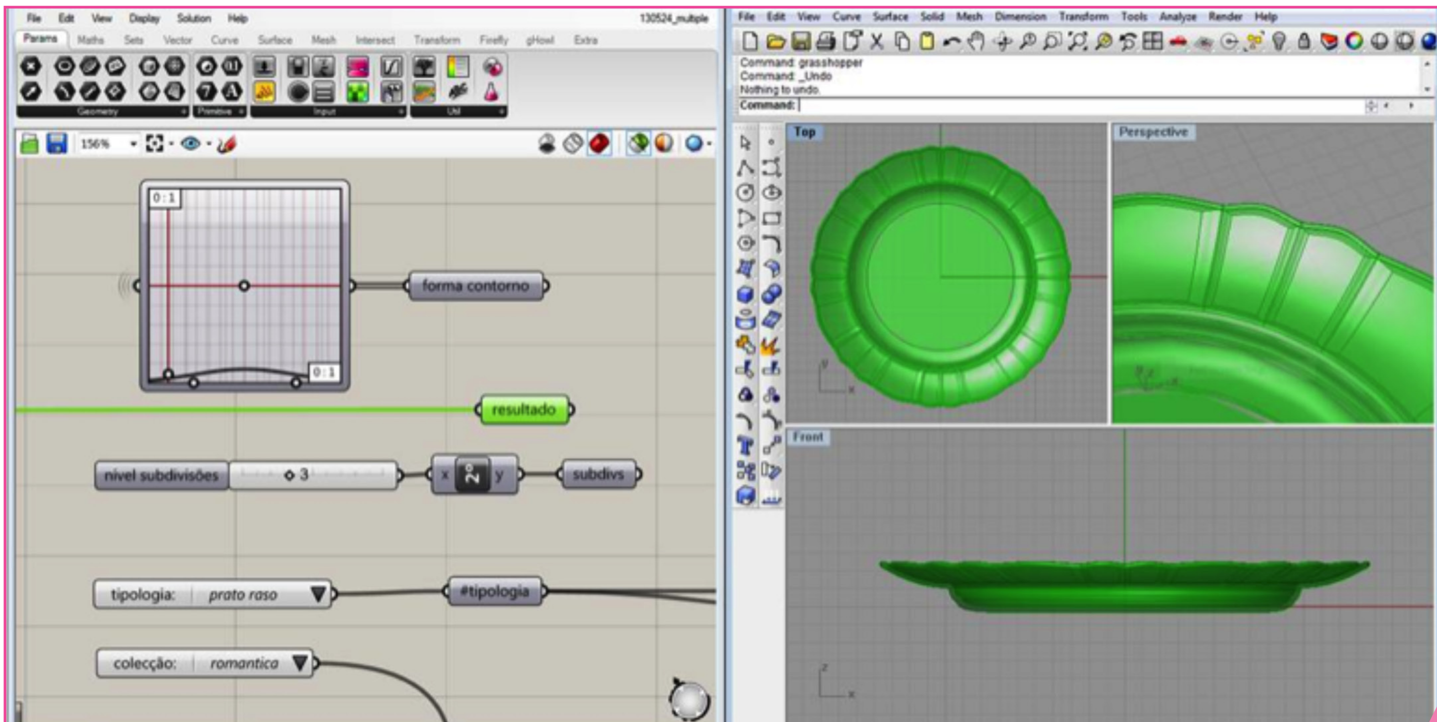

Figure 1 - Design system implementation in Grasshopper, showing different parameters, like curves, which can be changed (left), and a resulting plate design, displayed in the CAD program Rhinoceros (right).

MODELING FORM

Module II: Case Study II

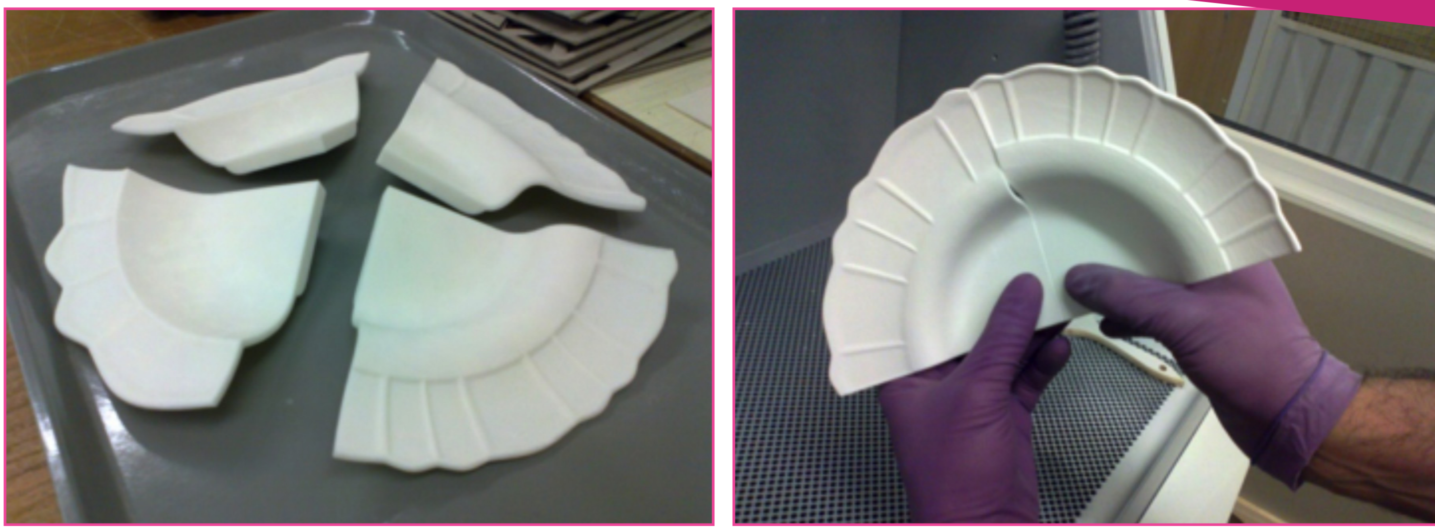

Figure 2 - 3-D printed prototypes of designs generated by the Grasshopper design system.

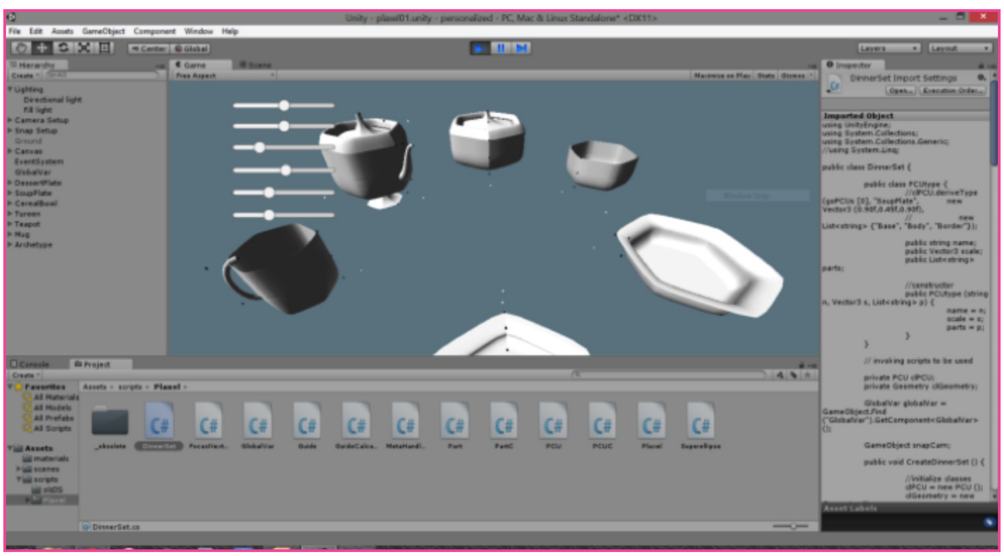

Figure 3 - Design system implementation in the game engine Unity. Notice the sliders in the upper-left that users can use to adjust the various parameters, like depth, number of sides, curves, and angles, of the tableware.

Figure 4 - Ceramic extrusion (3-D printing) of creamer design generated by the Grasshopper design system (Photo by Tom Lauerman).

MODELING FORM

Module II: Case Study II

PROJECT DESCRIPTION

Researchers Eduardo Castro e Costa and Jose Duarte have developed a research project in the field of ceramics design, focusing on the mass customization of ceramic tableware using the program Grasshopper (Castro e Costa & Duarte, 2013). The objective of their project is to grant potential designers, businesses, and customers the opportunity to design and model products according to their practical needs and personal preferences. This is done through a modeling software that uses **parametric modeling** to generate collections of digital objects that con later be taken into **CAD** environments for their manufacture. The creation of mass customizable ceramic tableware will thus allow companies in the industry to offer unique products and services to their clients (2013).

Castro e Costa and Duarte, are making use of computational paradigms such as parametric modeling and "shape grammars" to realize new ways of moss producing ceramic tableware (Stiny & Gips, 1972). "Shape grammars" means that, for example, a whole set of dinnerware (plates, teapots, mugs, and cups) can be made to fit a person with certain preferences (e.g. someone who likes sharp, angled shapes and serving large portions versus someone who likes thin curved shapes and wants long handles to serve others at a large table). Similar to how the whole grammar of a sentence changes if it is talking about "I" or "you" or "they."

The project thus anticipates a future world in which designing of everyday objects for manufacture can become a completely customizable experience according to the needs of the end user. Not only is the project planned to be beneficial to customers and designers in this way, but it also aims to improve product differentiation for the companies that will ultimately come to adopt this developed system (Castro e Costa & Duarte, 2013).

REFLECTION QUESTIONS

1. What other types of object might benefit from a “mass customization” model? What **parameters** would be the most useful or interesting ones to customize in that object?
2. What other uses might there be for this technology beyond making custom products for people to buy? What other fields, or other uses, might there be for easily-customized, easily-produced objects? (Are there potential medical, transportation, sport, or community uses?)
3. What are the advantages, if any, of a world where every object could be customized to your preference? What are the potential losses or problems, if any, of such a world?

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IMAGE ATTRIBUTIONS

Figure 1. Photo by Eduardo Castro e Costa.

Figure 2. Photo by Eduardo Castro e Costa.

Figure 3. Photo by Eduardo Castro e Costa.

Figure 4. Photo by Tom Lauerman.

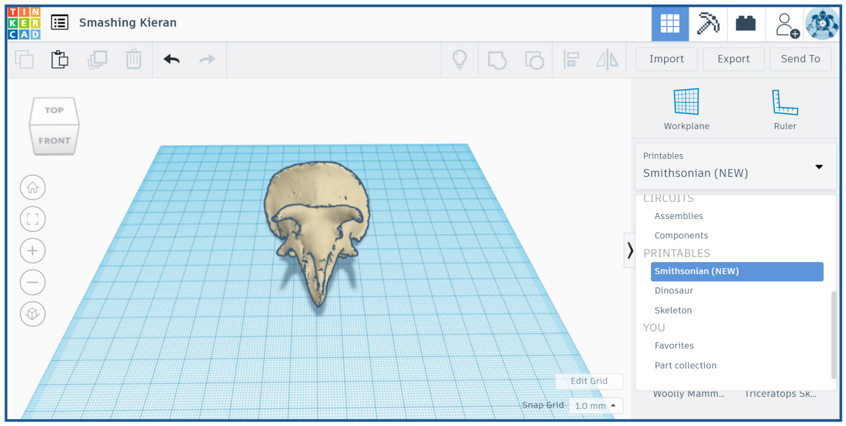
MODELING FORM

Module II: Handout

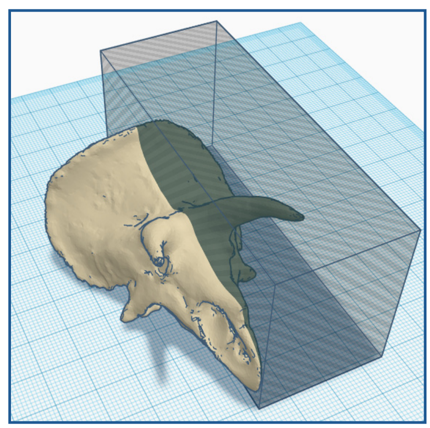
DIGITALLY MODELED FORMS

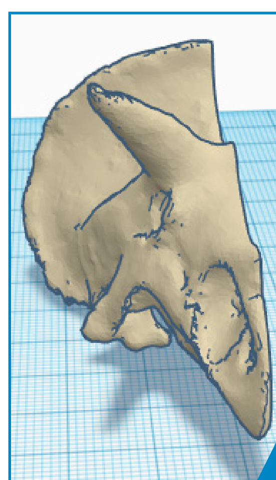
A digital model is needed in order to print objects on a 3-D printer.
Such models are created with **computer-aided design** software like TinkerCAD.

INTRODUCTION TO TINKER-CAD



1. After logging in, click **Create New Design** on your TinkerCAD home page.
2. One the right side, click on **Basic Shapes** to explore the shape library. Click on **Smithsonian,** under **PRINTABLES**, to explore the available forms.
3. Choose an artifact and drag it into the workspace.
4. Practice navigating the workspace by **right-clicking and dragging to rotate**, rolling the mouse wheel to zoom in and out and clicking and dragging the mouse wheel to pan left, right, up, and down.
5. To practice **subtractive sculpting**, return to **Basic Shapes** and drag a **Box Hole** (the gray, stripey box) into your workspace.
6. You can drag the box to position it, and drag the small squares on its edges, corners, and top to resize it. Align the box so that half of your chosen object is inside of it.
7. Holding **SHIFT**, click on both the artifact and the 'hole' so they are both selected. Then, in the upper-right, click **'Combine'**
(), and your shape will be cut in half! (It may take a few seconds to work first. Be patient.)
This tool is very powerful - you can turn **any** shape into a hole and use it to subtract material from any other shape!

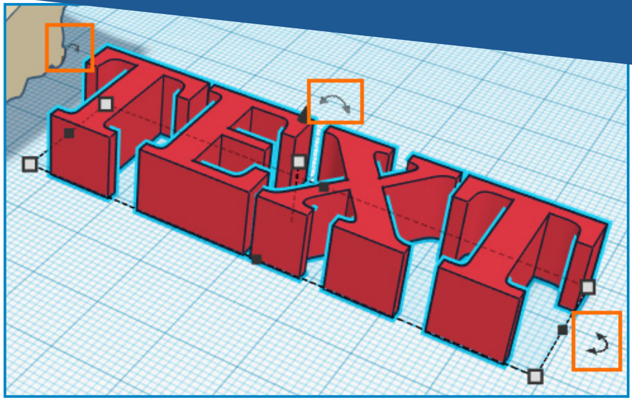


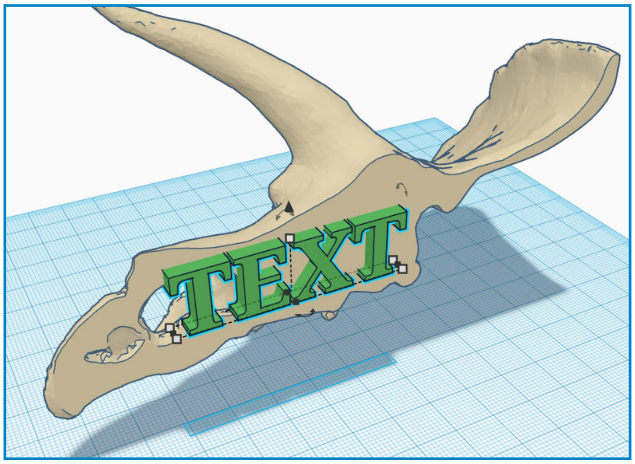


MODELING FORM

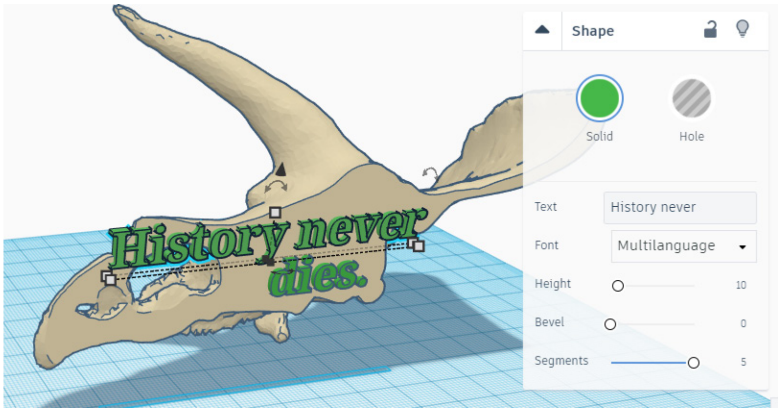
Module II: Handout

8. Now for some **additive sculpting.** Drag and drop the TEXT shape from the library of shapes on the right side of screen.
9. You can **resize** and **reposition** your text using the same tools we used above. You can also **rotate** the text by clicking on the small curved arrows on each side of the model.
10. Our goal is to position the text so that it is against the new, flat side of our sliced shape.





11. Now, edit the text in the "Shape" window in the upper-right of the screen. What could you write that would change the meaning or impact of the object you chose?



12. You can continue to experiment with **remixing** your form. How might further **additive** and **subtractive** choices transform it into something new?
13. When your design is complete, click **"Export"** in the upper-right of the screen, select **"Everything in the design,"** and save your file as an .STL for printing.

CAPTURING FORM

Module III: Lesson Plan

MODULE GOALS

3-D scanning is an alternative approach to digital modeling that functions by capturing the shape and exterior attributes of physical objects using a laser or infrared light to measure their surfaces. 3-D scanning is commonly used for manufacturing, design, and archival purposes due to its ability to make accurate digital replicas of existing forms. This module will expose students to accessible scanning technology (including Kinect, photogrammetry phone apps, or the Occipital Structure scanner for iPad) and broaden their understanding of where and how this technology can be applied to real-world projects. Students can build on their prior **remix** experiments by drawing from the physical world around them as well as repositories of digital models.

ESSENTIAL QUESTIONS

- What is 3-D scanning?
- What are the programs and devices that are used to scan 3-D objects?
- How does 3-D scanning technology work?
- What are the applications of 3-D scanning?
- What are the differences between modeling form and capturing form? What are the similarities?
- In what ways can scanning be used jointly with 3-D modeling programs and processes?
- How do objects change when they are expressed as data (e.g. a 3-D model)? How do the ways we work this them change? What new possibilities and limitations result from scanning an object?

MEANING AND ACQUISITION

- Students will gain a basic understanding of the various techniques and programs available for capturing forms digitally.
- Students will learn techniques for incorporating scanning into the design process, and how to apply 3-D scans to other digitally-modeled 3-D objects.
- Students will experience post processing of a scan in order to understand the potential for real-world application of captured forms.
- Students will create a new 3-D remix by recontextualizing or transforming a scanned object from their environment.

FORMATIVE ASSESSMENT STANDARDS

- Students demonstrate active problem-solving skills throughout the 3-D scanning and the digitization processes, converting their designs into functional digital forms **(Cr2.I.8a)**.
- Students know and use fundamental vocabulary relevant to the different object digitalization processes **(Cr3.1.1a)**.
- Students actively consider the meanings and implications of using a particular image or object as they incorporate these into their designs **(Re.7.2.4a)**.
- Students are able to discuss and explain 3-D scanning processes and techniques to their peers and help facilitate peer-to-peer learning **(CrI.1.11)**.

SUMMATIVE ASSESSMENT STANDARDS

- Student work exemplifies an effective use of materials, equipment and tools into the digitization of physical objects **(Cr2.1.IIa)**.
- Student work exemplifies a synthesis between creative and analytical principles and techniques of the visual arts and the sciences **(Cr2.3.IIa)**.
- Student work demonstrates how the introduction of digitalized objects into an existing design can provide new meaning to it **(Cr3.I.3a)**.
- Student work demonstrates the conceptualization and use of both traditional and contemporary technologies, merged by the scanning process, within the design **(CrI.2.IIa)**.

CAPTURING FORM

Module III: Lesson Plan

MATERIALS

- One or more of the following:
  - A free 3-D scanning app such as Scandy (iOS), Display.land (iOS/Android), Scann3D (Android), or Qlone (iOS/Android)
  - A Kinect or Structure sensor and computer with Skanect software
  - A Structure iPad sensor
- Wi-fi for using the free photogrammetry app on phone.
- Laptops, with mouse
- Clay
- Multiple flash drives
- Objects to be scanned

KEY TERMS

- **3-D scanning** - A process of capturing the shape of physical 3-D objects as digital data. This may involve a focused line of laser light that runs across the surface of the shape, or an infrared light shone of the surface of the shape. In both cases, the interaction of these lights with the surface of the object is captured by a sensor to determine depth information (See Figure 1).
- **Photogrammetry** - An alternative way of capturing 3-D information without special hardware. A program analyzes several photos taken from multiple angles of an object, and determines its 3-D form.

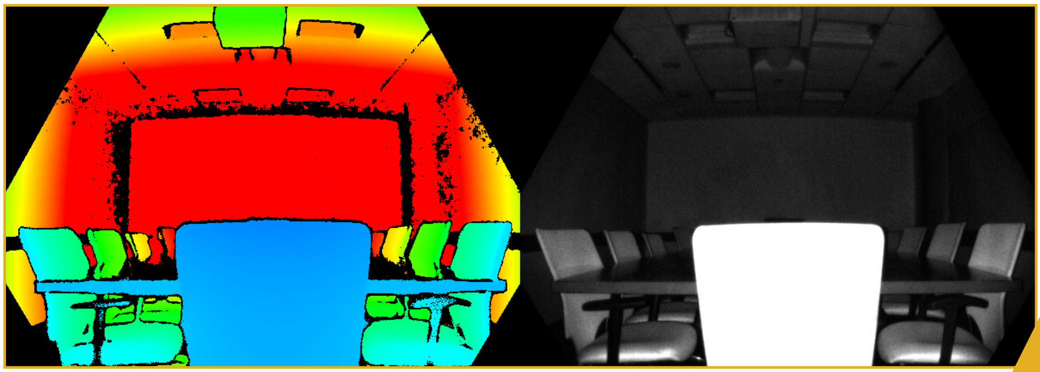


Figure 1. The infrared light shone by a Kinect sensor (right) and the depth image Kinect “sees” (left) with captured 3-D information.

CAPTURING FORM

Module III: Lesson Plan

PROPOSED ACTIVITY

1. Students will obtain a 3-D scan from their environment (of a found object, something they sculpt themselves, or of a person's body) using their smartphones and understand the photogrammetry method for scanning.
2. Students will use laser/infrared-based 3-D scanners (if available).
3. Students will work with the scanned model(s) in TinkerCAD, either extending their previous remix project, or developing a new one.

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from https://docs.microsoft.com/en-us/azure/kinect-dk/media/concepts/depth-camera-depth-ir.png

CAPTURING FORM

Module III: Case Study I

MATERIAL SPECULATION: ISIS

Realized by Iranian-American new media artist Morehshin Allahyari, Material Speculation: ISIS is a **3-D printing** project featuring the reconstruction of statues from the Roman period city of Hatra and Assyrian artifacts from Nineveh that were destroyed by ISIS in 2015 (Allahyari, 2017). Each recreated artifact contains a flash drive or memory card embedded inside of the printed object. Similar to the concept of a time capsule, these flash drives are meant for future generations and include images, maps, PDF files, and videos documented prior to the artefact's destruction (Soulellis, 2016, para. 3).

The project demonstrates how 3-D printing and scanning technology can be both a practical tool for documentation and an inherently political form of resistance (Soulellis, 2016, para. 6).

Figure 1. King Uthal. One of the destroyed artifacts meticulously reconstructed and 3-D printed by Allahyari.

Figure 2. Lamassu. Another of the destroyed artifacts meticulously reconstructed and 3-D printed by Allahyari. Visible in the body of the sculpture is a flash drive, containing 3-D data as well as other information about this artifact.

CAPTURING FORM

Module III: Case Study I

PROJECT DESCRIPTION

The recent and widespread destruction of precious cultural artifacts in Middle Eastern conflict zones and via natural disasters around the globe has inspired researchers, archeologists, and historians to reconsider the vulnerability of our cultural histories and the objects that represent them (Reilly, 2015, p. 225). Cyber Archeology, a form of archiving that uses images of historical artefacts to create 3-D reconstructions (i.e. photogrammetry), has gained momentum in recent years as a solution to offset some of these losses (2015).

However, using photogrammetry, 3-D scanning, and additive manufacturing to recreate history poses numerous challenges to traditional archeological study in that it problematizes conventional understandings of materiality and authenticity (Reilly, 2015, p. 225).

This contentious relationship is one of the many points of entry into Morehshin Allahyari's work in Material Speculation: ISIS. Allahyari exploits the illusory condition of the recurring copy that challenges concepts of memory, the past, and loss (Karimi & Rabbat, 2016, p. 2). In the traditional sense, the artifacts that Allahyari prints are considered obsolete. However, Allahyari's Material Speculation: ISIS utilizes cutting-edge technology to open up new possibilities for obsolescence with the understanding that these technologies will continue to evolve and get better in the future (Allahyari, 2017, para. 5).

By combining 3-D scanning, photogrammetry, and 3-D modeling, the artifact is resurrected and a new use-value is assigned to it (Karimi & Rabbat, 2016, p. 5). The objects themselves reside somewhere between tangible and ubiquitous as freely circulating open-source entities (2016, para. 10). The artefactual aura (Benjamin, 1969) is exchanged for immortality and guaranteed survival (Soulellis, 2016). In this way, Material Speculation simultaneously acknowledges the questionable authenticity of substituting digital recreations for lost cultural objects and hints at further possibilities born from forward-thinking technology.

Resource Materials:

The artist has provided a .zip folder of .STL and .OBJ files for some of her objects via The Download - a project by Rhizome "that considers posted files, the act of downloading, and the user's desktop as the space of exhibition" (Soulellis, 2016, para. 1).

REFLECTION QUESTIONS

1. In Material Speculation: ISIS, digital 3-D scanning is used in combination with 3-D modeling to create artistic pieces that not only preserve existing ones, but also add new meanings to them. In this sense, what are the artistic possibilities that 3-D scanning brings to the table? What is gained, and what is lost, in preserving artifacts this way?
2. Many museums have made 3-D scanned digital and printed objects of their collections available to the public for educational and research purposes. What are examples of other potential applications for photogrammetry and 3-D scanning?
3. Material Speculation: ISIS allows lost cultural objects from our past to be reborn. If you could recreate a landmark or artifact from your past, what would you recreate and why?

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Soulellis, P. (2016). The distributed monument: New work from Morehshin Allahyari's 'material speculation' series. https://rhizome.org/editorial/2016/feb/16/morehshin-allahyari/

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from http://www.morehshin.com/material-speculation-isis/

Figure 2. Retrieved from http://www.morehshin.com/material-speculation-isis/

BOOMcast

The BOOMcast is an example of how additive manufacturing can be used for medical applications. BOOMcast was initially created as a customized cast by Studio Fathom for T.V. personality Mike North of Prototype This! and Outrageous Acts of Science (Holterman, 2015, para. 1).

A design team that uses their expertise in 3-D printing and additive manufacturing to help customers find innovative solutions to problems, Studio Fathom was tasked with creating a support system for a broken fibula that would allow its wearer to maintain on active lifestyle and wouldn't compromise the healing process (2015, para. 2). They utilized computer software and **3-D scanning** technology to determine the most fitting shape for their client's leg. Outfitted with lights, bluetooth speakers, pressure sensors, on accelerometer, and wi-fi, the BOOMcast is capable of collecting real-time medical data and sending it to your doctor while simultaneously playing music from a smartphone ("North & FATHOM Take Medical To The Cloud", n.d., para. 1).

Despite the BOOMcast being a one-off project, it points to directions other innovators may take 3-D printing and scanning to better serve the particular medical needs of individual bodies.

Figure 1. Assembling the 3-D printed components of the BOOMcast.

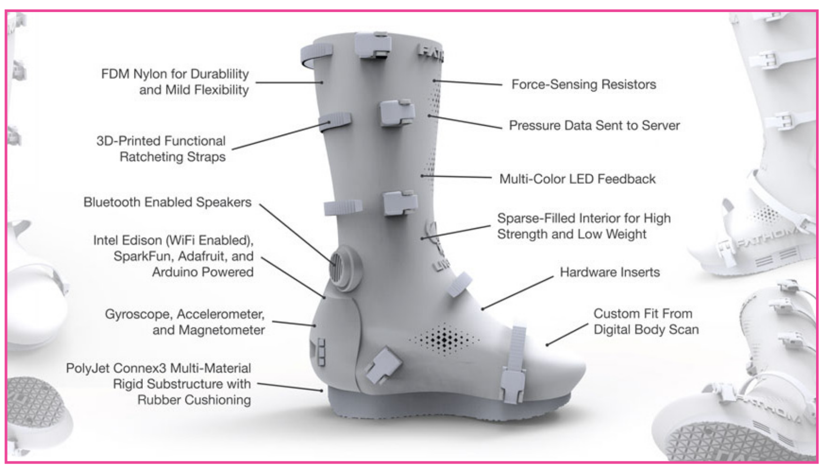

Figure 2. A rendering of the assembled BOOMcast, itemizing its various features.

CAPTURING FORM

Module III: Case Study II

PROJECT DESCRIPTION

3-D printing is becoming increasingly common within the healthcare field . Additive manufacturing is currently used to custom-print hearing aids, removable braces, prosthetics, and even replacement organs (Ventola, 2014, para. 1). In many ways, 3-D printing is already playing an important role in streamlining traditional medical treatments. As an easily customizable and less expensive option for production, 3-D printing is gaining more and more momentum in the medical field every day (2014, para. 5). The BOOMcast is one example of the potential for improving the way doctors treat broken bones by combining 3-D scanning, digital 3-D design, and additive manufacturing ("North & FATHOM Take Medical To The Cloud", n.d., para. 1).

As a television host who travels frequently, Mike North of Prototype This! And Outrageous Acts of Science needed a durable and easily removable cast to support the healing process after breaking his fibula. Many people's lives are hampered when they suffer an injury, and the BOOMcast exemplifies the ways in which 3-D printing can make a patient's specific needs more addressable (Holterman, 2015, para. 5). This particular cast takes customizability to the next level, since data from 3-D scanning processes and a special software were used to determine and generate a 3-D model that fitted North's leg. This is a process that can be found in other examples of 3-D printed medical casts as well (Holterman, 2015, para. 4). Also, North's cast integrates technology from industry-leading companies like Intel and Google: due to a hectic schedule, the cast is programmed to deliver medical information to a doctor in leu of office visits, map pressure and audio data, and contribute other extensive auxiliary features (Domanico, 2015, para. 2). Finally, the body of the cast and the straps that are used to hold it in place were printed in Nylon 12 filament, while the sole of the cast was built with PolyJet multi-materials (2015).

While BOOMcast is unlikely to become a full-fledged consumer product, it manages to demonstrate as proof-of-concept how open-source development, 3-D scanning, and 3-D modeling can be integrated and used to design and build novel and more effective products in the near future (Domanico, 2015, para. 9).

REFLECTION QUESTIONS

1. What are the possibilities and limitations of 3-D scanning for medical purposes? What other medical uses can you imagine for 3-D scanning technology?
2. What about beyond medical uses? How else might 3-D scanning be used to customize items? What are the potential possibilities and setbacks of this technology?
3. What will happen with the BOOMcast when Mike North is done wearing it? Are customizable, single-use items a sustainable practice, from an environmental or resource-conscious perspective? How might we address these issues?

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FATHOM (n.d.). North & FATHOM take medical to the cloud. http://studiofathom.com/boomcast/

Holterman, T. (2015). BOOMcast: 3-D printed disco leg cost includes music and mood lighting. https://3dprint.com/86160/3d-printed-boomcast/

Ventola, C. L. (2014). Medical applications for 3-D printing: Current and projected uses. Pharmacy and Therapeutics, 39(10), 704-711.

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from http://studiofathom.com/boomcast/

Figure 2. Retrieved from http://studiofathom.com/boomcast/

CAPTURING FORM

Module III: Handout

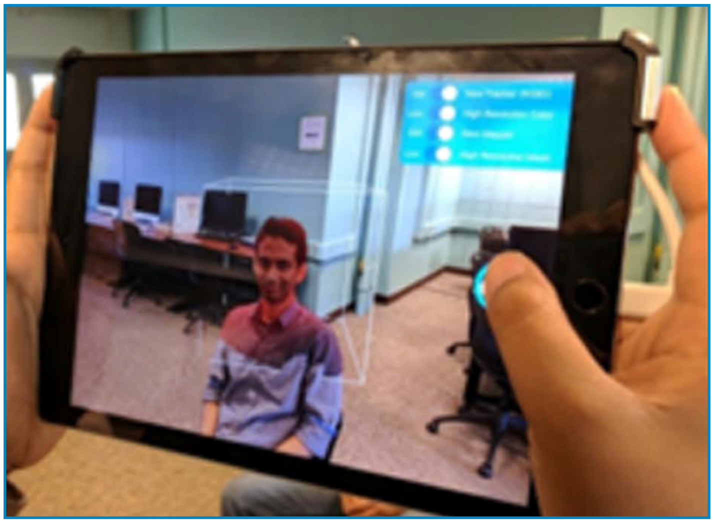
3-D SCANNING

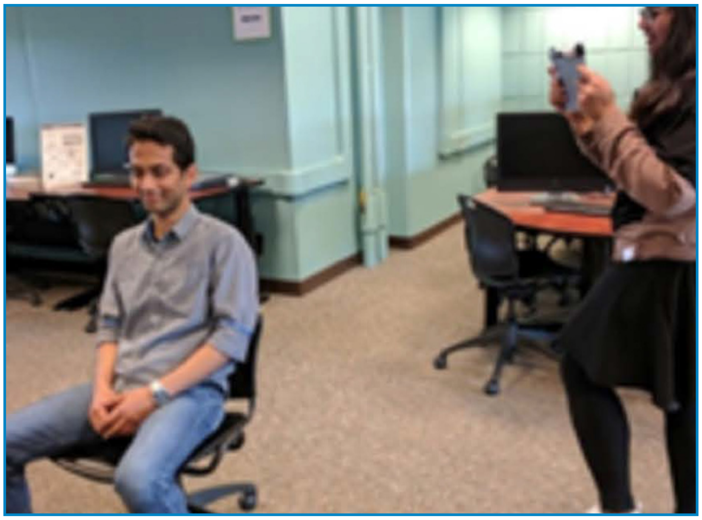
Capturing form is an alternative approach to
digital modeling. This technique can be applied for solving real-world challenges.

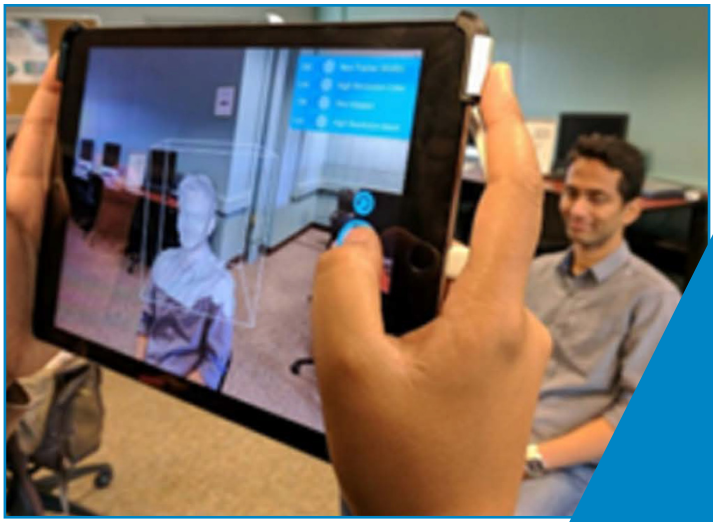
INFRARED-BASED 3-D SCANNING WITH STRUCTURE SCANNER

The Occipital Structure Sensor , for the iPad, is one available tool for 3-D scanning. Infrared dots are projected onto the object, which is used by the infrared camera to create a pattern and visualize the shape and distance of an object. This tutorial focuses on this tool, but others are available.

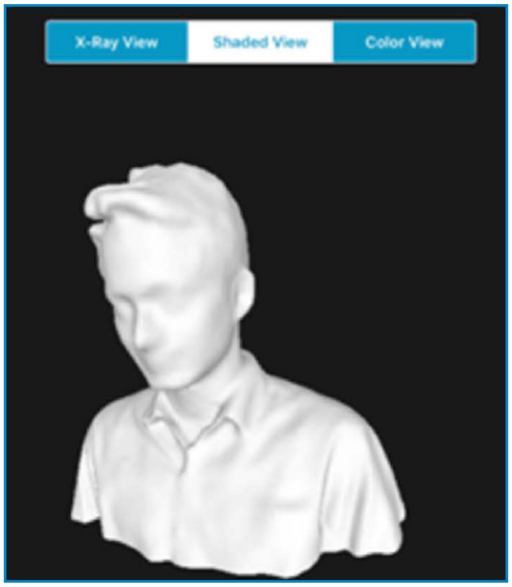
1. To scan an object or person, place it/them in a properly lit area and, make sure to have a one meter of walkable radius free around it.
2. Hold the scanner at an appropriate distance, adjust the enclosure box accordingly in the Occipital app.
3. Once the object is captured in the box, and is tinted red. Walk around the object slowly, to capture the 3-D model.
4. Be sure to capture the top, and, if necessary, the bottom of your scanned object/person!



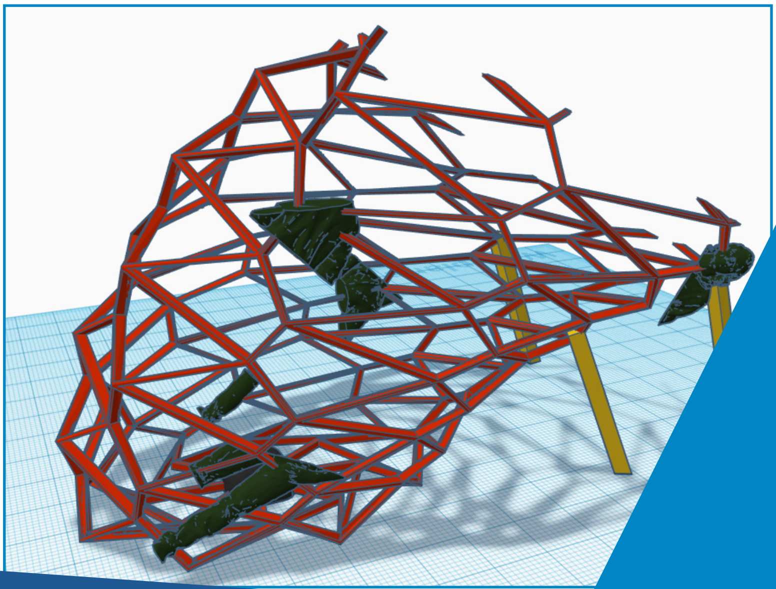




5. Once complete, preview the three views (X-Ray, Shaded, and Color) in the Occipital app. If you are satisfied with the scan, email it to yourself.



6. **Post-processing** means taking the scanned image and "cleaning it up" before printing. This might mean getting rid of unnecessary extra bits the scanner captured, or fixing holes in areas the scanner didn't capture.
7. We can open our models in TinkerCAD to post-process them, and also to transform, extend, and remix them.
8. Once in a TinkerCAD project, import the .obj file from your scan, by clicking the **Import** button in the upper-right.
9. Your scan will probably be tiny initially, so scale it up by holding the shift key and dragging one of the corners.
10. Now, explore and play! You can add this scan to the remix from the previous module, or turn it into something new. If you notice any messy or unnecessary bits of the scan, you can remove them with 'hole' shapes.



CAPTURING FORM

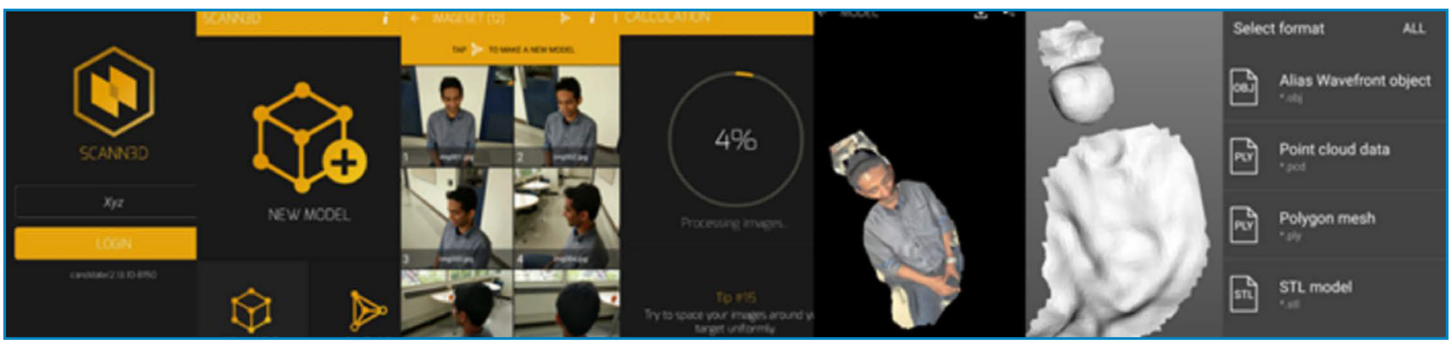
Module III: Handout

PHOTOGRAMMETRY

Photogrammetry is 3-D scanning through smart phones, with no special hardware required. Software analyzes photos taken from multiple perspectives around an object and uses them to construct a 3-D model of the object being photographed.

AVAILABLE TOOLS

SCANN3D for Android, pictured here, is one tool for photogrammetry, though there are many options. Each of the available apps is designed to be self-explanatory. If you seek out your own, make sure to use an app that allows you to download or export your model for free. At the time of writing this, Scandy (iOS), Display.land (iOS/Android), or Qlone (iOS/Android) are potential options.



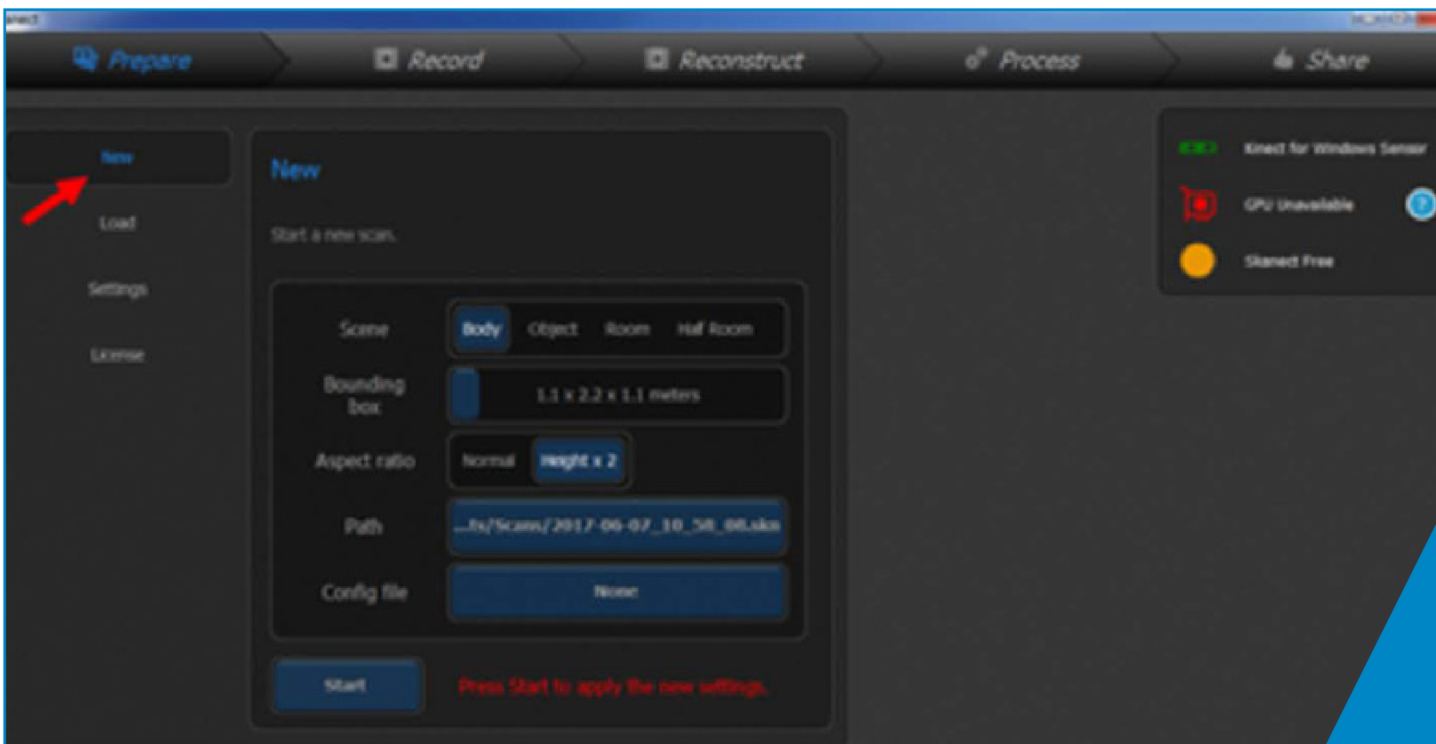
INFRARED-BASED 3-D SCANNING WITH KINECT SCANNER

The Microsoft Kinect, initially designed for gaming applications on the XBox, was quickly adapted by hackers and artists for other uses, and soon supported by Microsoft as a tool for 3-D scanning and interaction with computers. There are several software tools that allow for scanning with a Kinect, including Skanect and KScan. The Kinect projects infrared dots onto an object, which is used by the infrared camera to create a pattern and visualize the shape and distance of an object.

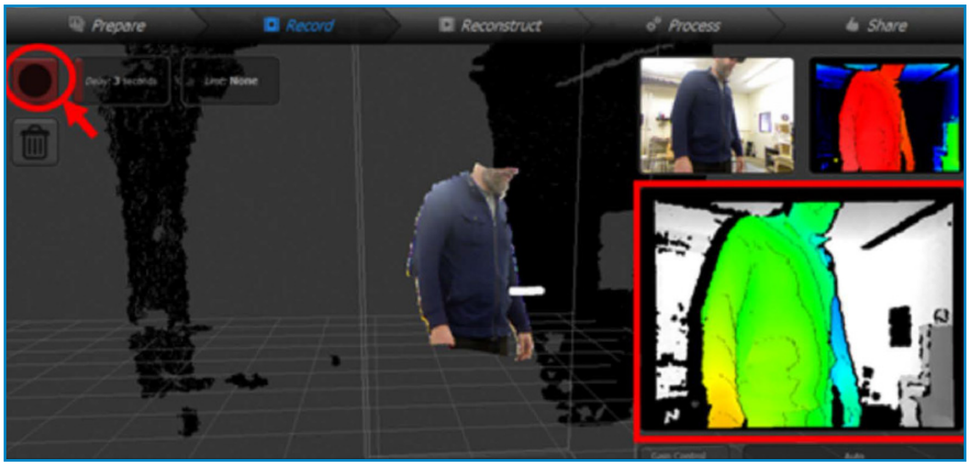
This tutorial focuses on using Skanect software with a Kinect v1 device, but other options are also totally viable, depending on what your have available.

USING SKANECT + KINECT v1

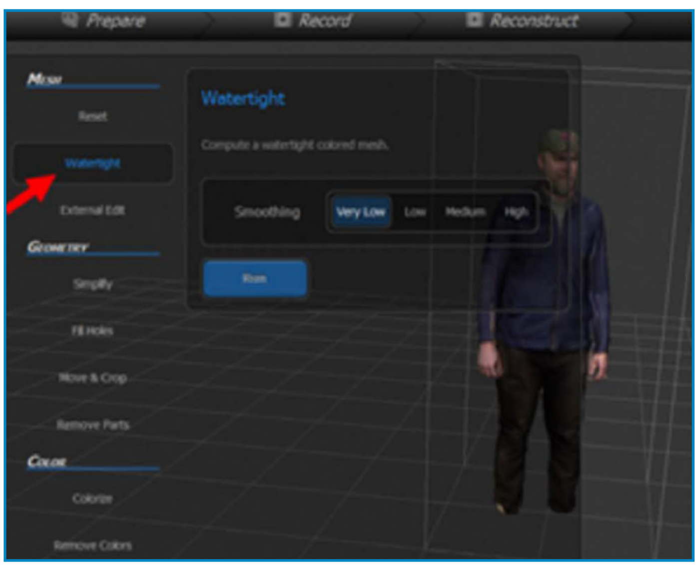
1. Open Skanect on the computer the Kinect is attached to. Prepare a new scan, adjust settings as required. A bounding box is the enclosure in which the object to be scanned must fit.

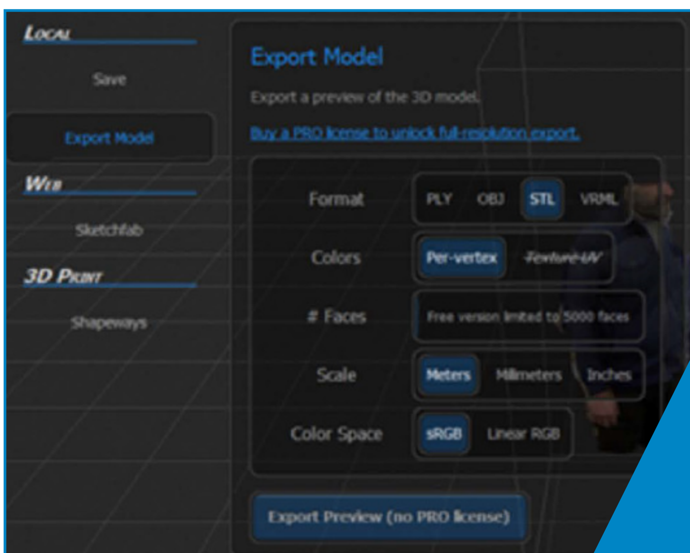


2. Place the object or person to be scanned on the lazy Susan. Adjust the Kinect such that the object to be scanned turns green on the screen. Start the scan, and switch on the rotation of the lazy Susan. Stop by clicking the button again, once all the sides are captured.



3. Once the reconstruction is done, go to Process, and Mesh the file to Watertight. Once complete, share your file in any file format.





EXTRUSION

Module IV: Lesson Plan

MODULE GOALS

Extrusion type printing is the most accessible, simple, and robust type of 3-D printing. An extensive understanding of how it works will help students to understand the parameters that impact the final part quality. In this module, students will engage in material experimentation with hand-held plastic extrusion devices ("3-D printing pens"), and become acquainted with how their operation reflects the ways 3-D printers **additively** build form.

ESSENTIAL QUESTIONS

- What is the **extrusion** process?
- What is a **filament**?
- How do forms build in the **additive** manufacturing process?
- What kinds of objects can and cannot be produced by using extrusion?
- What are some of the material limitations usually faced within the extrusion process?
- What tools or software are used to manipulate the extrusion process?

MEANING AND ACQUISITION

- Students will learn about the material extrusion process of 3-D printing. The process of melting filament, extruding it, and its solidification.
- Students will understand extrusion-specific limitations and opportunities. For example: the need for support and flexibility in design, and the need for methodical, layer-by-layer construction.
- Students will experiment with a 3-D pen extruder.
- Students will learn about the variety of material that can be used for extrusion as well as material-specific limitations and opportunities.

EXTRUSION

Module IV: Lesson Plan

FORMATIVE ASSESSMENT STANDARDS

- Students demonstrate willingness to experiment and develop skills in new art-making techniques, such as the 3-D drawing with 3-D pens **(Cr2.1.5a)**.
- Students know and use fundamental vocabulary relevant to the extrusion process **(Cr3.1.1a)**.
- Students demonstrate quality attention to craft by carefully using the materials and tools provided **(Cr.2.2.Sa)**.
- Students are able to discuss and explain the extrusion process to their peers and help facilitate peer-to-peer learning **(Crl.1.II)**.

SUMMATIVE ASSESSMENT STANDARDS

- Student work exemplifies an effective use of materials, equipment and tools into the creation of 3-D objects **(Cr2.1.IIa)**.
- Student work exemplifies a synthesis between creative and analytical principles and techniques of the visual arts and the sciences **(Cr2.3.IIa)**.
- Student work demonstrates an understanding of the different approaches utilized in creating 3-D objects from scratch in a creative way **(Crl.1.Ia)**.
- Student work demonstrates the conceptualization and use of both traditional and contemporary techniques and technologies (hand and 3-D pen drawing) within the design **(Crl.2.IIa)**.

MATERIALS

- Work table
- Handouts
- Paper
- 3-D pens
- (Optional) Physical objects (including old or failed 3-D prints!) to extend, connect, revisit, and adjust using the 3-D pens

EXTRUSION

Module IV: Lesson Plan

KEY TERMS

- **Additive manufacturing** - Also known as 3-D printing or digital fabrication, additive manufacturing is creating physical objects, by building up, layer by layer, building material (General Electric, n.d.).
- **Extrusion** - The process of forcing a soft material, such as clay or heated plastic or metal, through an opening for manufacturing purposes (ScienceDirect, 2005).
- **Filament** - A slender, threadlike object/material. In 3-D printing, plastic filament is extruded through the 3-D printer or 3-D pen to build forms.

Derived from:

General Electric. (n.d.). What is additive manufacturing? https://www.ge.com/additive/additive-manufacturing

ScienceDirect. (2005). Extrusion. https://www.sciencedirect.com/topics/materials-science/extrusion

PROPOSED ACTIVITY

1. Students will use the 3-D Pens to create a 3-D monogram:
   - Students will write/design a monogram using their initials on a piece of paper.
   - Students will trace and fill the letterforms on the paper using the 3-D pen, then peel off the plastic once it has cooled down.
   - Students will make a rectangular base with the pen, and attach it to the monogram/letters so it stands.
   - Look at the handout for more specific instructions.
2. Students will use the 3-D Pens to mimic a 3-D printer, in order to understand how the extrusion process works:
   - By tracing the 2-D shapes on the provided sheets, and building them up vertically, layer by layer, students will build a 3-D form.
3. After these exercises, students will use the 3-D Pens to create their own free-form design by drawing in 3 dimensions:
   - Draw anchor points on a surface.
   - Draw vertically from the anchor points to create a 3-D form.
     - Refer to the handout for more specific instructions.

EXTRUSION

Module IV: Case Study I

TOM LAUERMAN

Tom Lauerman is an artist and professor at the Pennsylvania State University whose practice integrates traditional techniques such as sculpture, craft, and design, along with contemporary digital processes that aid creative ways of working (Lauerman, n.d., para. 1). Beginning in the Fall of 2015, Lauerman became interested in developing and exploring extrusion-based processes for 3-D printing in clay, and his current work spans methodological and technical boundaries, seeking to synthesize traditional craft techniques with digital fabrication strategies (Lauerman, n.d., para. 1). Lauerman's innovations in the field, including his progressive development of an open source 3-D clay printer, is shared freely with the public ("Shaping Code, Shaping Clay: Developing, Sharing, and Teaching via Open Source Tools and Techniques for 3-D Printing in Clay", 2017). In this way, Lauerman hopes that innovators in the field will continue to develop and evolve 3-D clay printing (Lauerman, n.d. para. 8).

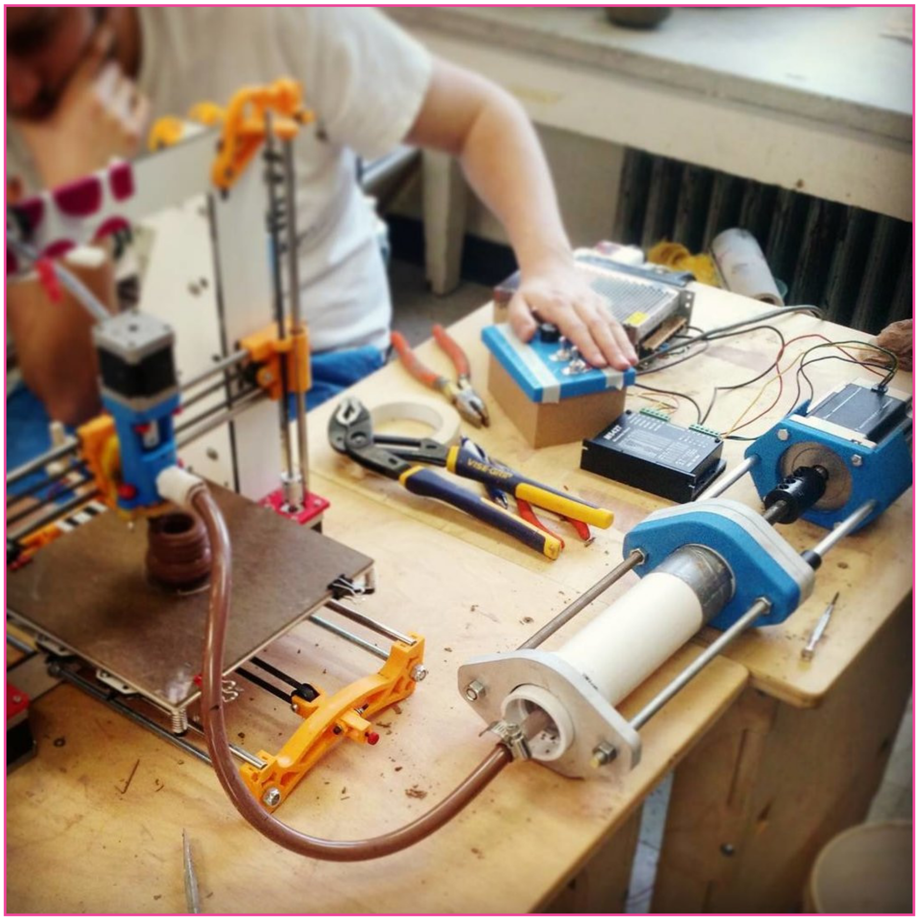


Figure 1. Experimental clay printing with PSU capstone students in 2016.

EXTRUSION

Module IV: Case Study I

PROJECT DESCRIPTION

Although rapid prototyping (3-D printing) technologies have been around since the invention of resin printing* in the late 1980s, clay extrusion printing didn't become a focus of makers and innovators until the early 2000s ("A Detailed History of 3-D Printing and 3-D Printing Technologies", 2017, para. 8).

The Unfold Design Studio in Antwerp first began developing clay extruded projects as a 3-D printing method in 2009, using an altered printer inspired by the 2005 RepRap open source 3-D printing project (Wornier & Verbruggen, 2009, para. 5).

Lauerman himself become motivated to enter the conversation and begin experimenting with this new art-making technique in 2014, when British potter Jonathan Keep shared on an internet forum on how to build a 3-D printer from scratch (Lauerman, n.d. para. 8).

Over time, 3-D printing and digital fabrication technologies have begun to alter the landscape of making and design at all levels ("Shaping Code, Shaping Clay", 2017). From factory production to fine art, 3-D printing sits at the intersection of digital technology and the physical object, giving it the potential to significantly impact the culture of making, manufacturing, and education (Lauerman, n.d. para. 9).

It is because of this potential that artists and innovators like Tom Lauerman offer their ideas to the public via open source content. By sharing his progress with the public, the underlying processes make his ideas accessible, able to be studied or duplicated, and even altered (n.d.). Additionally, the solutions offered by makers like Lauerman are low-cost, openly shared, and self-made, subsequently opening up the field of additive manufacturing to those who might not otherwise have access. This open-source approach empowers the individual "tinkerer" with a limited budget, and encourages creative risk-taking and experimentation that challenges traditional means of creating form ("Shaping Code, Shaping Clay", 2017).

*Resin printing is a form of 3-D printing that doesn't use extrusion. Instead, a liquid called resin is chemically treated to become hard when hit with a laser. A computer-controlled laser is fired at a container of resin, and hardens it, layer by layer, to additively build the form.

REFLECTION QUESTIONS

1. What other unconventional materials might be used in additive manufacturing (3-D printing)? What kinds of artifacts or projects can you imagine making with a 3-D printer that worked with something other than plastic?
2. What are possibilities does extruded (3-D printed) clay have that traditional clay-making does not? What are possibilities it has that traditional plastic 3-D printing does not? What are limitations of this way of working?
3. How might the open source nature of Lauerman's 3-D clay printer affect how and when is 3-D clay printing used? What are the benefits of this open-sourcing of his design? What are the limits or drawbacks? Could you build a printer with his open-source design? What factors in your life contribute to your answer?

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Lauerman, T., & Keep, J. (2017). Shaping code, shaping clay: Developing, sharing, and teaching via open source tools and techniques for 3-D printing in clay [Abstract]. Digitally Engaged Learning conference. http://www.digitallyengagedlearning.net/2017/sessions/shaping-code-shaping-clay-developing/

Warnier, C., & Verbruggen, D. (2009). Ceramic 3-D printing. http://unfold.be/pages/ceramic-3d-printing

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from http://www.tomlauerman.com/3d-printing-in-clay-1/

FELFIL- OPEN AND DIY FILAMENT EXTRUDER

Felfil is on open-source DIY filament extruder that makes custom filament from recycled plastic pellets and failed print material (Nelli, 2016, para. 1). The project was created by Collettivo Cocomeri (CC), an Italy-based collective founded by alumni from Politecnico di Torino with a focus on multi-disciplinary and sustainable design solutions (Severini, Posquero, Crovino, & Mesiana, 2017).

The Felfil project focuses on open-source solutions for recovering and repurposing plastic waste to reduce its environmental impact. It also aims to address concerns regarding the cost of, and access to, additive manufacturing for individuals (Grunewald, 2015, para. 3). The open-source nature of the project promotes equitable access to additive manufacturing by effectively utilizing unsuccessful prints, old models, packaging or plastic pellets to reduce waste and save money for makers (Severini et. al., 2017).

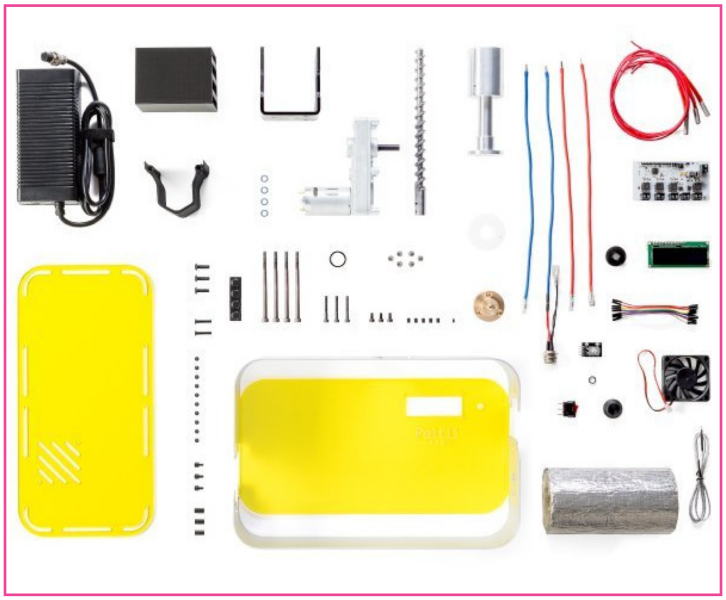

Figure 1. The Felfil EVO kit. Makers can buy an assembled Felfil filament extruder, or save money by buying the kit and assembling the device themselves. This aims to keep the project equitable to creative people with different resources.

Figure 2. An assembled Felfil extruder.

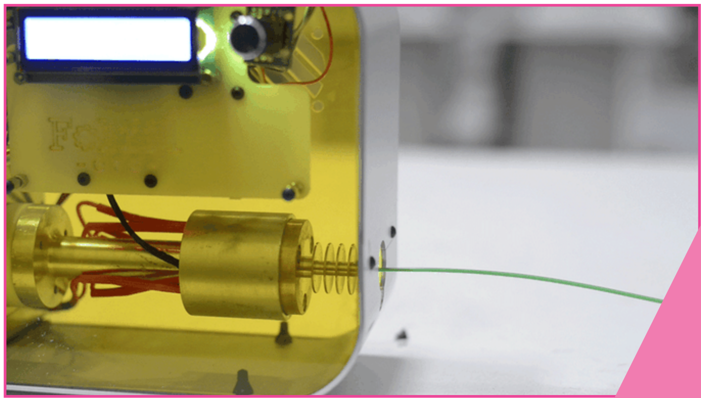

Figure 3. A Felfil device, extruding filament made from recycled pellets.

PROJECT DESCRIPTION

As 3-D printing increases in popularity and applications, many in the field are concerned with its environmental impacts and the future of plastic waste management (McAlister & Wood, 2014). Many of the filaments available on the market are created from new polymers, and while there are biodegradable materials such as Polylactic Acid (PLA) filament with the potential to lessen the burden of plastic waste over time, it can take years for the decomposition process to be realized (Brice, 2017).

An unsettling reality of additive manufacturing is that the process can end up leaving behind a substantial amount of waste (Kurman & Lipson, 2013). On rare occasions this plastic byproduct can be reused, but in most cases the material properties of the plastic become corrupted as a result of printing and are therefore unfit for recycling (2013).

In direct response to this issue are innovations like Collettivo Cocomeri's Felfil. Felfil is a DIY filament extruder invented by Alessandro Severini, Fabrizio Pasquero, Giulio Cravino, and Fabrizio Mesiana (Nelli, 2016, para. 3). It was initially developed as part of a thesis project born from an Ecodesign course at the Politecnico di Torino in 2011 (Severini, et al., 2017). The Felfil extruder can treat any thermoplastic polymer which has a melting temperature of up to 300 ° C, giving it the potential to create filament from a broad range of materials such as plastic bottles in addition to failed print material and raw plastic pellets (Severini, et al., 2017).

As such, the goal was to increase the variety of available materials for extrusion, thus providing the public with the ability to create their own custom filament for 3-D printing that is fully recycled and therefore more financially and environmentally sustainable for independent makers (Nelli, 2016, para. 4).

Since its conception, the original Felfil extruder has been further developed into the Felfil EVO, a streamlined electronic system compatible with Arduino, a programmable device popular with makers (Nelli, 2016, para. 6). In the tradition of the maker movement, the instructions for the original Felfil extruder and the Felfil EVO are open-source and readily downloadable from the project's web site, https://www.felfil.com/ (Severini, et al., 2017).

EXTRUSION

Module IV: Case Study II

REFLECTION QUESTIONS

1. The plans for the Felfil extruder were released under the Creative Commons License, which allows anyone to build or modify their own versions. What are the potential implications of individuals creating custom filaments, in terms of both design and sustainability issues?
2. What kinds of limitations may plastic filament have? In addition to plastic waste, what are some of the potential environmental impacts to consider when weighing the sustainability of 3-D printing against other forms of manufacturing?
3. In what ways can extrusion-based 3-D printing technologies solve current issues of sustainability in manufacturing and design? What new issues/problems might they produce?

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Brice, A. (2017, February 15). As 3-D printing grows, so does need to reclaim plastic waste Berkeley News. http://news.berkeley.edu/2017/02/15/3d-printer-filament-reclamation-project/

Grunewald, S. (2015). Make your own 3-D printer filament by building your own filament extruder. https://3dprint.com/56759/diy-filastruder-instructables/

Kurman, M., & Lipson, H. (2013). Is eco-friendly 3-D printing a myth? Live Science. http://www.livescience.com/38323-is-3d-printing-eco-friendly.html

McAlister, C. & Wood, J . (2014). The potential of 3-D printing to reduce the environmental impacts of production. Paper presented at ECEE 2014 Summer Study, The Netherlands. https://www.eceee.org/library/conference_proceedings/eceee_Industrial_Summer_Study/2014/2-sustainable-production-design-and-supply-chain-initiatives/the-potential-of-3d-printing-to-reduce-the-environmental-impacts-of-production/

Nelli, F. (2016). Open hardware & Felfil EVO -A filament extruder for 3-D printing. Meccanismo Complesso. https://www.meccanismocomplesso.org/en/open-hardware-felfil-evo-a-filament-extruder-for-3d-printing/

IMAGE ATTRIBUTIONS

Figures 1 and 2. Retrieved from https://felfil.com/felfilevo-filament-extruder/

Figure 3. Retrieved from https://atmelcorporation.wordpress.com/2015/10/22/felfil-evo-is-an-open-source-filament-extruder/

EXTRUSION

Module IV: Handout

EXTRUSION

Extrusion has been used for forming many materials for centuries, long before 3-D printing. If you've ever squirted Play-Doh through a hole or frosting out of a tube, you've used extrusion.

Most common 3-D printers use extrusion to build forms out of plastic filament. By experimenting with a hand-held extrusion tool - a 3-D pen - you can develop an embodied understanding of how 3-D printing works, and what makes for an effective 3-D print.

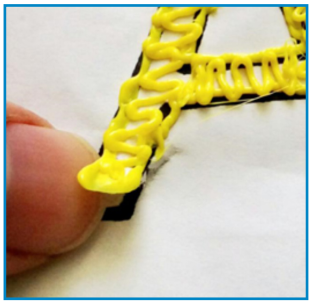
Monogrammed business card by Amanda Salcido.

“Love,” by Robert Indiana.

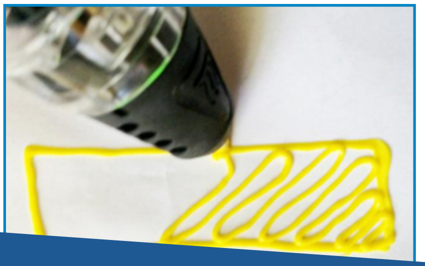
ACTIVITY 1: EXTRUDING with 3-D PENS

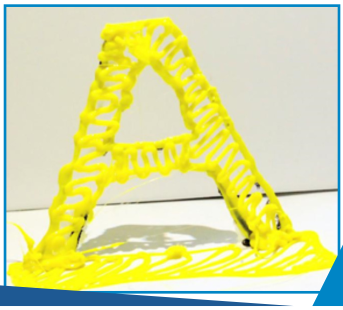
A good starting activity with 3-D pens is to create 2-D shapes like letters, and then peel them off of the page.

1. On paper, with a thick pen, develop an interesting shape using letter forms. You could create a **monogram** by artfully combining your initials, or create **typographic art** that emphasizes a meaningful word in a visually interesting way.
2. Using your warmed-up 3-D pen, outline your letterforms on the paper and use zig-zagged lines to fill it in. Peel the letters off of the paper after it cools down.



3. Next, create a rectangular base plate using the same strategy. Then attach your letterforms to it with the 3-D pen.





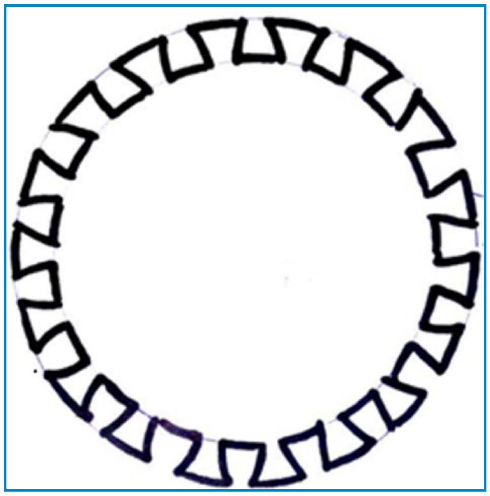
EXTRUSION

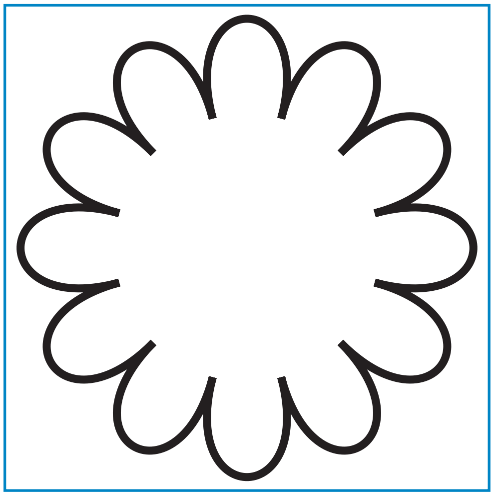
Module IV: Handout

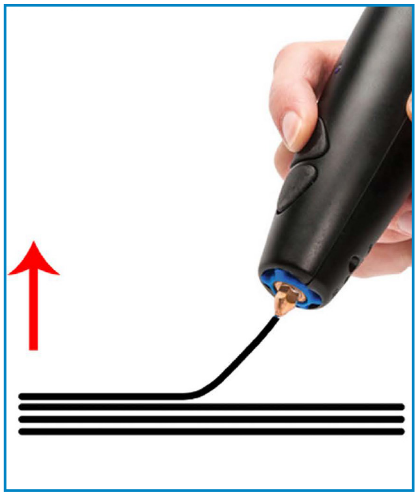
ACTIVITY 2: ADDITIVELY BUILDING A 3-D FORM

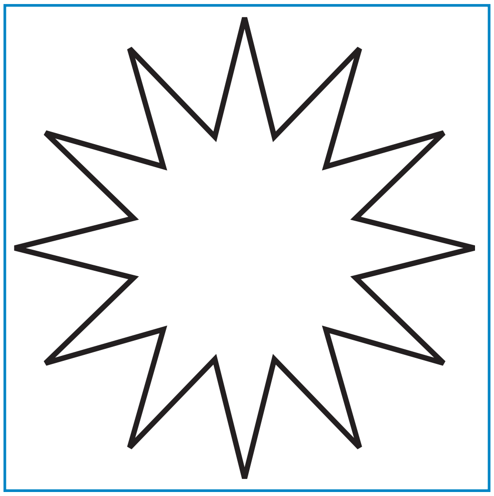
By building up from a 2-D shape layer-by-layer, a 3-D pen can build a 3-D shape using a similar additive process to a 3-D printer. In this exercise, we'll experiment with building up form.

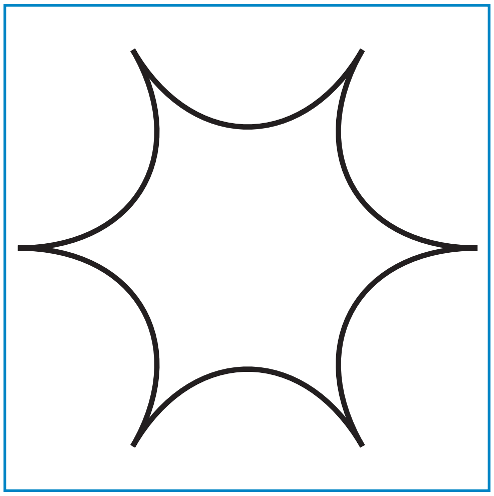
1. Try tracing one of the shapes below repeatedly in order to increase the height of your object. How tall can you make your structure?

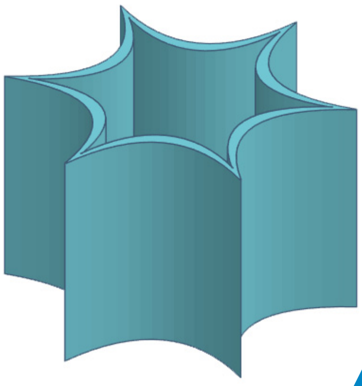










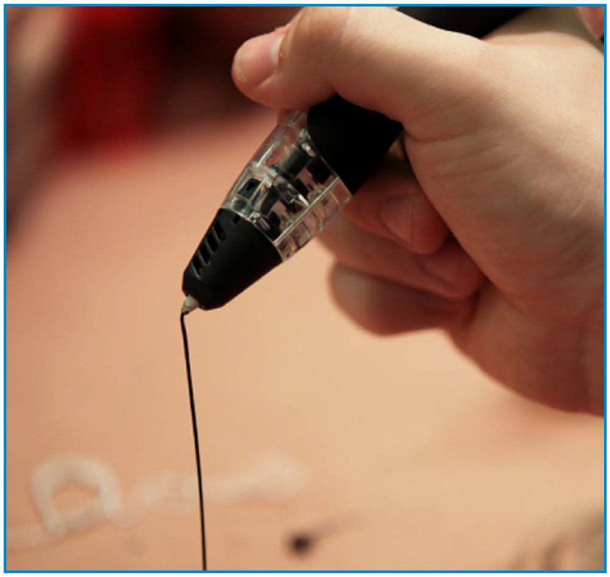


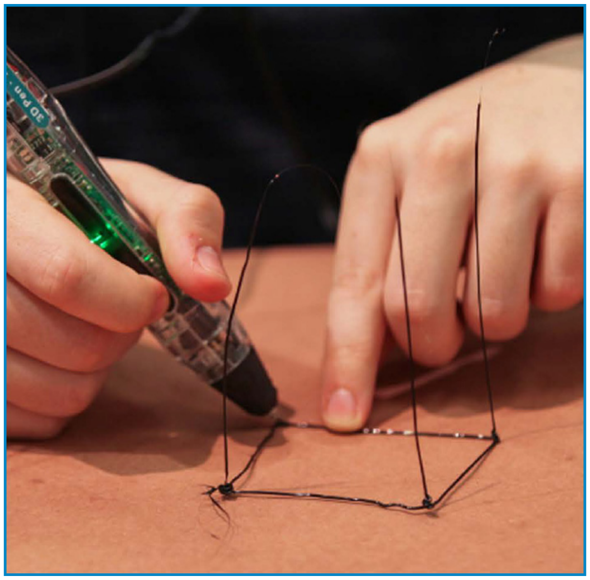
EXTRUSION

Module IV: Handout

ACTIVITY 3: DRAWING FORM - CREATE YOUR OWN FREE-FORM DESIGN

1. The ability to make freehand 3-D drawings in space is a unique feature of the 3-D pen. To begin, start with a solid anchor point by making a large dot of plastic on a flat surface.
2. From the anchor point, lift the pen slowly and carefully into the air. Try to match the speed at which the pen's extruder pushes out the plastic. When you reach the point where you want the line to end, hold the pen still for a few seconds without extruding new material. This will let the filament harden before you pull the pen away.





3. As you create your 3-D free form design, consider how you might use different colors and filaments in meaningful or visually-interesting ways.

PROCESS

Module V: Lesson Plan

MODULE GOALS

In arts and craft traditions, process is at least as important as the final creative product. Some art practices, like the mandala, place all of the importance in the process of making, destroying the product as soon as it is finished. But even traditions like manufacturing, where the product is the focus, demand careful attention to the creative process in order to create a high-quality artistic product.

Designing and digitally creating a 3-D form via online platforms like TinkerCAD is the first step in additive manufacturing. In order to correctly prep your form and make sure the design is readable to 3-D printers, print settings, file formatting, and other aspects of the printing process must be taken into account. In this module, students will gain a greater understanding of how to successfully prepare and set up their design for printing. By better understanding the process of designing and producing a successful 3-D print, students will develop a greater agency over that process, enabling them to experiment with, or fine-tune to process with artistic intent.

ESSENTIAL QUESTIONS

- What process(es) does a digital design need to go through in order to be 3-D printed?
- What types of files can a 3-D printer read?
- What do the different file types (**.STL, .OBJ**) mean?
- How does **infill** affect a 3-D print?
- How does layer thickness affect a 3-D print?
- How does the orientation of a digital design affect the way it is printed?
- How do artists manipulate the 3-D printing process(es) to artistic ends?

PROCESS

Module V: Lesson Plan

MEANING AND ACQUISITION

- Students will know what file type **.STL** means and how it is created and interpreted by the 3-D printer.
- Students will be able to prepare their own designs for print.
- Through the process of prepping their own designs for printing, students will understand how print settings affect an object's print time.
- Through the process of prepping their own designs for printing, students will understand how print settings affect post-processing efforts.
- Through the process of prepping their own designs for printing, students will understand how print settings affect print orientation and support material for printing.
- Through the process of prepping their own designs for printing, students will understand how print settings affect an object's surface quality.
- Students will be able to choose the most appropriate print settings for their object, including layer thickness, infill density, and orientation on the plate.

FORMATIVE ASSESSMENT STANDARDS

- Students demonstrate willingness to experiment and develop skills in new art-making technologies **(Cr2.l.5a)**.
- Students know and use fundamental vocabulary relevant to the processes involved in the preparation of digital files for printing **(Cr3.1.1a)**.
- Students show willingness to revise and modify their existing models in relation to the information obtained through the digital file preparation process **(Cr.1.1.lla)**.
- Students are able to discuss and explain the printing preparation process to their peers and help facilitate peer-to-peer learning **(Crl.1.11)**.

PROCESS

Module V: Lesson Plan

SUMMATIVE ASSESSMENT STANDARDS

- Student work exemplifies an effective use of equipment and digital tools into the preparation of 3-D designs for their printing **(Cr2.1.IIa)**.
- Student work exemplifies a synthesis between creative and analytical principles and techniques of the visual arts and technical concepts from the sciences **(Cr2.3.IIa)**.
- Student work demonstrates the exploration of new art-making technologies and the approaches associated with these **(Cr2.I.4a)**.

MATERIALS

- Laptop with slicing software (this tutorial will use Cura, but other options, such as Slic3r, will work well, too).
- A mouse.
- Example objects:
  - Objects printed with different STL resolutions.
  - Objects printed with supports, at different orientations.
  - Successful and unsuccessful prints.
  - Examples using different materials (e.g. metal, flexible material, multi-material, wood, food).
- One or more 3-D printers.

KEY TERMS

- **Build plate** - The surface where an object is 3-D printed.
- **Infill** - An internal support structure for printed objects. Making them completely solid would waste a lot of plastic, so infill is usually a grid of supportive plastic inside the model. Infill can be adjusted to be more or less dense, resulting in a sturdier object that uses more material, or a less sturdy object that uses less material.
- **G-code** - A digital file format that represents a 3-D model as a series of stacked layers for a 3-D printer to print.
- **Layer height/thickness** - Height of the horizontally printed layers of a 3-D printed object. The thicker this is, the more visible "ridges" there are on a model. The thinner this is, the more layers the printer needs to print, taking more time.
- **OBJ** - A common digital file format for a 3-D model. Short for "object file," OBJ files often include information about surface color and texture in an attached MTL ("material") file. This makes them useful for applications like game design, but less suited for 3-D printing.
- **Orientation** - The rotation and position of the 3-D model. Some orientations are better-suited for 3-D printing than others (for example, having a flat side of your model on the bottom is generally a more stable orientation).
- **Slicer** - Software that converts STL files or other 3-D model formats into G-code files for 3-D printing.
- **STL** - A digital file format for a 3-D model, imported into a slicer to convert it to G-code. STL is short for "stereolithography," an older 3-D printing technology. STL is one of the older 3-D file formats, and just contains data on the shape of an object, without any color or surface data, making it an efficient file type for 3-D printing.
- **Support** - Removable and discarded 3-D printed material used to prop up overhangs, bridges, and negative space during printing.

Derived from Budmen. (2019). Preparing your model for 3-D printing. https://budmen.com/support/3d-course/lesson-4/

PROCESS

Module V: Lesson Plan

PROPOSED ACTIVITY

1. For understanding process, students will prepare their designs for 3-D printing:
   - Go through the handout and play around with example parts.
2. Students will prepare the STL file for its printing:
   - Use the computer and follow the instructions to create the STL file from their model.
3. Students will prepare the print by experimenting with different print settings:
   - Use the example models to understand how each setting influences the print time and surface finish.
4. Learn about **part orientation** by modifying the settings.
5. Learn about **infill density** by modifying the settings.
6. Learn about **layer thickness** by modifying the settings.
7. Learn about how to use the **print preview** to achieve a desirable result.

SOPHIE KAHN

Visual artist Sophie Kahn challenges the ways in which, usually, artists and designers make use of the 3-D printing and 3-D scanning technologies. By misusing advanced 3-D laser scanners with the goal of generating glitchy outcomes,

Kahn aims not at fabricating formally correct 3-D printed objects; instead, she creates defective files of failed 3-D scans to print as incomplete or imperfect sculptures. Following other glitch artists, Kahn defies the idea that technology and production (and in this particular case, digital fabrication) need to be flawless.

Kahn utilizes not only 3-D scanning and 3-D modeling techniques as part of her design process, but she also incorporates the post-production stage as part of her artistic practice. It is through the digital alteration of her defective files that Kahn's artworks can materialize.

Figure 1. Repaired glitchy 3-D digital model being exported into a STL file for printing.

Figure 2. "Torso of a Woman (II), Degraded Fragment." 3-D print from 3-D laser scan, gesso, watercolor pigment.

PROCESS

Module V: Case Study

PROJECT DESCRIPTION

Industrial and technological development has largely focused on developing the ability to increasingly produce larger numbers of flawless products. However, glitch artists question this assumed value. Glitch artists think that technology-driven production is more complex than just the search for visually or technically correct results, which they call "an elitist discourse and dogma widely pursued by the naive victims of a persistent upgrade culture" (Menkman, 2011, p. 339).

In order to question perfectionist assumptions in digital fabrication technologies, visual artist Sophie Kahn creates sculptures born from failed technological processes. In her process, she purposefully misuses 3-D scanners by moving the scanned subjects, in order to produce the glitchy 3-D files that will then become her art pieces.

After the scanning takes place, Kahn begins the post-production process. When flawed 3-D scans are imported as digital models into 3-D modeling software, they cannot become printable files without going through a repair process. Kahn has to fill empty spaces in the scan, fix imperfect edges, and smooth ruptured surfaces.

However, Kahn manipulates these digital processes designed to repair her imperfectly 3-D scanned models, in order to maintain the original glitches, holes, and imperfections of the scans while still producing a 3-D printable file.

This way, Kahn fabricates artworks that can question culture's focus on achieving perfection through technological improvement: "an incomplete 3-D scan reveals the incompleteness of human vision; made from a single perspective, it only takes a slight rotation to reveal the gaps and blind spots, all the things we do not see" (Kahn, 2017).

REFLECTION QUESTIONS

1. Technically, Kahn's work relies more on the post-production process than the modeling process. How could you incorporate other post-production processes (such as manipulating support materials, layer thickness, or infill density) into the creative practice of producing a 3-D printed object? Is there a way you could do them "wrong" that might have interesting results?
2. Kahn's artworks prove that sometimes errors con become virtues. Considering the potential technical errors that can take place when 3-D modeling, scanning, and printing, what other creative uses of technical errors in digital fabrication con you think of?
3. How con workflow mistakes in processes involving, among others, layer thickness, printing speed, or infill density affect a 3-D model's chances of being successfully printed? Are there any errors that are so dire that they cannot be turned into art, or is any mistake an opportunity?

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Kahn, S. (2017). On Preserving the Glitch. In M. Allahyari, D. Rourke, & M. Rosch (Eds.), The 3-D additivist cookbook (pp. 327-329). Institute of Network Cultures.

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from The 3-D Addivist Cookbook. https://additivism.org/cookbook

Figure 2. Photograph by Danielle Ezzo. https://www.sophiekahn.net/torso-of-a-woman-sculpture

PROCESS

Module V: Handout

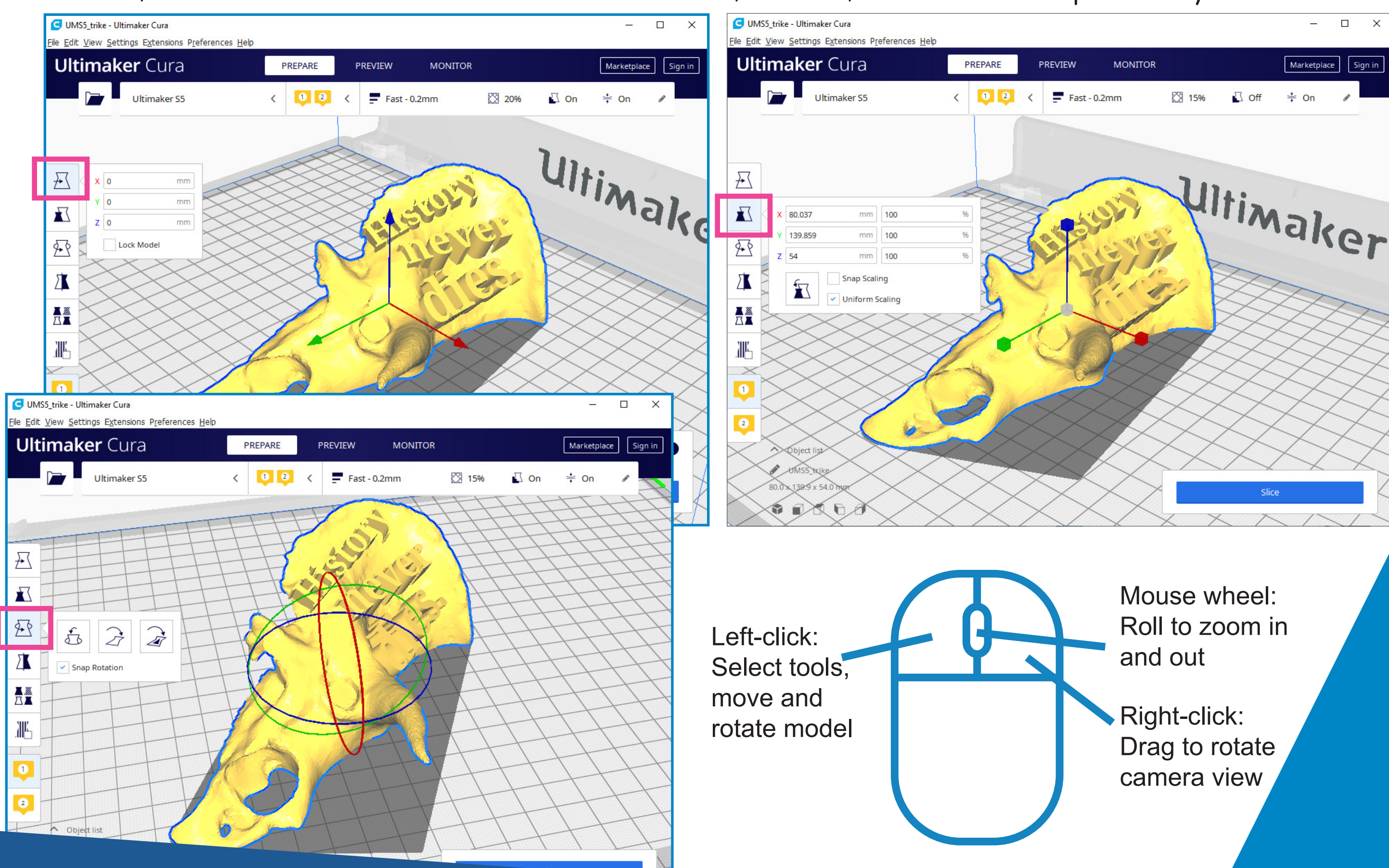
ADDITIVE MANUFACTURING

Also known as 3-D printing, additive manufacturing is the process of manufacturing parts by adding material layer by layer. The quality, print time, and the material usage for these 3-D printed parts depend on various manufacturing process parameters. An understanding of these parameters and how to manipulate them can help artist achieve their desired outcomes with 3-D printing, as well as experiment with the processes (as Sophie Kahn does).

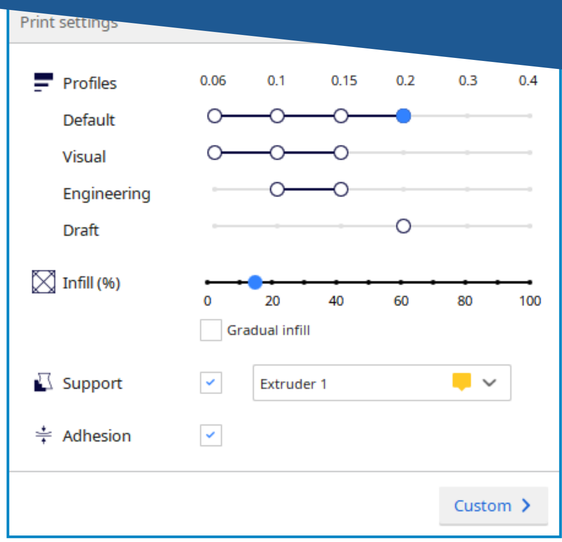
USING SLICER SOFTWARE

There are a variety of free slicer software tools available. These include Slic3r and Cura, among others. In this tutorial, we will be using Cura, but other tools can also be used successfully.

1. Open Cura, and open an STL file in the program. Use the tools on the left, as illustrated below, to control the view of the model. Move, Rotate, and Scale the part as you wish.

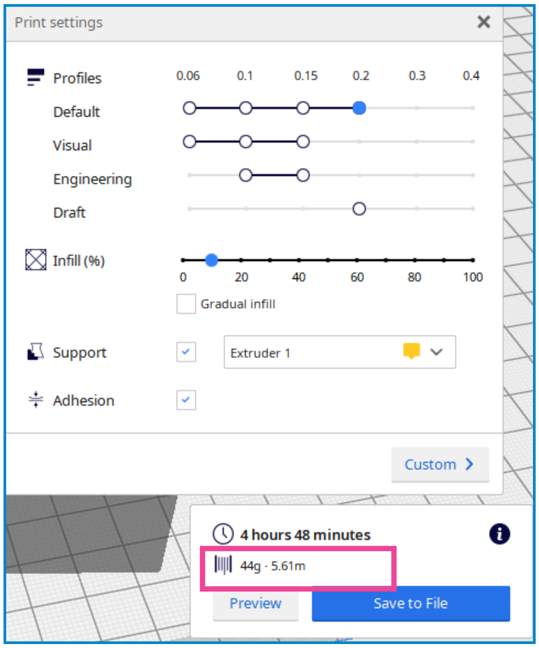


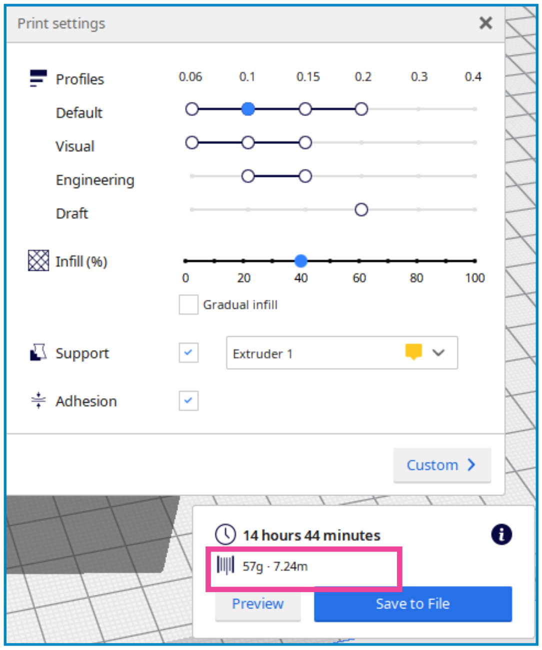
2. Click on the settings at the top of the screen to adjust the **Print Settings** regarding layer height, infill, and supports.



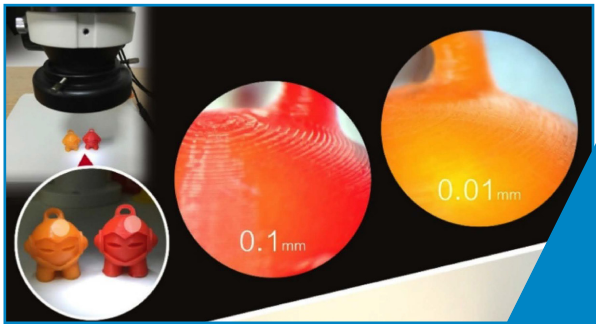
3. Click the **Slice** button in the bottom-right. The program will work for a moment generating a 'sliced' version of your model.

   It will also create a time estimate for your print. Experiment with different layer thicknesses and infill densities (as well as different scales and rotations), and notice how the estimated print time varies.





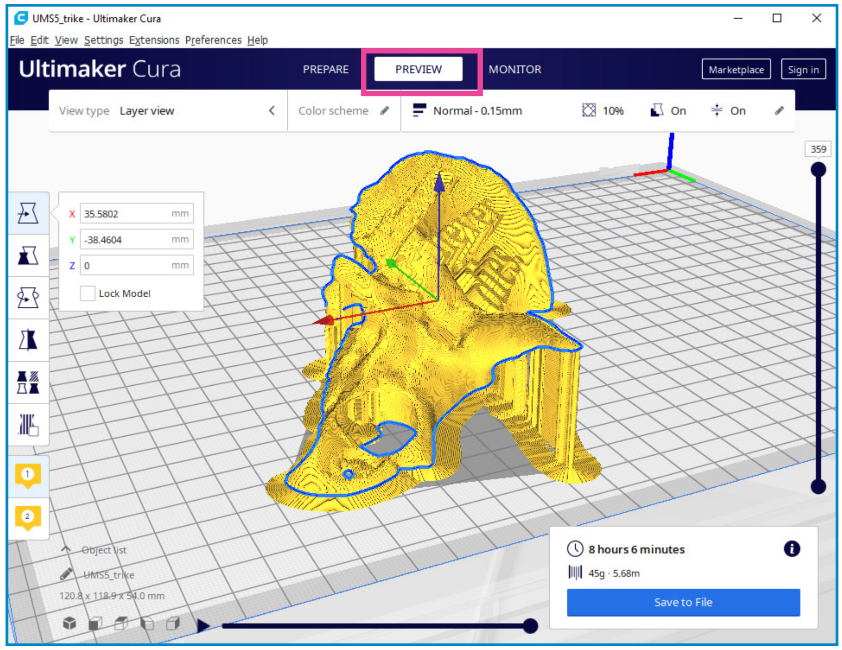
Choosing a layer height involves a trade-off between smoothness of the final print (right) and length of time the print takes (above).
What layer height best suits your model?

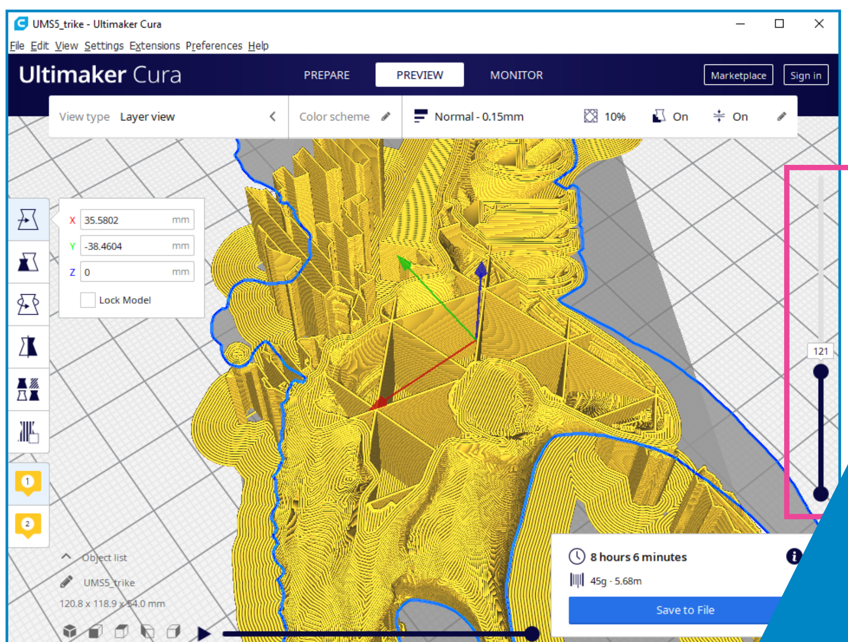


4. If you click the **PREVIEW** button at the top of the screen, you can see the 'sliced' version of your model, as well as any supports that will be produced in the final print. In the image below, notice how the horn of my dinosaur skull now has supports.

5. You can also drag the slider at the right to see the different layers of your model, including the infill.

6. When your print quality and print time suit the needs for your project (or for your class's requirements), you can press **Save to File** to export the **g-code** file to send to the printer.





MATERIAL VARIETY

Module VI: Lesson Plan

MODULE GOALS

This module will familiarize students with the different types of materials that con be used in additive manufacturing. A variety of special filaments will help to demonstrate how even desktop 3-D printers can make parts with different properties.

Having familiarized themselves with 3-D printing processes over the last five modules, this module encourages students to move beyond conventional processes and materials, and experiment.

ESSENTIAL QUESTIONS

- What is the difference between traditional **ABS** and **PLA** filament types?
- What other, less traditional, materials are available for 3-D printing, both with the tools at hand in the student's place of learning, and in general?
- What is multi-material printing?
- When and why does a particular material address specific creative problems better than others?

MEANING AND ACQUISITION

- Students will understand the difference between **filament**, **liquid resin**, and **powder** materials for use in additive manufacturing.
- Students will learn about the unique opportunities allowed by different filaments for material extrusion.
- Students will gain knowledge regarding what printing parameters may impact their ability to extrude printed material.
- Students will think critically about how the choice of materials is itself a potentially meaningful, impactful, and ethically weighty artistic choice.
- Students will understand that 3-D printing, like any creative practice, is not a strictly prescriptive process, and invites material experimentation and exploration.

MATERIAL VARIETY

Module VI: Lesson Plan

FORMATIVE ASSESSMENT STANDARDS

- Students demonstrate willingness to experiment and develop skills in new art-making technologies and materials **(Cr2.1.5a)**.
- Students know and use fundamental vocabulary relevant to understand the different materials used in an additive manufacturing environment **(Cr3.1.1a)**.
- Students actively engage with different materials and assess their potential use in a creative fashion **(Cr.1.1.Ia).**
- Students are able to discuss and explain the differences between materials to their peers and help facilitate peer-to-peer learning **(CrI.1.11)**.

SUMMATIVE ASSESSMENT STANDARDS

- Student work demonstrates reflectivity on how artists and designers use different processes and materials to produce their pieces **(Re7.1.3a)**.
- Student work demonstrates an understanding of the synthesis between creative and analytical principles and techniques of the visual arts, and technical concepts from the sciences, such as those present in discussions about materials **(Cr2.3.IIa)**.
- Student work demonstrates the exploration of new art-making technologies and materials, and the different uses associated with these **(Cr2.1.4a)**.

MATERIALS

- Multiple different filament material types.
- 3-D printer (with multi-material extrusion for full material exploration).
- Example objects printed using different materials.

MATERIAL VARIETY

Module VI: Lesson Plan

KEY TERMS

- **ABS plastic** - A common plastic used in a great deal of manufacturing, including Lego bricks, electronics, and car bumpers. ABS has a higher printing temperature than PLA, which can cause warping with smaller details. ABS is more flexible and less brittle than PLA, making it more popular for manufacturing non-disposable objects. ABS is short for "Acrylonitrile Butadiene Styrene."
- **Filament** - A thin, thread-like piece of material. Plastic filament is used in most common 3-D printers, which use an FDM ("Fused Deposition Modeling") method. The filament is extruded through a heated printer head which gradually builds up layers from a base.
- **Liquid** - Some FDM printing doesn't use a molten filament, but rather extrudes a thick liquid, such as soft clay, concrete, or molten chocolate, which then dries and is solidified.
- **PLA plastic** - A biodegradable (when disposed of properly) plastic derived from renewable sources such as corn starch or sugarcane. One of the most popular "bioplastics," it is often used in disposable cups and medical implants. PLA has a lower melting temperature than ABS, making it easier to print with, and less likely to warp, allowing for finer detail. PLA is short for "Polylactic Acid."
- **Powder** - SLS printing ("selective laser sintering") use a high-powered laser to fuse small particles of plastic powder, layer by layer, as the powder is added to a tank. The un-fused powder supports the printed forms, meaning powder-based printing doesn't require support structures like FDM or SLA printing. SLS is the most common form of additive manufacturing in industrial applications, as the resulting objects are almost as strong as traditionally-manufactured parts.
- **Resin** - Resin is the printing material used for stereolithography ("SLA"), one of the oldest forms of 3-D printing. In stereolithography, a computer-controlled laser is fired into a tank of liquid resin chemically treated to harden into plastic when hit by light. Like FDM printing, the model is slowly built up, layer by layer. SLA prints are typically sturdier than FDM prints, as the resin has been chemically bonded, rather than applied in layers.

Derived from:

- FormLabs. (n.d). 3-D printing technology comparison: FDM vs. SLA vs. SLS. https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/
- Giang, K. (n.d.). PLA vs. ABS: What's the difference? https://www.3dhubs.com/knowledge-base/pla-vs-abs-whats-difference/#what-are-abs-and-pla

MATERIAL VARIETY

Module VI: Lesson Plan

PROPOSED ACTIVITY

1. Students will learn about the different materials used in additive manufacturing:
   - Explore the handout and see the provided information.
   - Check the spools holding diverse materials to see the differences between them.
2. Students will learn about the multiple uses of different materials:
   - Use the handout to review the examples.
   - Explore the example printed objects to see how different materials have been used to create multiple objects.
3. Students will understand what multi-material 3-D printing is:
   - Observe and reflect on how the multi-material printing process works, and when should it be used for a particular design.

ALEX LE ROUX

Using the technique of material extrusion as the base for his invention, and considering the potential of this technique to work with a wide array of different materials, engineer Alex Le Roux designed and built a 3-D printer capable of printing a small house out of concrete ("Baylor engineering grad builds America's first 3D-printed tiny house", 2016, para. 1).

Utilizing a second iteration of his 3-D concrete printer known as the Vesta, Le Roux successfully printed what is believed to be America's first livable 3-D-printed shelter (Scott, 2016, para. 1).

Adapted from open-source RepRap designs, the 3-D concrete printer measures eight feet cubed and was able to print an 8 x 5 x 7 foot structure in just 24 hours (2016, para. 3). After completing the tiny house structure, Le Roux began working on a third iteration of the concrete printer in on effort to continue evolving the potential of additive manufacturing in architecture and construction ("Baylor engineering grad builds America's first 3D-printed tiny house", 2016, para. 3).

Figure 1. The tiny house during the printing process.

Figure 2. Le Roux with the printed tiny house.

PROJECT DESCRIPTION

The intersection between design and additive manufacturing is a growing field that's being explored and expanded more and more every day, thanks in part to accessible technology and open-source content. The use of 3-D printing technology in architecture and construction was once inconceivable, and now there ore companies and individuals across the globe who ore successfully implementing entire homes via additive manufacturing (Scott, 2016, para. 5).

Alex Le Roux, an engineer located in the United States, is an example of the innovative potential to be realized in the expanding field of 3-D printing. Using the possibilities given by the extrusion process and its flexibility to function with different materials, Le Roux built his 3-D concrete printer, adapted entirely from open source RepRap printer technology. With it, he has printed the first livable 3-D printed house in the United States.

The structure, located in Houston, Texas, was funded portly by Le Roux as part of a senior project at Baylor University, and portly by a Michigan-based architectural firm that favors environmentally friendly methods of construction (Alec, 2016, para. 3). Le Roux's printer, called the Vesta, involves limited labor and only requires one person to operate the computer and another to feed the concrete to the printer (Scott, 2016, para. 4). While able to print at a speed of .3 feet per second, Le Roux is hoping to create a third iteration of the printer which will be even more streamlined and will experiment with more environmentally friendly cements ("Baylor engineering grad builds America's first 3D-printed tiny house", 2016, para. 3). In doing so, Le Roux will continue to pursue the potentials of 3-D printed architecture, including increased customization, reduced construction waste, reduced manual labor needs, and faster build times (Scott, 2016, para. 3).

MATERIAL VARIETY

Module VI: Case Study

REFLECTION QUESTIONS

1. Even though the construction and manufacturing industries are dominated by corporations with extensive budgets, many small startups and individuals have been responsible for some of the most inventive 3-D printing innovations. What communities and resources foster these smaller-scale, non-corporate projects? How might accessible 3-D printing technology change the landscape of architectural and construction initiatives?
2. What do you think are some of the limitations of using concrete as a material for 3-D printing? What kinds of shapes could not be achieved through printing with this type of material? What kind of housing could not be made?
3. Additive manufacturing technologies allow for the use of different materials. Le Roux adapted an existing open-source printer to extrude concrete. What other materials do you imagine could be used for 3-D printing? What could be gained from using them?

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Alec (2016). Alex Le Roux 3-D prints livable concrete structure 'Tiny House' in just 24 hours. http://www.3ders.org/articles/20160620-alex-le-roux-3d-prints-livable-concrete-structure-tiny-house-in-just-24-hours.html

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IMAGE ATTRIBUTIONS

Figure 1. Retrieved from https://www.3printr.com/concrete-3d-printer-creates-livable-tiny-house-3340343/

Figure 2. Retrieved from https://www.3printr.com/concrete-3d-printer-creates-livable-tiny-house-3340343/

MATERIAL VARIETY

Module VI: Handout

PRINTING MATERIALS

Different types of materials can be used in additive manufacturing. The unique properties of these materials create different opportunities based on their capabilities, which are affected by printing parameters.

Two of the most common printing filaments ore Acrylonitrile Butadiene Styrene (ABS) plastic and Polylactic Acid (PLA) plastic. While they look similar; each has its own pros and cons:

POLYLACTIC ACID (PLA)		ACRYLONITRILE BUTADIENE STYRENE (ABS)	
PROS	CONS	PROS	CONS
• Can be printed on a cold surface • More environmentally friendly (biodegradable, made from plant-based sources) • Shinier and smoother appearance • Potential for finer detail • No harmful fumes during printing • Higher print speed	• Can easily deform due to heat • Less sturdy than ABS 	• Sturdier and less brittle than PLA • Suitable for machine or car parts • Higher melting point • Longer lifespan 	• Oil-based. Not biodegradable, and made from non-renewable sources • Deforms if not printed on heated surface • Toxic plastic fumes when printing (requires ventilation) • Slower, more difficult to print • Resulting objects cannot be used with food

MATERIAL VARIETY

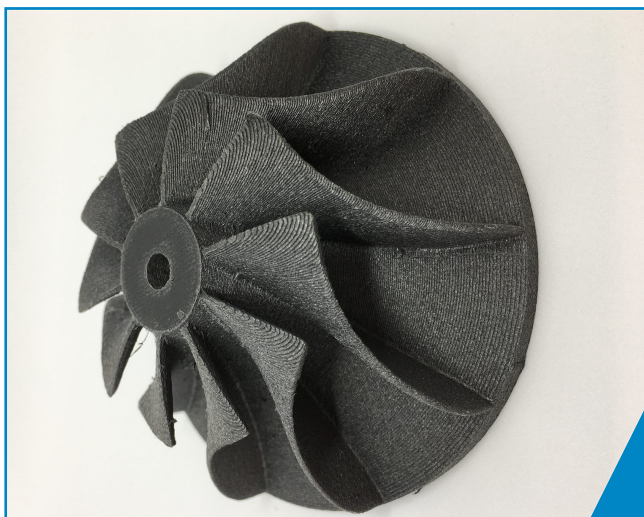
Module VI: Handout

Material extrusion isn't just limited to ABS or PLA. There
ore a variety of other material types available for printing that con give objects unique properties or characteristics.

Flexible Filament: Used to create flexible hinges or stretchable objects. Can eliminate the need to design assemblies with moveable joints.

Wood Polymer Filament: A PLA filament infused with wood particles. Used to create decorative objects where the appearance and feel of wood has sensory importance.

Metal-Loaded Filament: Used to give objects slight metallic properties. Allows parts to be polished and gives them more weight than traditional plastics.



Carbon Fiber Filament: Used to increase the strength of printed parts without additional weight. Makes ports more rigid, but can wear down a print nozzle.