UIST 2023

Fluid Reality

High-Resolution, Untethered Haptic Gloves Using Electroosmotic Pump Arrays

Vivian Shen Tucker Rae-Grant Joe Mullenbach Chris Harrison Craig Shultz

FUTURE INTERFACES GROUP

FLUID™ REALITY

Carnegie Mellon University

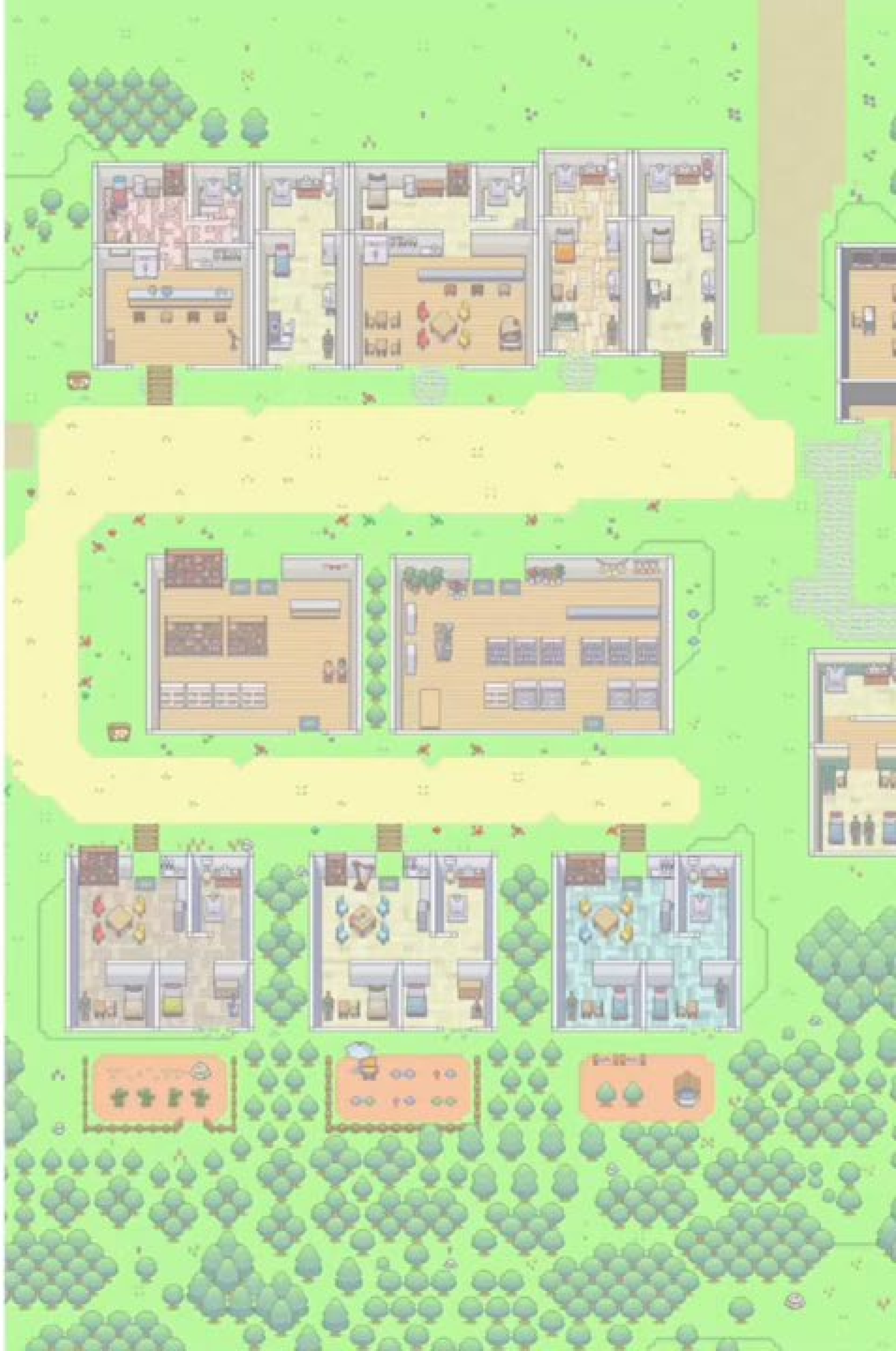
UIST 2023

Generative Agents

Interactive Simulacra of Human Behavior

Joon Sung Park • Joseph C. O'Brien • Carrie J. Cai
Meredith Ringel Morris • Percy Liang • Michael S. Bernstein

STANFORD HCI GROUP
Stanford NLP
Google Research



CMSC730 - Fall 2023
University of Maryland

[Assignment 9]

SMALL
_ARTIFACTS
LAB;

Laser Cut Group Project Sign

Abstract

In this assignment, you will use a laser cutter to create an add-on or sign for your group project. This can either be integrated with the project you build throughout the semester, or it can be a standalone sign displaying your group project information at the demo desk during your project demonstration. The assignment will be graded on a group basis. Your design should be created using any vector tool, such as Adobe Illustrator or Inkscape. We will provide several sheets of plywood in various sizes and thicknesses. You can drop by IRB0102 and ask TA for the material. If the material provided is insufficient for your ambitious ideas, please inform us and coordinate with the Sandbox managers to acquire materials suitable for your design.

Description

Below is the minimal requirement for this assignment.

1. All group members must complete the Sandbox laser cutter training for the VLS laser and submit a screenshot confirming completion of the module.
2. The design must feature both vector cutting and rastering.
3. Use red (255,0,0) for stroke only (vector cut) to cut through. The line width should be 0.01mm or any suitable design parameter for your choice of vector design software.
4. Use black (0,0,0) for area only (raster) to engrave.
5. The design must utilize at least 1 technique (for groups of 3 or fewer), 2 techniques (for groups of 4), or 3 techniques (for groups of 5 or more) from the following: stacking, living hinge, finger joints, and laser bending, to create 3D features.
6. Save your file as an SVG and upload it to ELMS.
7. Use the VLS laser to cut your design.

Delivery

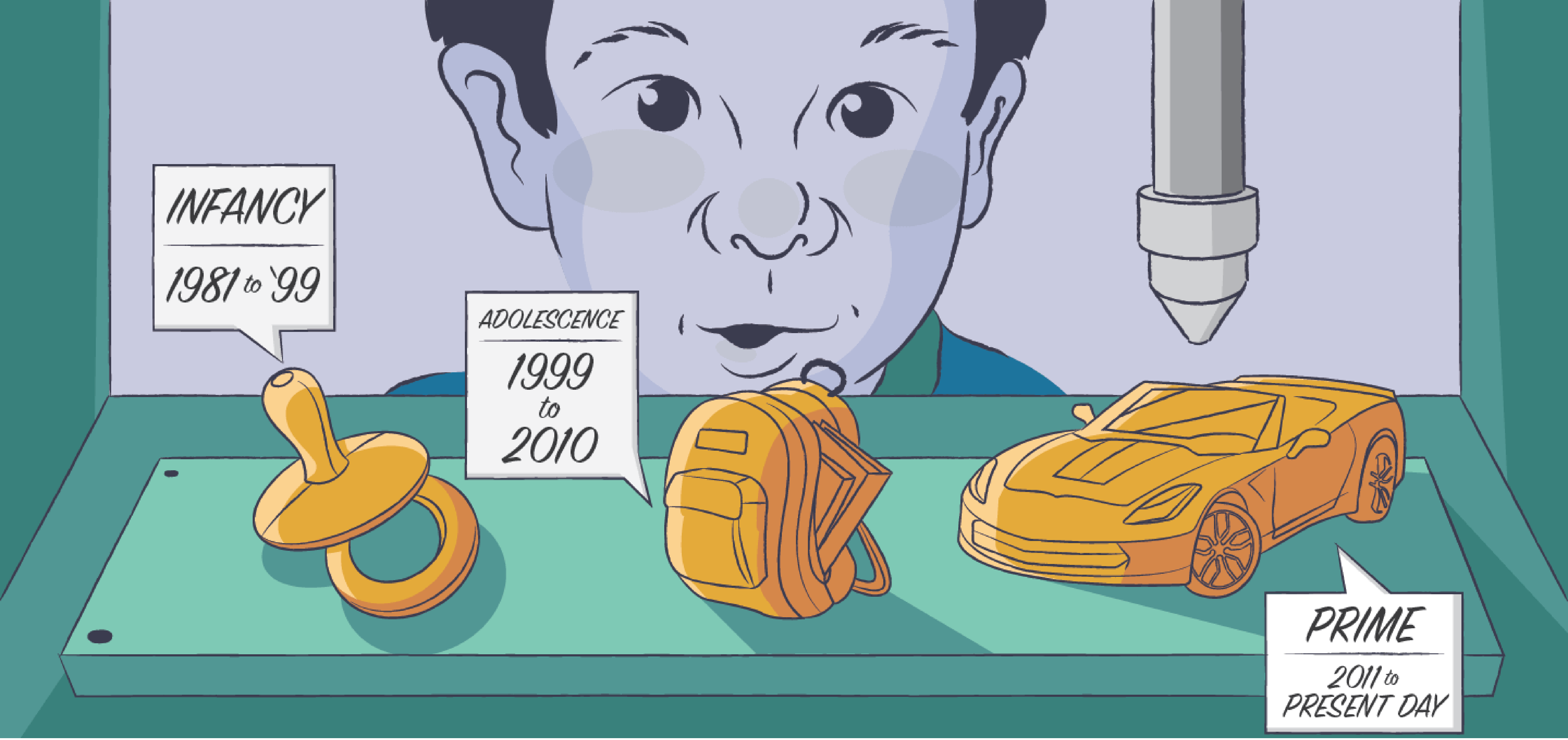
a. Bring your group sign to the demo.

b. Upload a zip file — including 1) **training screenshots** 2) the **SVG file** of your design and 3) one or two **photos of your actual cut**, to Elms. Name format: "Your groupNumber.zip"

Due Date

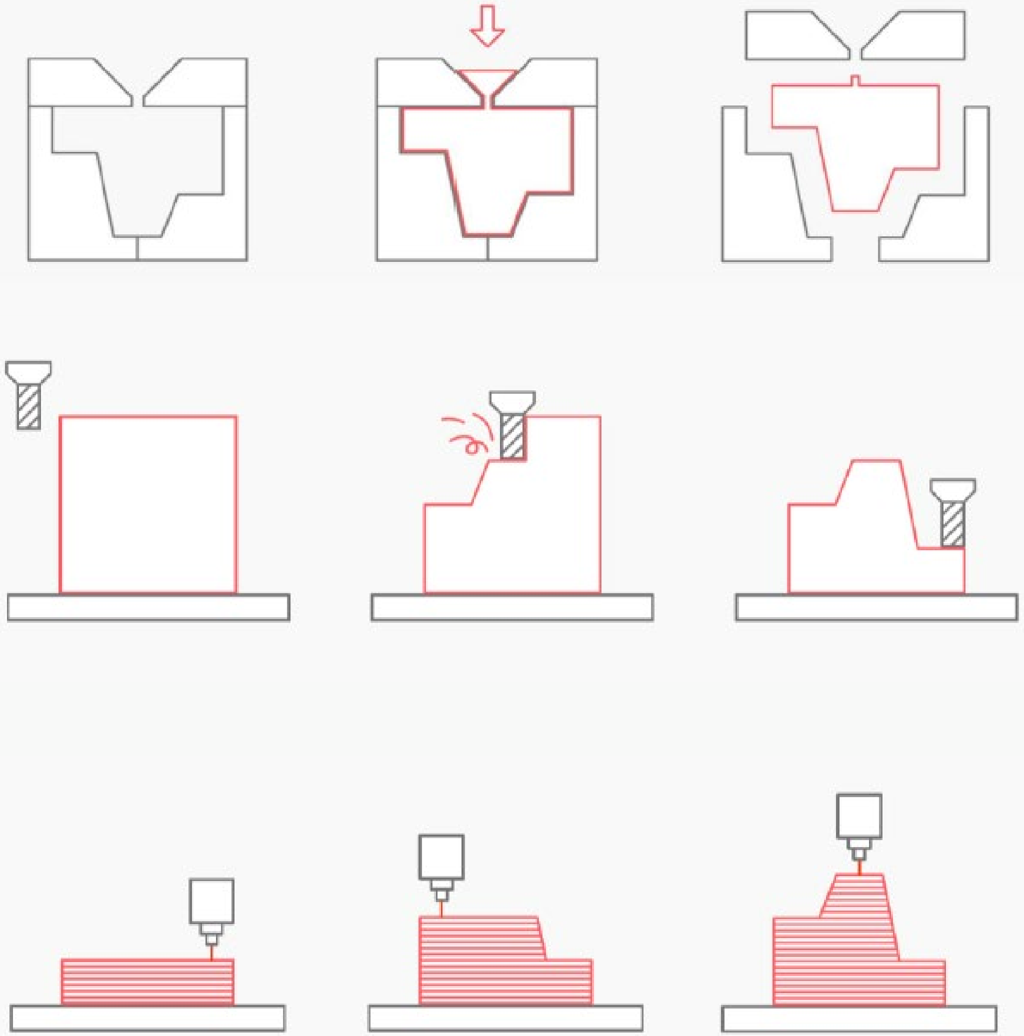
Wed Dec 11th, 11:59 PM EST

Last Modified Date: Nov 19th, 2023



Additive Manufacturing

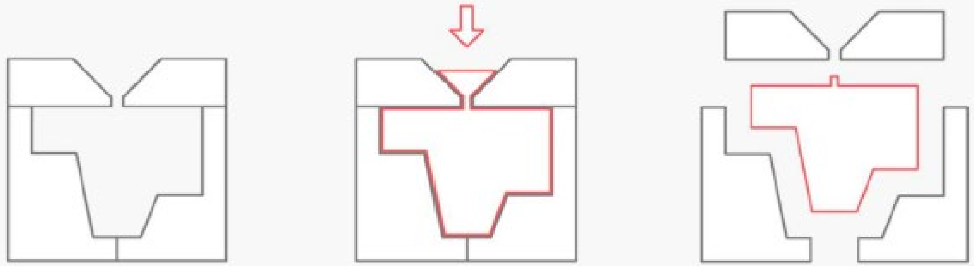
Huaishu Peng | UMD CS | Fall 2023



Formative manufacturing

Subtractive manufacturing

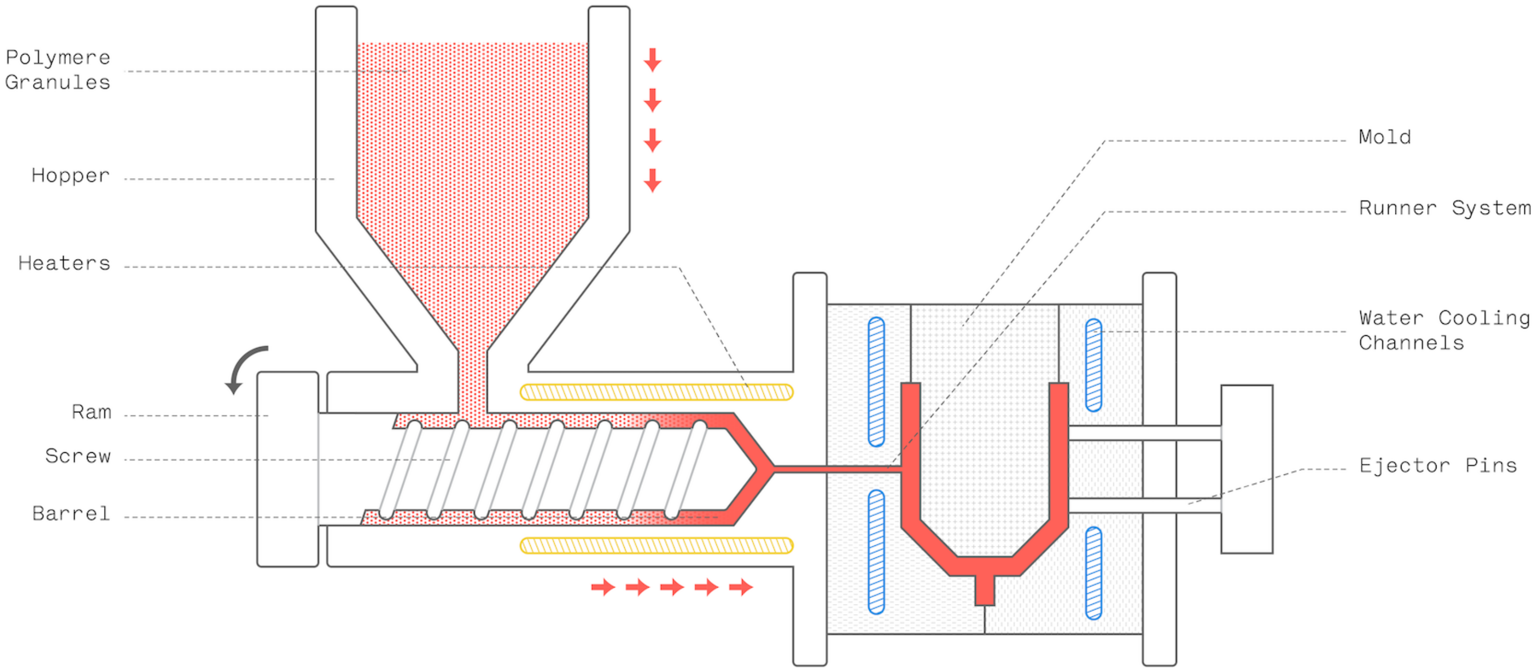
Additive manufacturing

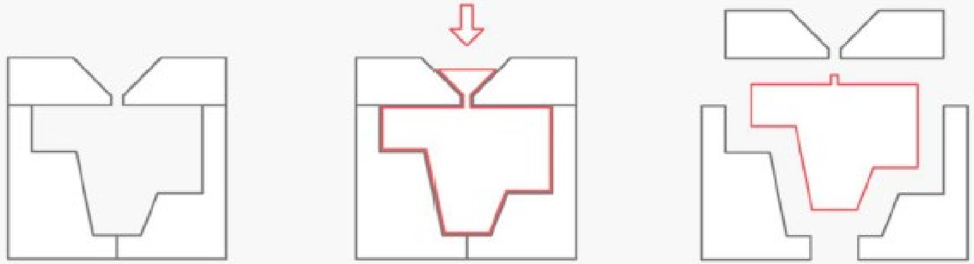


Formative manufacturing

no material is removed, i.e. they are deformed and displaced.

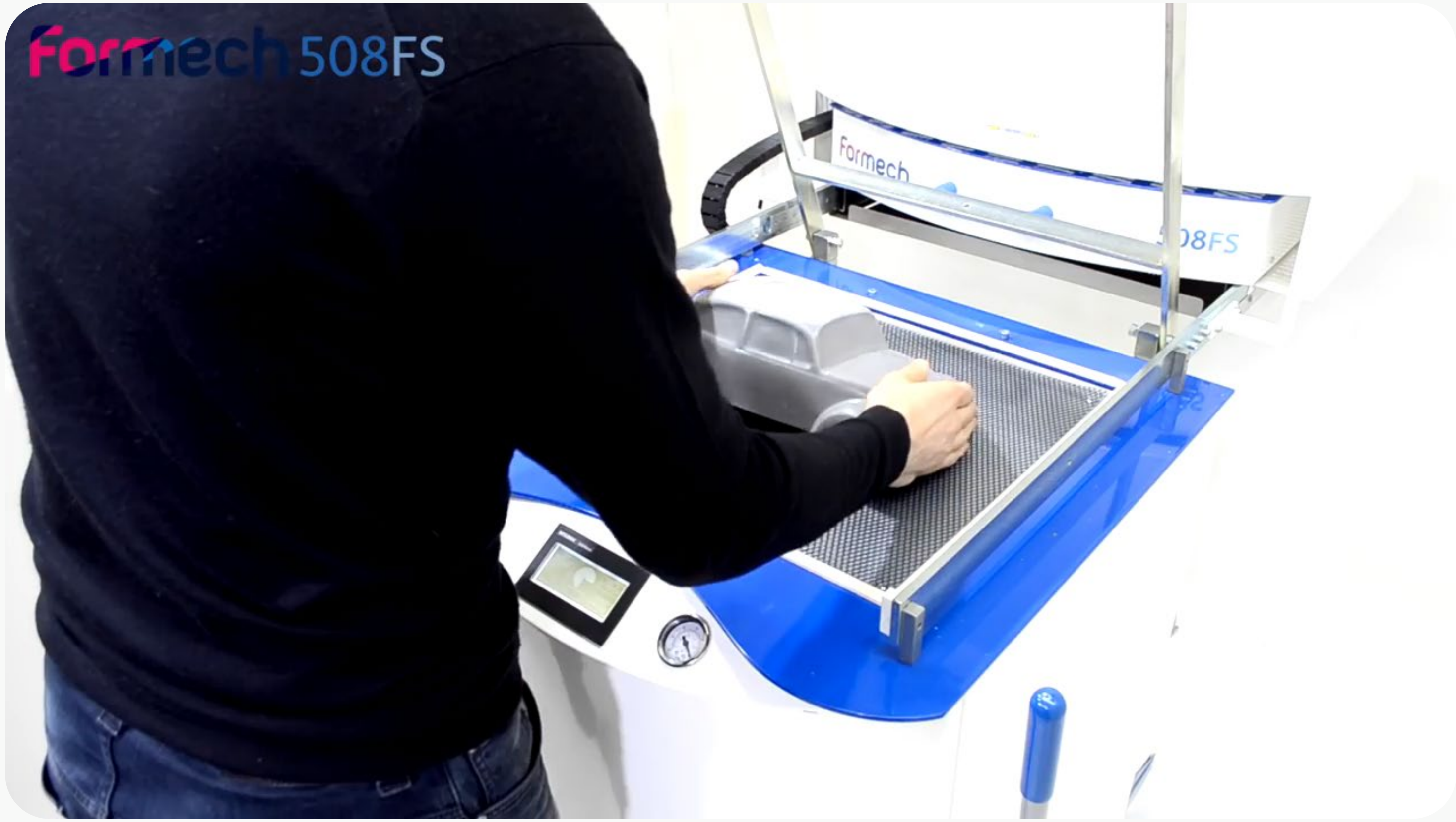
Injection Molding



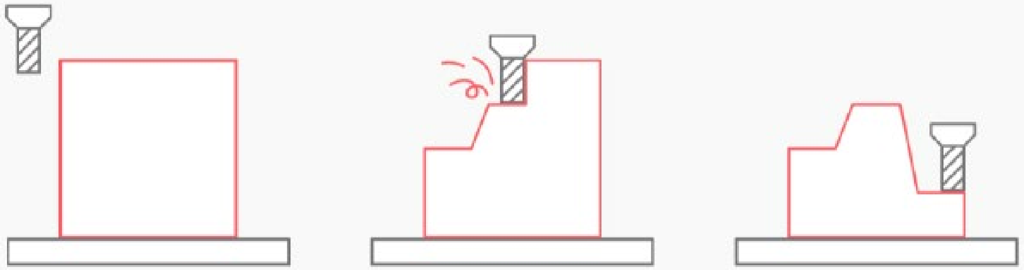


Formative manufacturing

no material is removed, i.e. they are deformed and displaced.

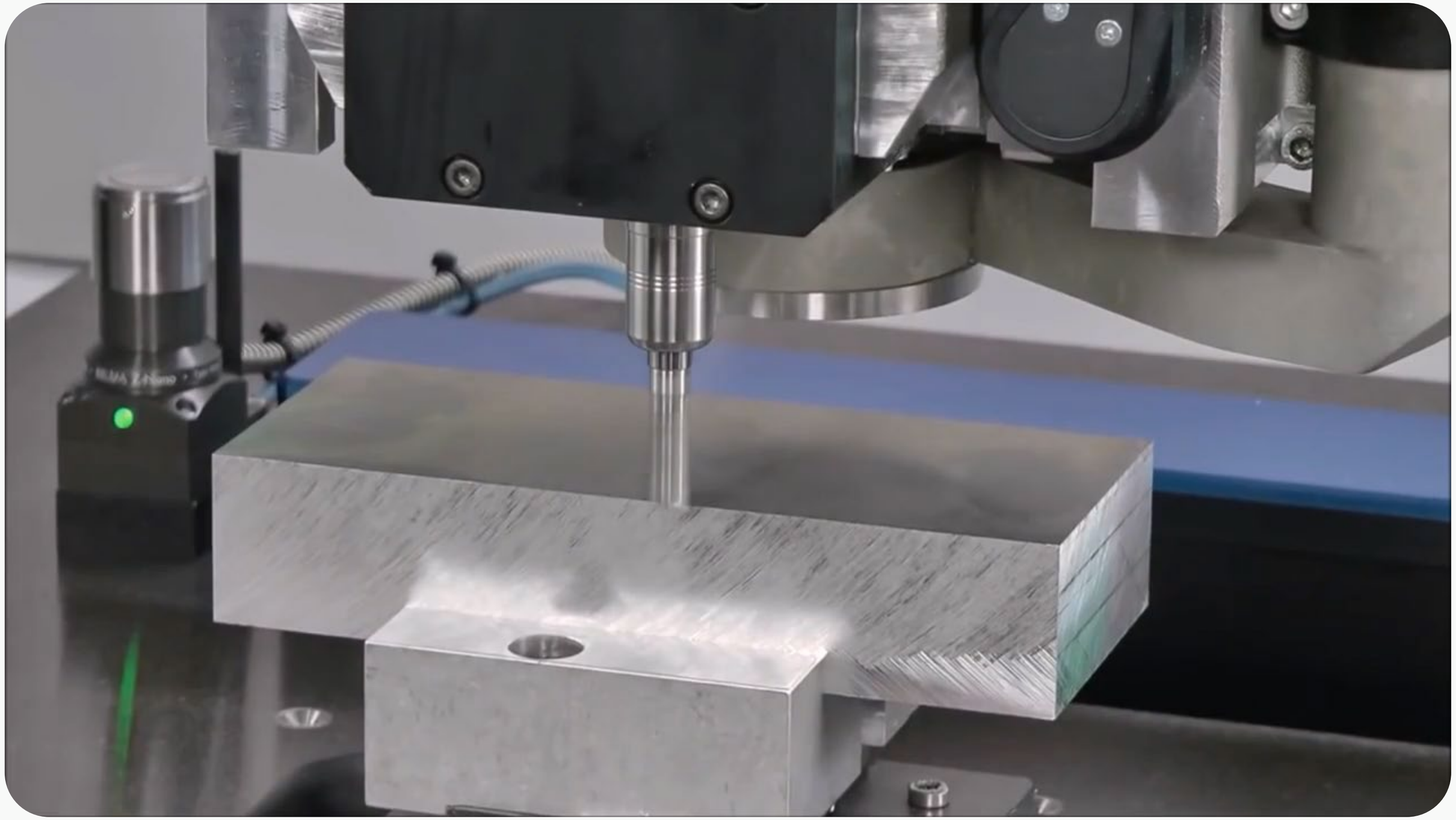


Thermoforming



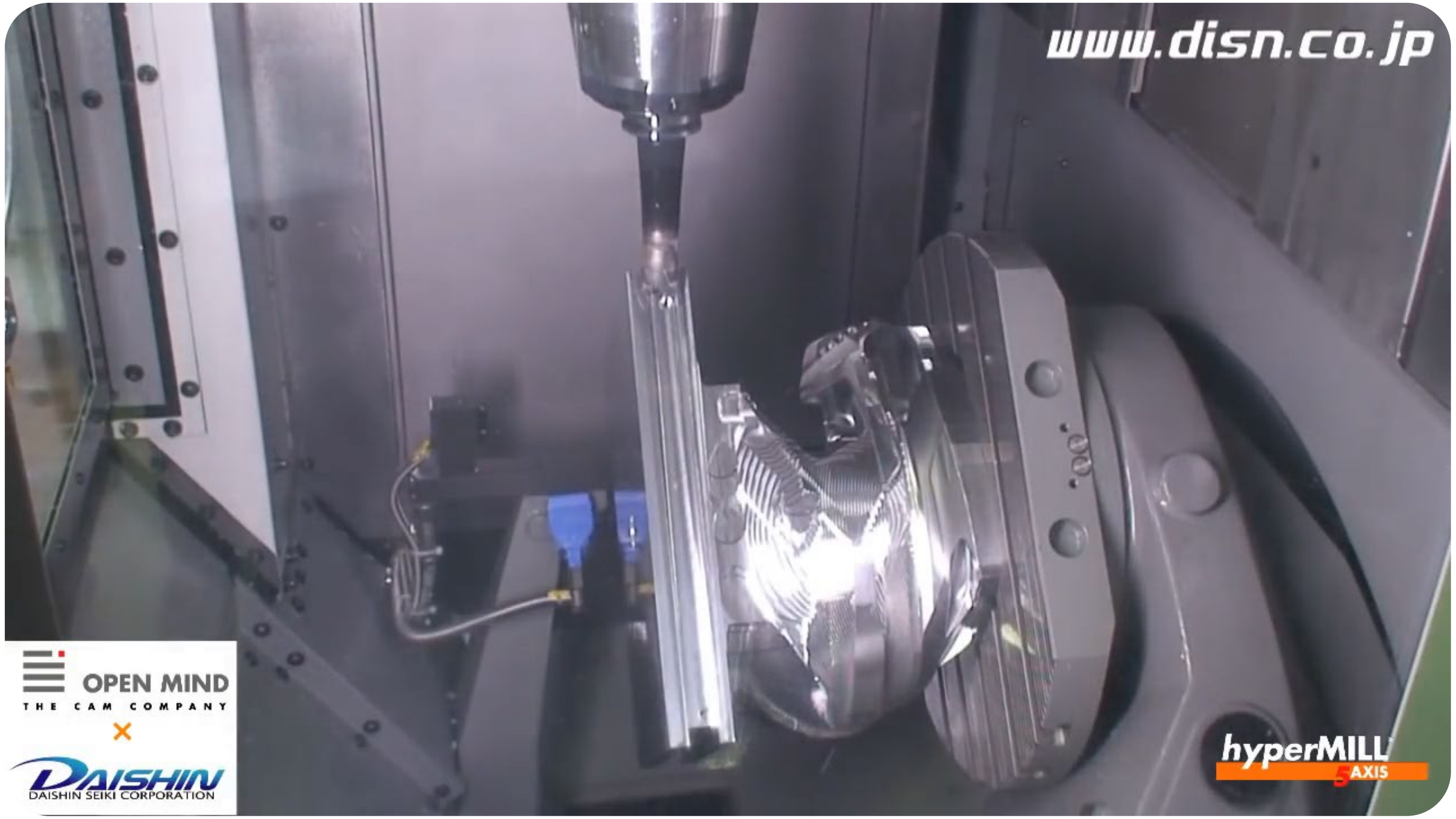
Subtractive manufacturing

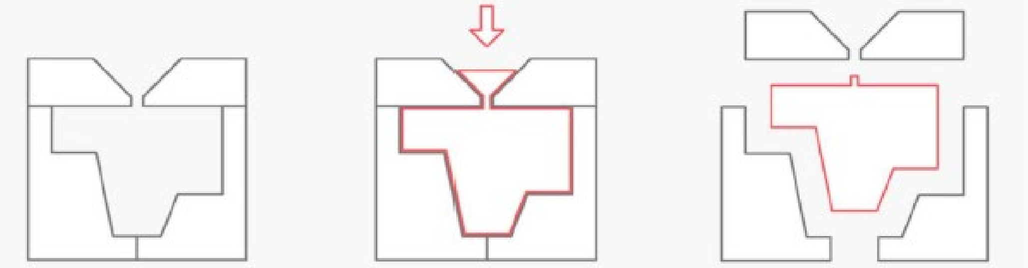
3D objects are constructed by successively cutting material away from a solid block of material.



Subtractive manufacturing

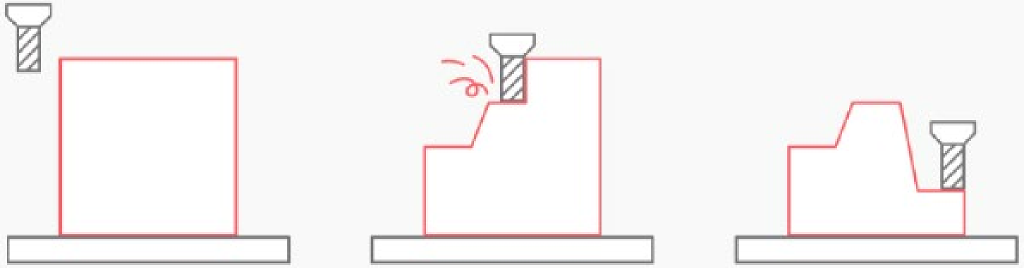
3D objects are constructed by successively cutting material away from a solid block of material.





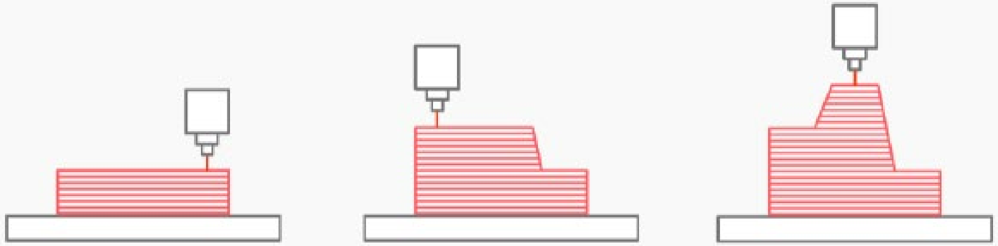
Formative manufacturing

no material is removed, i.e. they are deformed and displaced.



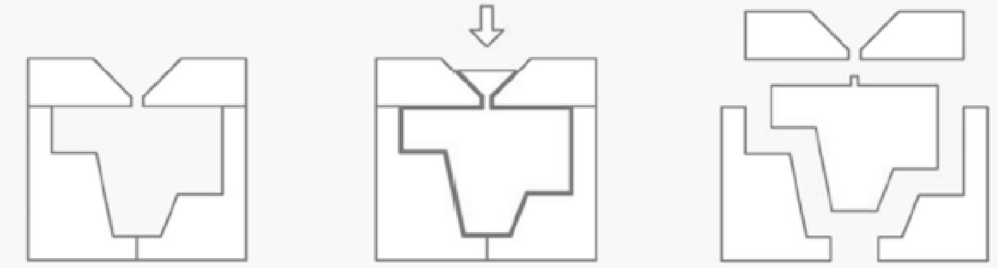
Subtractive manufacturing

3D objects are constructed by successively cutting material away from a solid block of material.



Additive manufacturing

the process of joining materials to make objects from 3D model data, usually layer upon layer

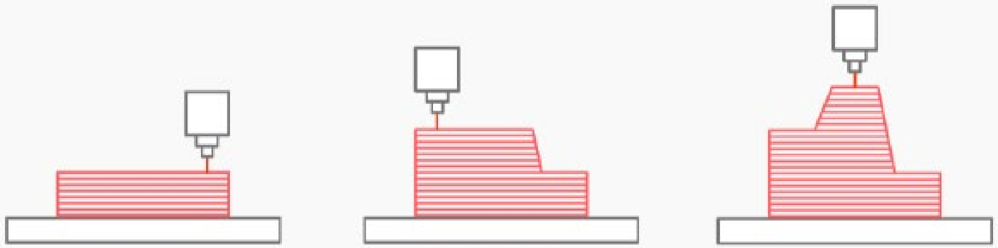


Formative manufacturing

no material is removed, i.e. they are deformed and displaced.

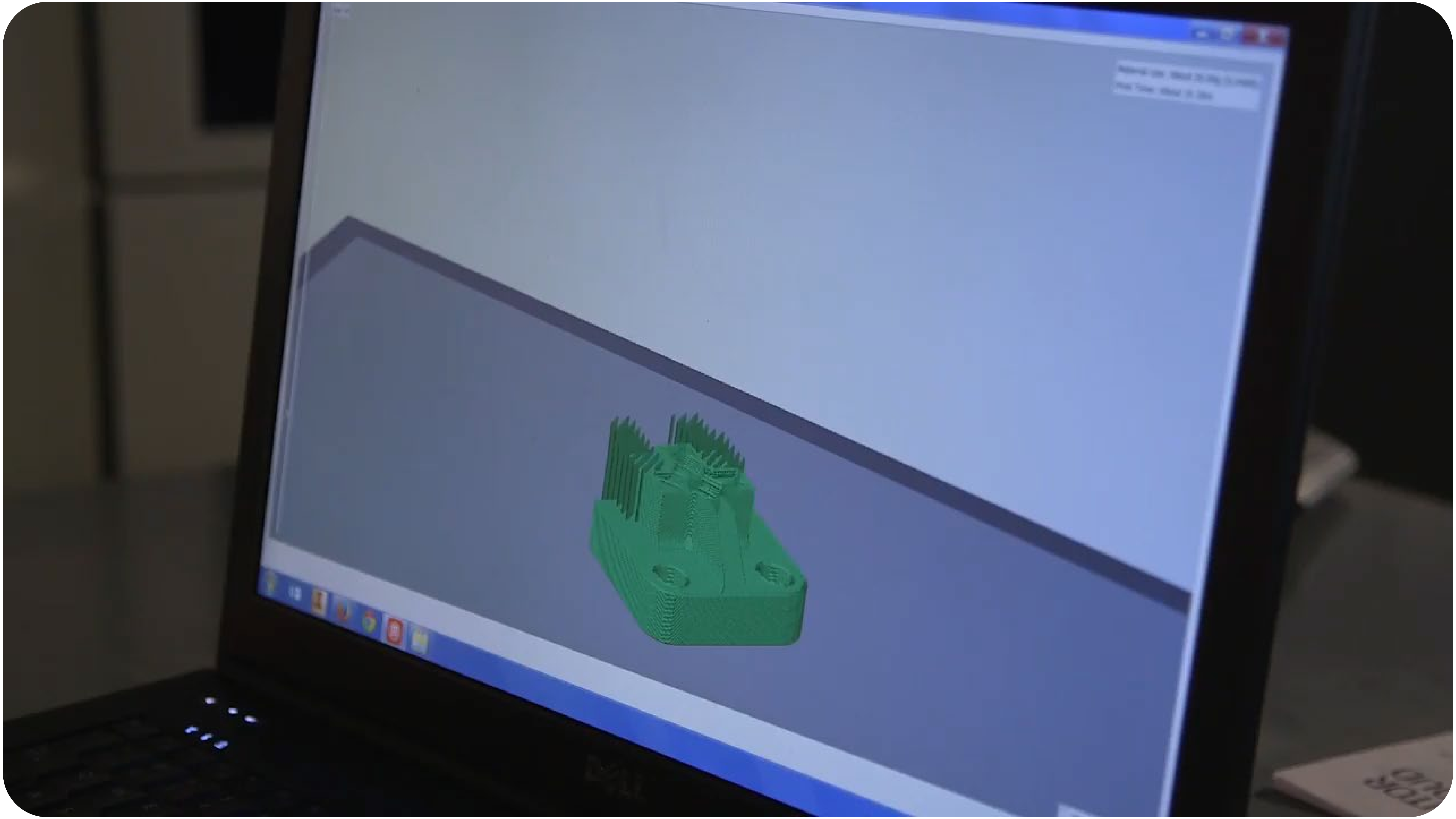
Subtractive manufacturing

3D objects are constructed by successively cutting material away from a solid block of material.



Additive manufacturing

the process of joining materials to make objects from 3D model data, usually layer upon layer



Benefits?

Complexity is free

Perfect for one-off’s – (cheaper, faster)

Empowers new designers

New materials

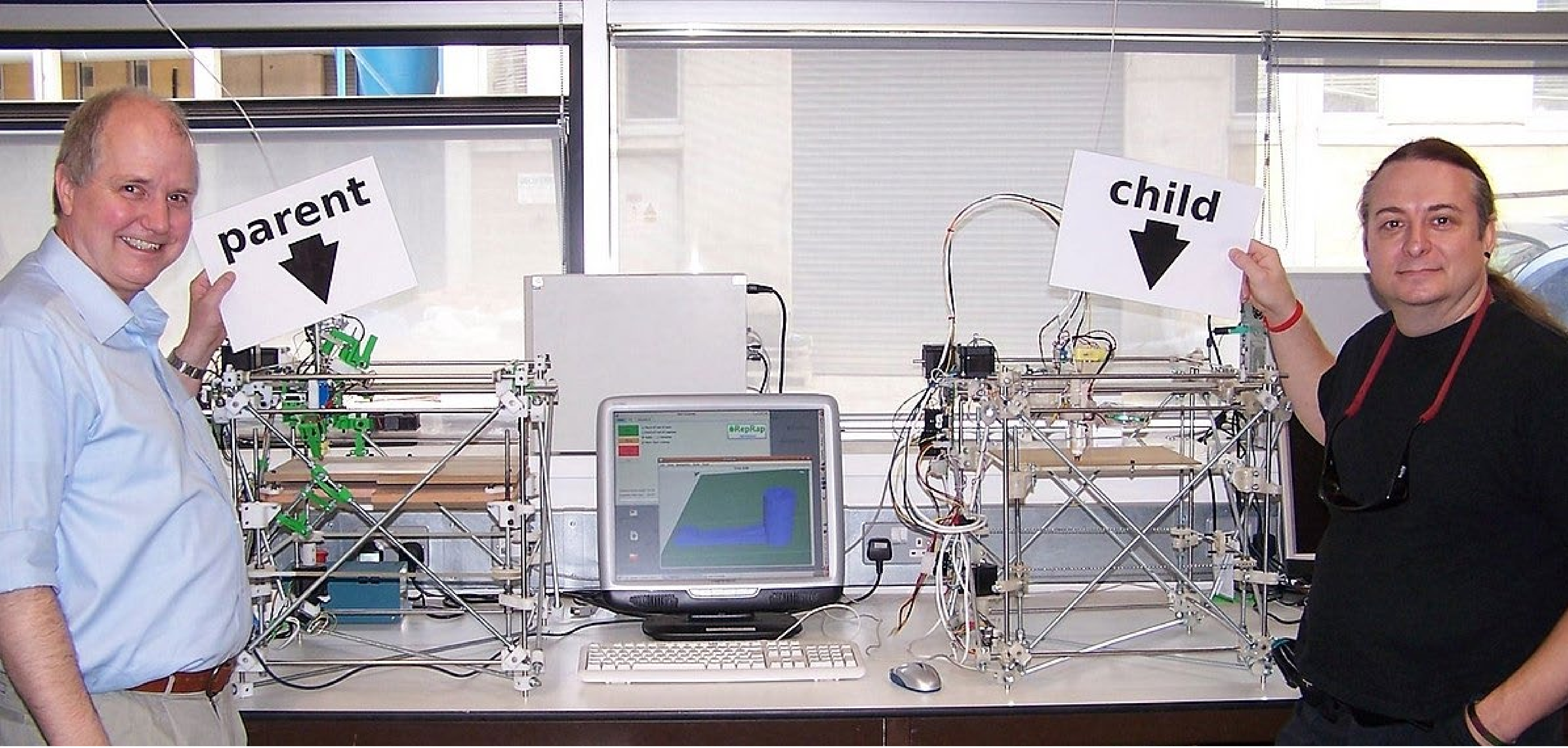
Compare to the other manufacturing approaches,
additive manufacturing (3D printing) is the youngest one

The first commercial 3D printer
SLA-1 printer
1987

The first commercial **FDM**
3d printer
1992

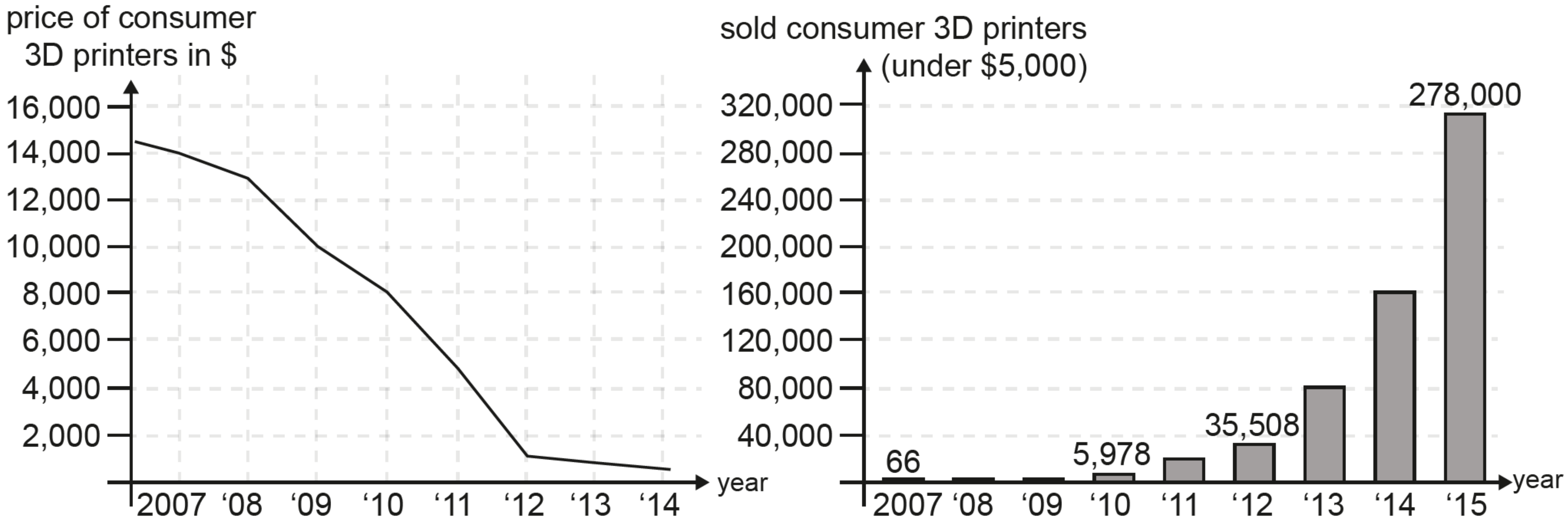
The idea for the technology came to Crump in 1988 when he decided to **make a toy frog for his young daughter using a glue gun** loaded with a mixture of polyethylene and candle wax. He thought of creating the shape layer by layer and of a way to automate the process. In April 1992, Stratasys sold its first product, the 3D Modeler


PSH 100
Production Process Supply Chain
SLM
Solutions GmbH
BASIC-PLUS
100
LISTA



RepRap project started in 2005 at the University of Bath to develop a low-cost 3D-printer that could print most of its components. RepRap stands for **replicating rapid prototype**.

MakerBot founded in **2009** by Adam Mayer, Zach “Hoeken” Smith, and BrePettis to build on **RepRap project**.



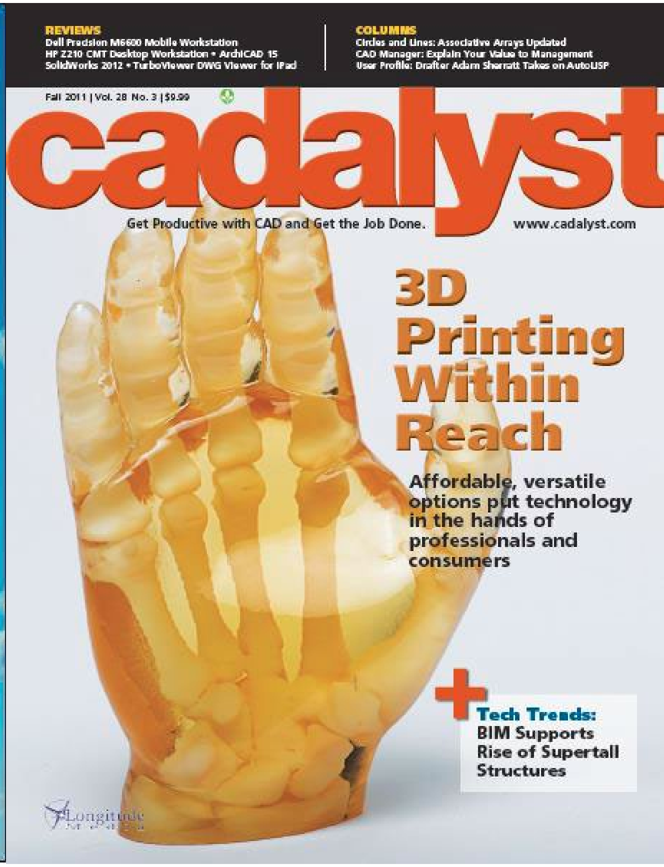
Wohlers Report 2016

The “new era” of personal fabrication

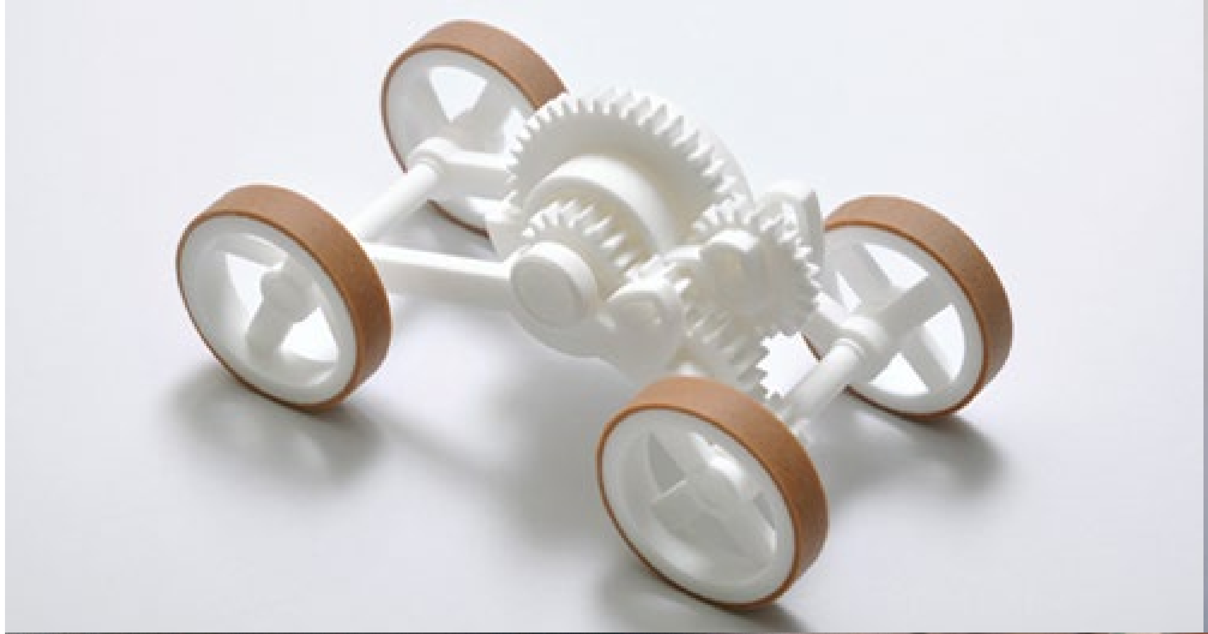

Mit Stellenmarkt
c't magazin für computer technik
€ 3,90
11
Räumlich scannen mit Kamera oder Kinect
Kopieren in 3D
Gratis-Software • Webdienste • 3D-Drucker im Test
Die große CPU-Übersicht
Konkurrenz für Google Maps
Quad-Core-Smartphone
SkyDrive, Google Drive
3D-TV ohne Brille
55 Alternativtinten im Test
Billiger drucken
UEFI mit Linux
Do Not Track in der Praxis
WebGL-Programmierung
Drucken im heterogenen Netz
Empfehlungen der Redaktion
Die besten Android-Apps
So machen Sie mehr aus Ihrem Smartphone

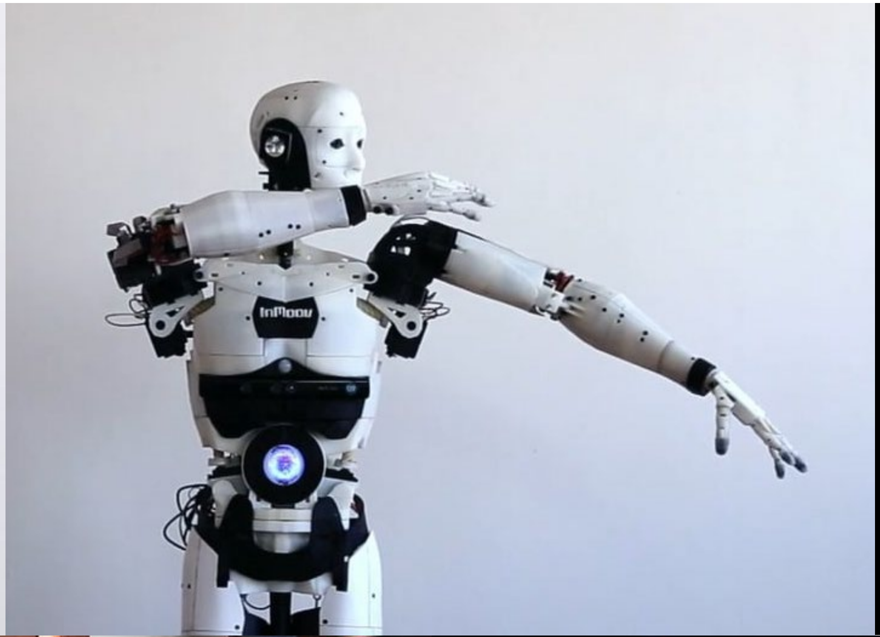

THE DESIGN ISSUE
INSIDE NERF / MAKING GORILLA GLASS / BUILDING A SKYSCRAPER IN 15 DAYS / ETSY GOES PRO
WIRED
MAKE BELIEVE | OCT 2012
THIS MACHINE WILL CHANGE THE WORLD
This man [MAKERBOT'S BRE PETTIS] will show you how.
Print amazing objects at home!
THE NEW REPLICATOR 3-D PRINTER

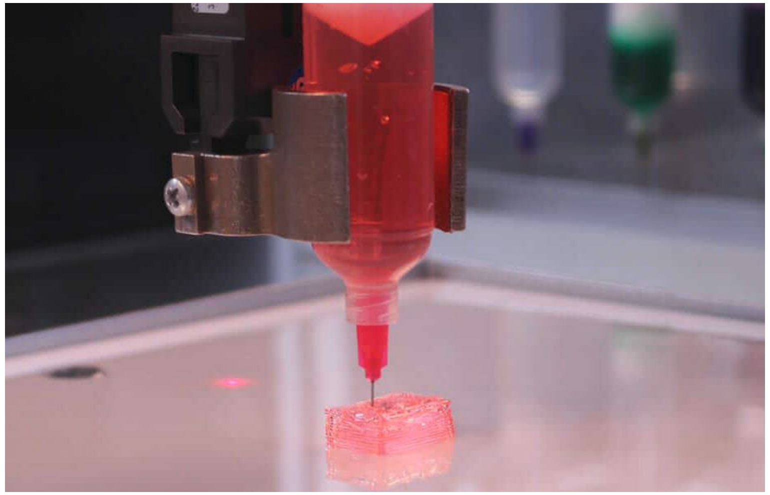

The Economist
FEBRUARY 12TH–18TH 2011
Economist.com
Europe loses the mobile-phone war
Africa's new wealth
Japan's tea party
How to switch off the internet
The shoe-thrower's index
Print me a Stradivarius
The manufacturing technology that will change the world
This violin was made using an EOS laser-sintering 3D printer (and it plays beautifully)

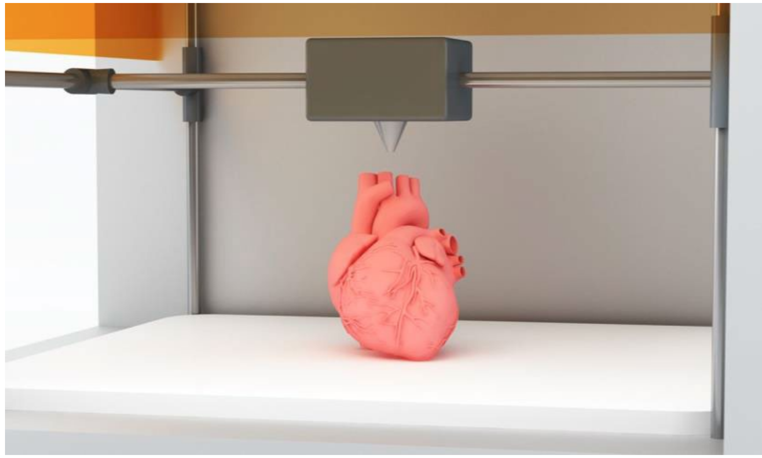

REVIEWS
Dell Precision M6600 Mobile Workstation
HP Z210 CMT Desktop Workstation • ArchiCAD 15
SolidWorks 2012 • TurboViewer DWG Viewer for iPad
COLUMNS
Circles and Lines: Associative Arrays Updated
CAD Manager: Explain Your Value to Management
User Profile: Drafter Adam Sherratt Takes on AutoLISP
Fall 2011 | Vol. 28 No. 3 | $9.99
cadalyst
Get Productive with CAD and Get the Job Done.
www.cadalyst.com
3D Printing Within Reach
Affordable, versatile options put technology in the hands of professionals and consumers
Tech Trends: BIM Supports Rise of Supertall Structures
Longitude

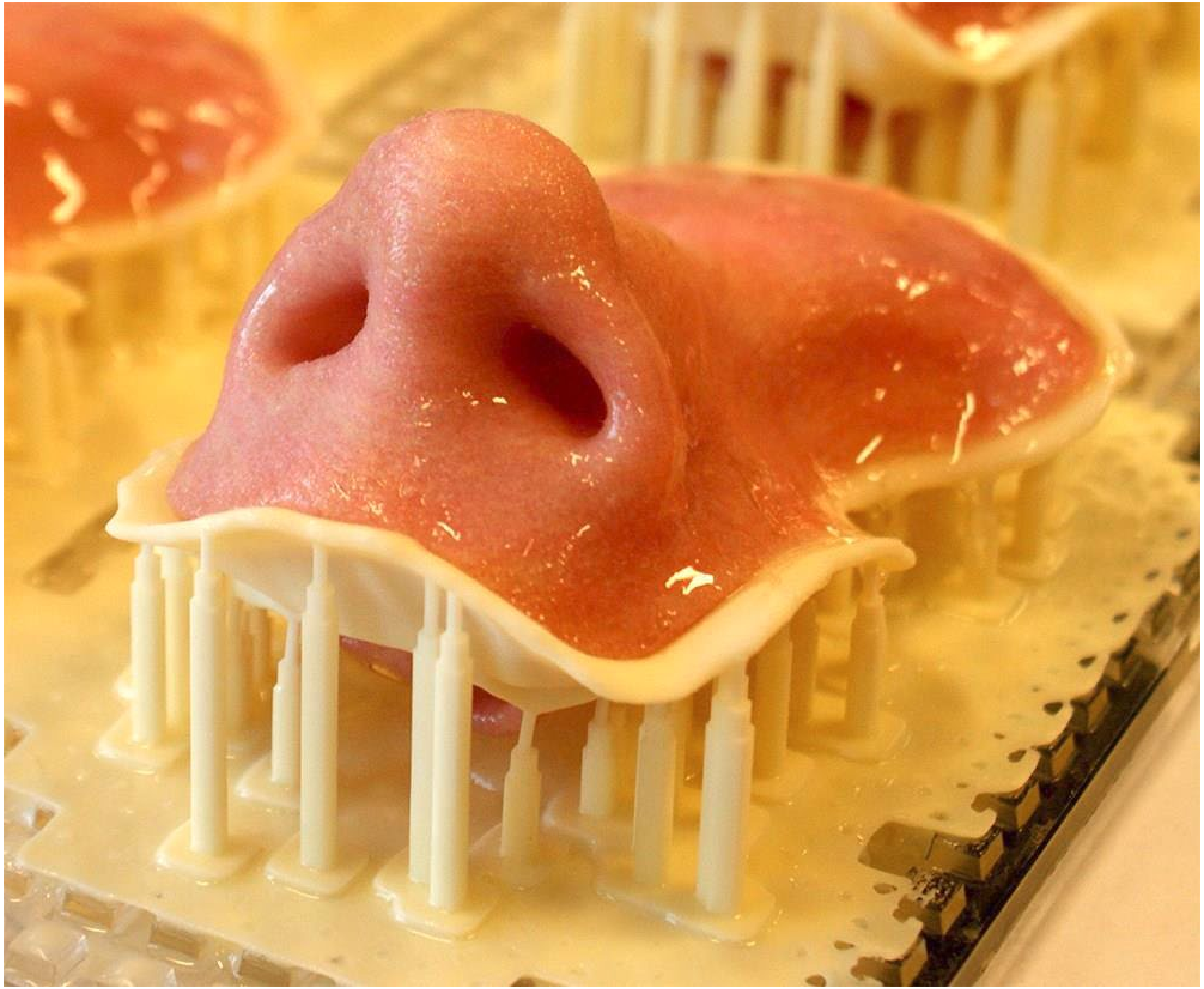
What are the things we know that can be 3D printed?



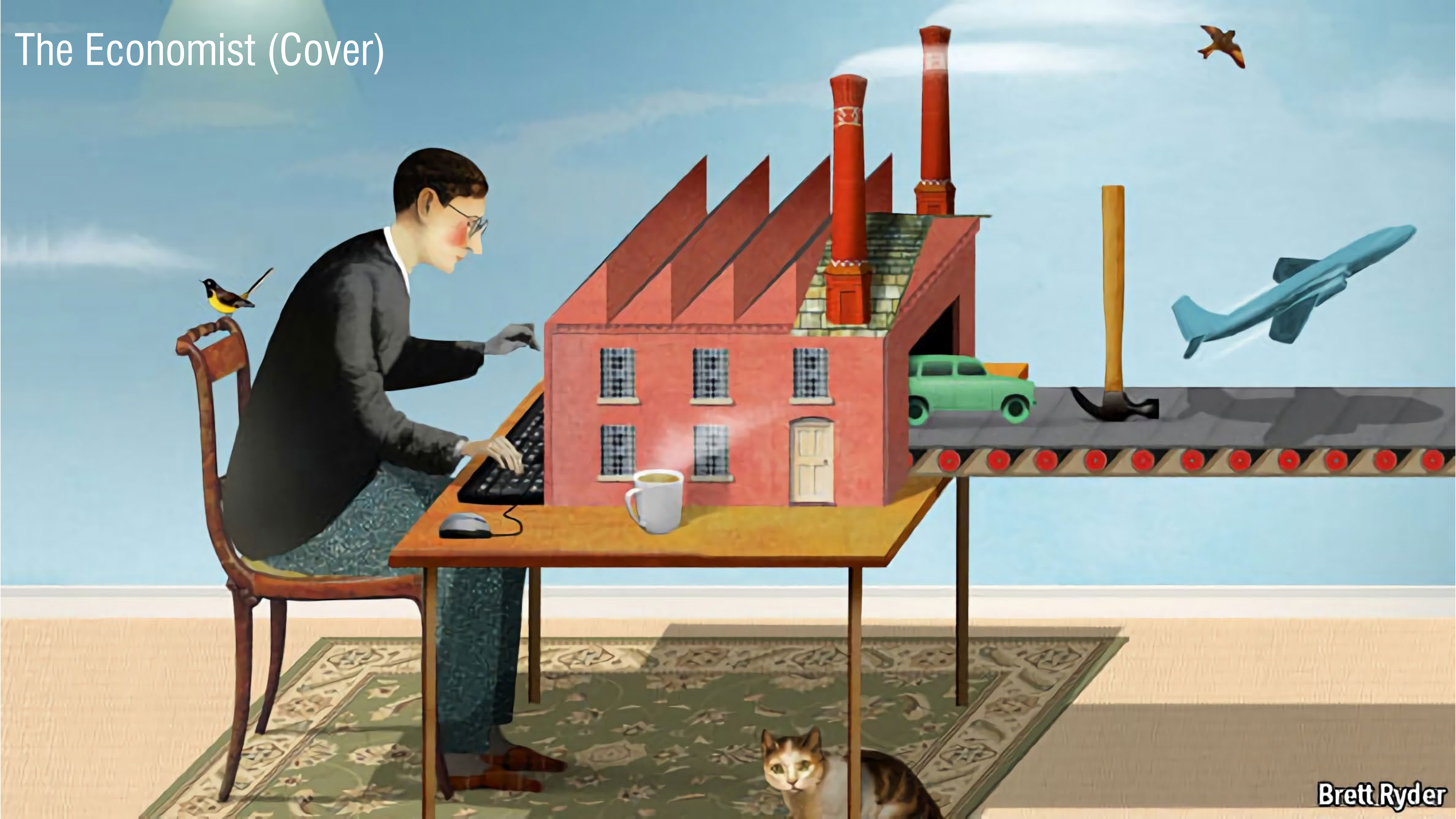


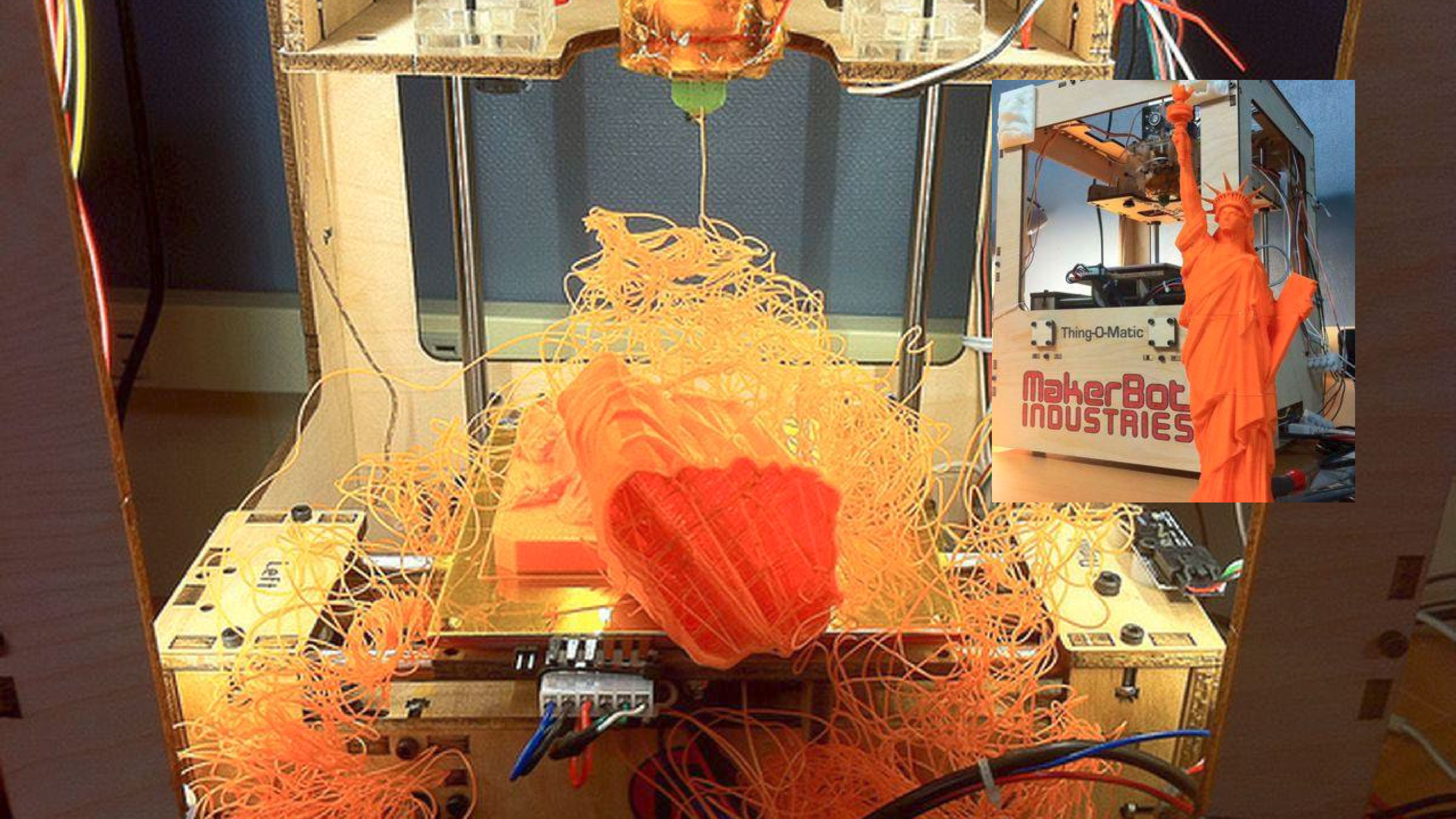




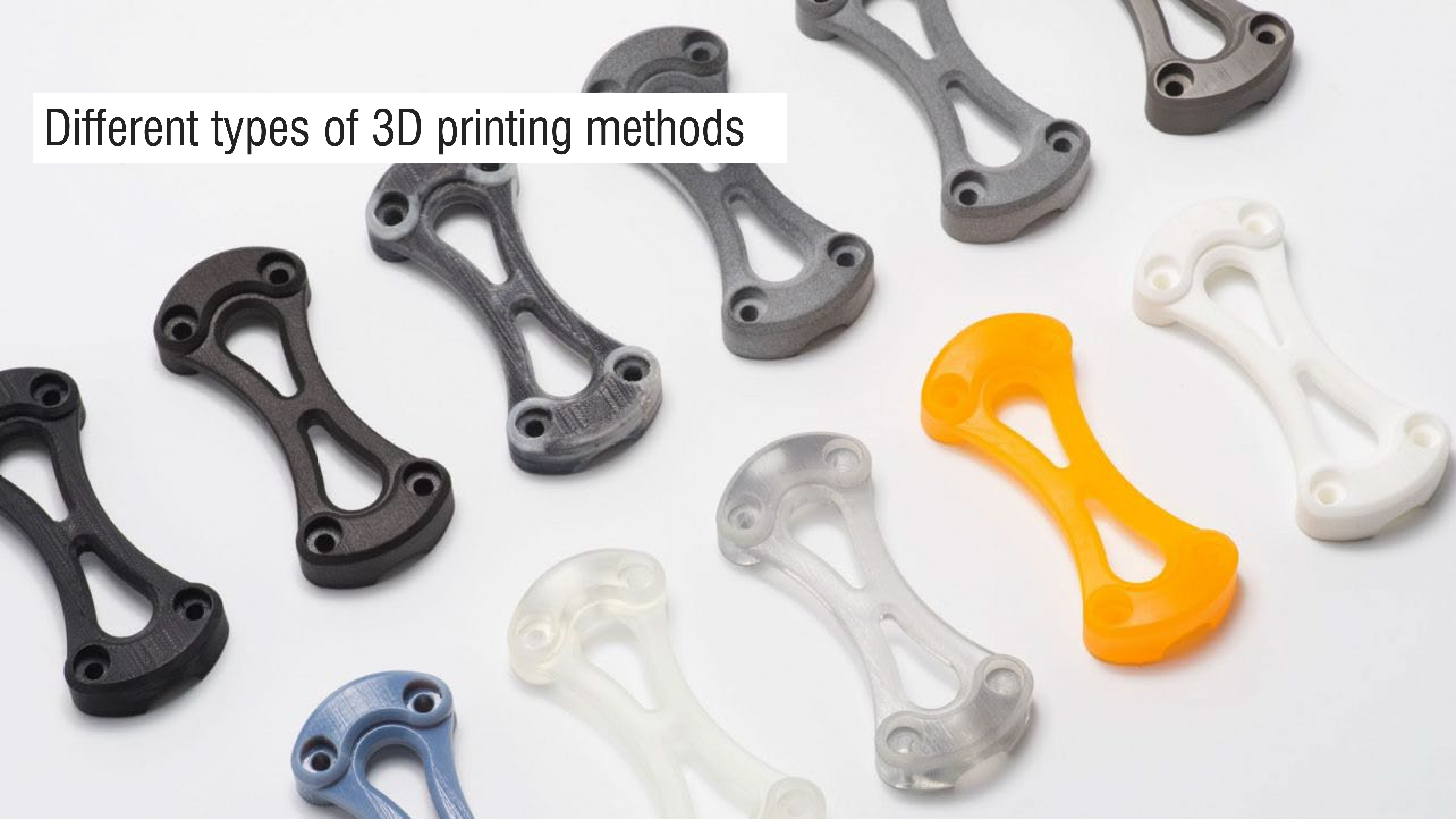


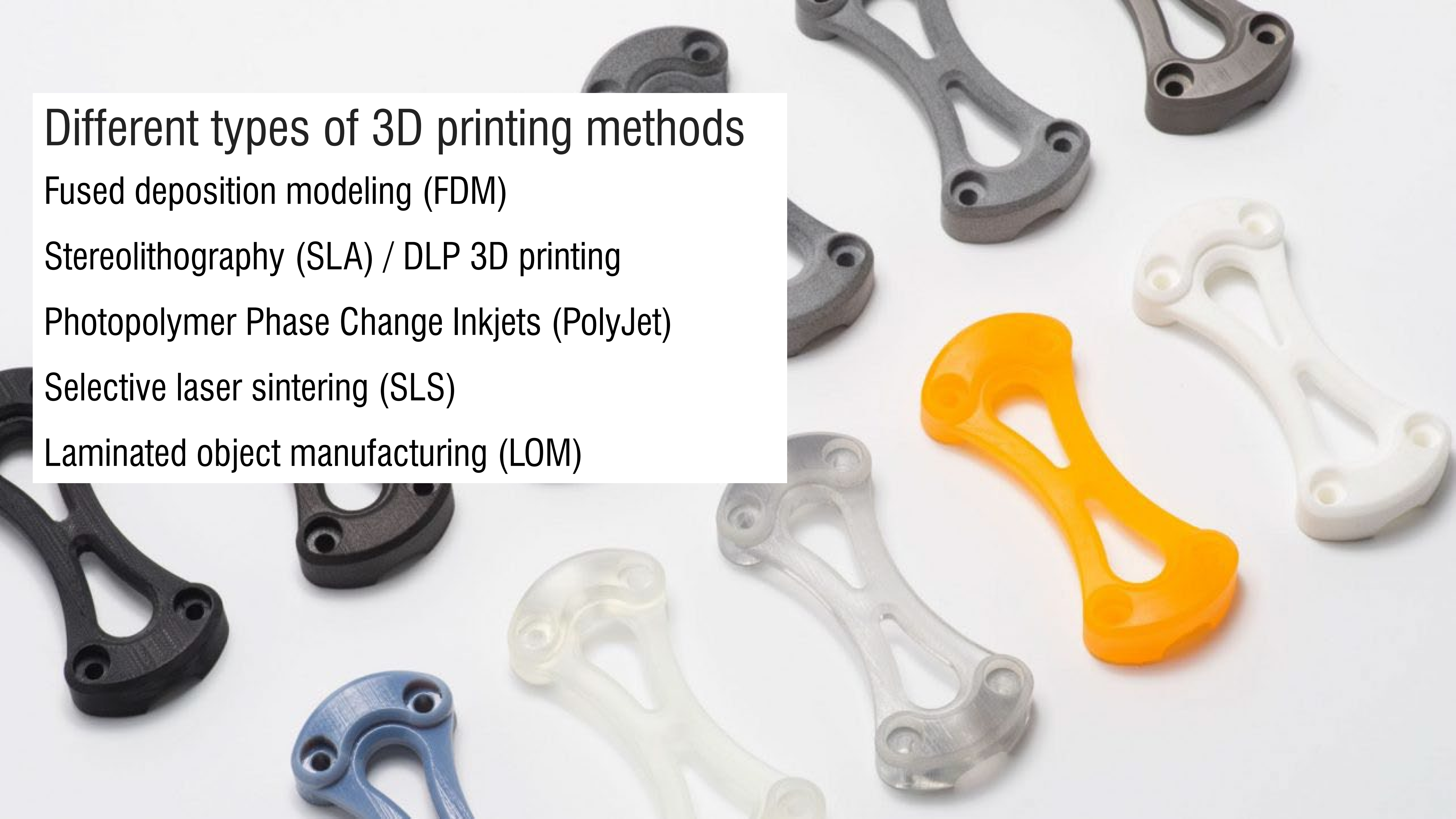
The Economist (Cover)




Thing-O-Matic
MakerBot
INDUSTRIES

Different types of 3D printing methods





Different types of 3D printing methods

Fused deposition modeling (FDM)

Stereolithography (SLA) / DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)

Different types of 3D printing methods

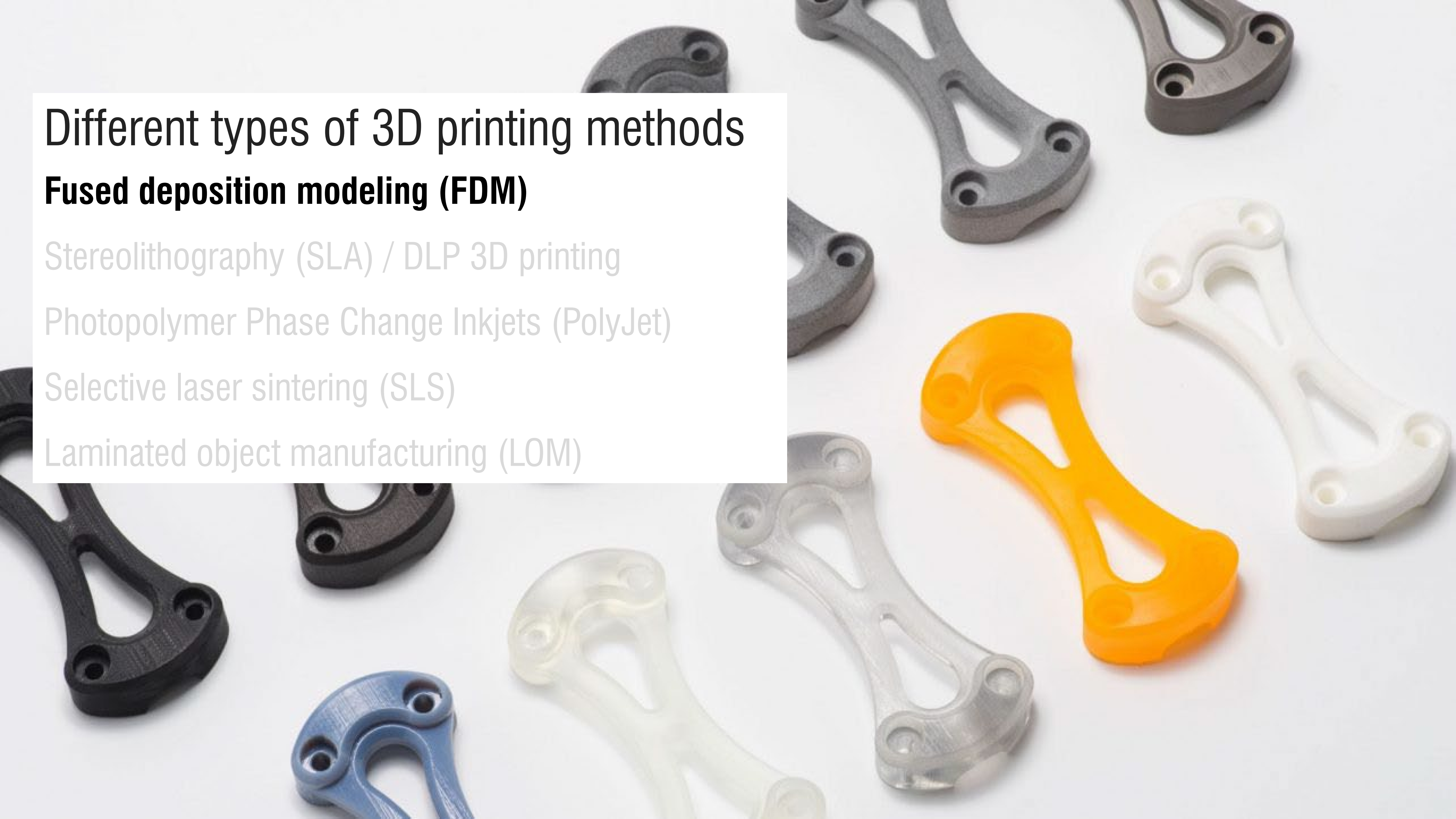
Fused deposition modeling (FDM)

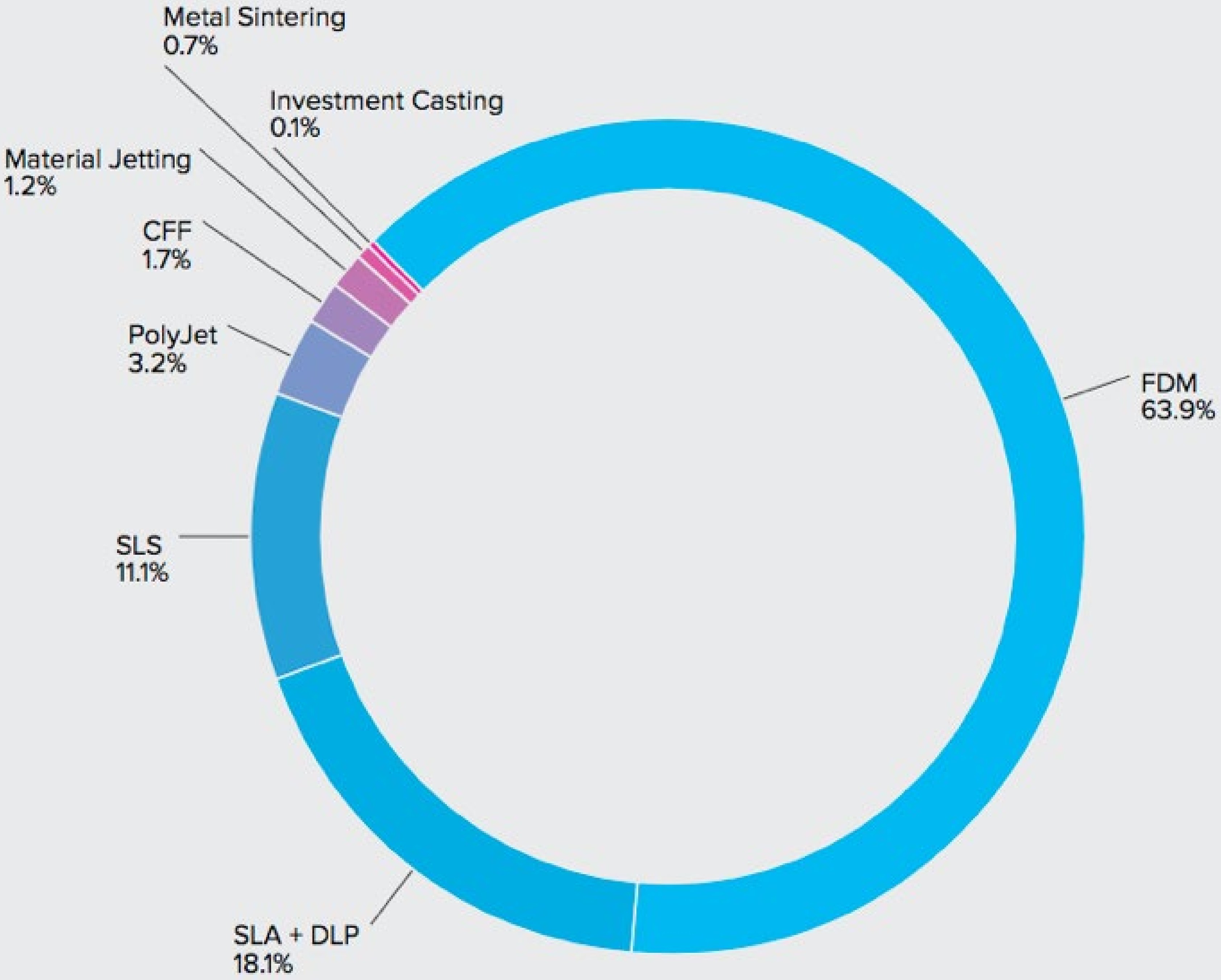
Stereolithography (SLA) / DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

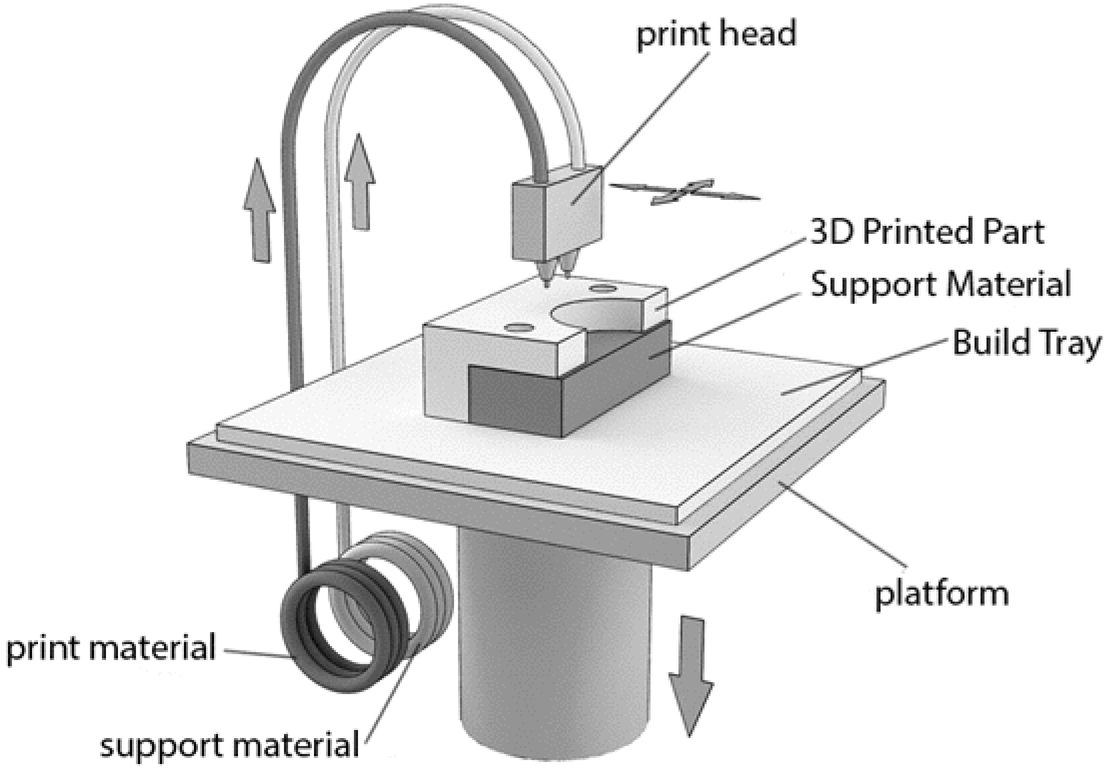
Laminated object manufacturing (LOM)




Metal Sintering
0.7%
Investment Casting
0.1%
Material Jetting
1.2%
CFF
1.7%
PolyJet
3.2%
FDM
63.9%
SLS
11.1%
SLA + DLP
18.1%

Fused deposition modeling (FDM)

Developed by Scott and Lisa Crump in the late 80s FDM is trademarked by Stratasys AKA Fused Filament Fabrication (FFF)



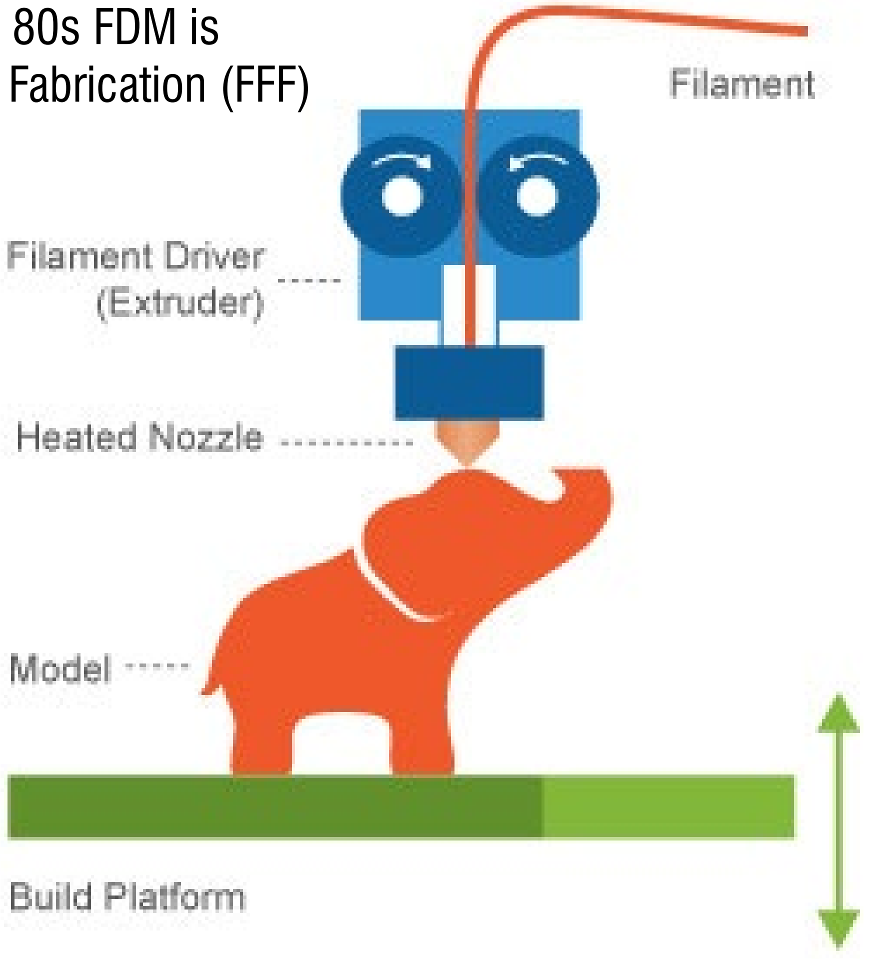
plastic filament on spools

pushed through a **hot extruder nozzle**

melts when going through the nozzle and solidifies when placed on the build platform

Fused deposition modeling (FDM)

Developed by Scott and Lisa Crump in the late 80s FDM is trademarked by Stratasys AKA Fused Filament Fabrication (FFF)

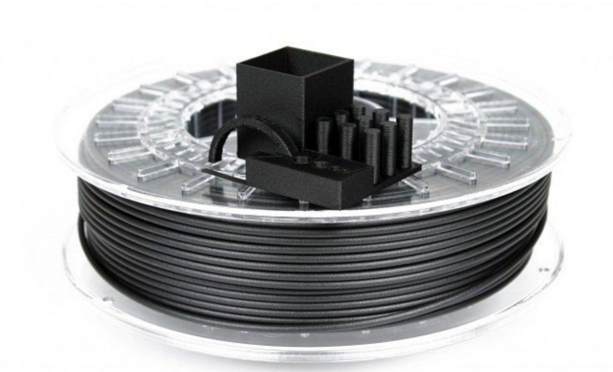


Fused Deposition Modeling (FDM)

Fused deposition modeling (FDM)

Filament is made of **thermoplastic** materials

- –**Acrylonitrile butadiene styrene** (**ABS**)
- –**Polylactide** (**PLA**) -> biodegradable
- –Many new materials



Carbon Fiber PLA

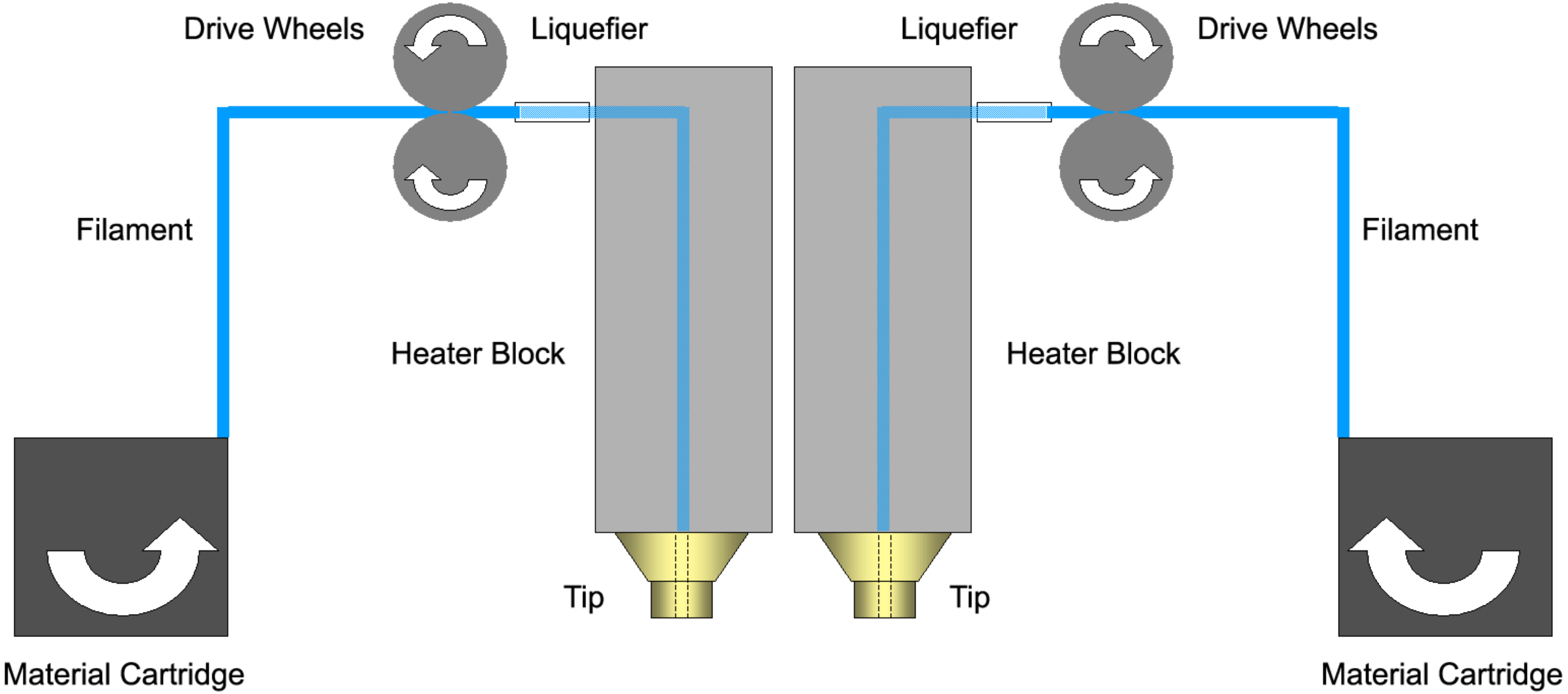
Flexible PLA

Wood PLA

Copper PLA

Fused deposition modeling (FDM)

Dual extruder machines exist



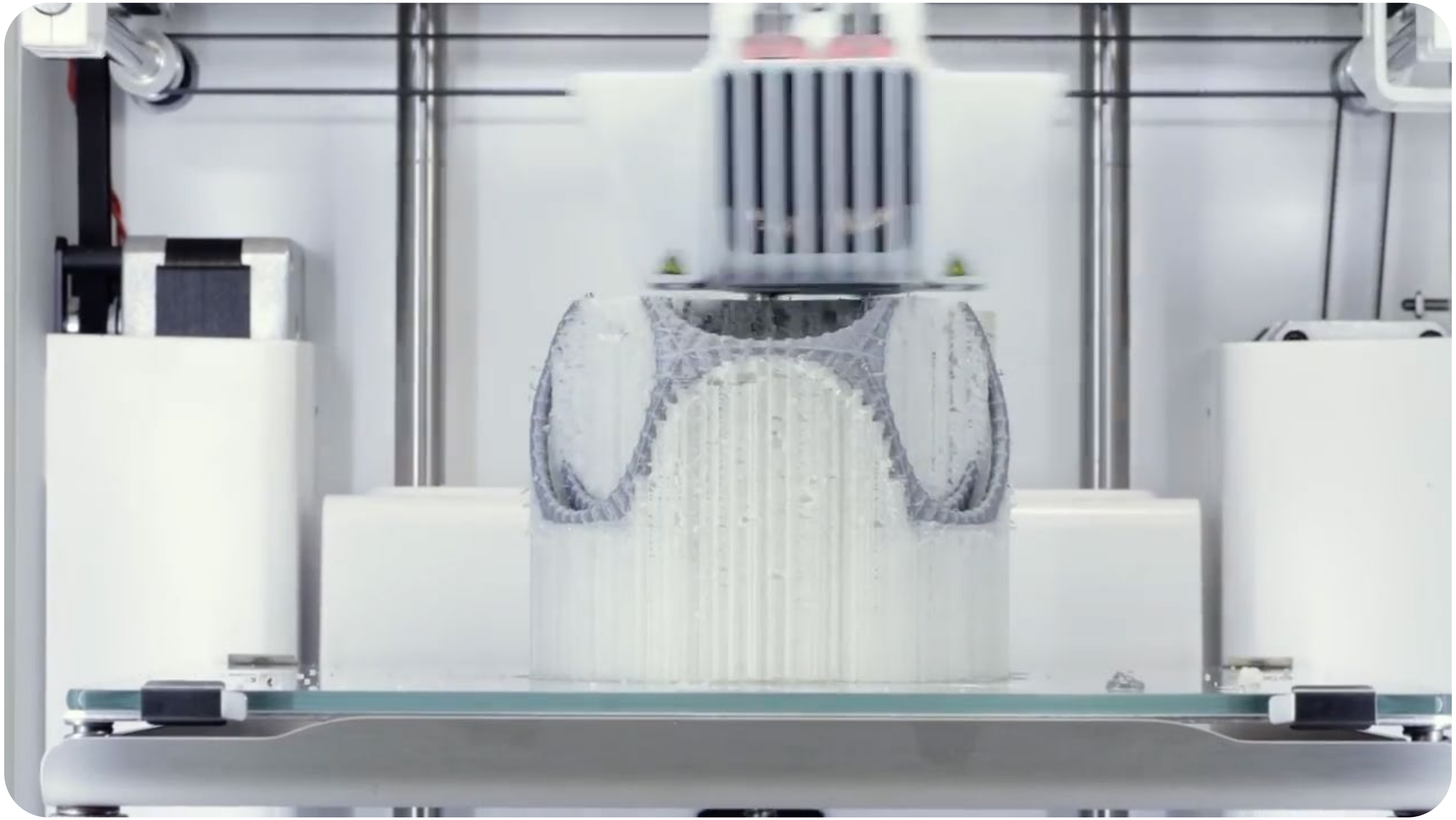
Why?

Fused deposition modeling (FDM)

Dual extruder machines exist

Fused deposition modeling (FDM)

Dual extruder machines exist



Fused deposition modeling (FDM)

Recycle?

filament extruders

old crushed plastic parts in
new filament out
but: only works a few times, filament becomes brittle

is this really helping with **sustainability?**

Fused deposition modeling (FDM)

Recycle?

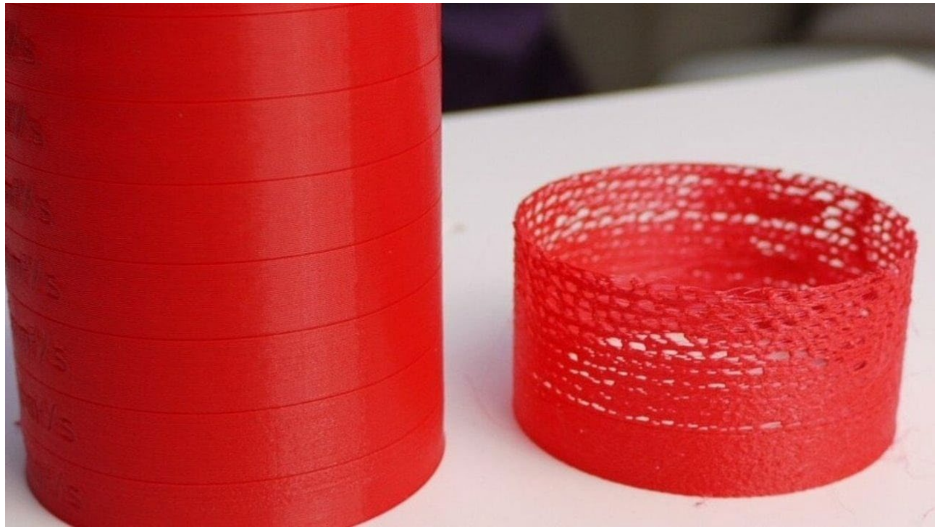
filament extruders

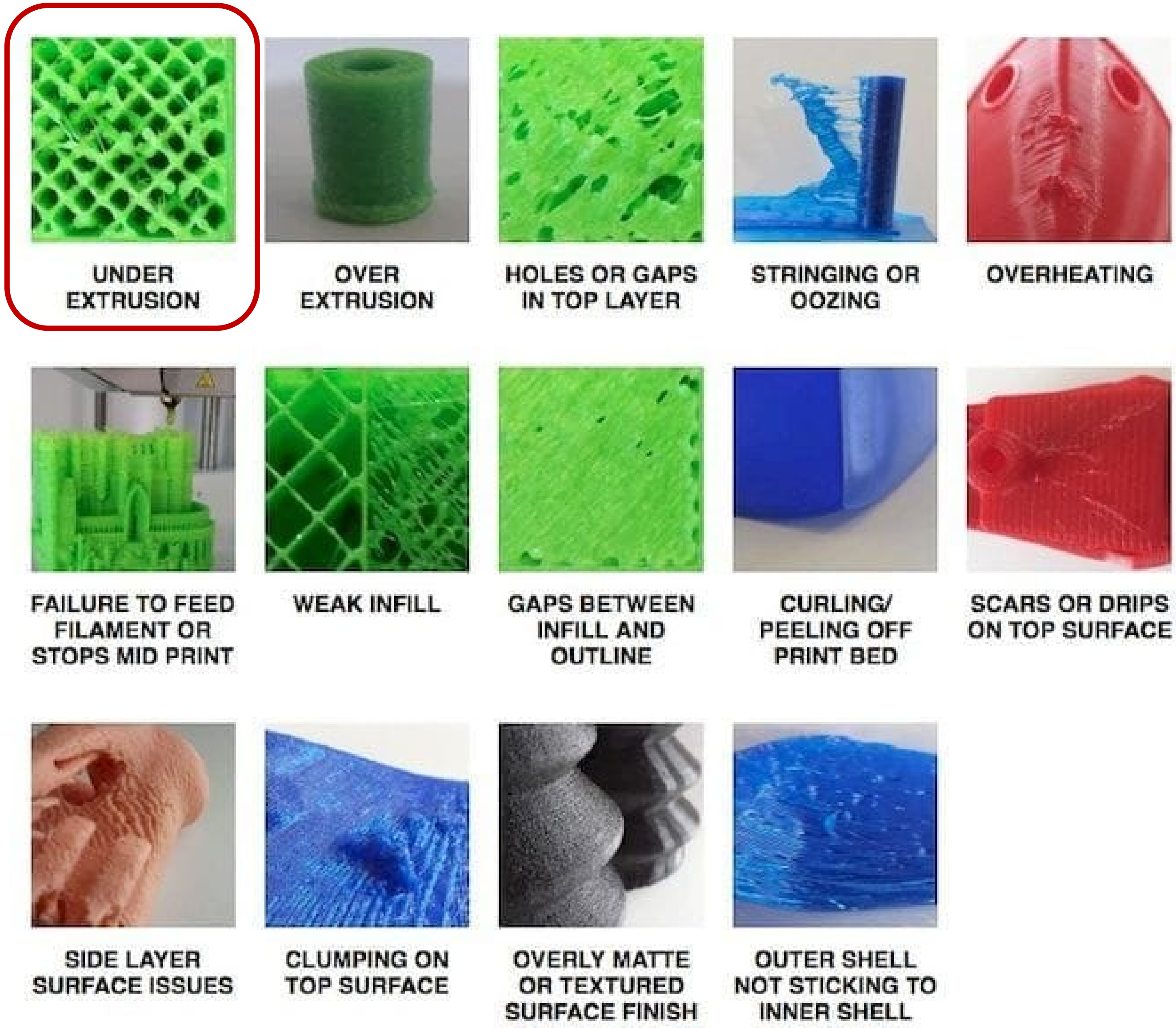
old crushed plastic parts in
new filament out
but: only works a few times, filament
becomes brittle

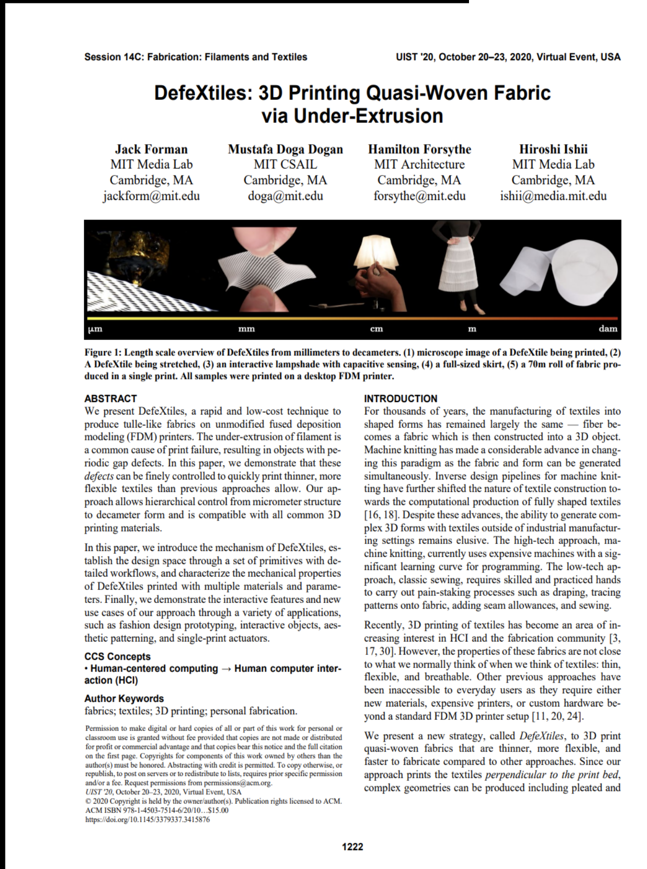
yes, because you don’t trash the material.
no, because it requires energy to be recycled. (need careful calculation)

is this really helping with
sustainability?

Common FDM printing problems







DefeXtiles: 3D Printing Quasi-Woven Fabric via Under-Extrusion

Jack Forman
MIT Media Lab
Cambridge, MA
jackform@mit.edu

Mustafa Doga Dogan
MIT CSAIL
Cambridge, MA
doga@mit.edu

Hamilton Forsythe
MIT Architecture
Cambridge, MA
forsythe@mit.edu

Hiroshi Ishii
MIT Media Lab
Cambridge, MA
ishii@media.mit.edu

Figure 1: Length scale overview of DefeXtiles from millimeters to decameters. (1) microscope image of a DefeXtile being printed, (2) A DefeXtile being stretched, (3) an interactive lampshade with capacitive sensing, (4) a full-sized skirt, (5) a 70m roll of fabric produced in a single print. All samples were printed on a desktop FDM printer.

ABSTRACT

We present DefeXtiles, a rapid and low-cost technique to produce tulle-like fabrics on unmodified fused deposition modeling (FDM) printers. The under-extrusion of filament is a common cause of print failure, resulting in objects with periodic gap defects. In this paper, we demonstrate that these *defects* can be finely controlled to quickly print thinner, more flexible textiles than previous approaches allow. Our approach allows hierarchical control from micrometer structure to decameter form and is compatible with all common 3D printing materials.

In this paper, we introduce the mechanism of DefeXtiles, establish the design space through a set of primitives with detailed workflows, and characterize the mechanical properties of DefeXtiles printed with multiple materials and parameters. Finally, we demonstrate the interactive features and new use cases of our approach through a variety of applications, such as fashion design prototyping, interactive objects, aesthetic patterning, and single-print actuators.

CCS Concepts
• Human-centered computing → Human computer interaction (HCI)

Author Keywords
fabrics; textiles; 3D printing; personal fabrication.

UIST '20, October 20–23, 2020, Virtual Event, USA

ACM ISBN 978-1-4503-7514-6/20/10…$15.00
https://doi.org/10.1145/3379337.3415876

INTRODUCTION

For thousands of years, the manufacturing of textiles into shaped forms has remained largely the same — fiber becomes a fabric which is then constructed into a 3D object. Machine knitting has made a considerable advance in changing this paradigm as the fabric and form can be generated simultaneously. Inverse design pipelines for machine knitting have further shifted the nature of textile construction towards the computational production of fully shaped textiles [16, 18]. Despite these advances, the ability to generate complex 3D forms with textiles outside of industrial manufacturing settings remains elusive. The high-tech approach, machine knitting, currently uses expensive machines with a significant learning curve for programming. The low-tech approach, classic sewing, requires skilled and practiced hands to carry out pain-staking processes such as draping, tracing patterns onto fabric, adding seam allowances, and sewing.

Recently, 3D printing of textiles has become an area of increasing interest in HCI and the fabrication community [3, 17, 30]. However, the properties of these fabrics are not close to what we normally think of when we think of textiles: thin, flexible, and breathable. Other previous approaches have been inaccessible to everyday users as they require either new materials, expensive printers, or custom hardware beyond a standard FDM 3D printer setup [11, 20, 24].

We present a new strategy, called *DefeXtiles*, to 3D print quasi-woven fabrics that are thinner, more flexible, and faster to fabricate compared to other approaches. Since our approach prints the textiles *perpendicular to the print bed*, complex geometries can be produced including pleated and

UIST 2020

Forman et.al.

DefeXtiles: 3D Printing Quasi-Woven Fabric via Under-Extrusion

An approach that allows flexible, thin textiles of many materials to be quickly printed into arbitrary forms with tunable properties using a unmodified, inexpensive 3D printer

Session 14C: Fabrication: Filaments and Textiles UIST '20, October 20–23, 2020, Virtual Event, USA

DefeXtiles: 3D Printing Quasi-Woven Fabric via Under-Extrusion

Jack Forman
MIT Media Lab
Cambridge, MA
jackform@mit.edu

Mustafa Doga Dogan
MIT CSAIL
Cambridge, MA
doga@mit.edu

Hamilton Forsythe
MIT Architecture
Cambridge, MA
forsythe@mit.edu

Hiroshi Ishii
MIT Media Lab
Cambridge, MA
ishii@media.mit.edu

Figure 1: Length scale overview of DefeXtiles from millimeters to decameters. (1) microscope image of a DefeXtile being printed, (2) A DefeXtile being stretched, (3) an interactive lampshade with capacitive sensing, (4) a full-sized skirt, (5) a 70m roll of fabric produced in a single print. All samples were printed on a desktop FDM printer.

ABSTRACT

We present DefeXtiles, a rapid and low-cost technique to produce tulle-like fabrics on unmodified fused deposition modeling (FDM) printers. The under-extrusion of filament is a common cause of print failure, resulting in objects with periodic gap defects. In this paper, we demonstrate that these *defects* can be finely controlled to quickly print thinner, more flexible textiles than previous approaches allow. Our approach allows hierarchical control from micrometer structure to decameter form and is compatible with all common 3D printing materials.

In this paper, we introduce the mechanism of DefeXtiles, establish the design space through a set of primitives with detailed workflows, and characterize the mechanical properties of DefeXtiles printed with multiple materials and parameters. Finally, we demonstrate the interactive features and new use cases of our approach through a variety of applications, such as fashion design prototyping, interactive objects, aesthetic patterning, and single-print actuators.

CCS Concepts
• Human-centered computing → Human computer interaction (HCI)

Author Keywords
fabrics; textiles; 3D printing; personal fabrication.

UIST '20, October 20–23, 2020, Virtual Event, USA

ACM ISBN 978-1-4503-7514-6/20/10…$15.00
https://doi.org/10.1145/3379337.3415876

INTRODUCTION

For thousands of years, the manufacturing of textiles into shaped forms has remained largely the same — fiber becomes a fabric which is then constructed into a 3D object. Machine knitting has made a considerable advance in changing this paradigm as the fabric and form can be generated simultaneously. Inverse design pipelines for machine knitting have further shifted the nature of textile construction towards the computational production of fully shaped textiles [16, 18]. Despite these advances, the ability to generate complex 3D forms with textiles outside of industrial manufacturing settings remains elusive. The high-tech approach, machine knitting, currently uses expensive machines with a significant learning curve for programming. The low-tech approach, classic sewing, requires skilled and practiced hands to carry out pain-staking processes such as draping, tracing patterns onto fabric, adding seam allowances, and sewing.

Recently, 3D printing of textiles has become an area of increasing interest in HCI and the fabrication community [3, 17, 30]. However, the properties of these fabrics are not close to what we normally think of when we think of textiles: thin, flexible, and breathable. Other previous approaches have been inaccessible to everyday users as they require either new materials, expensive printers, or custom hardware beyond a standard FDM 3D printer setup [11, 20, 24].

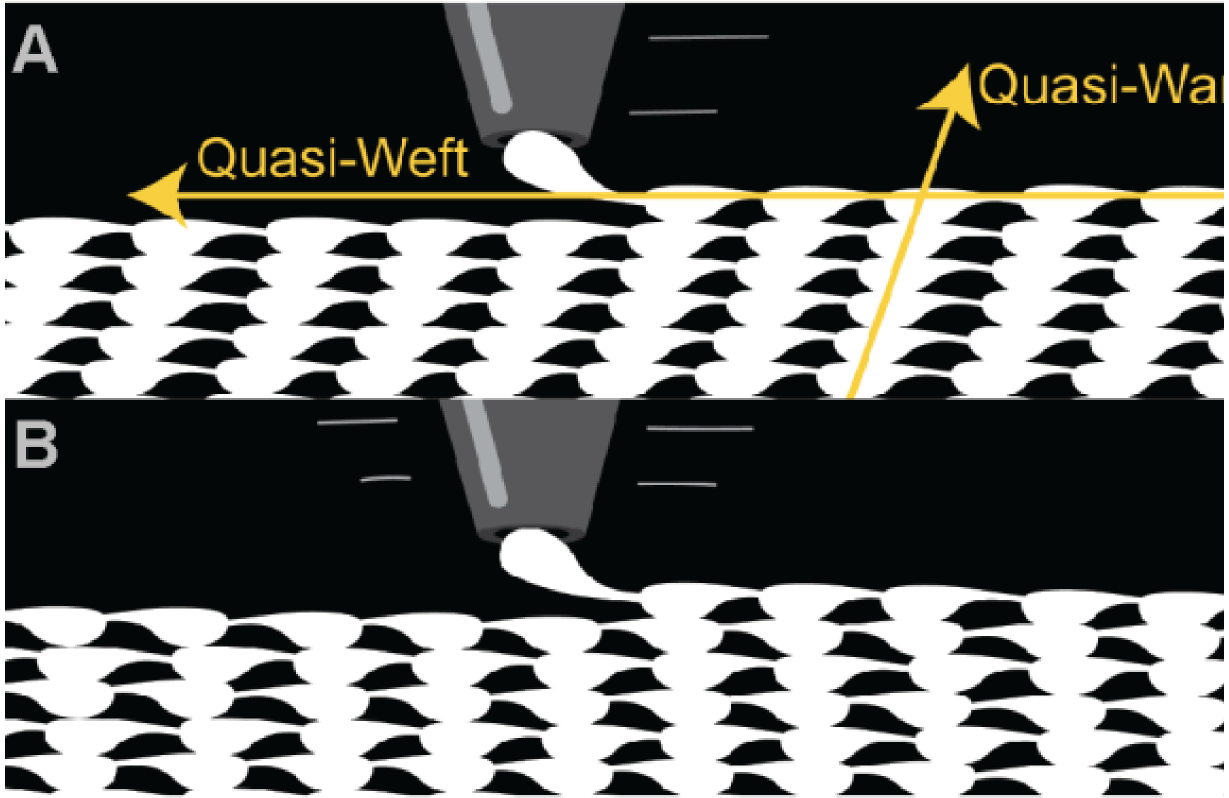
We present a new strategy, called *DefeXtiles*, to 3D print quasi-woven fabrics that are thinner, more flexible, and faster to fabricate compared to other approaches. Since our approach prints the textiles *perpendicular to the print bed*, complex geometries can be produced including pleated and

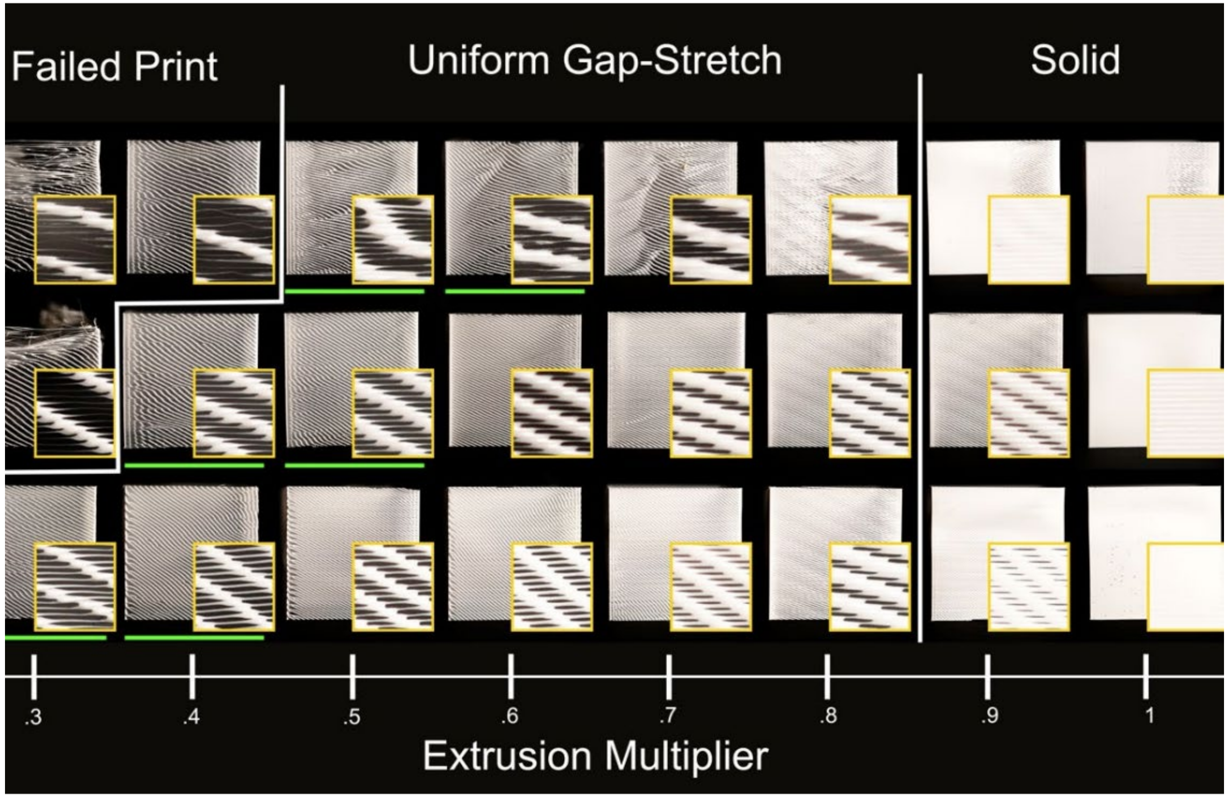
1222

UIST 2020

Forman et.al.

DefeXtiles: 3D Printing Quasi-Woven Fabric via Under-Extrusion





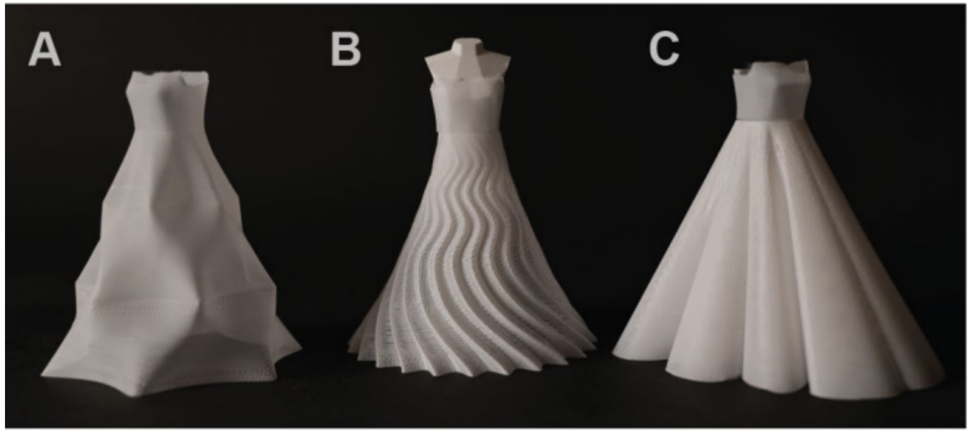


Figure 6: Three miniature dresses printed with PLA all 140cm in height. A) is a dress with a complex non-developable garment. In B) the dress and the dress form are printed simultaneously. C) shows a wedding gown with 3 layers of fabric affording opacity.

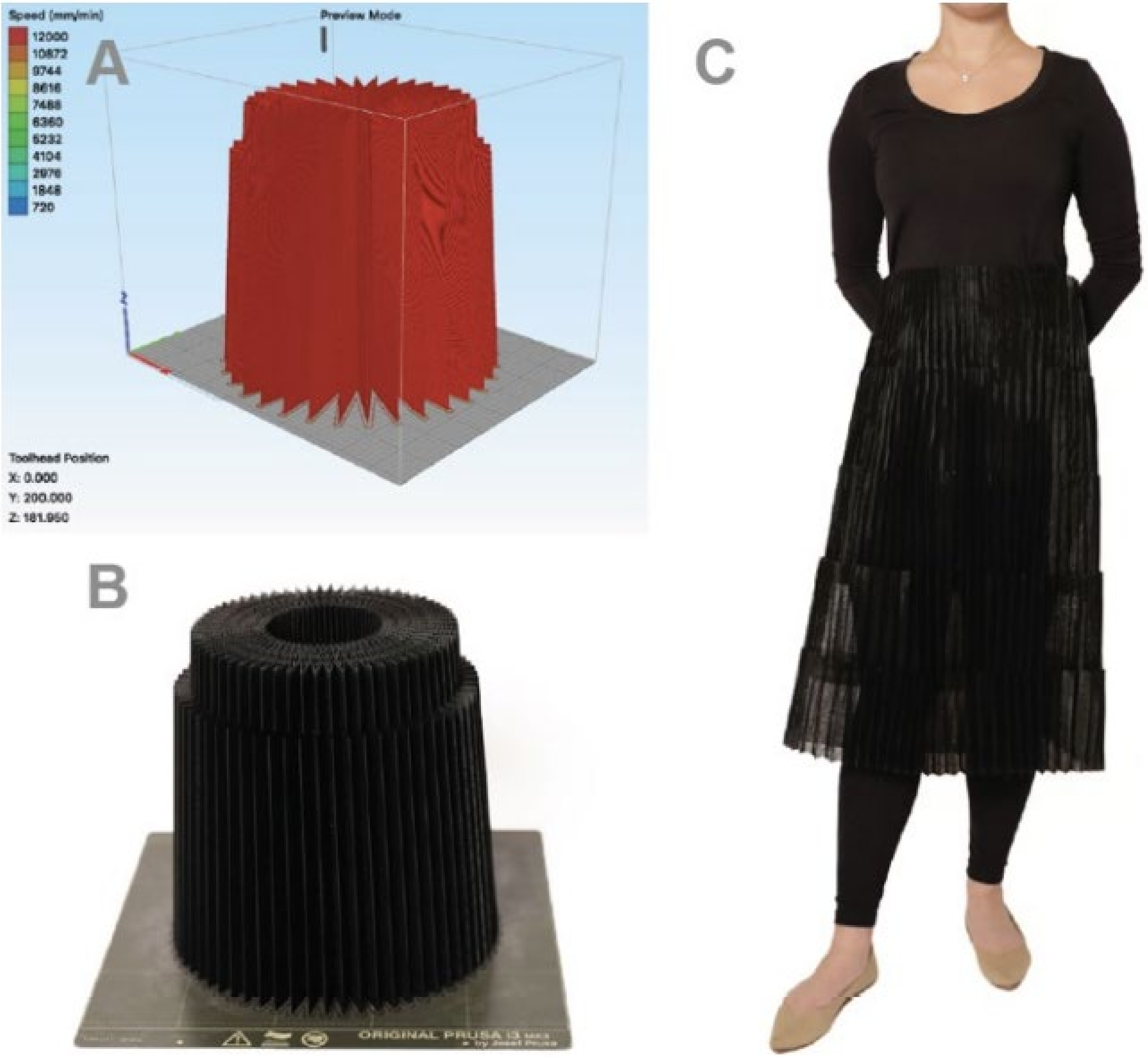
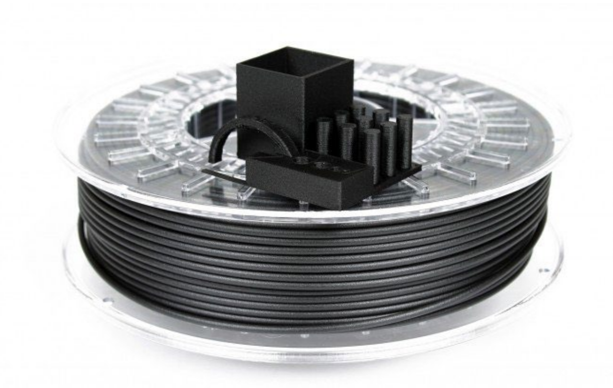


Figure 7: A) The digital version of the pleated skirt design. B) The 3D printed version. C) The unpacked version worn.

What if FDM printing could be combined with forms of material beyond traditional filament?



Carbon Fiber PLA

Flexible PLA

Wood PLA

Copper PLA

A 3D Printer for Interactive Electromagnetic Devices

A FDM printer +

5DOF Printing Platform &

Wire Winder?

A 3D Printer for Interactive Electromagnetic Devices

Huaishu Peng[1,2] **François Guimbretière**[1,2] **James McCann**[1] **Scott E. Hudson**[1,3]

Disney Research Pittsburgh[1]
Pittsburgh, PA 15213
jmccann@disneyresearch.com

Computing and Information Science[2]
Cornell University
Ithaca, NY 14850
{hp356, fvg3}@cornell.edu

HCI Institute[3]
Carnegie Mellon University
Pittsburgh, PA 15213
scott.hudson@cs.cmu.edu

Figure 1. 3D printed electromagnetic devices. a) Solenoid used to actuate the cat hand; b) A Ferrofluid display; c) A movement sensor based on coupling strength; d) The stator and the rotor of a reluctance motor. The electromagnetic components are printed with a soft iron core, wound in place, and multiple layer of copper wire.

ABSTRACT

We introduce a new form of low-cost 3D printer to print interactive electromechanical objects with *wound in place* coils. At the heart of this printer is a mechanism for depositing wire within a five degree of freedom (*5DOF*) fused deposition modeling (FDM) 3D printer. Copper wire can be used with this mechanism to form coils which induce magnetic fields as a current is passed through them. Soft iron wire can additionally be used to form components with high magnetic permeability which are thus able to shape and direct these magnetic fields to where they are needed. When fabricated with structural plastic elements, this allows simple but complete custom electromagnetic devices to be 3D printed. As examples, we demonstrate the fabrication of a solenoid actuator for the arm of a *Lucky Cat* figurine, a 6-pole motor stepper stator, a reluctance motor rotor and a Ferrofluid display. In addition, we show how printed coils which generate small currents in response to user actions can be used as input sensors in interactive devices.

UIST '16, October 16 - 19, 2016, Tokyo, Japan

ACM 978-1-4503-4189-9/16/10 $15.00
DOI: http://dx.doi.org/10.1145/2984511.2984523

Author Keywords

3D printing; computational crafts; electromagnets; rapid prototyping; interactive devices; fabrication.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

3D printing technology has moved beyond simply instantiating 3D geometries to printing functional and interactive objects. Recent work has considered how a range of functional objects might be fabricated, including 3D printed optical components [30], speakers [11], hydraulic robots [14], and pneumatic devices for haptic feedback [28]. By using conductive filament, ink, or fabric sheets, several projects also explored embedding three-dimensional conductive traces inside printed objects to create simple electronic devices [24, 29, 17]. This opens the possibility of eventually using 3D printing for the on-demand fabrication of highly custom interactive devices, as well as greatly expanding our ability to rapidly prototype sophisticated devices. However, to date we have not been able to directly fabricate most functional devices needing actuators, but instead these required either assembly with, or addition of, pre-manufactured parts into a print.

In this paper, we introduce a new type of 3D printer that can print interactive objects with embedded electromagnetic coil components such as those illustrated in Figure 1, including a solenoid actuator for the arm of a *Lucky Cat* figurine (Figure 1a), a Ferrofluid display (Figure 1b), an electromagnetic input sensor (Figure 1c), and both the stator and rotor for an

UIST 2016

Peng et.al.

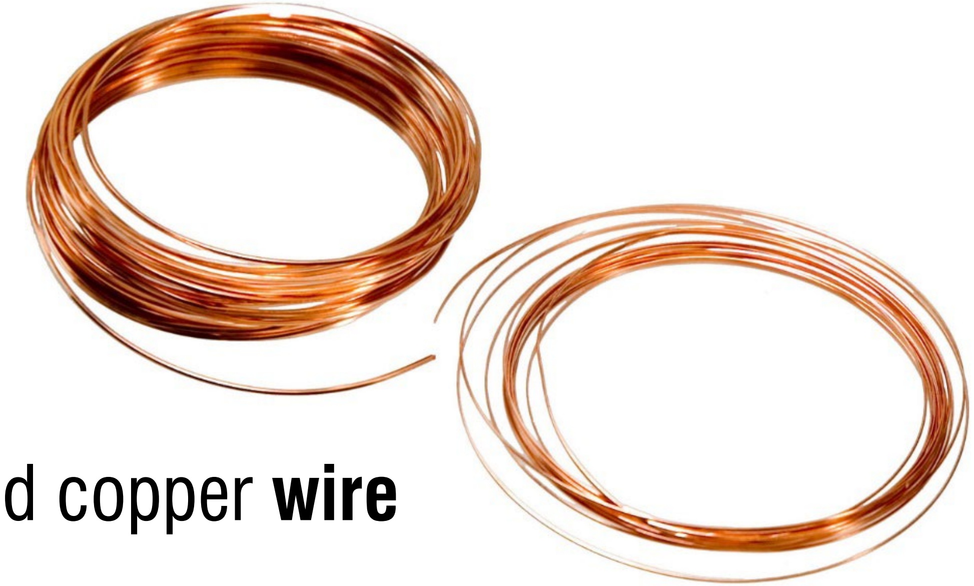
A 3D Printer for Interactive Electromagnetic Devices

Huaishu Peng | François Guimbretière | James McCann | Scott Hudson

Disney Research
Cornell University
Carnegie Mellon

UIST 2016

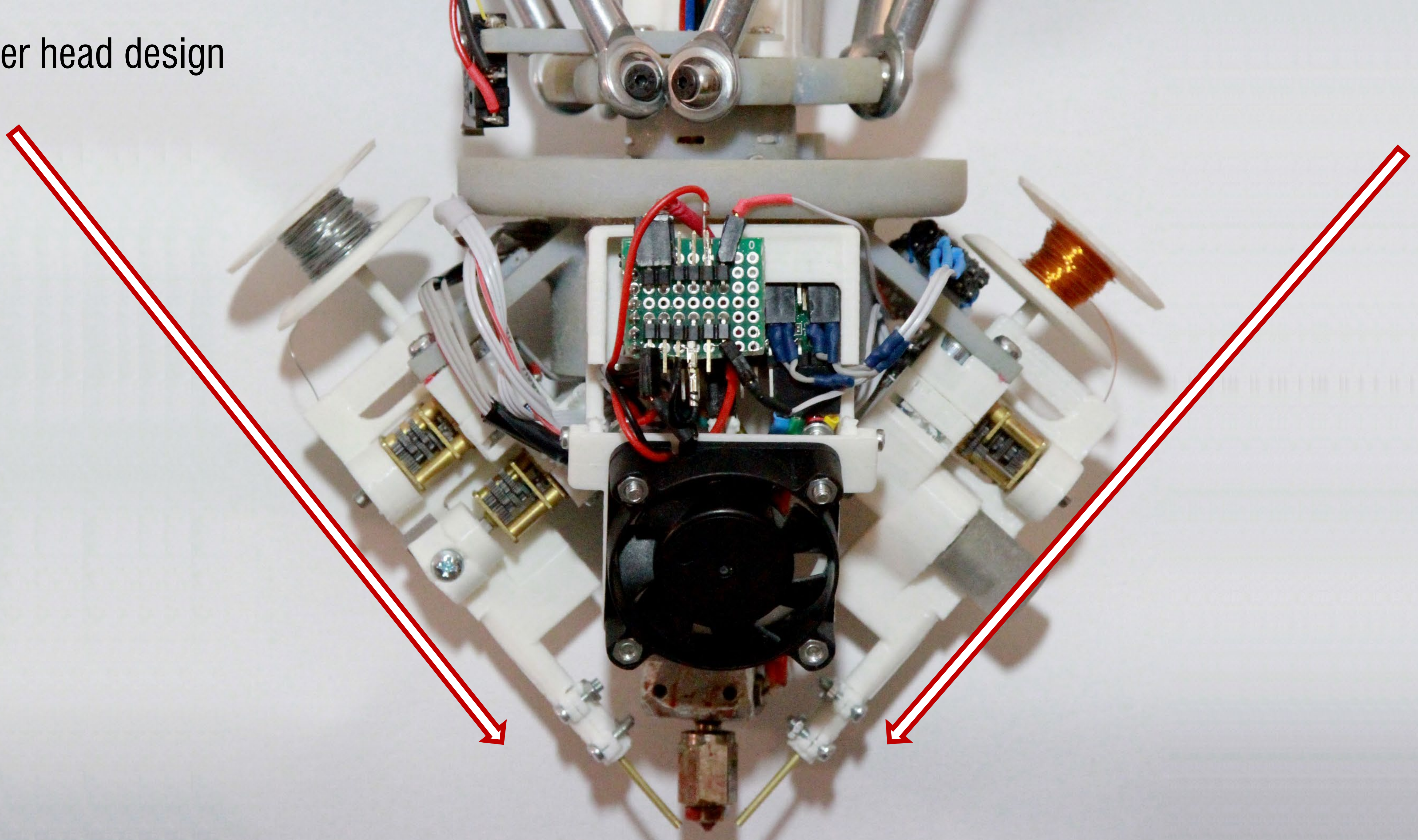
Winding continuous strands of **wire**
inside a 3D printed object across printed layers



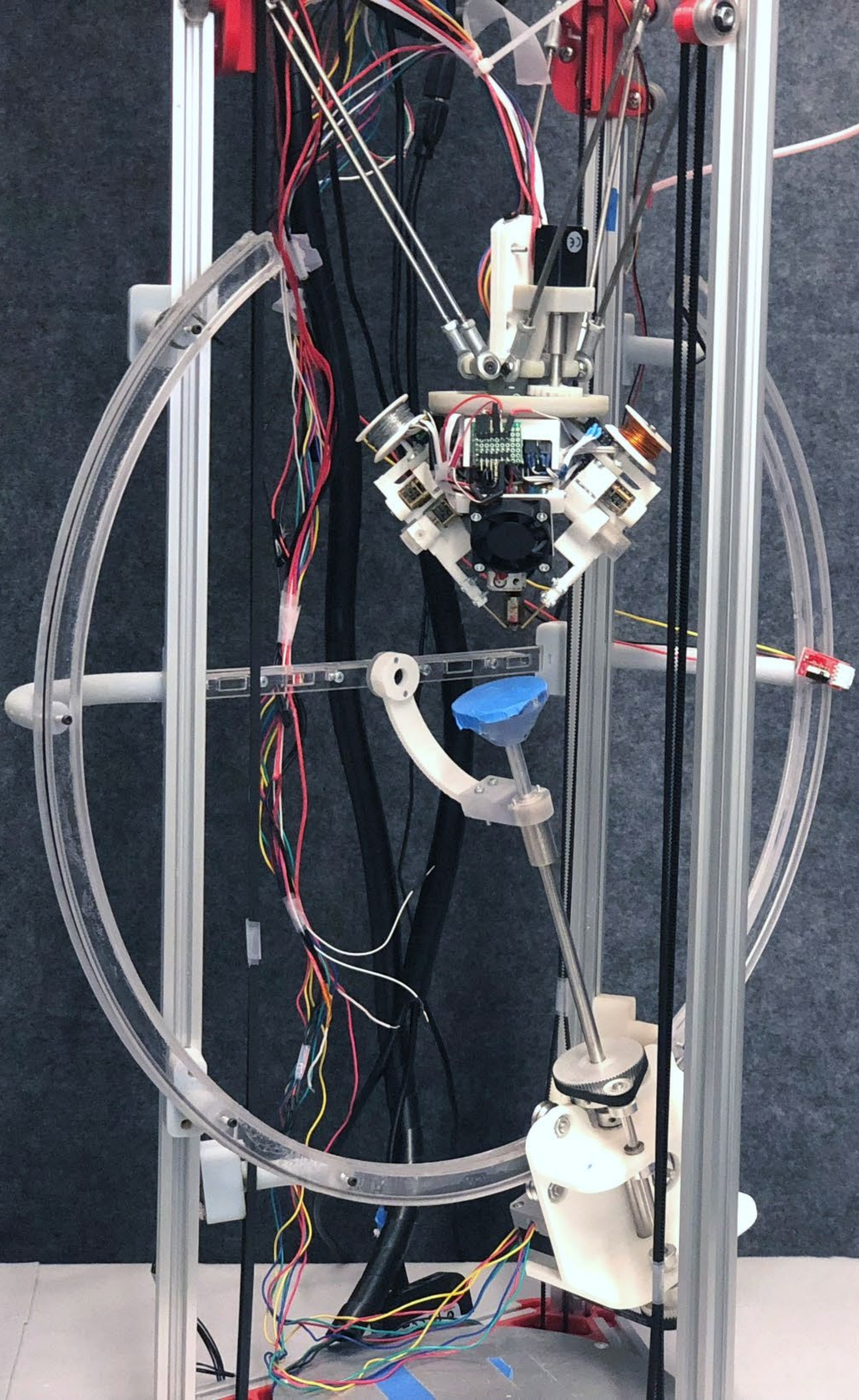
Isolated copper **wire**

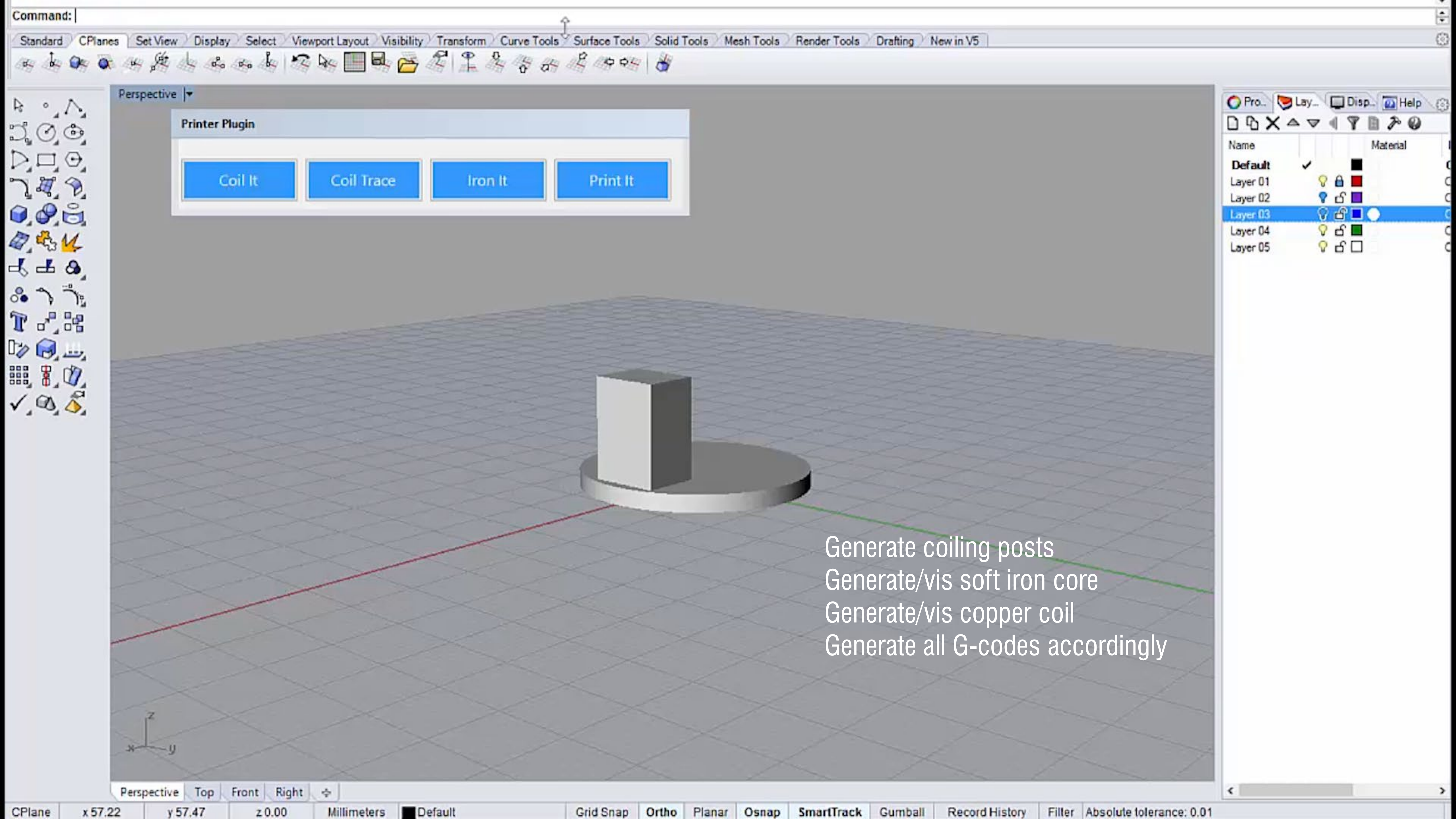
Soft iron **wire**

Printer head design

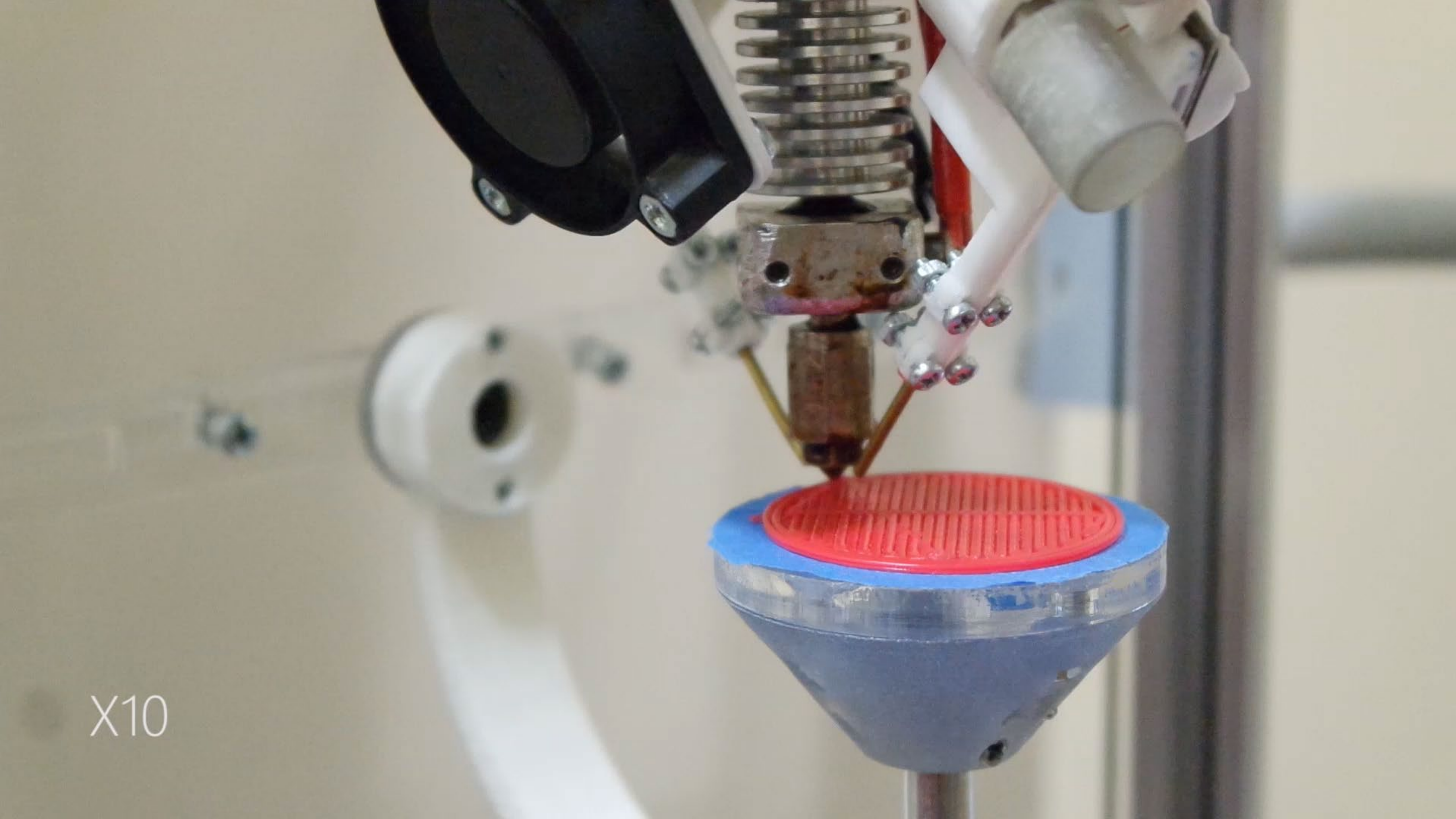


5DOF printing platform





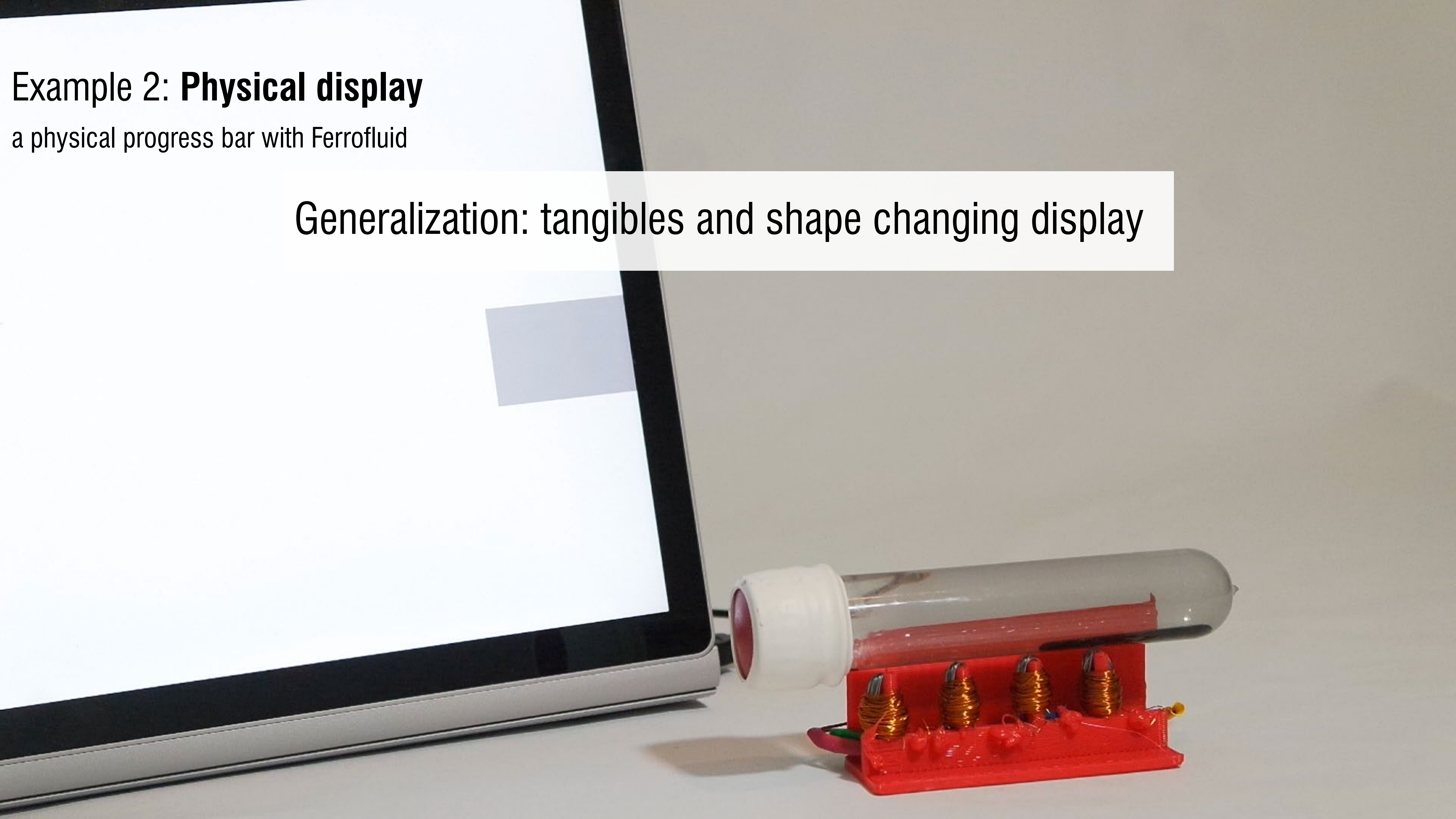
Generate coiling posts
Generate/vis soft iron core
Generate/vis copper coil
Generate all G-codes accordingly


X10

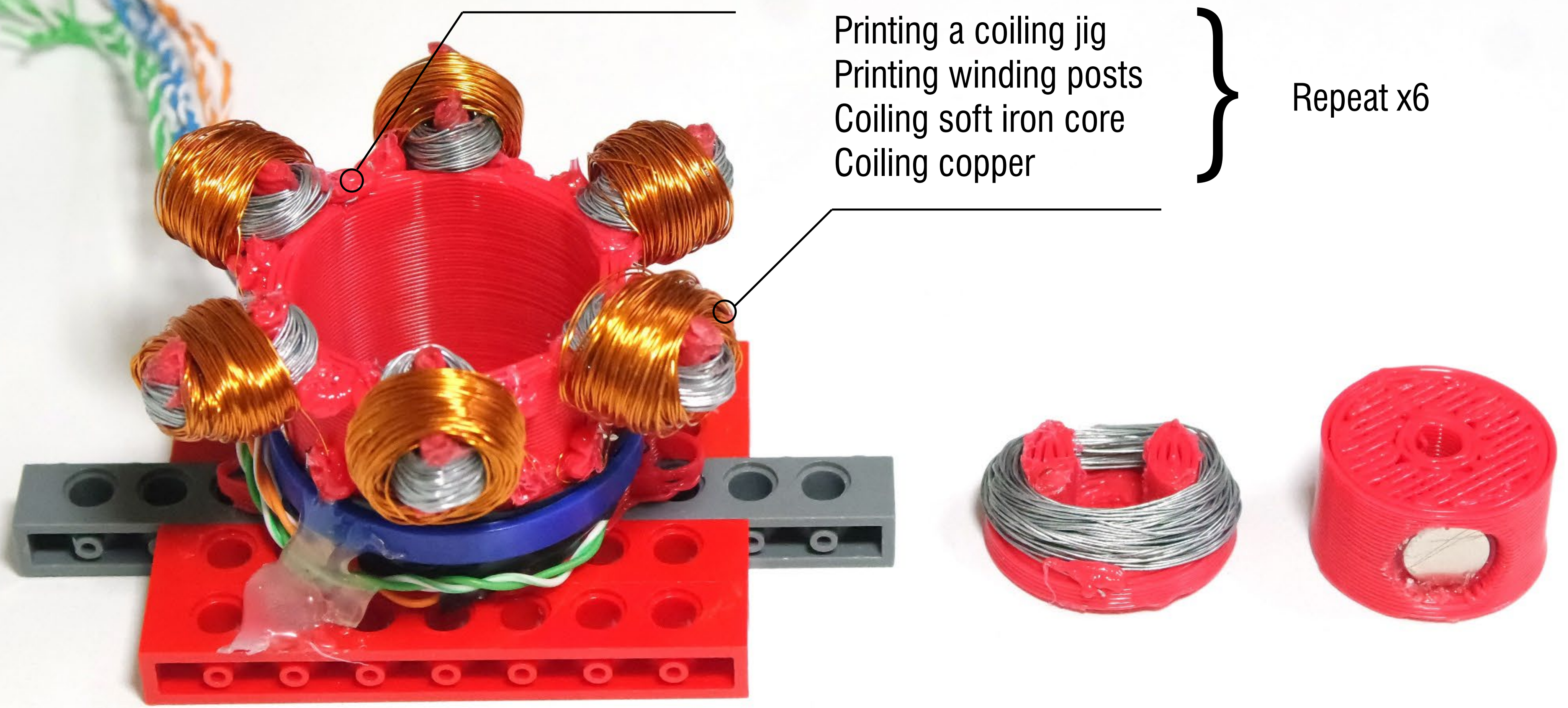
Example 2: **Physical display**

a physical progress bar with Ferrofluid

Generalization: tangibles and shape changing display



Example 4: **Printing motors**



Printing circular base

Printing a coiling jig
Printing winding posts
Coiling soft iron core
Coiling copper

} Repeat x6

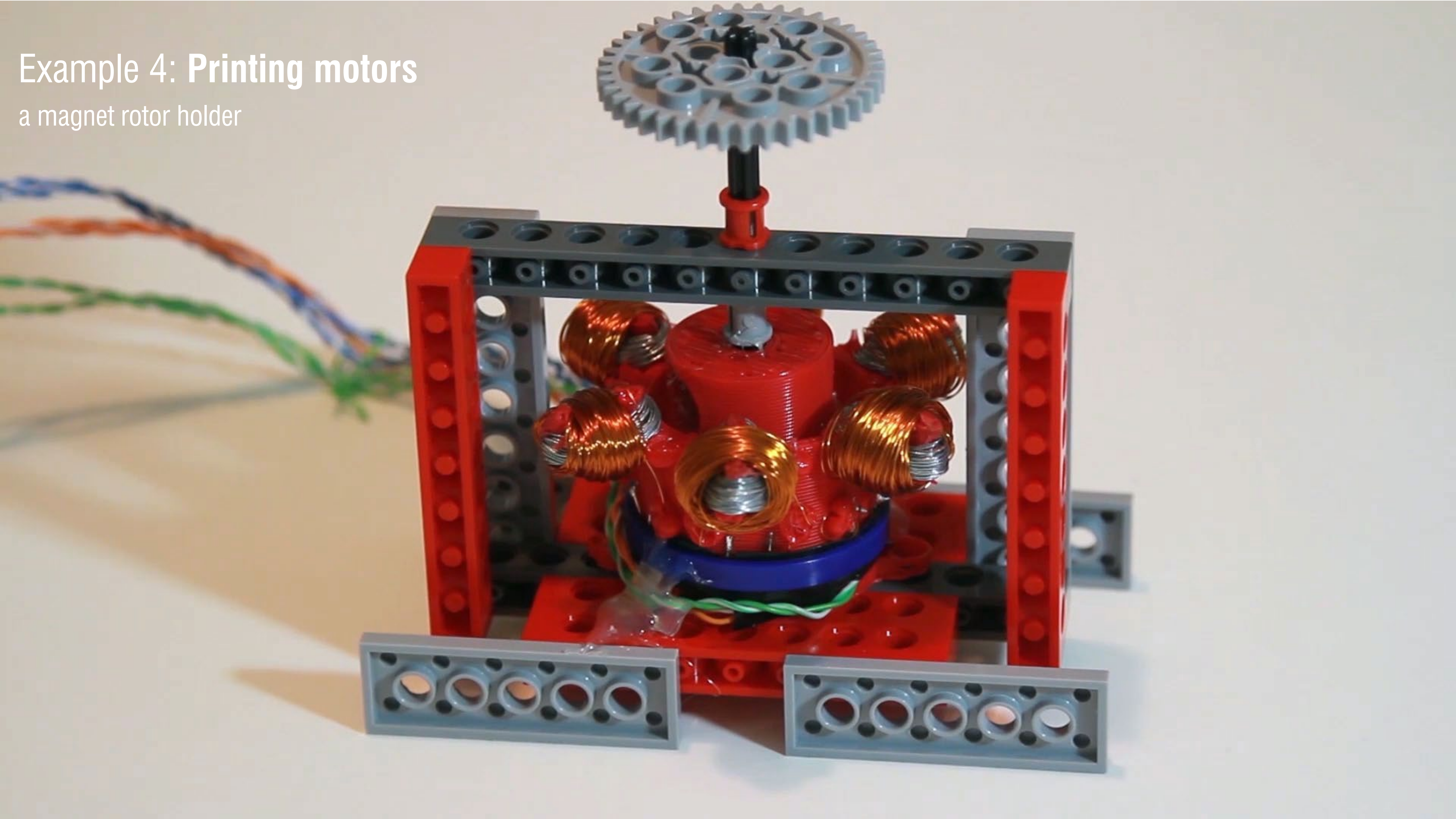
Motor stator

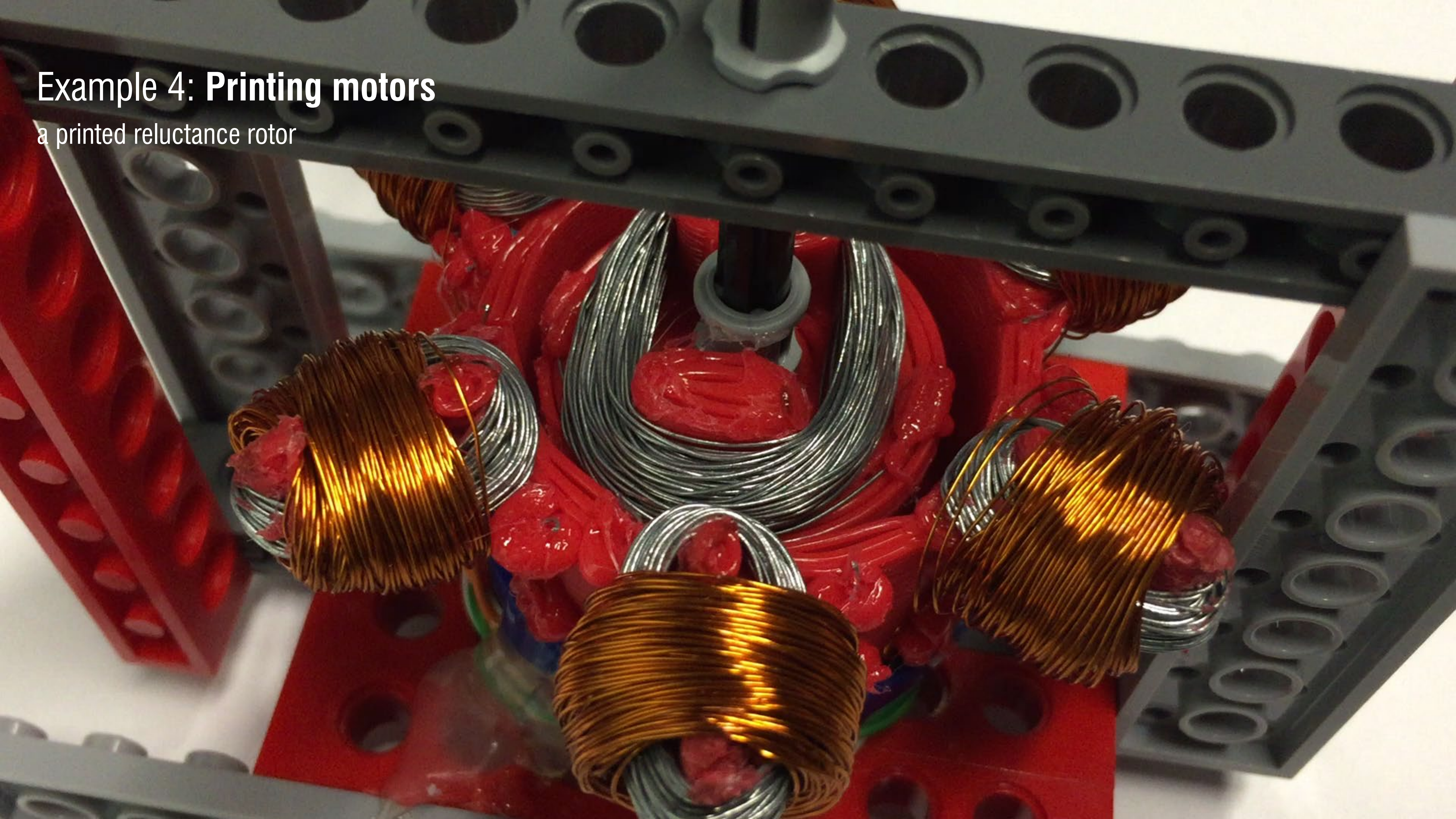
Reluctance rotor

Magnet rotor

Example 4: **Printing motors**

a magnet rotor holder





Example 4: **Printing motors**

a printed reluctance rotor

3D Printing Magnetophoretic Displays

A FDM printer +
injector &
iron powder liquid mixture?

3D Printing Magnetophoretic Displays

Zeyu Yan
zeyuy@umd.edu
University of Maryland
College Park, Maryland, USA

Hsuanling Lee
lee3050@purdue.edu
Purdue University
West Lafayette, Indiana, USA

Liang He
lianghe@purdue.edu
Purdue University
West Lafayette, Indiana, USA

Huaishu Peng
huaishu@umd.edu
University of Maryland
College Park, Maryland, USA

Figure 1: Printing pipeline overview. a) A modified FDM 3D printer with an additional syringe injector. b) A 3D editor that converts a model into a magnetophoretic display. c) Printing in-progress. d) The appearance of the printed model can be post edited.

ABSTRACT

We present a pipeline for printing interactive and always-on magnetophoretic displays using affordable Fused Deposition Modeling (FDM) 3D printers. Using our pipeline, an end-user can convert the surface of a 3D shape into a matrix of voxels. The generated model can be sent to an FDM 3D printer equipped with an additional syringe-based injector. During the printing process, an oil and iron powder-based liquid mixture is injected into each voxel cell, allowing the appearance of the once-printed object to be editable with external magnetic sources. To achieve this, we made modifications to the 3D printer hardware and the firmware. We also developed a 3D editor to prepare printable models. We demonstrate our pipeline with a variety of examples, including a printed Stanford bunny with customizable appearances, a small espresso mug that can be used as a post-it note surface, a board game figurine with a computationally updated display, and a collection of flexible wearable accessories with editable visuals.

CCS CONCEPTS

• **Human-centered computing** → **Interaction devices**; **Systems and tools for interaction design**.

KEYWORDS

Magnetophoretic, 3D Printing Display, Low Power Display, Liquid Injection, 3D printing, 3D Printer Modification

ACM Reference Format:
Zeyu Yan, Hsuanling Lee, Liang He, and Huaishu Peng. 2023. 3D Printing Magnetophoretic Displays. In *The 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23), October 29–November 01, 2023, San Francisco, CA, USA.* ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3586183.3606804

1 INTRODUCTION

Research advancements in 3D printing have enabled end users to design and fabricate a variety of 3D dynamic artifacts. For example, research has shown that 3D printed bespoke objects can deform [14, 15], produce sound [17], and exhibit a range of mechanical behaviors [28, 41]. However, printing 3D artifacts with appearances that are non-static or interactive remains challenging.

Recent studies, such as Printed Optics [59], PAPILLON [5], and computational light routing [42], propose to alter the appearance of a 3D printed artifact by printing embedded transparent pipes that redirect images and lights from a 2D digital display. Since the optic pipes must be printed with high resolution in the direction of pipe

---

UIST '23, October 29–November 01, 2023, San Francisco, CA, USA

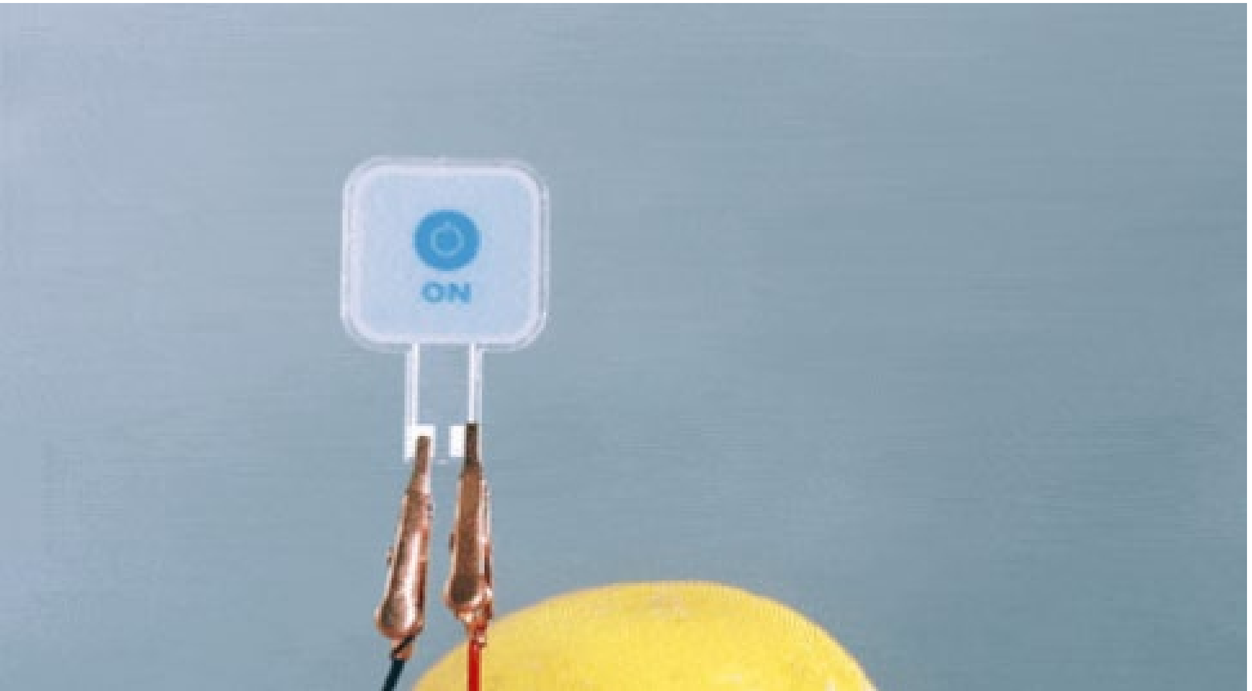
ACM ISBN 979-8-4007-0132-0/23/10…$15.00
https://doi.org/10.1145/3586183.3606804

UIST 2023

Peng et.al.


CASIO
0
DUAL CALC
GT
%
EXCH
TAX-
TAX+

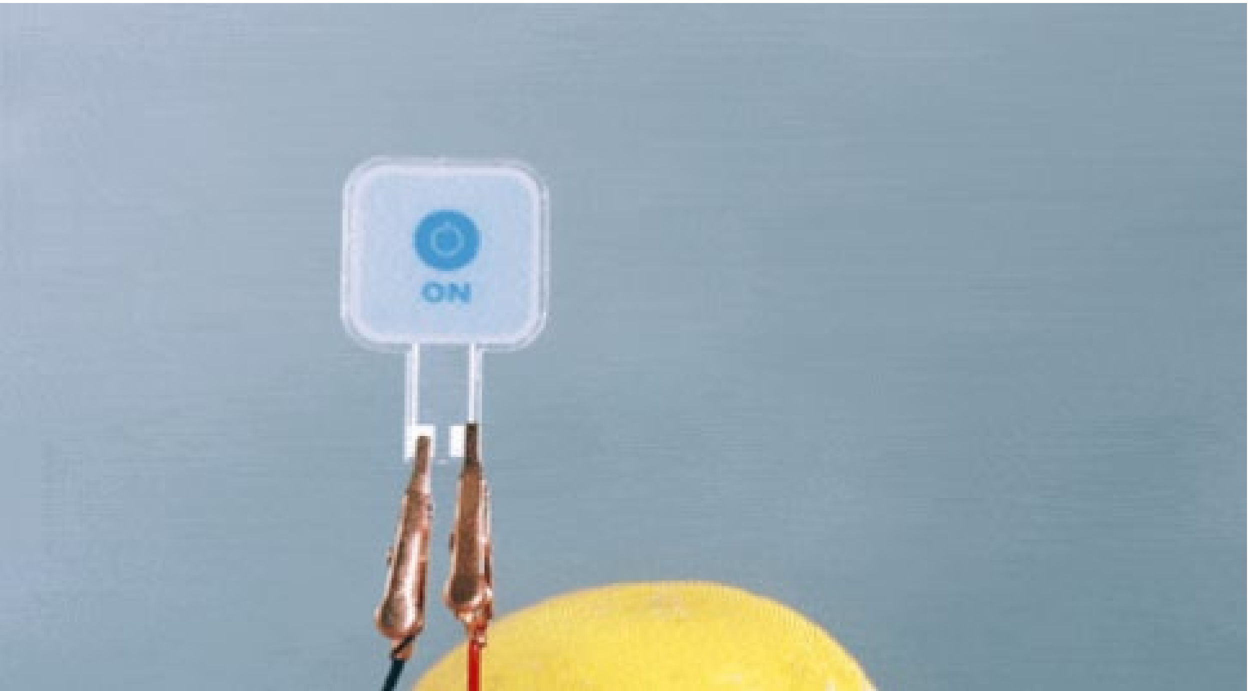

23°~29°
May 7th
12:34


ON


hello

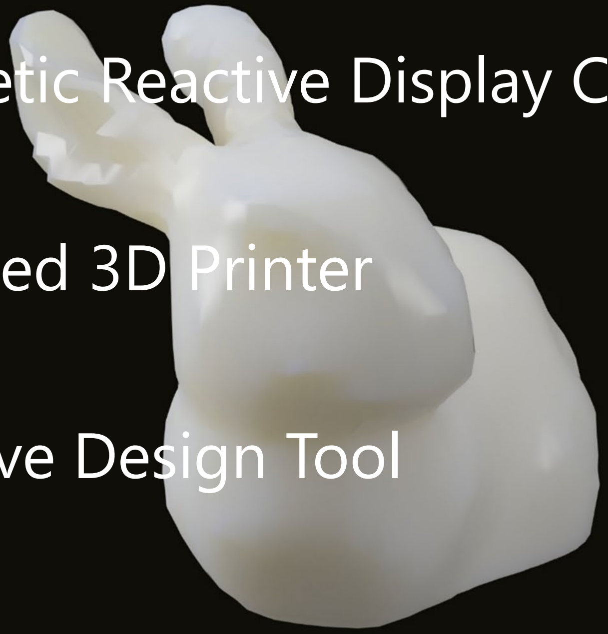

CASIO
78429514
0
DUAL CALC
GT
%
EXCH
TAX-
TAX+


23°~29°
May 7th
12:34


ON


hello

3D Printing Magnetophoretic Displays

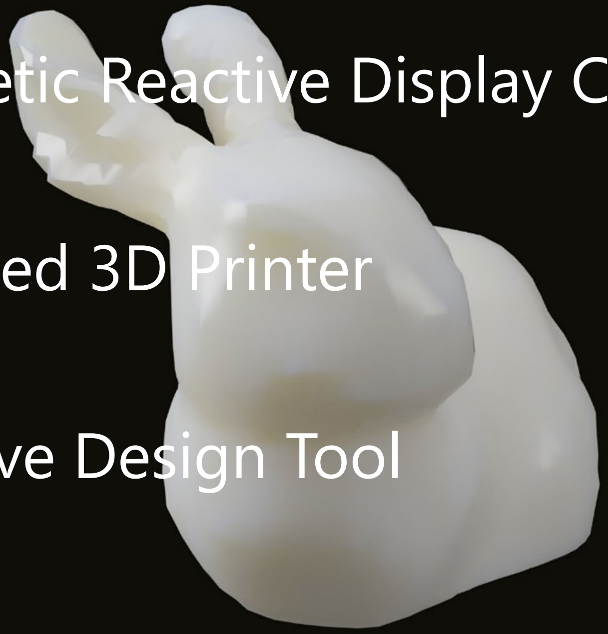


Magnetic Reactive Display Cells

Modified 3D Printer

Assistive Design Tool

3D Printing Magnetophoretic Displays

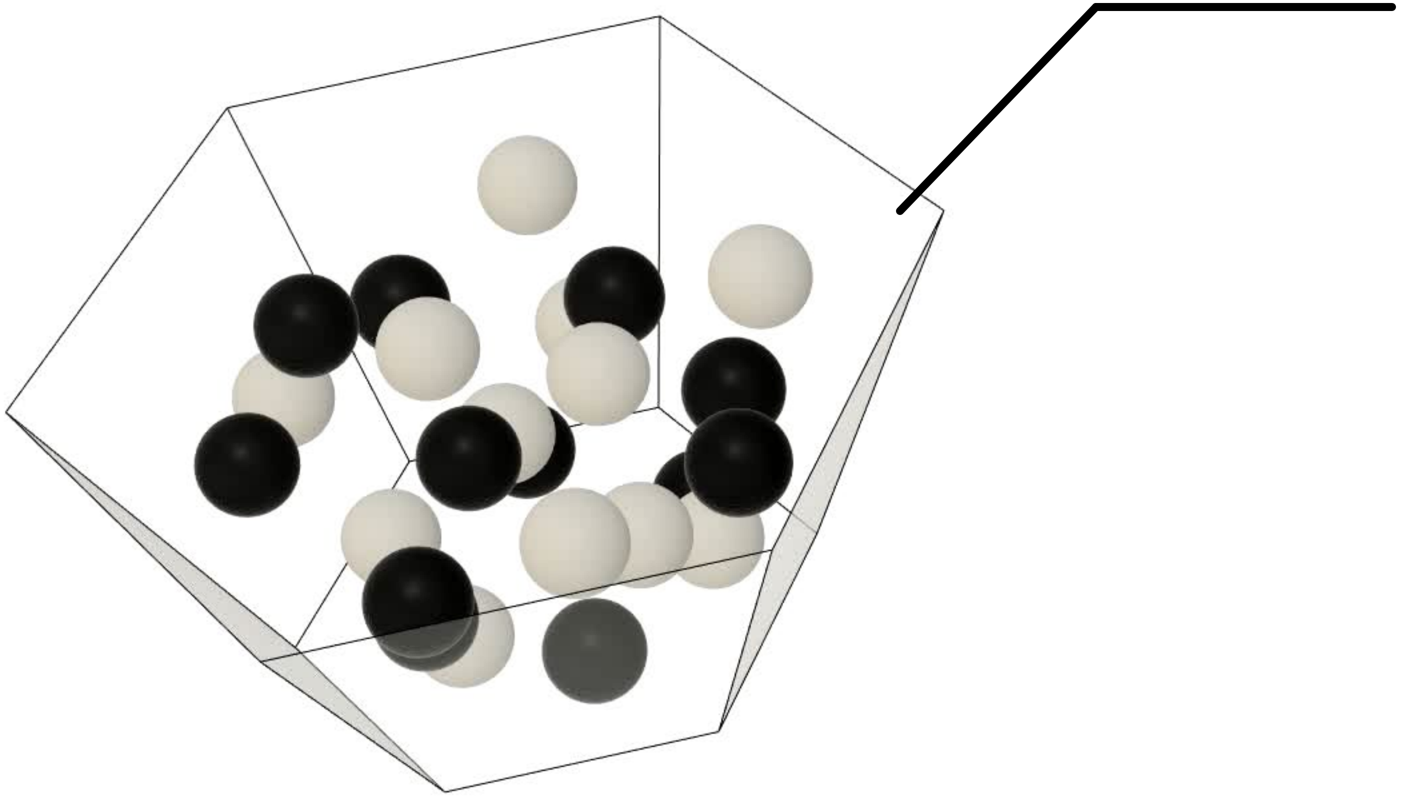


Magnetic Reactive Display Cells

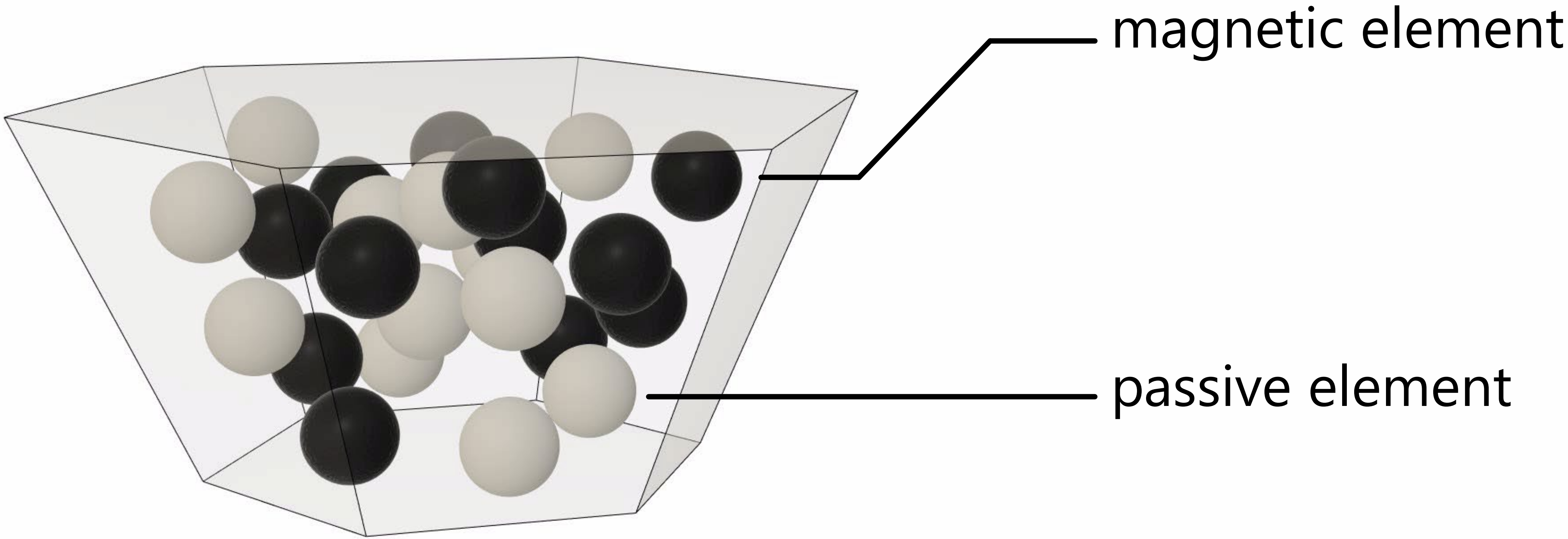
Modified 3D Printer

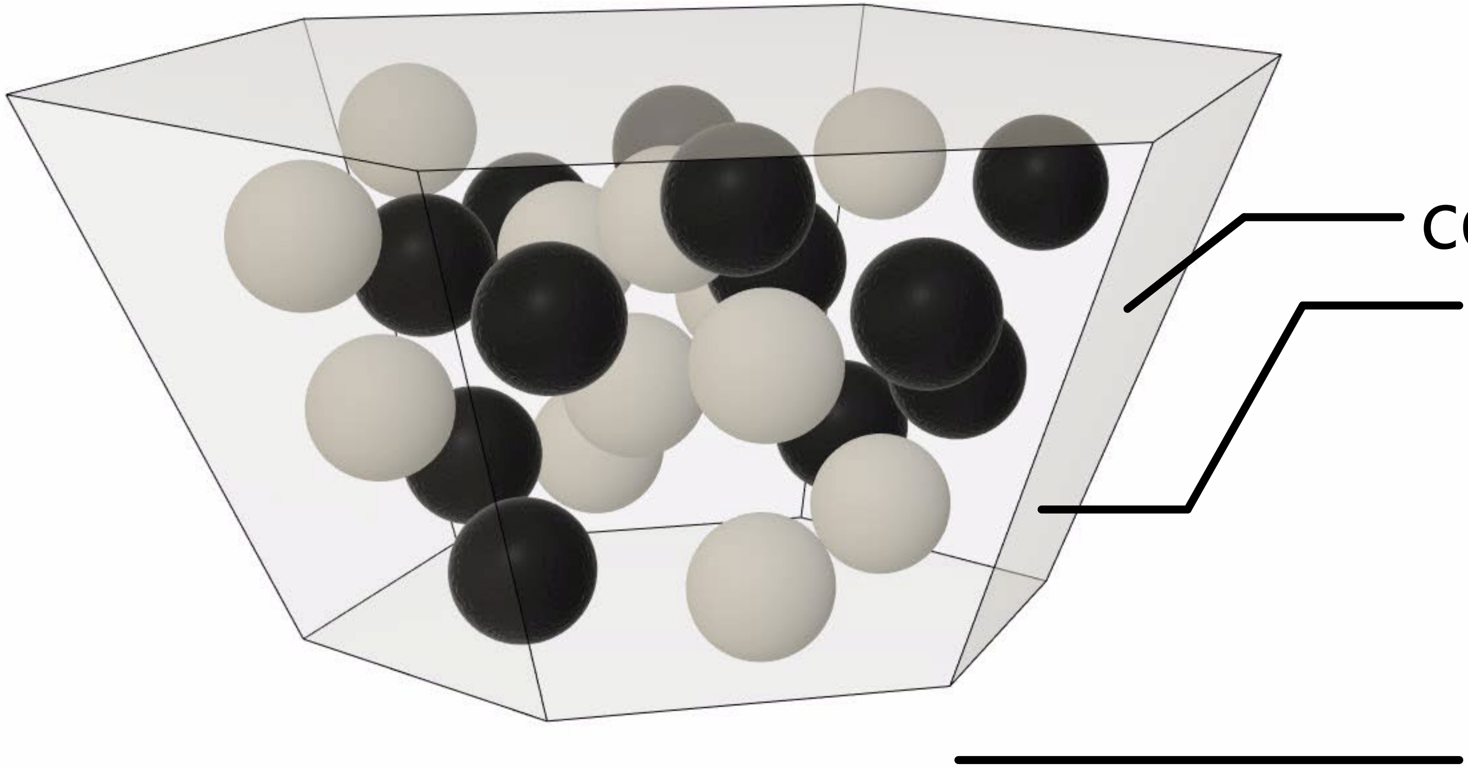
Assistive Design Tool

Magnetophoretic Displays Principle



display cell

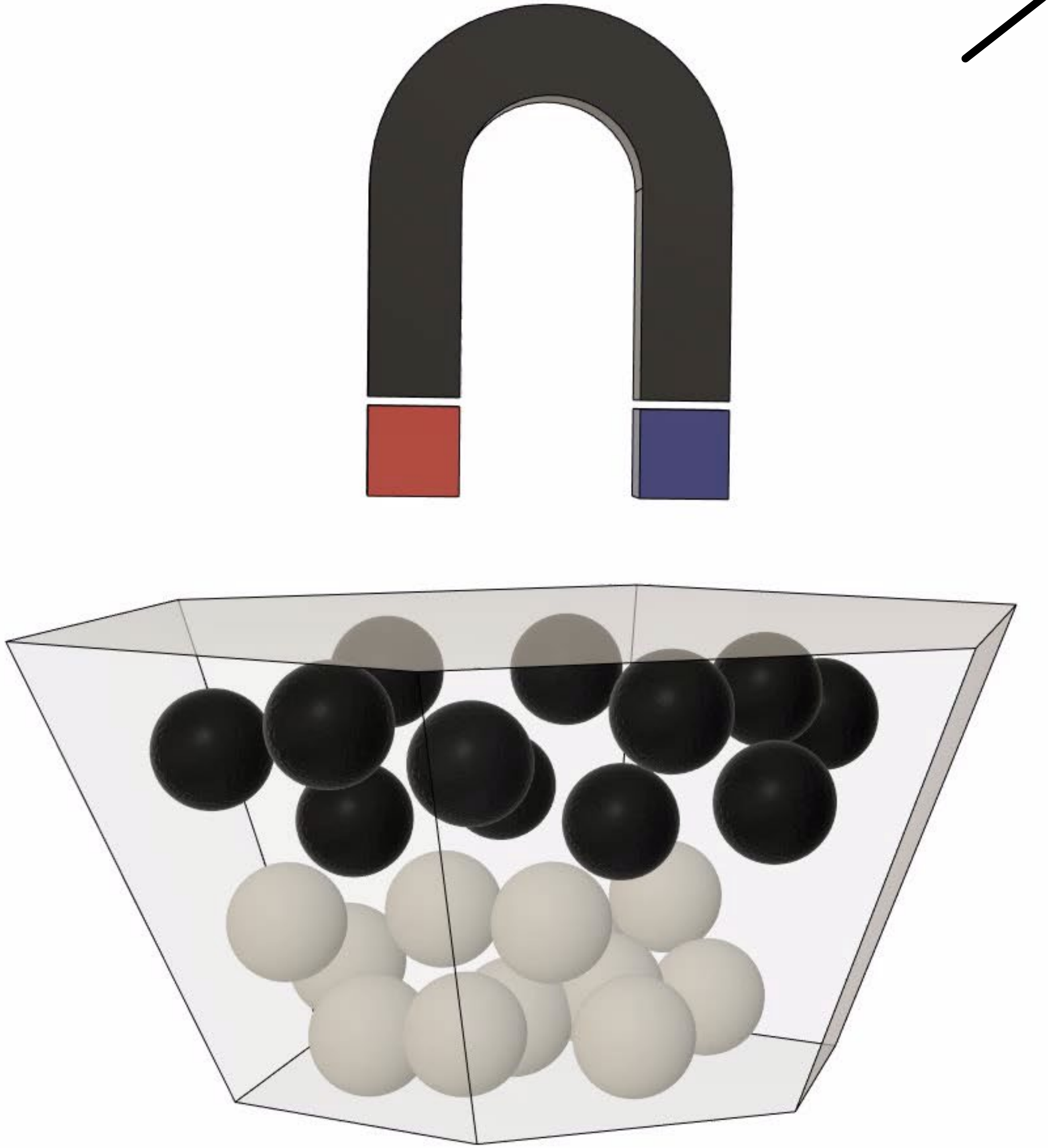

magnetic element
passive element



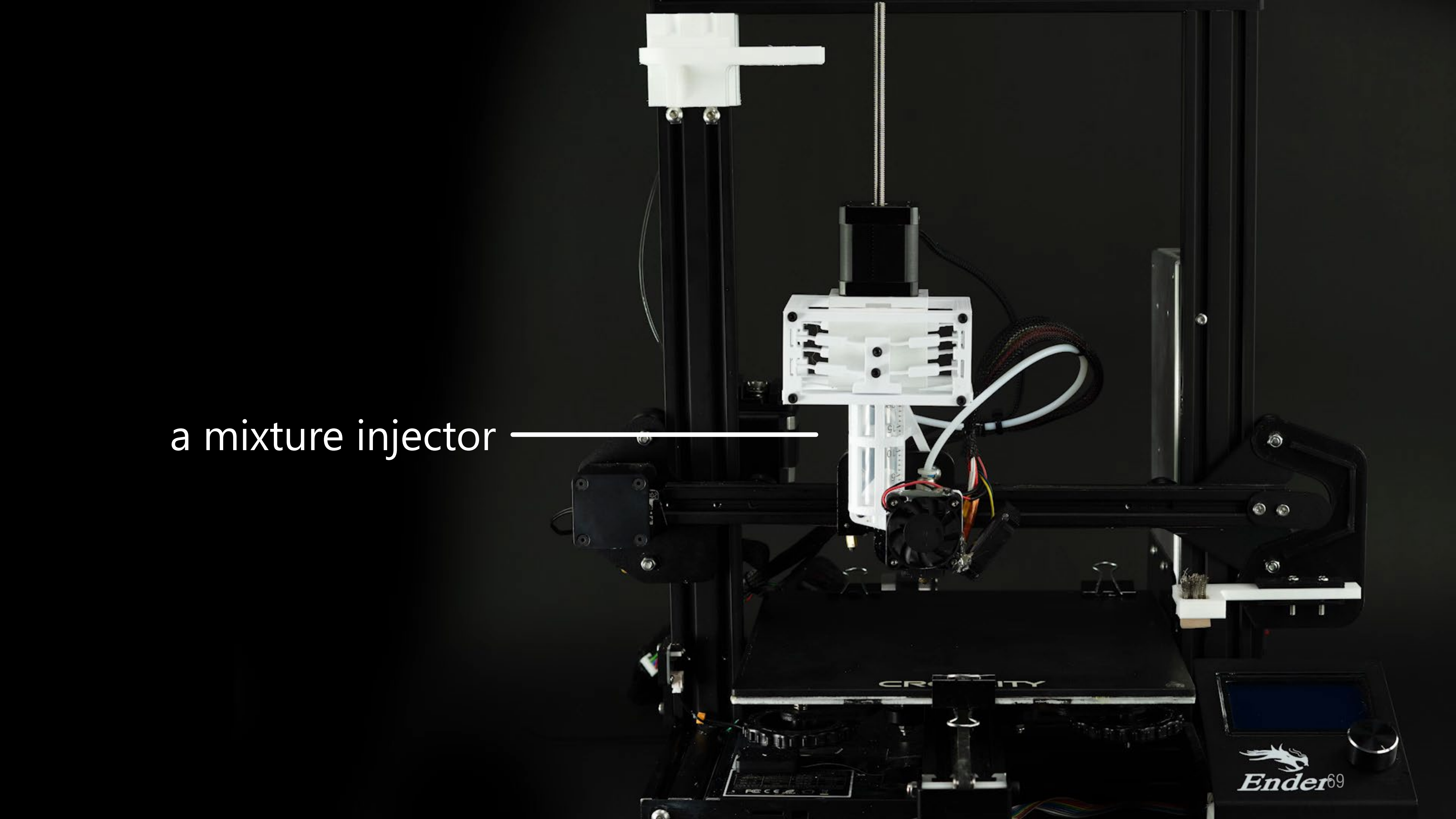
cell displays dark color

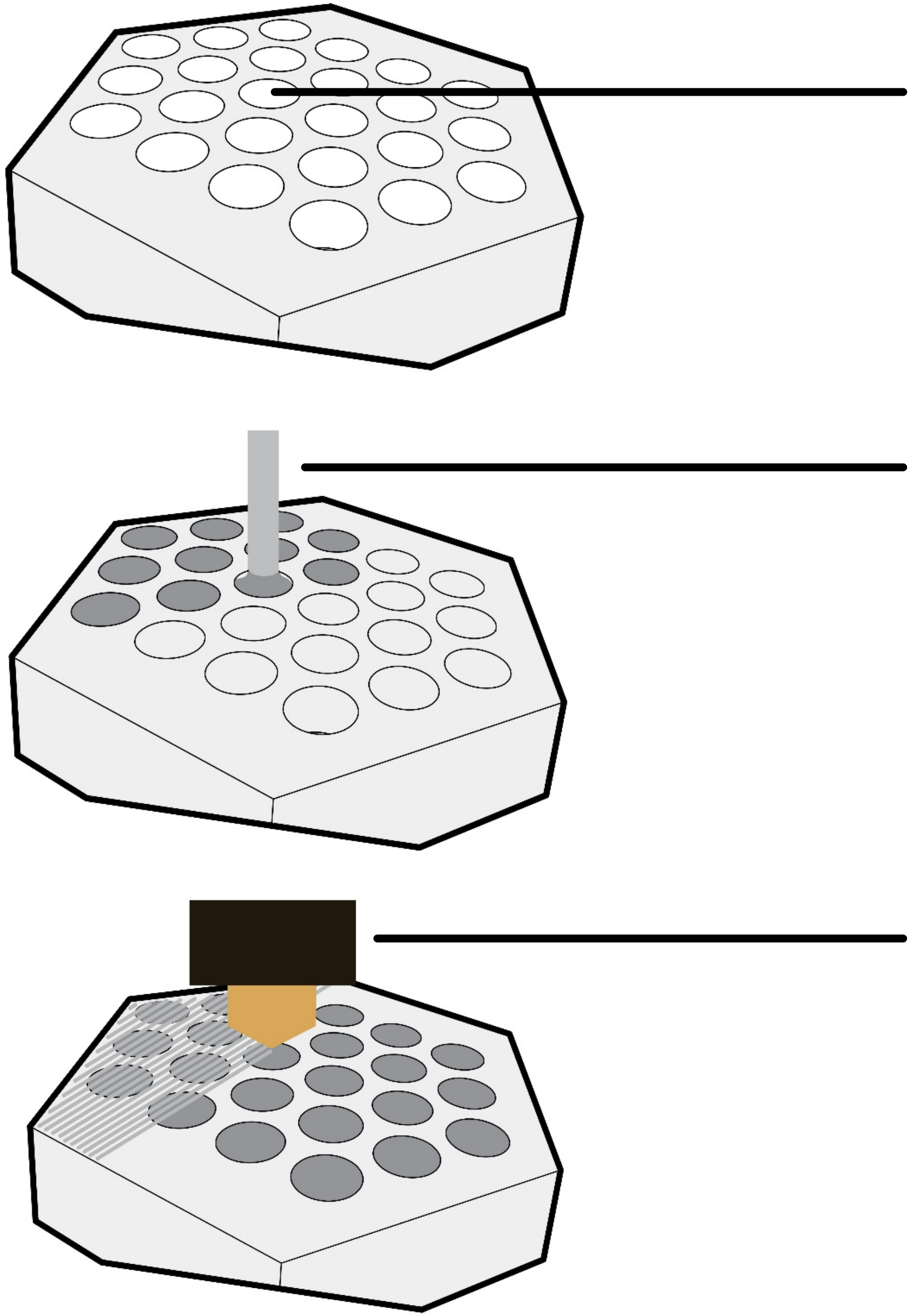
magnetic element
attracted to the magnet

passive element pushed
to the opposite side



cell display bright color

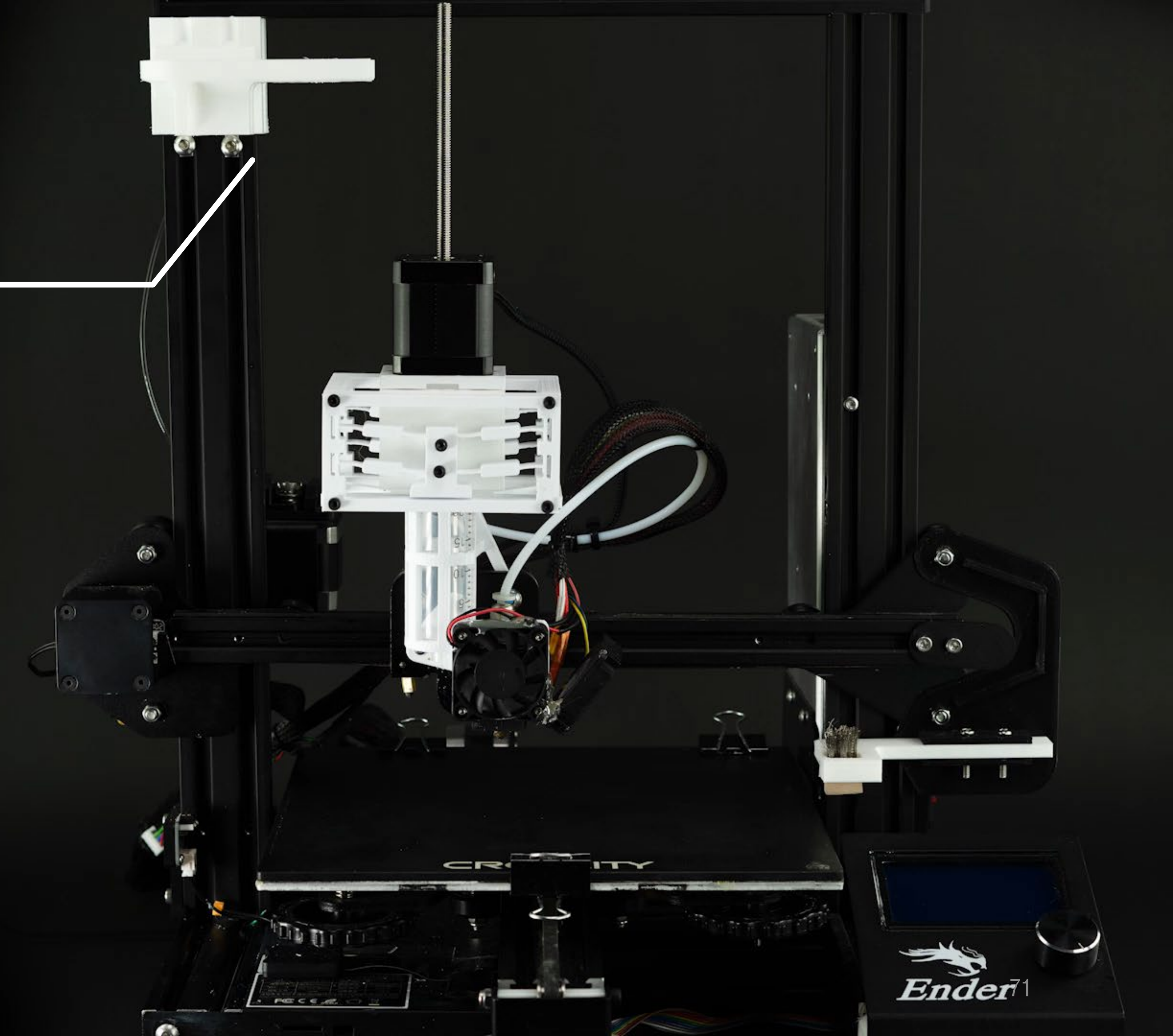

a mixture injector



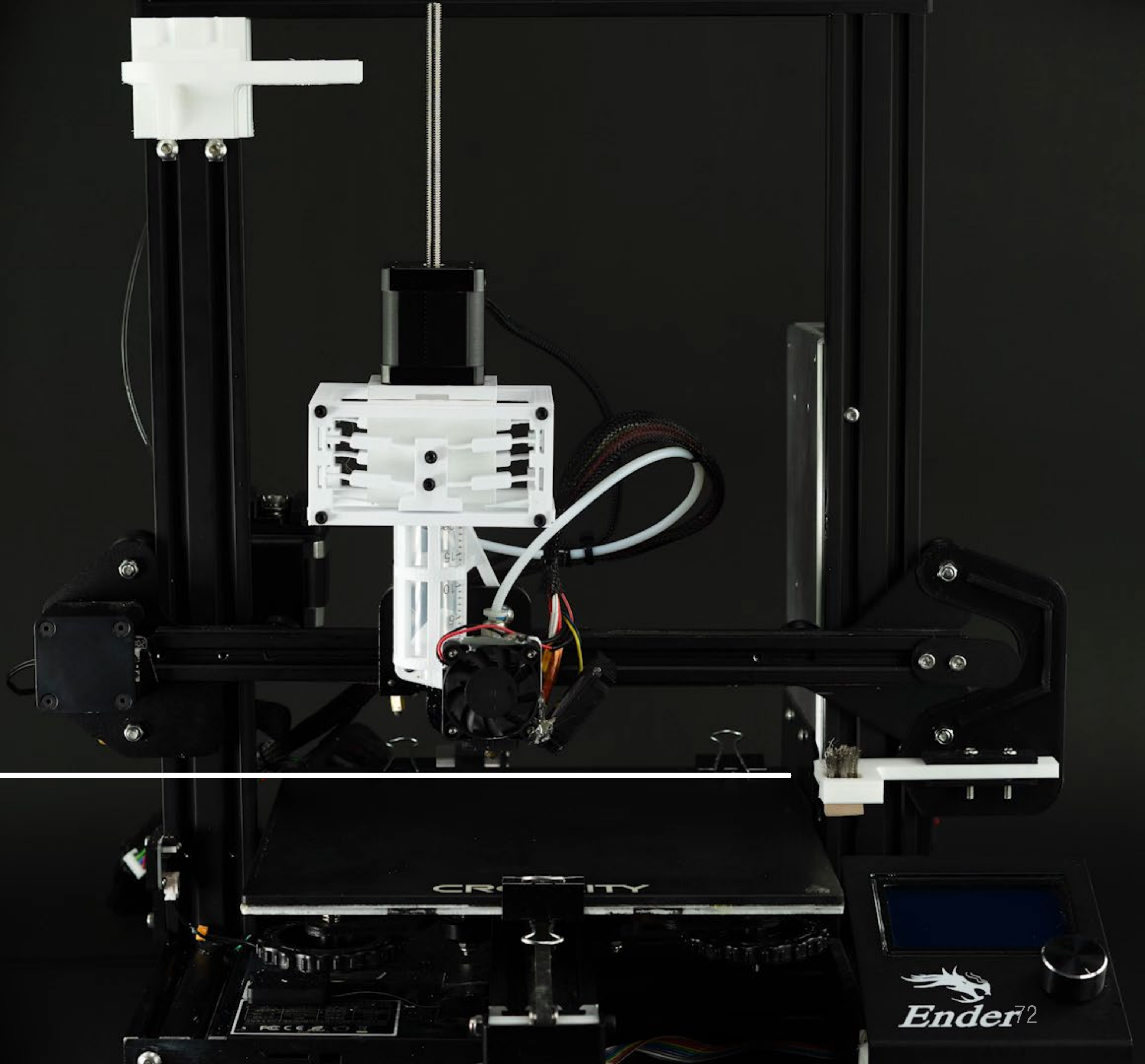
display cell ready for injection (FDM paused)

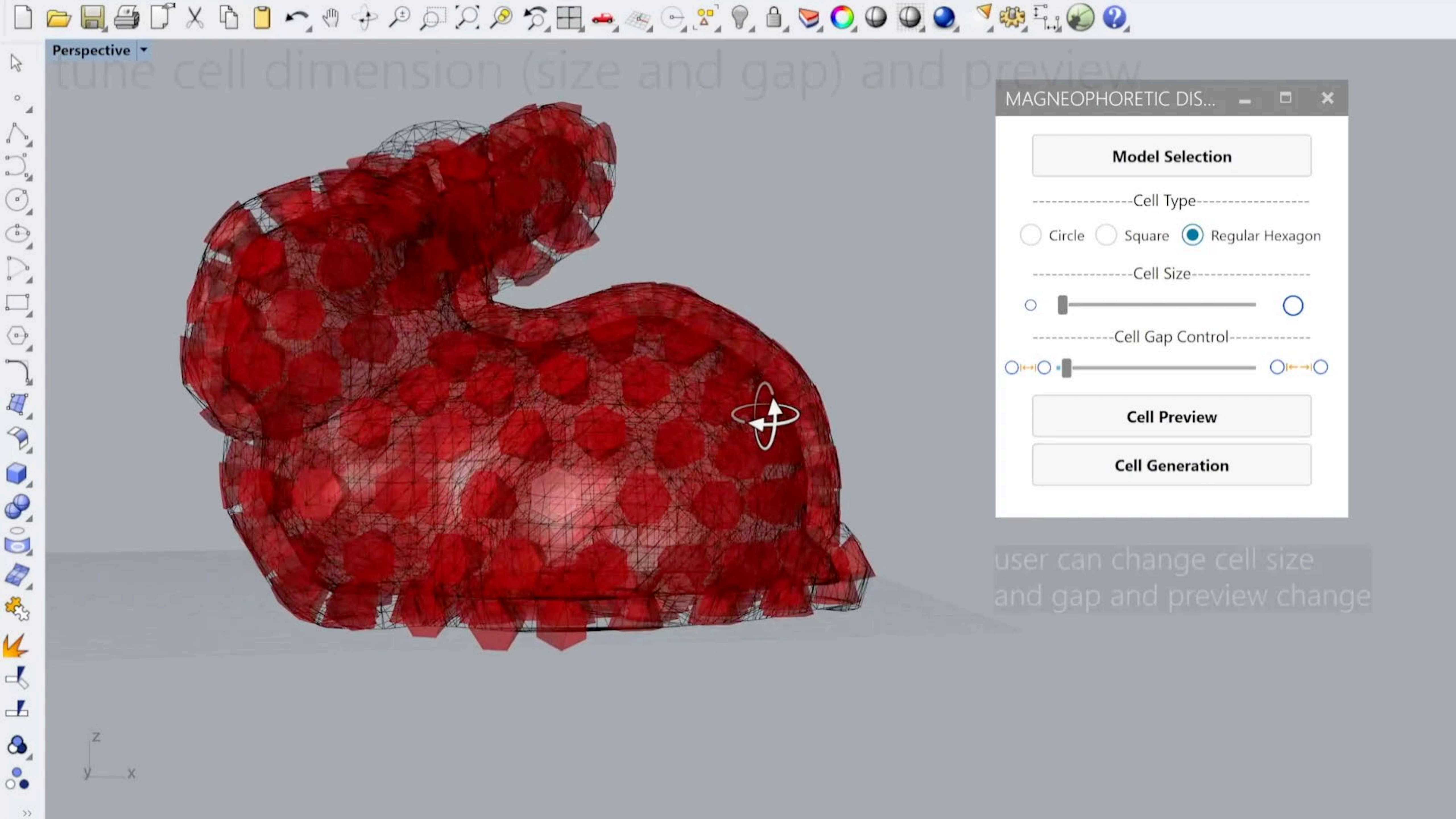
injector deposits mixture

FDM nozzle resumes and closes the cells



shifting mechanism


FDM nozzle brush
CREALITY
Ender-2



tune cell dimension (size and gap) and preview

-Cell Type-

○ Circle ○ Square ● Regular Hexagon

-Cell Size-

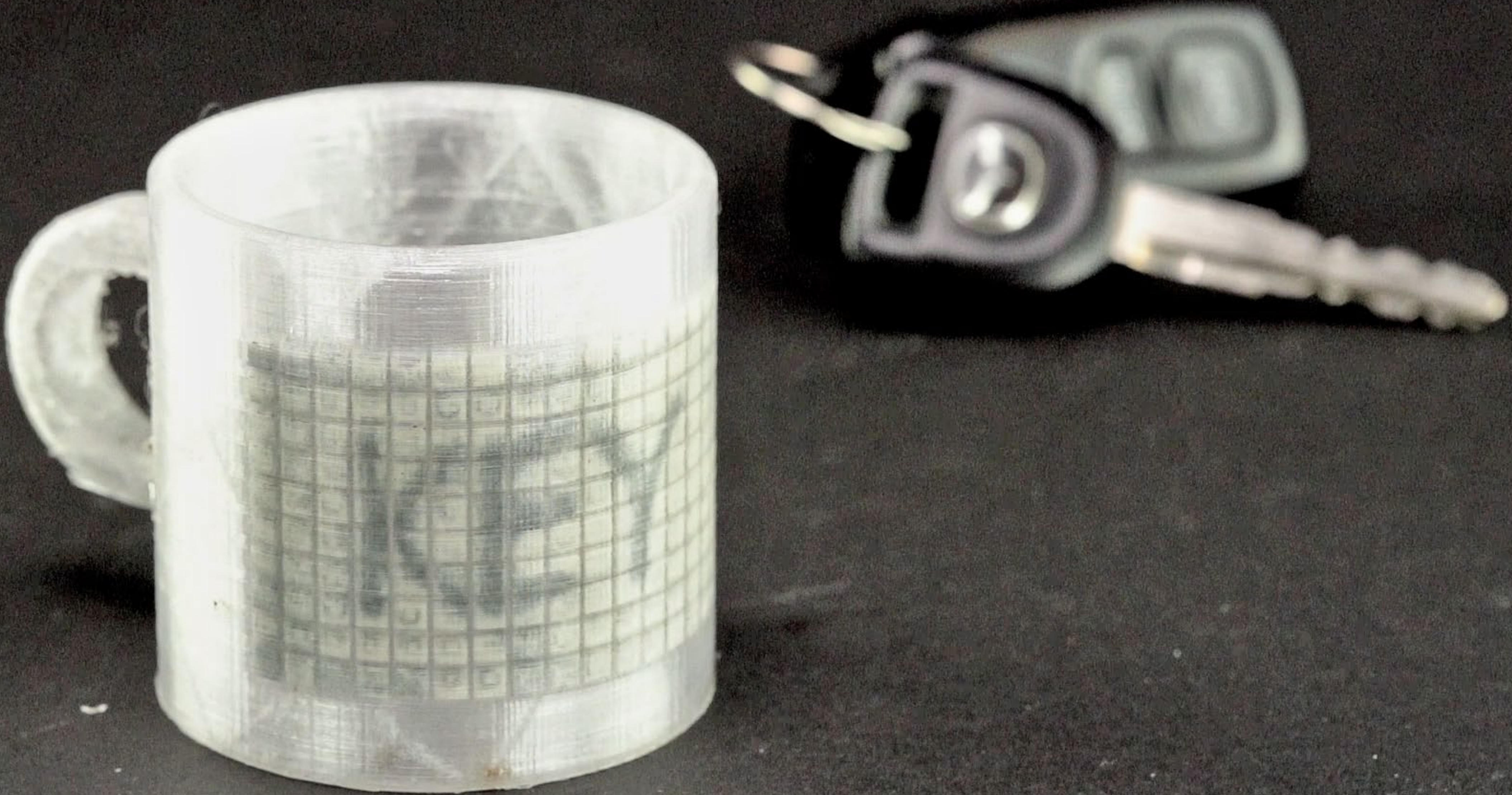
-Cell Gap Control-

user can change cell size and gap and preview change

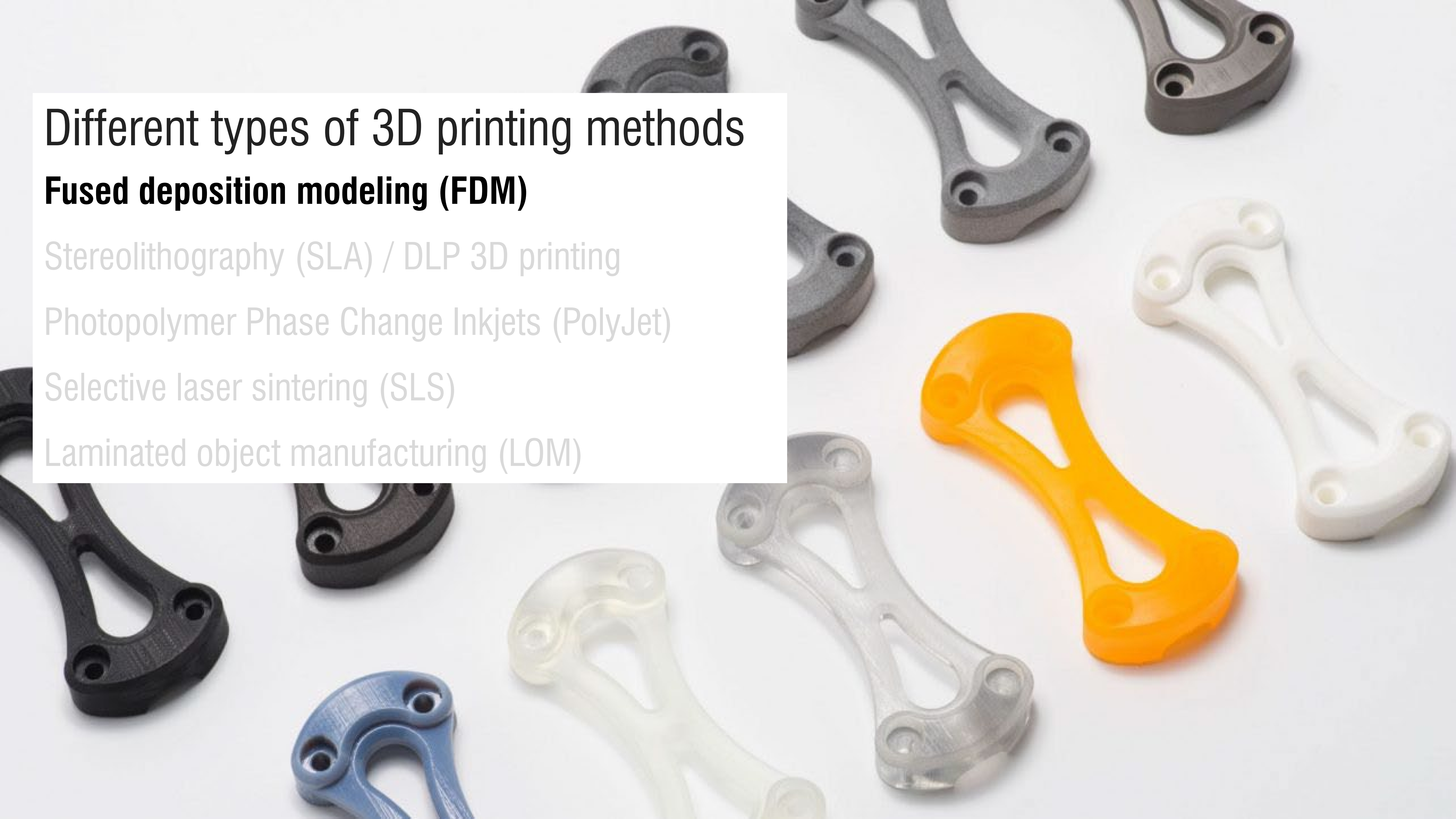
board game figurine

personalized handbag

espresso mug as post-it



KEY
HELLO
WORLD



Different types of 3D printing methods

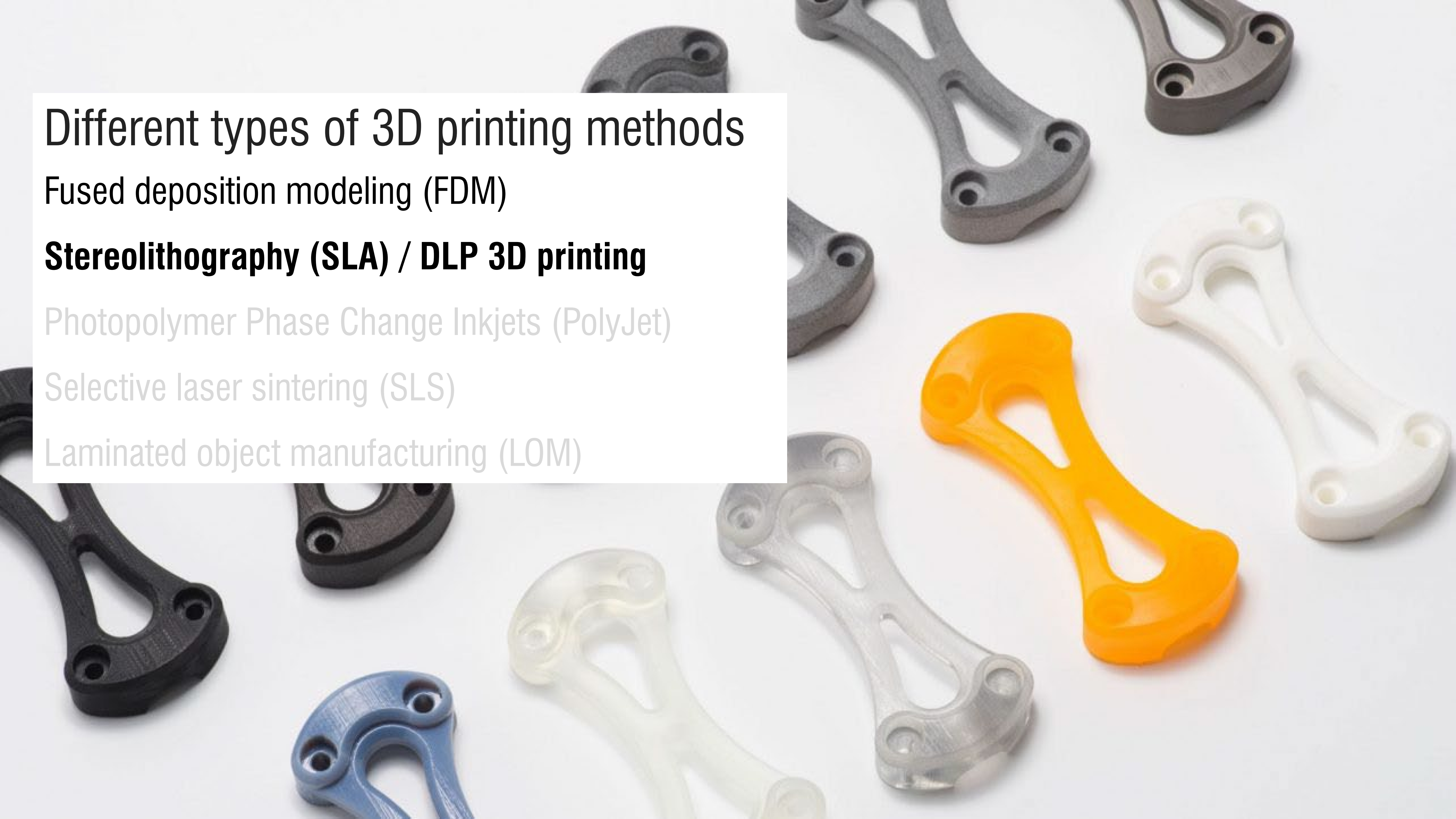
Fused deposition modeling (FDM)

Stereolithography (SLA) / DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)



Different types of 3D printing methods

Fused deposition modeling (FDM)

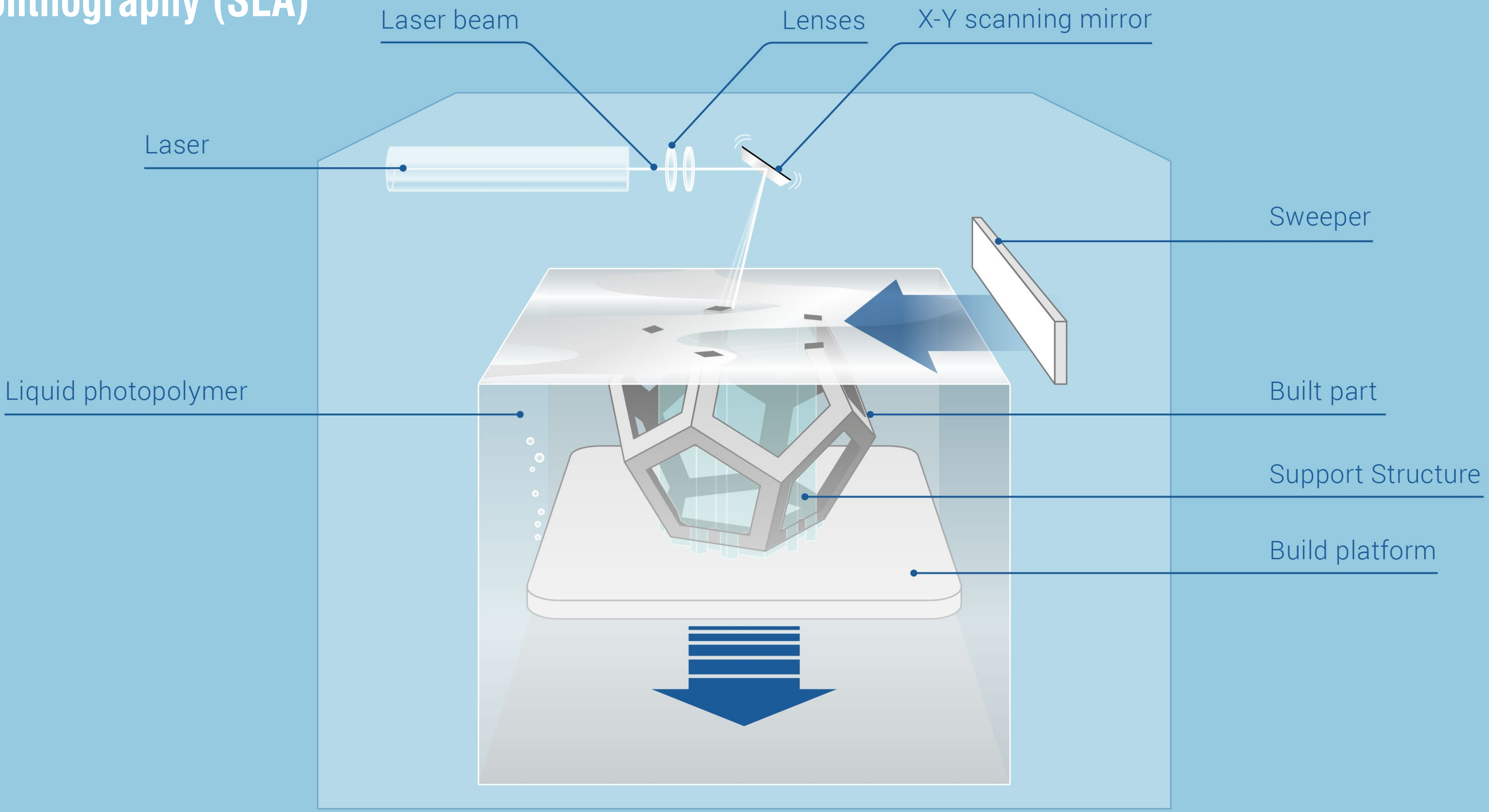
Stereolithography (SLA) / DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

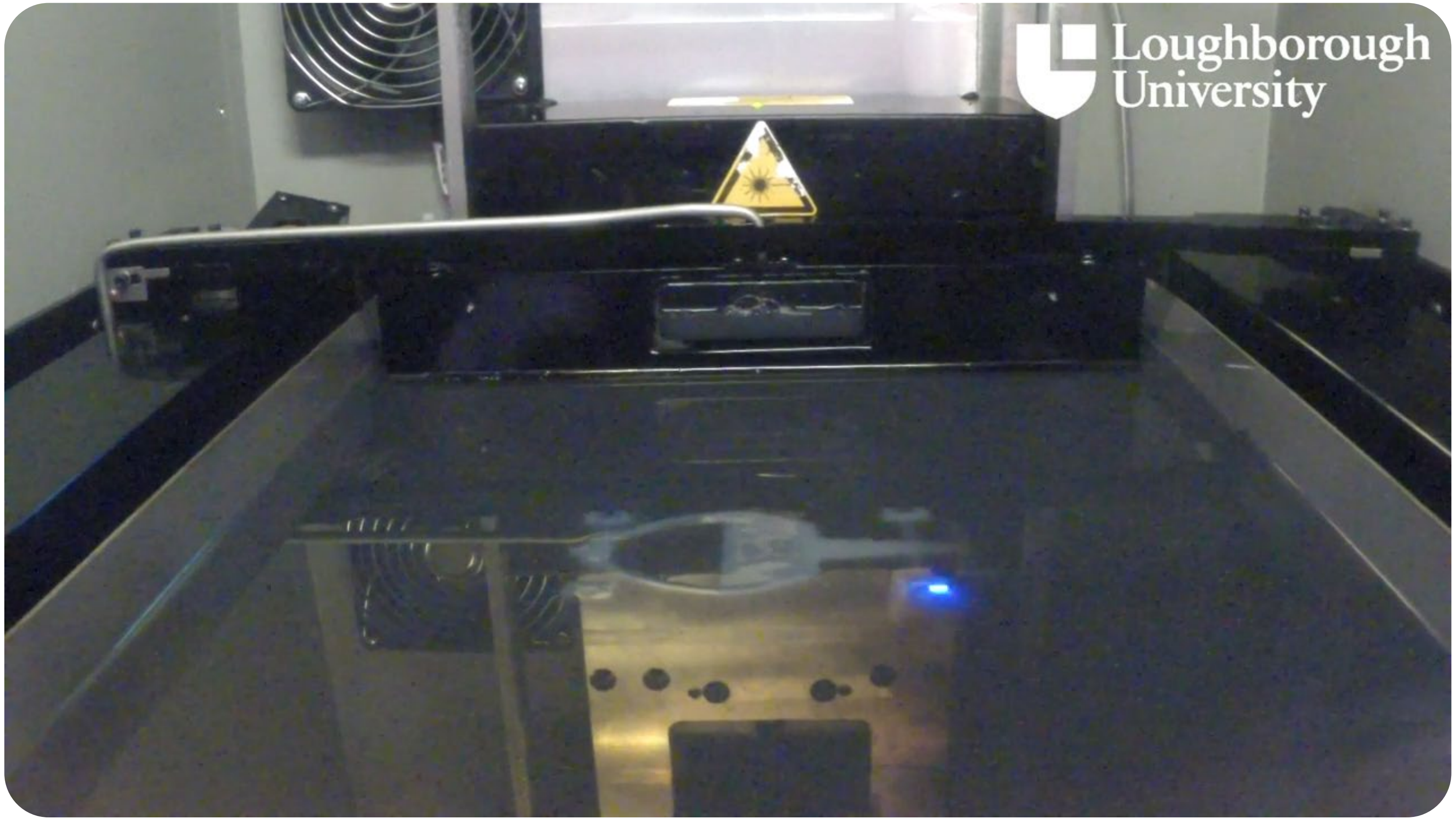
Laminated object manufacturing (LOM)

Stereolithography (SLA)



© **additively**.com

Stereolithography (SLA)



liquid photo-reactive resin in a tank

laser selectively hardens top layer of resin

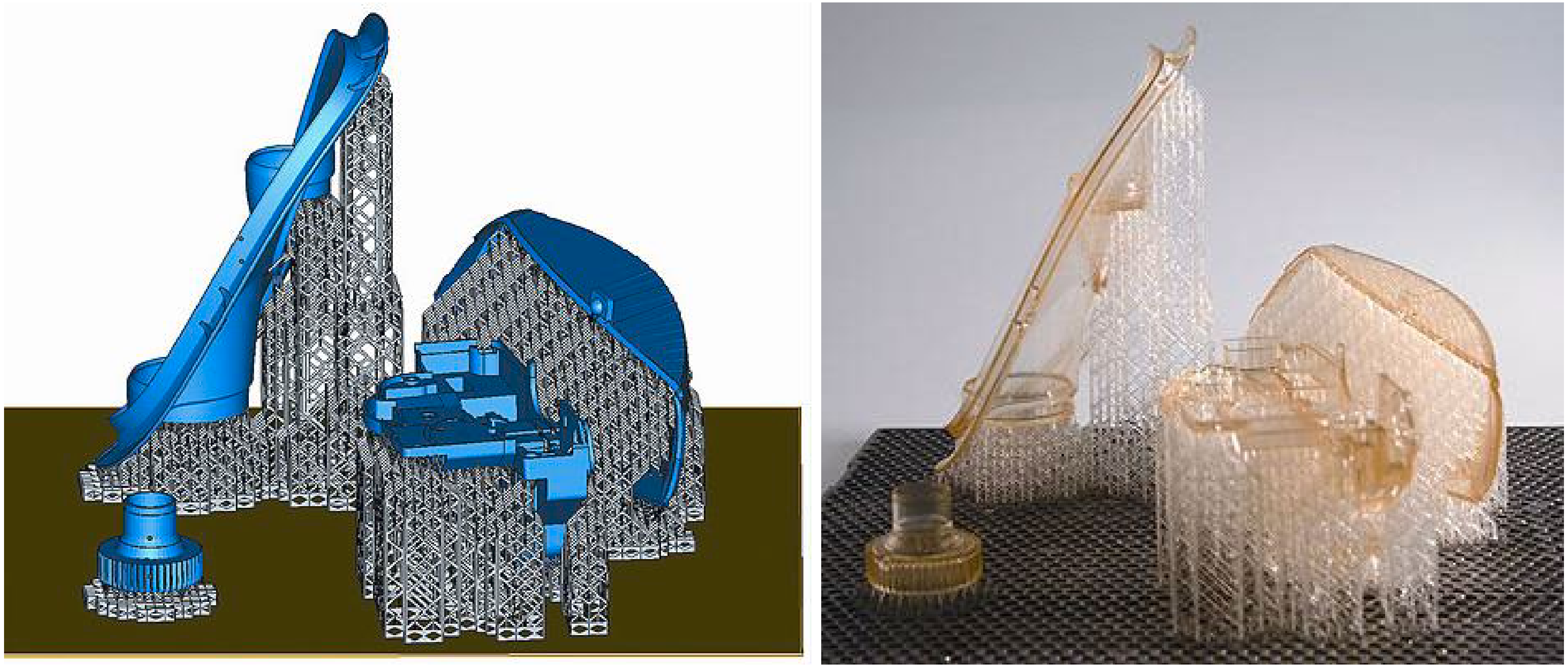
the platform descends by one layer

sweeper equally distributes resin for new layer

Stereolithography (SLA)

Support structure

–thin support lattice can be broken off

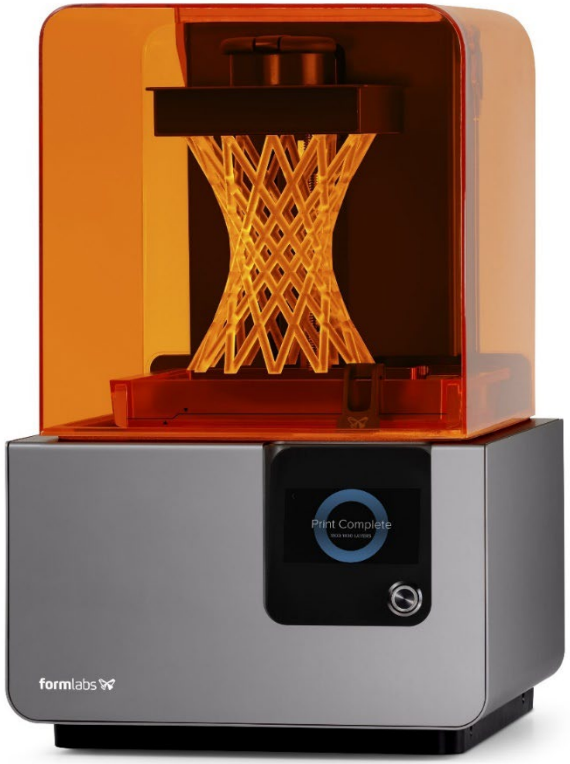


Stereolithography (SLA)

Developed by Charles Hull
–Coined term stereolithography
–Founded 3D Systems in 1986

Stereolithography (SLA)

Consumer-grade SLA Form 2

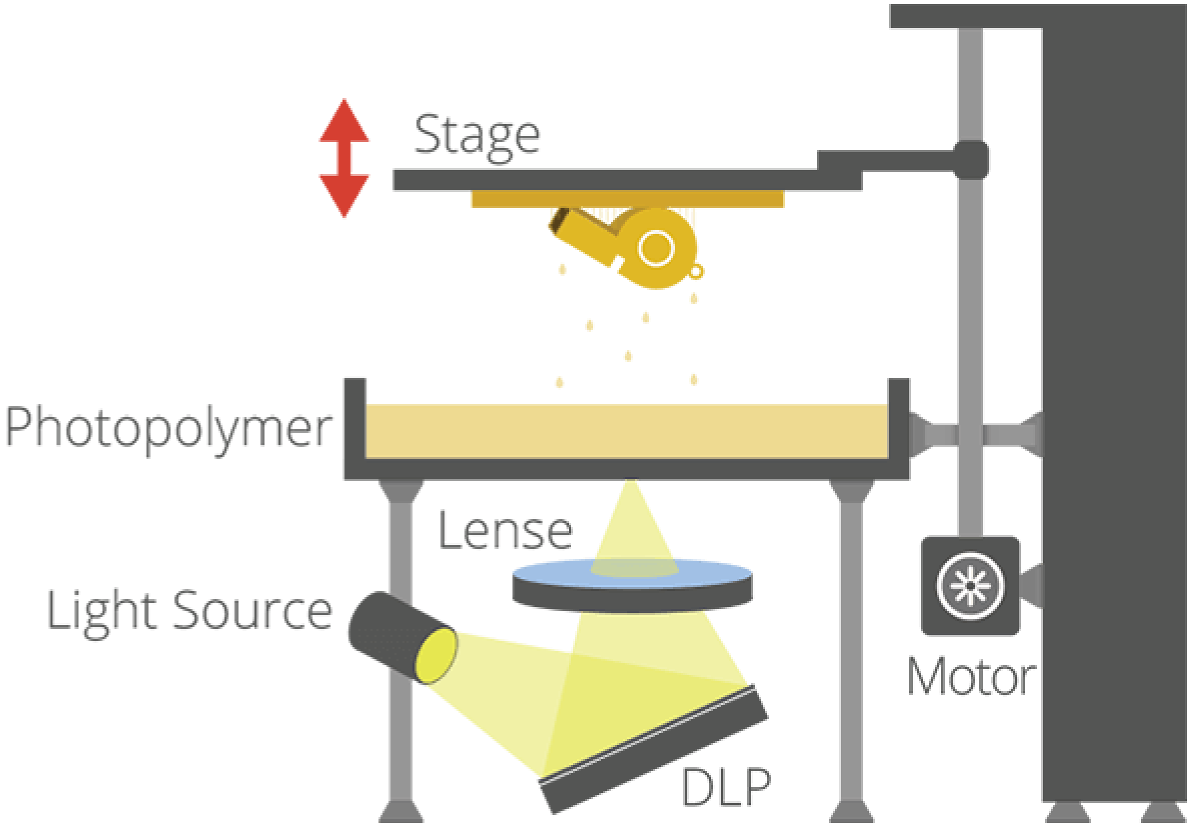


what is a **benefit** of using a laser over an extruder?

FDM vs SLA

	FDM	SLA
3D printing costs	$25 per kg	$80 to $150 per liter of resin
Materials and colors	vary	limited/mono-color
Precision and Smoothness	warping/misalignment /Z-thickness	super fine details

Digital Light Projector (DLP) 3D Printing



same as SLA, just uses a **projector** not a laser

How many degree of freedom?

Digital Light Projector (DLP) 3D Printing

Similar to SLA
- laser+mirror is replaced by a projector

Simple design
- only one degree of freedom

Faster than SLA
- exposes one layer at a time

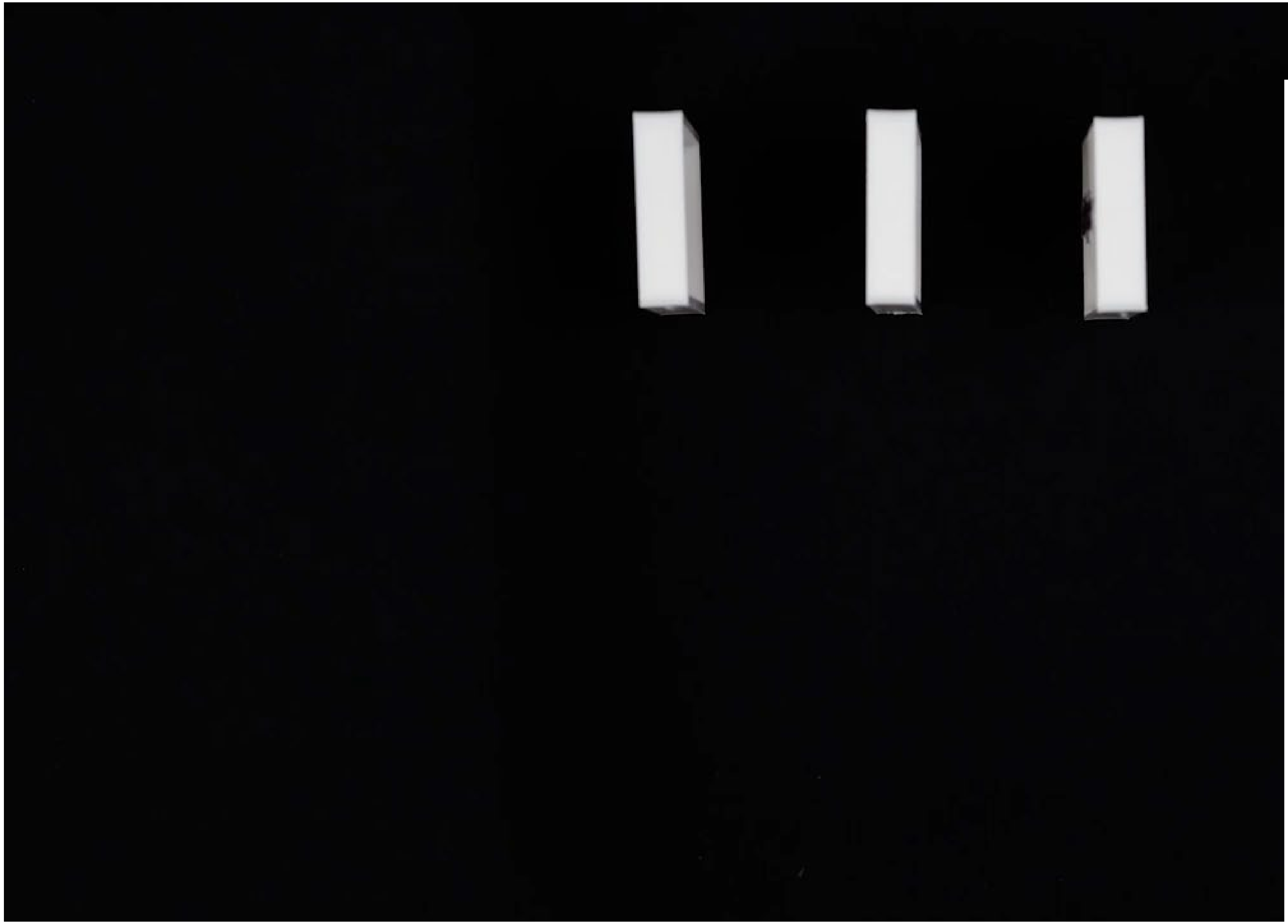
Materials
- same as SLA

how can you make this a **mobile 3D printer?**

Use cellphone screen as a “projector”
Play a slow-motion movie

how can you make this a **mobile 3D printer?**

Use cellphone screen as a “projector”
Play a slow-motion movie



FabHydro: Printing Interactive Hydraulic Devices with an Affordable SLA 3D Printer

Zeyu Yan
Department of Computer Science, University of Maryland, College Park
College Park, MD, USA
zeyuy@umd.edu

Huaishu Peng
Department of Computer Science, University of Maryland, College Park
College Park, MD, USA
huaishu@umd.edu

Figure 1: *FabHydro* overview: a) an off-the-shelf SLA printer with a modified tank and printing plate; b) a complete hydraulic device with a bellows generator and a bending actuator connected with a short piece of tubing; c) a bending actuator is activated by an automatic generator; d) a printed lamp lights up with the change of its posture; e) a phone stand acts as an ambient display when the phone rings.

ABSTRACT

We introduce *FabHydro*, a set of rapid and low-cost methods to prototype interactive hydraulic devices based on an off-the-shelf 3D printer and flexible photosensitive resin. We first present printer settings and custom support structures to warrant the successful print of flexible and deformable objects. We then demonstrate two printing methods to seal the transmission fluid inside these deformable structures: the *Submerged Printing* process that seals the liquid resin without manual assembly, and the *Printing with Plugs* method that allows the use of different transmission fluids without modification to the printer. Following the printing methods, we report a design space with a range of 3D printable primitives, including the hydraulic generator, transmitter, and actuator. To demonstrate the feasibility of our approaches and the breadth of new designs that they enable, we showcase a set of examples from a printed robotic gripper that can be operated at a distance to a mobile phone stand that serves as a status reminder by repositioning the user's phone. We conclude with a discussion of our approach's limitations and possible future improvements.

CCS CONCEPTS

- **Human-centered computing** → **Interactive systems and tools**; **Interaction devices**.

KEYWORDS

Fabrication, 3D Printing, Interaction, Design

ACM Reference Format:

Zeyu Yan and Huaishu Peng. 2021. FabHydro: Printing Interactive Hydraulic Devices with an Affordable SLA 3D Printer. In *The 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21), October 10–14, 2021, Virtual Event, USA.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3472749.3474751

1 INTRODUCTION

One of the long-term visions for additive manufacturing is to print devices with functionalities and interactivities [51]. For example, recent research has shown different approaches to print interactive components, including 3D speakers that generate sound with diaphragm coating [20], light bulbs that are printed with custom light channels using transparent material [3], and touch sensors with conductive thermoplastic [39]. They allow 3D printed objects to have sound, light, and sensing capabilities, but these printed objects cannot move.

To offer mechanical motion, recent research looks for ways of incorporating mechanical actuators into the printed object – some use pre-manufactured actuators [15]; others aim to print actuators directly. For example, Peng et al. [32] design a custom 3D printer that can embed magnetic wires into the printing process to build reluctant motors. MacCurdy et al. [25] propose to seal droplets inside a printed cavity to make hydraulic walking robots. These approaches show the potential to print one-off objects with mechanical motion, but the fabrication process remains challenging. They either require custom 3D printers with complex hardware designs such as a five-degree-of-freedom printing platform, or require high-end industrial 3D printers with multi-material printability. These machines often cost over 200,000 US dollars and are not accessible by many.

UIST '21, October 10–14, 2021, Virtual Event, USA

ACM ISBN 978-1-4503-8635-7/21/10…$15.00
https://doi.org/10.1145/3472749.3474751

UIST 2021

Yan et.al.

FabHydro: Printing Interactive Hydraulic Devices with an Affordable SLA 3D Printer

A set of rapid and low-cost methods to prototype interactive hydraulic devices based on an of-the-shelf 3D printer and flexible photosensitive resin.

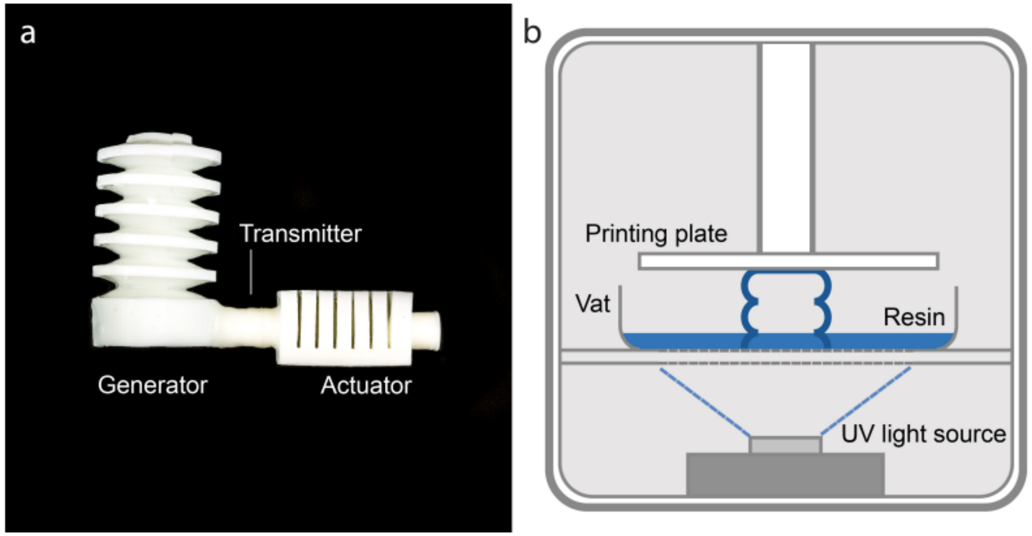


Figure 2: a) An overview of one *FabHydro* device, including a generator, a short piece of tubing, and a bending actuator; b) the conventional SLA printer with single material and an upside-down printing process.

FabHydro: Printing Interactive Hydraulic Devices with an Affordable SLA 3D Printer

Zeyu Yan
Department of Computer Science, University of Maryland,
College Park
College Park, MD, USA
zeyuy@umd.edu

Huaishu Peng
Department of Computer Science, University of Maryland,
College Park
College Park, MD, USA
huaishu@umd.edu

Figure 1: *FabHydro* overview: a) an off-the-shelf SLA printer with a modified tank and printing plate; b) a complete hydraulic device with a bellows generator and a bending actuator connected with a short piece of tubing; c) a bending actuator is activated by an automatic generator; d) a printed lamp lights up with the change of its posture; e) a phone stand acts as an ambient display when the phone rings.

ABSTRACT

We introduce *FabHydro*, a set of rapid and low-cost methods to prototype interactive hydraulic devices based on an off-the-shelf 3D printer and flexible photosensitive resin. We first present printer settings and custom support structures to warrant the successful print of flexible and deformable objects. We then demonstrate two printing methods to seal the transmission fluid inside these deformable structures: the *Submerged Printing* process that seals the liquid resin without manual assembly, and the *Printing with Plugs* method that allows the use of different transmission fluids without modification to the printer. Following the printing methods, we report a design space with a range of 3D printable primitives, including the hydraulic generator, transmitter, and actuator. To demonstrate the feasibility of our approaches and the breadth of new designs that they enable, we showcase a set of examples from a printed robotic gripper that can be operated at a distance to a mobile phone stand that serves as a status reminder by repositioning the user's phone. We conclude with a discussion of our approach's limitations and possible future improvements.

CCS CONCEPTS

- **Human-centered computing → Interactive systems and tools**; **Interaction devices**.

KEYWORDS

Fabrication, 3D Printing, Interaction, Design

ACM Reference Format:
Zeyu Yan and Huaishu Peng. 2021. FabHydro: Printing Interactive Hydraulic Devices with an Affordable SLA 3D Printer. In *The 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21), October 10–14, 2021, Virtual Event, USA.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3472749.3474751

1 INTRODUCTION

One of the long-term visions for additive manufacturing is to print devices with functionalities and interactivities [51]. For example, recent research has shown different approaches to print interactive components, including 3D speakers that generate sound with diaphragm coating [20], light bulbs that are printed with custom light channels using transparent material [3], and touch sensors with conductive thermoplastic [39]. They allow 3D printed objects to have sound, light, and sensing capabilities, but these printed objects cannot move.

To offer mechanical motion, recent research looks for ways of incorporating mechanical actuators into the printed object — some use pre-manufactured actuators [15]; others aim to print actuators directly. For example, Peng et al. [32] design a custom 3D printer that can embed magnetic wires into the printing process to build reluctant motors. MacCurdy et al. [25] propose to seal droplets inside a printed cavity to make hydraulic walking robots. These approaches show the potential to print one-off objects with mechanical motion, but the fabrication process remains challenging. They either require custom 3D printers with complex hardware designs such as a five-degree-of-freedom printing platform, or require high-end industrial 3D printers with multi-material printability. These machines often cost over 200,000 US dollars and are not accessible by many.

UIST '21, October 10–14, 2021, Virtual Event, USA

ACM ISBN 978-1-4503-8635-7/21/10…$15.00
https://doi.org/10.1145/3472749.3474751

UIST 2021

Yan et.al.

FabHydro: Printing Interactive Hydraulic Devices with an Affordable SLA 3D Printer

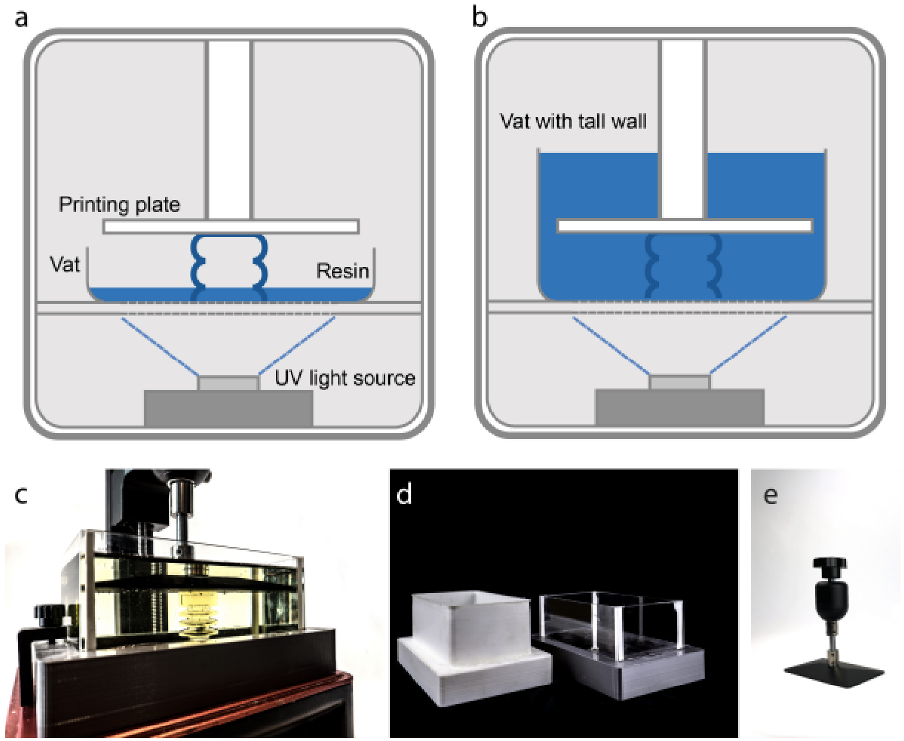


Figure 8: a) The conventional SLA 3D printer structure; b) the *Submerged Printing* process; c) the modified printer assembly filled with standard transparent resin for a clear presentation; and d) the modified vat made with PLA and acrylics; e) the extended printing plate.

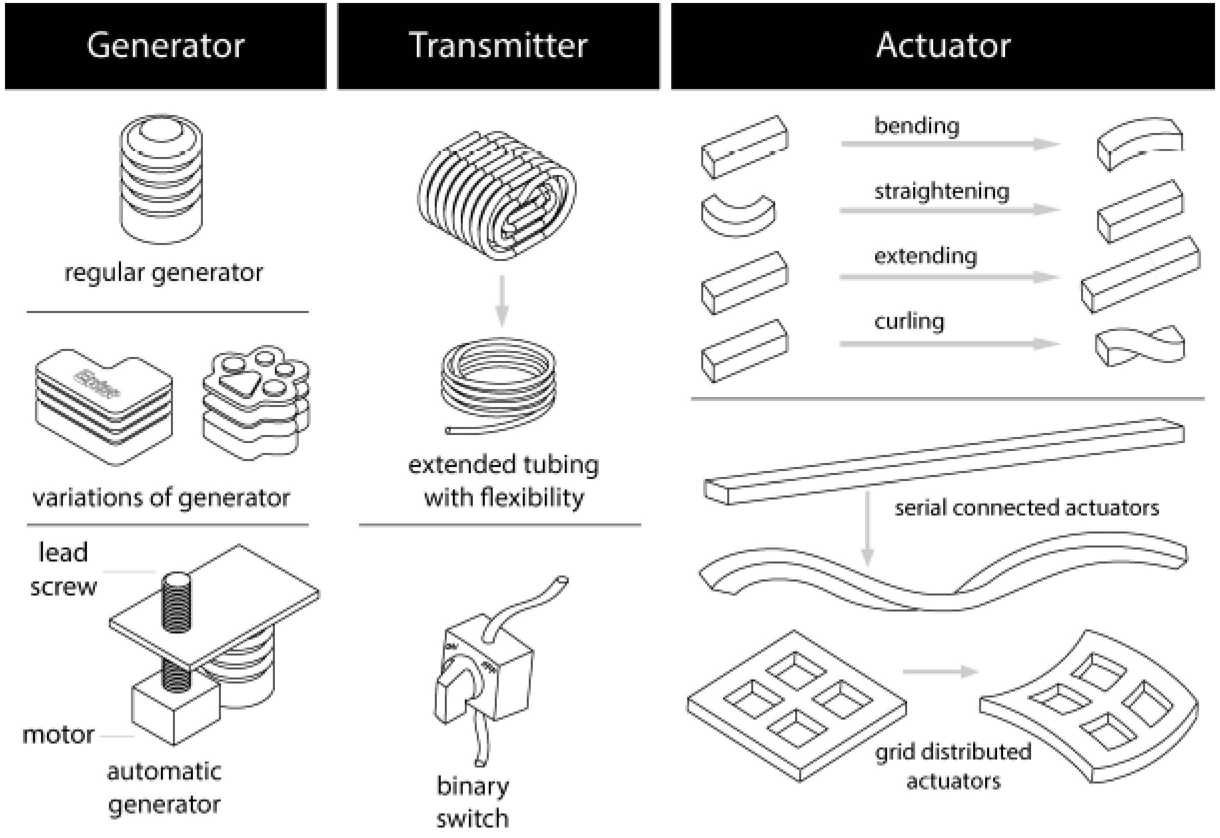
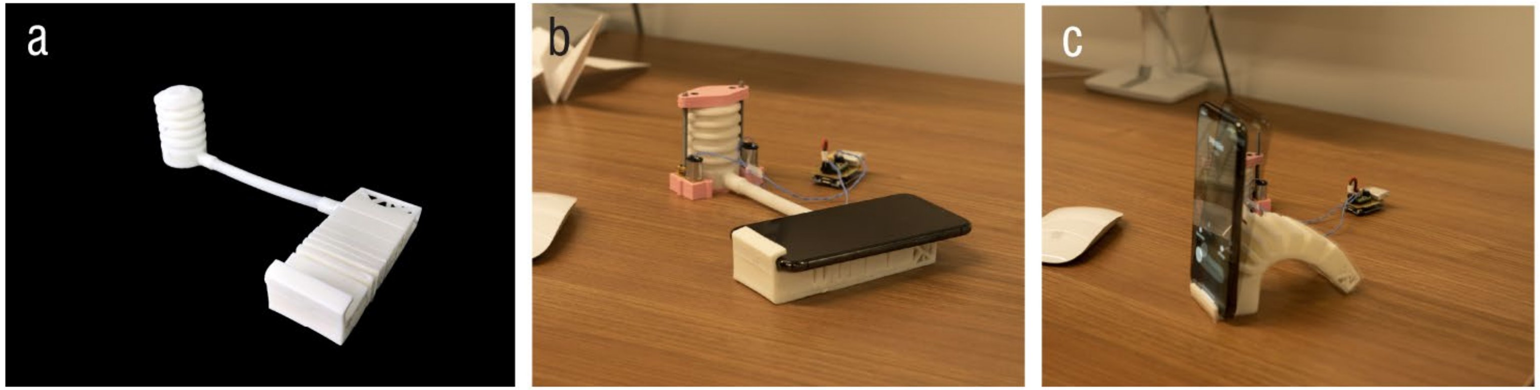
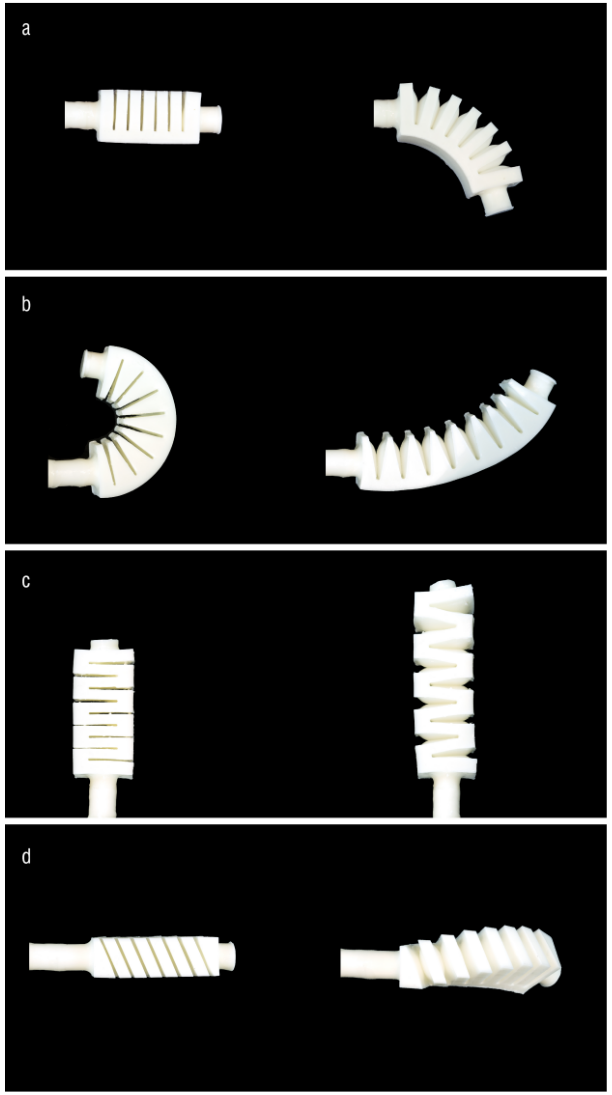


Figure 10: Design space: building blocks of *FabHydro*.

FabHydro: Printing Interactive Hydraulic Devices with an Affordable SLA 3D Printer





Different types of 3D printing methods

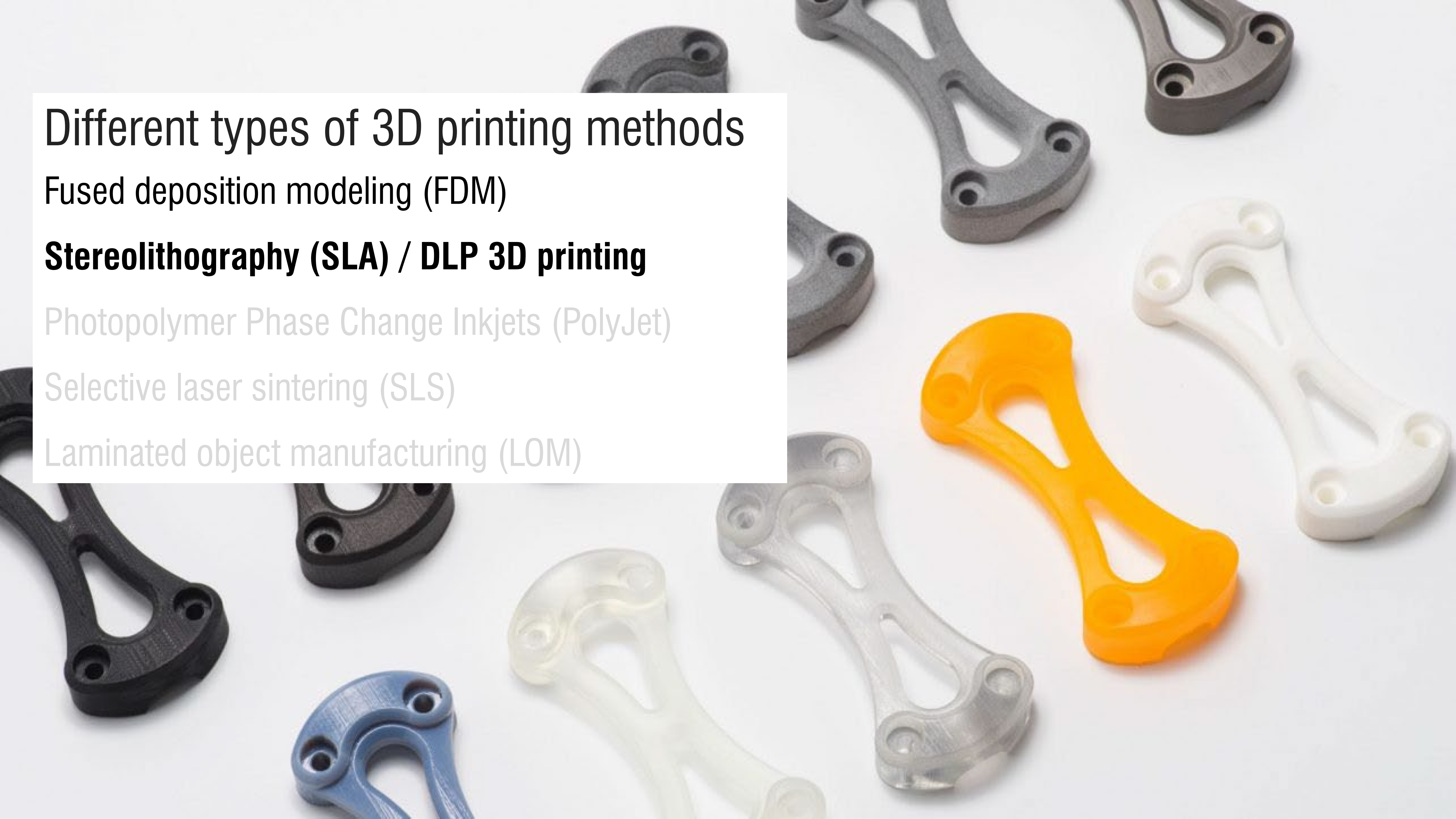
Fused deposition modeling (FDM)

Stereolithography (SLA) / DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)



Different types of 3D printing methods

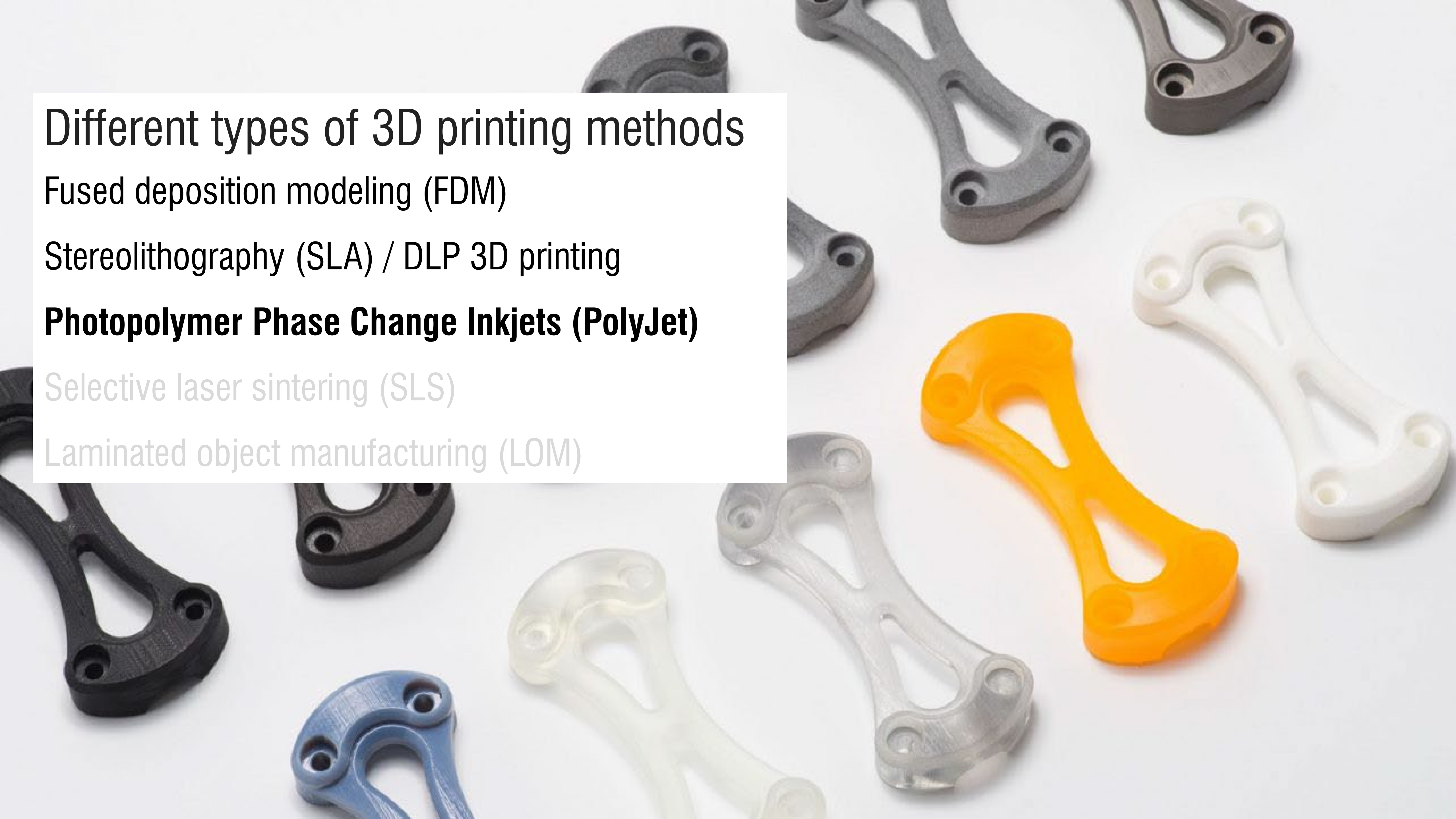
Fused deposition modeling (FDM)

Stereolithography (SLA) / DLP 3D printing

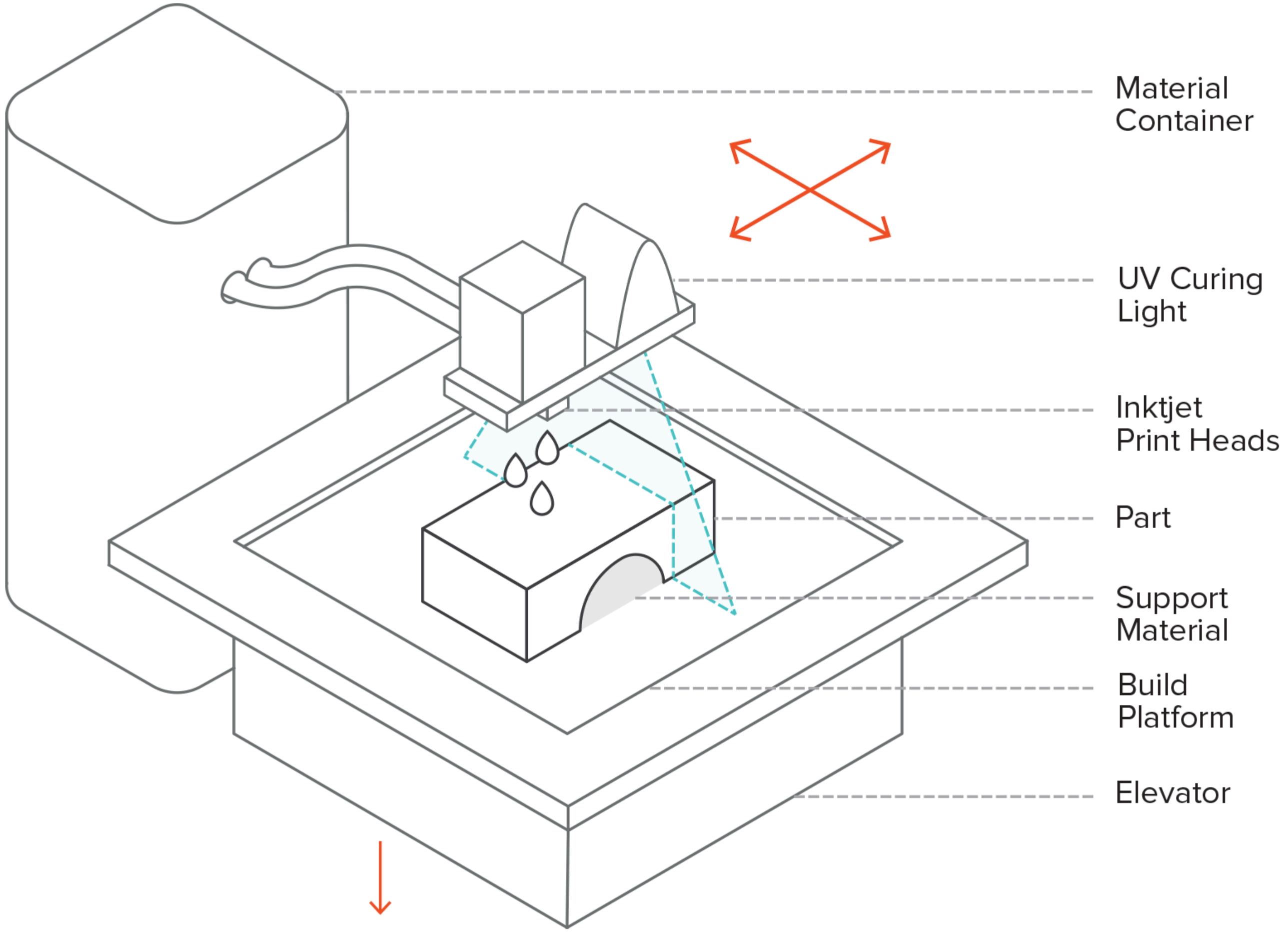
Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)



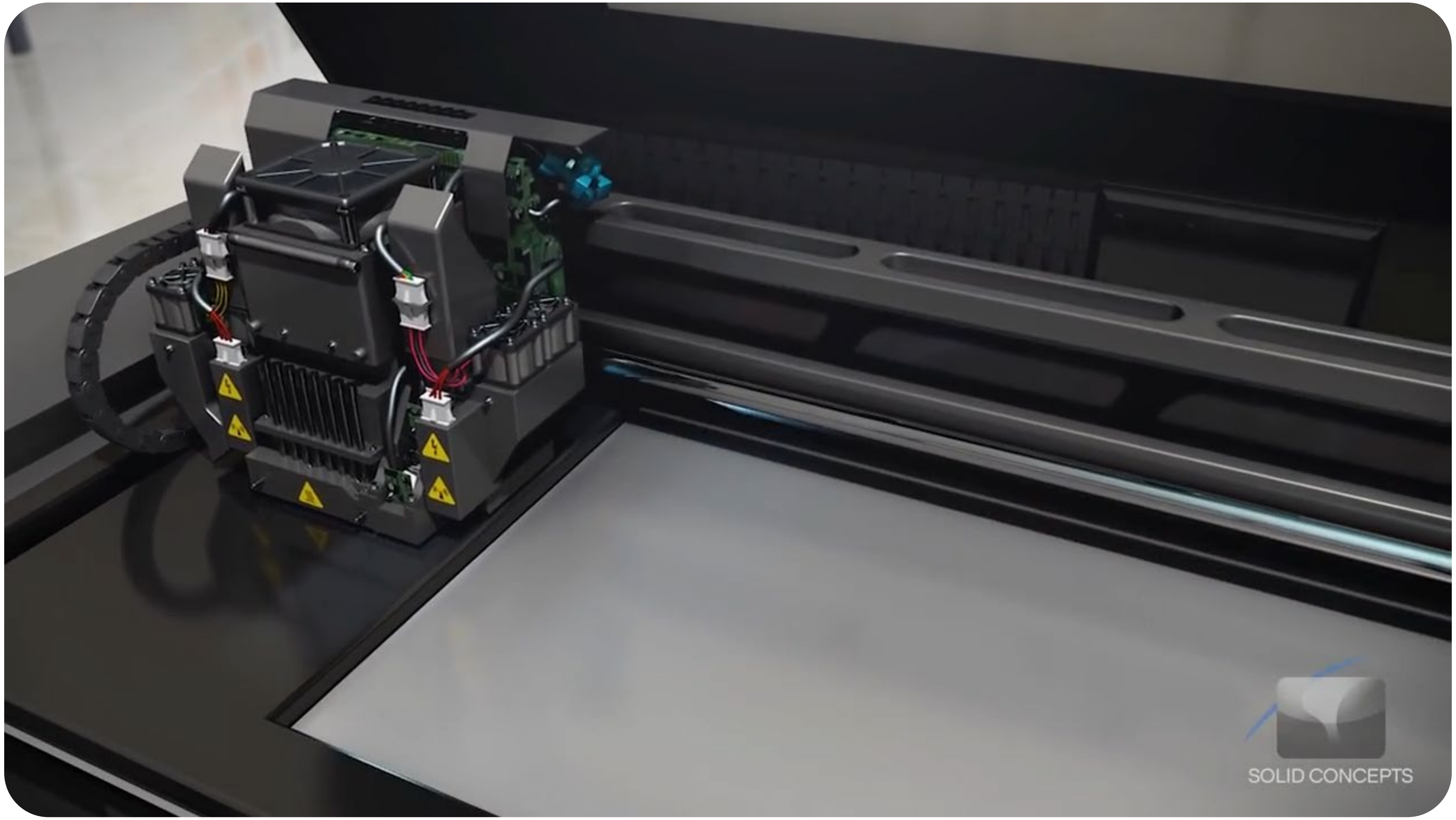
Photopolymer Phase Change Inkjets



A PolyJet 3D printer works like an inkjet printer

Jets drops of photopolymer that solidify when exposed to UV light.

Photopolymer Phase Change Inkjets



Photopolymer Phase Change Inkjets

Similar to SLA
  - Also uses photopolymers

Supporting **multiple** materials
  - Currently two + support material

Materials
  - Photopolymers only
    - Can be mixed before curing -> graded materials
    - Soft, rigid, opaque, transparent, different color

Photopolymer Phase Change Inkjets




Printed Optics: 3D Printing of Embedded Optical Elements for Interactive Devices

Karl D.D. Willis[1,2] **Eric Brockmeyer**[1] **Scott E. Hudson**[1,3] **Ivan Poupyrev**[1]
Disney Research Pittsburgh[1]
4720 Forbes Avenue
Pittsburgh, PA 15213
{karl, eric.brockmeyer, ivan.poupyrev}
@disneyresearch.com

Computational Design Lab[2], HCI Institute[3]
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
scott.hudson@cs.cmu.edu

Figure 1: Custom optical elements are fabricated with 3D printing and embedded in interactive devices, opening up new possibilities for interaction including: unique display surfaces made from 3D printed 'light pipes' (a), novel internal illumination techniques (b), custom optical sensors (c), and embedded optoelectronics (d).

ABSTRACT

We present an approach to 3D printing custom optical elements for interactive devices labelled *Printed Optics*. *Printed Optics* enable sensing, display, and illumination elements to be directly embedded in the casing or mechanical structure of an interactive device. Using these elements, unique display surfaces, novel illumination techniques, custom optical sensors, and embedded optoelectronic components can be digitally fabricated for rapid, high fidelity, highly customized interactive devices. *Printed Optics* is part of our long term vision for interactive devices that are 3D printed in their entirety. In this paper we explore the possibilities for this vision afforded by fabrication of custom optical elements using today's 3D printing technology.

ACM Classification: H.5.2 [Information Interfaces and Presentation]: User Interfaces.

Keywords: 3D printing; optics; light; sensing; projection; display; rapid prototyping; additive manufacturing.

UIST'12, October 7–10, 2012, Cambridge, Massachusetts, USA.

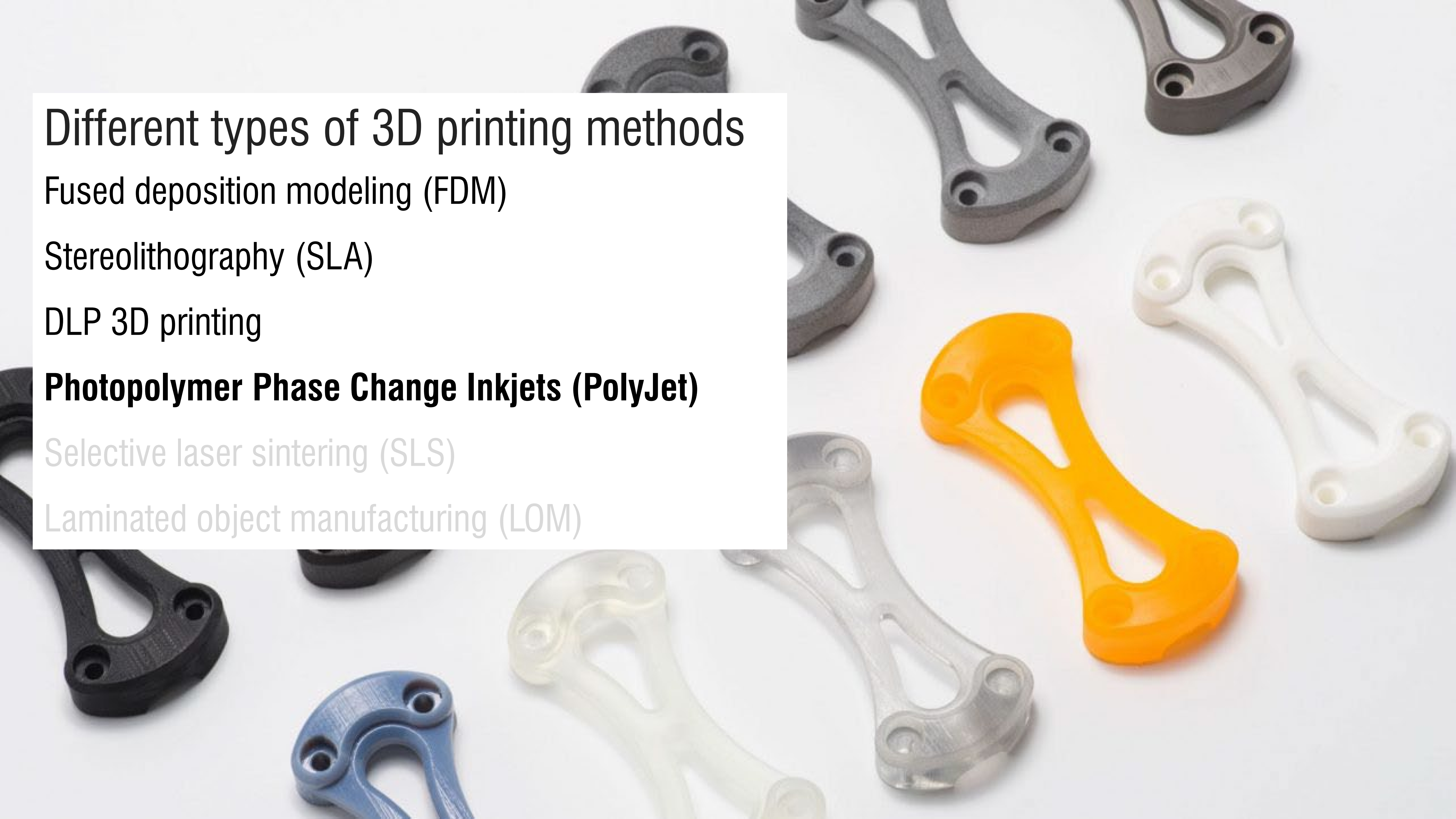
INTRODUCTION

3D printing is becoming increasingly capable and affordable. We envision a future world where interactive devices can be printed rather than assembled; a world where a device with active components is created as a single object, rather than a case enclosing circuit boards and individually assembled parts (Figure 2). This capability has tremendous potential for rapid high fidelity prototyping, and eventually for production of customized devices tailored to individual needs and/or specific tasks. With these capabilities we envision it will be possible to design highly functional devices in a digital editor — importing components from a library of interactive elements, positioning and customizing them, then pushing 'print' to have them realized in physical form. In this paper we explore some of the possibilities for this vision afforded by today's 3D printing technology. Specifically, we describe an approach for using 3D printed optical elements, *Printed Optics*, as one category of components within a greater library of reusable interactive elements.

Custom optical elements have traditionally been expensive and impractical to produce due to the manufacturing precision and finishing required. Recent developments in 3D printing technology have enabled the fabrication of high resolution transparent plastics with similar optical properties to plexiglas^{TM}. One-off 3D printed optical elements can be designed and fabricated literally within minutes for significantly less cost than conventional manufacturing; greatly increasing accessibility and reducing end-to-end prototyping time. 3D printed optical elements also afford new optical form-factors that were not previously possible, such as fab-

UIST 2012

Willis et.al.



Different types of 3D printing methods

Fused deposition modeling (FDM)

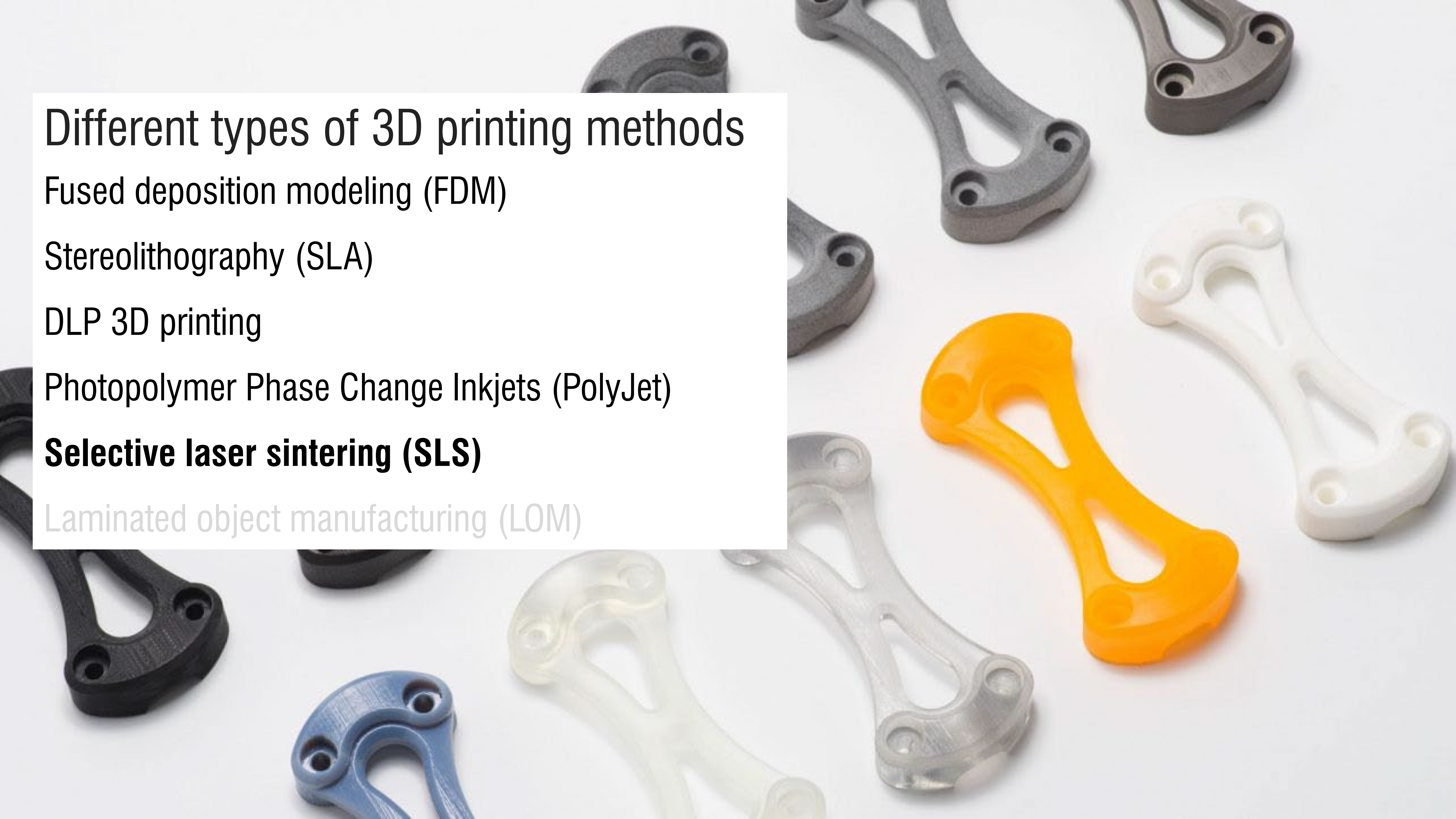
Stereolithography (SLA)

DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)



Different types of 3D printing methods

Fused deposition modeling (FDM)

Stereolithography (SLA)

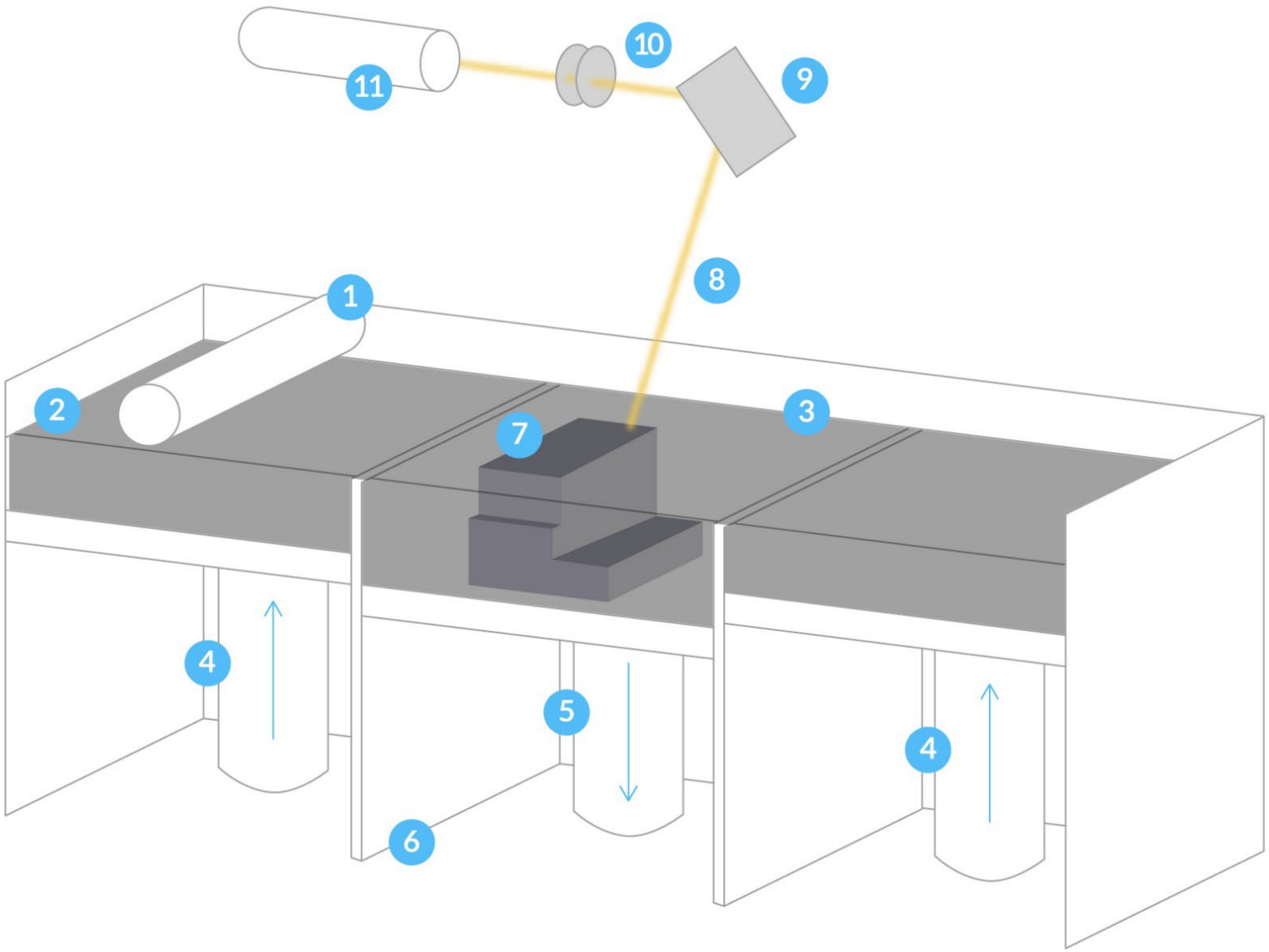
DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)

Selective Laser Sintering (SLS)/Direct Metal Laser Sintering (DMLS)



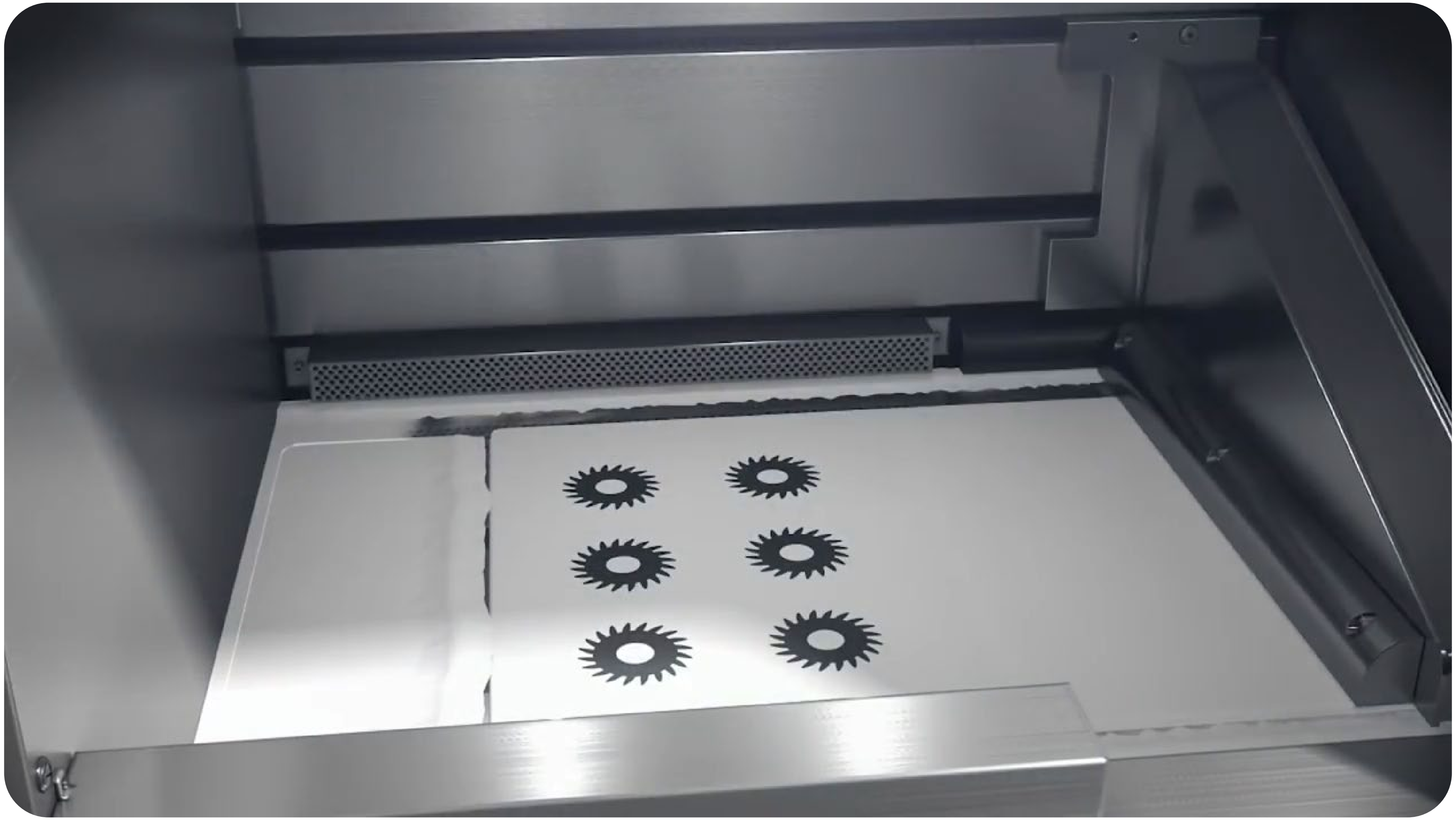
similar to SLA

use a bed of **powders** (made of plastic, metal, ceramic, or glass)

High-power laser traces one layer on the surface of the powder bed fusing the particles

The platform descends by one layer and more material is added

Selective Laser Sintering (SLS)/Direct Metal Laser Sintering (DMLS)



Selective Laser Sintering (SLS)/Direct Metal Laser Sintering (DMLS)

Laser and scanner system

- –Similar do SLA but laser is more powerful

Bulk material can be preheated

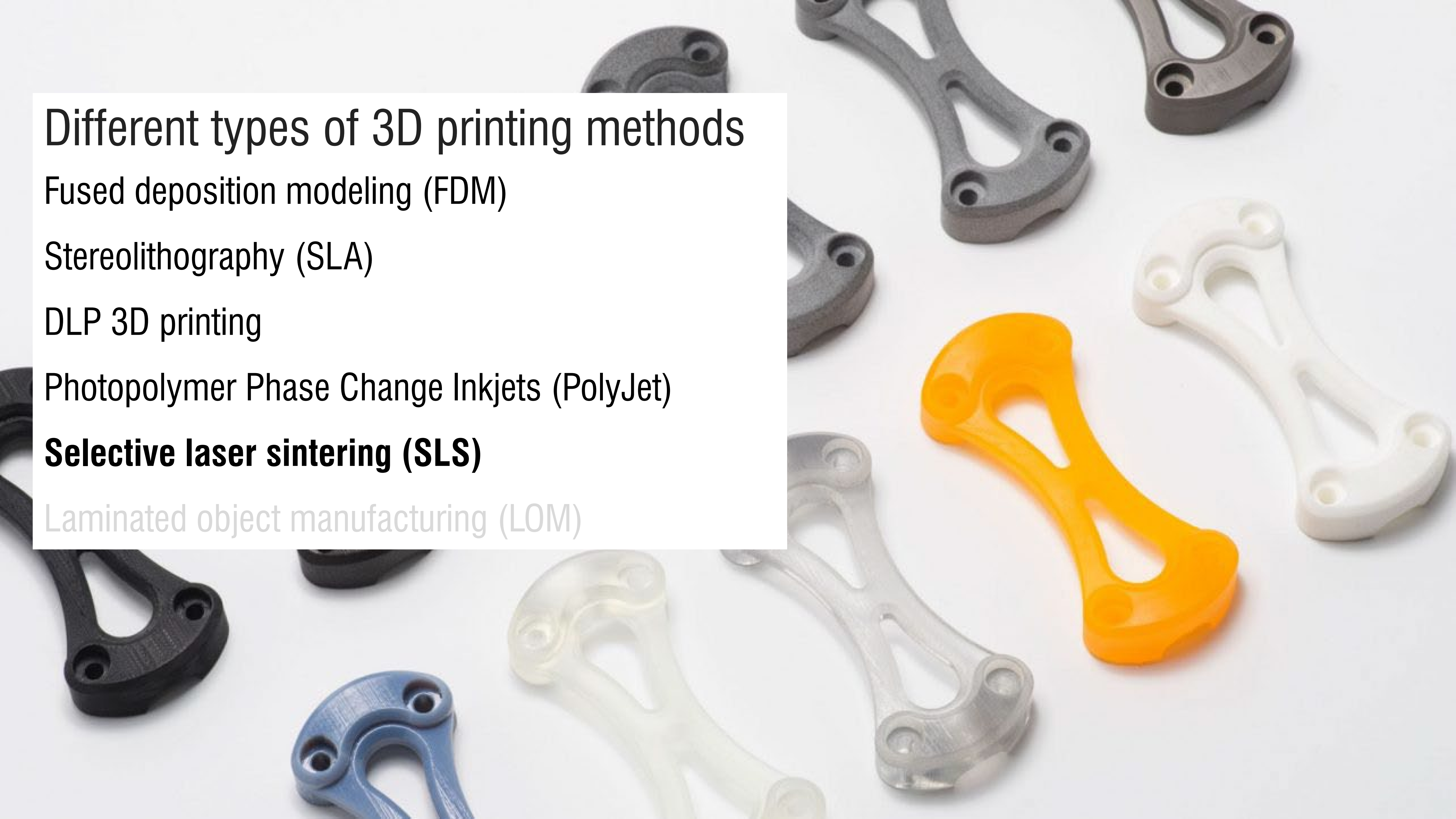
- –Reduces the required energy to melt it

Materials

- –One material at a time
- –**Glass**, polymers (e.g., nylon, polysterine), **metals** (e.g., steel, titanium, alloys), **ceramic**

Support structure?

- –No support material. Overhangs are supported by powder material



Different types of 3D printing methods

Fused deposition modeling (FDM)

Stereolithography (SLA)

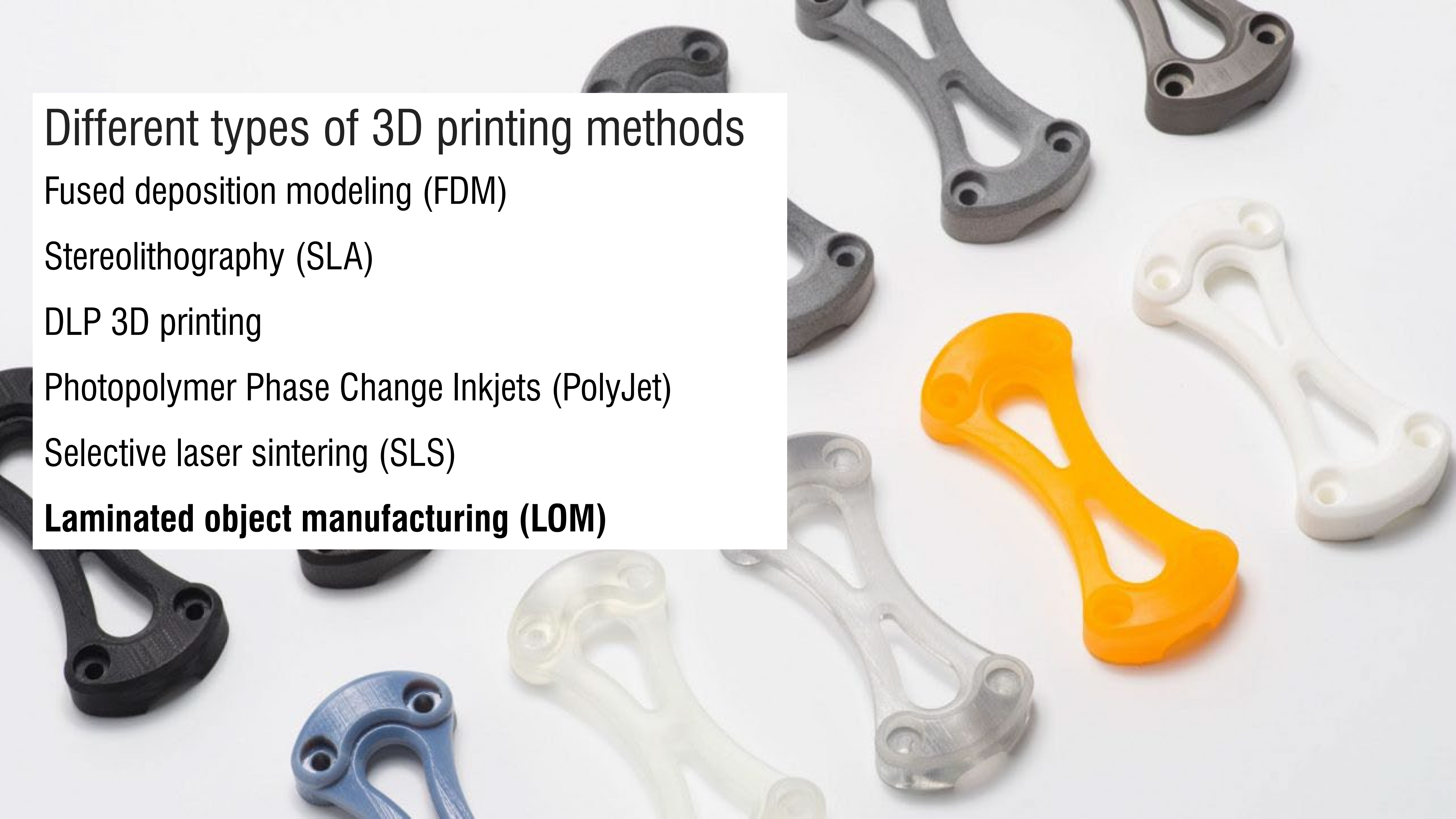
DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)

Different types of 3D printing methods



Fused deposition modeling (FDM)

Stereolithography (SLA)

DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

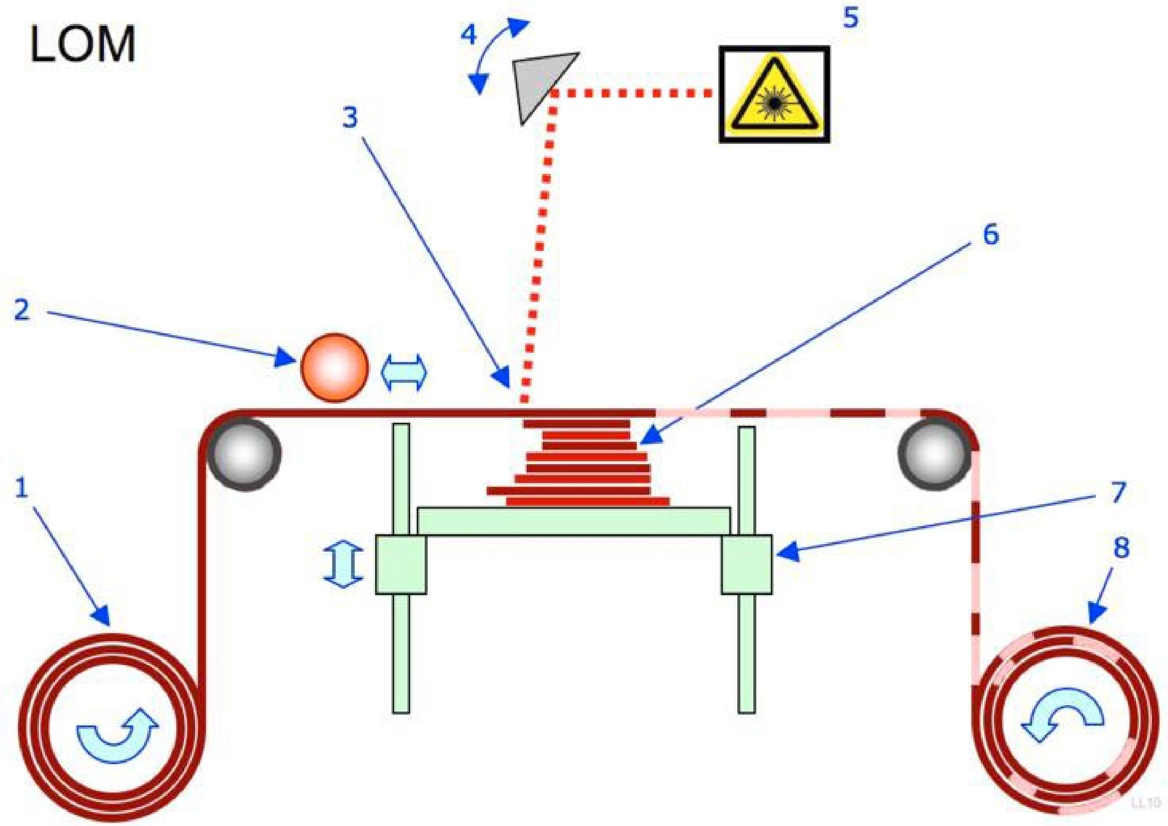
Laminated object manufacturing (LOM)

What do you think these are made of?

Paper

How?

Laminated Object Manufacturing (LOM)



first sheet is **2D color printed**

then **glued** onto the build plate

then **cut** into shape

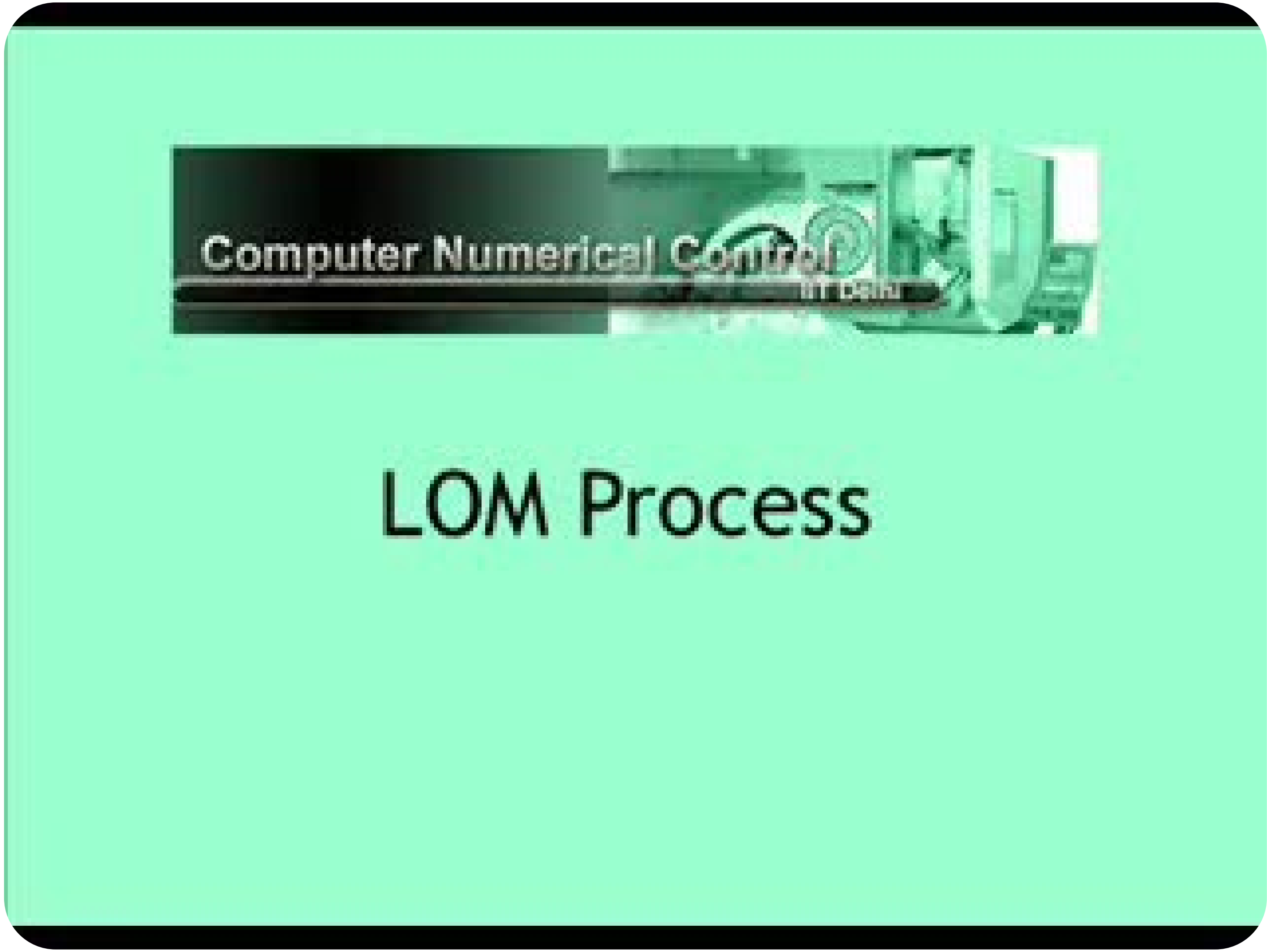
second sheet (fresh roll) is 2D color printed

glued onto build plate

cut into shape

repeat

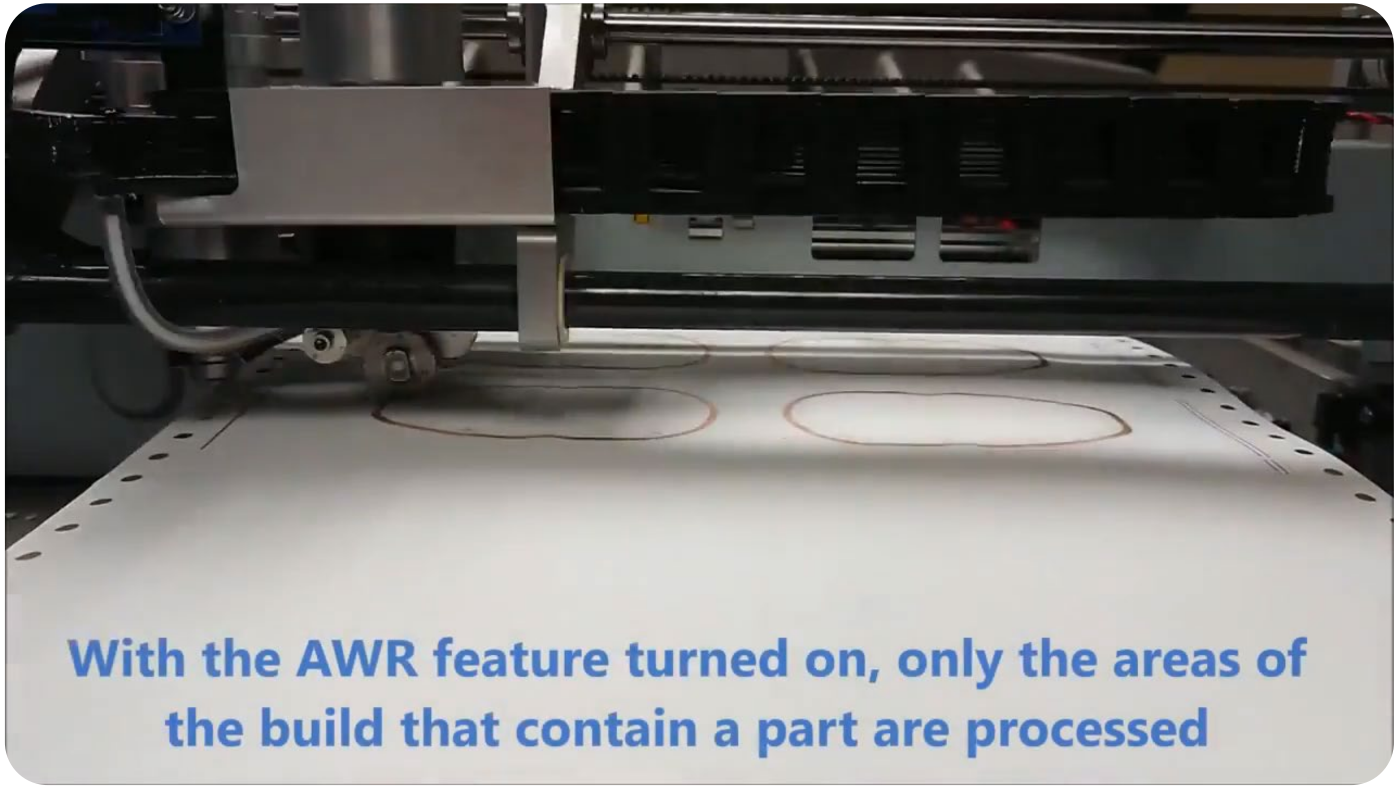
Laminated Object Manufacturing (LOM)



Computer Numerical Control

LOM Process

Laminated Object Manufacturing (LOM)



Inexpensive – low material cost

Print resolution is lower than other methods

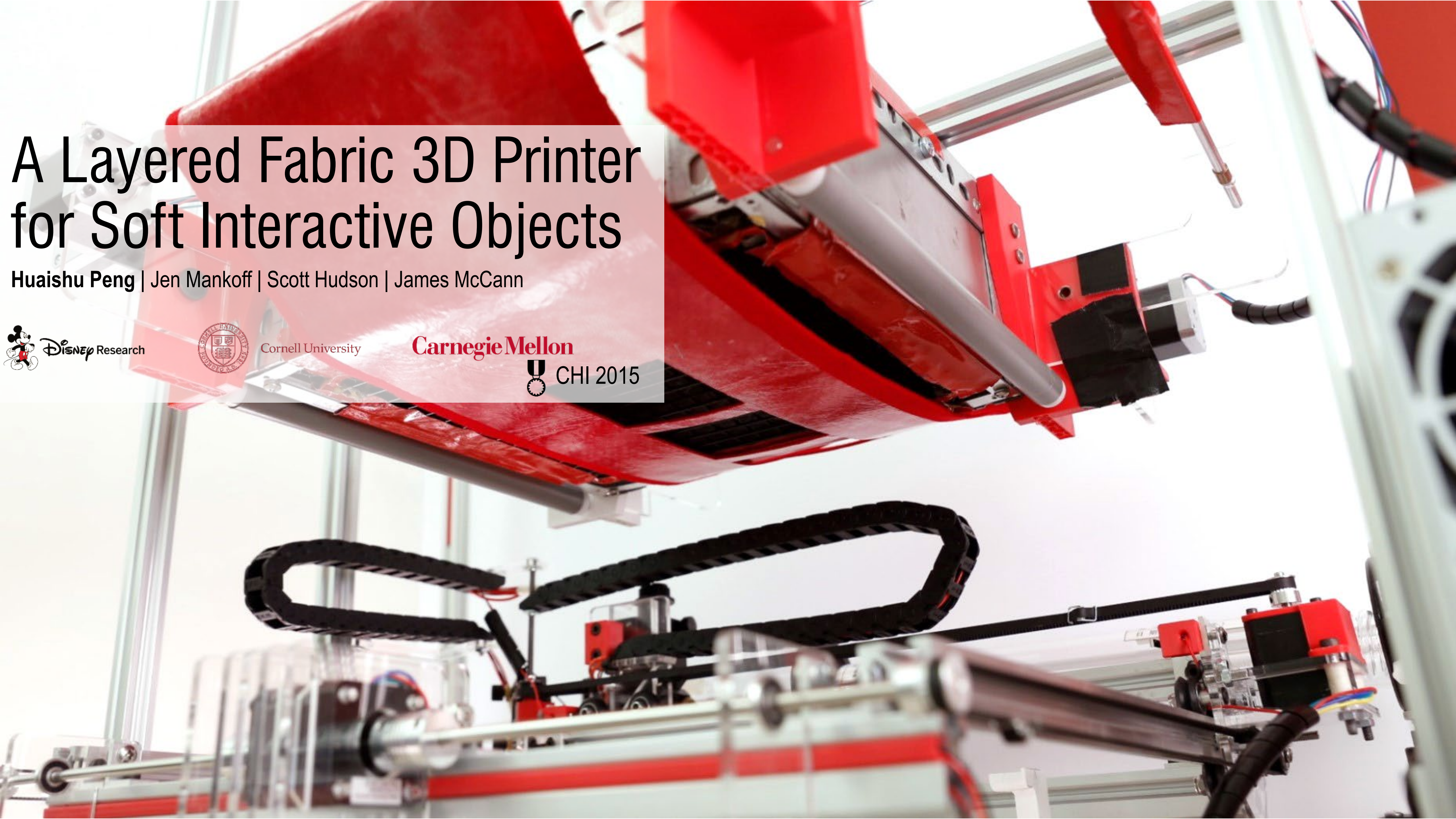
Color can be added using additional printhead

Materials

- –Paper (most common), plastics, metal, ceramics

Support material

- –Same material can be used as support

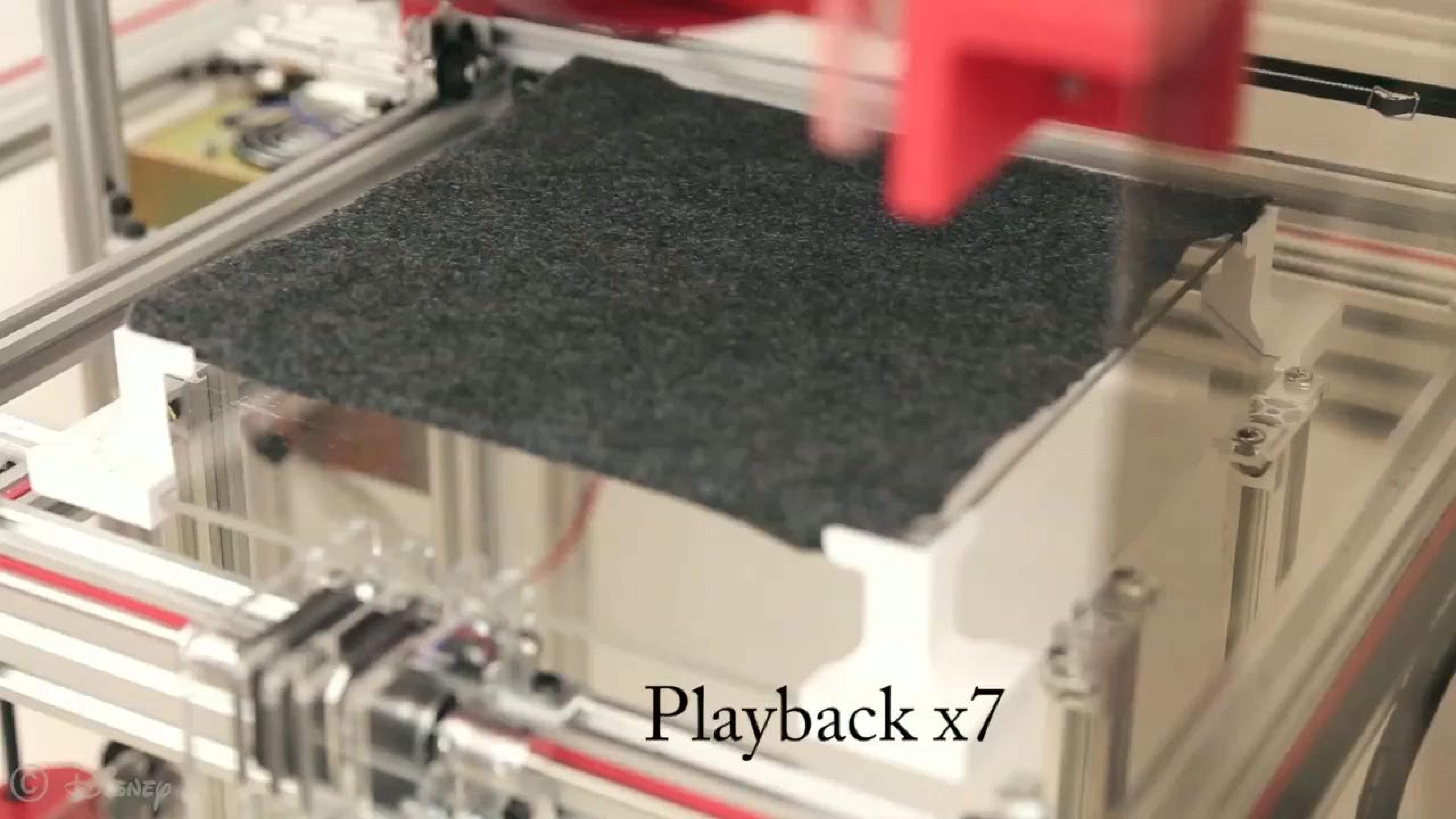


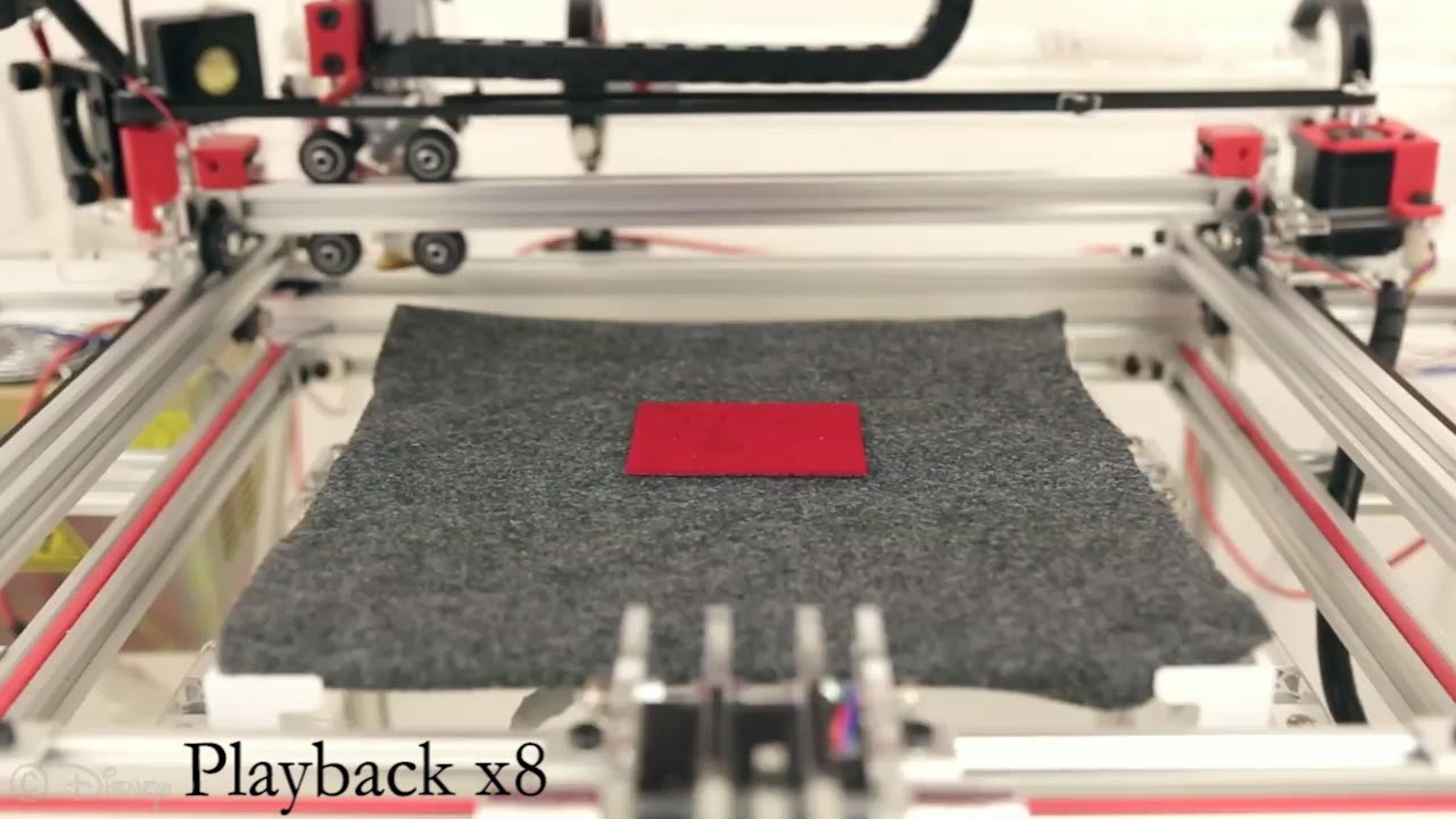
A Layered Fabric 3D Printer for Soft Interactive Objects

Huaishu Peng | Jen Mankoff | Scott Hudson | James McCann

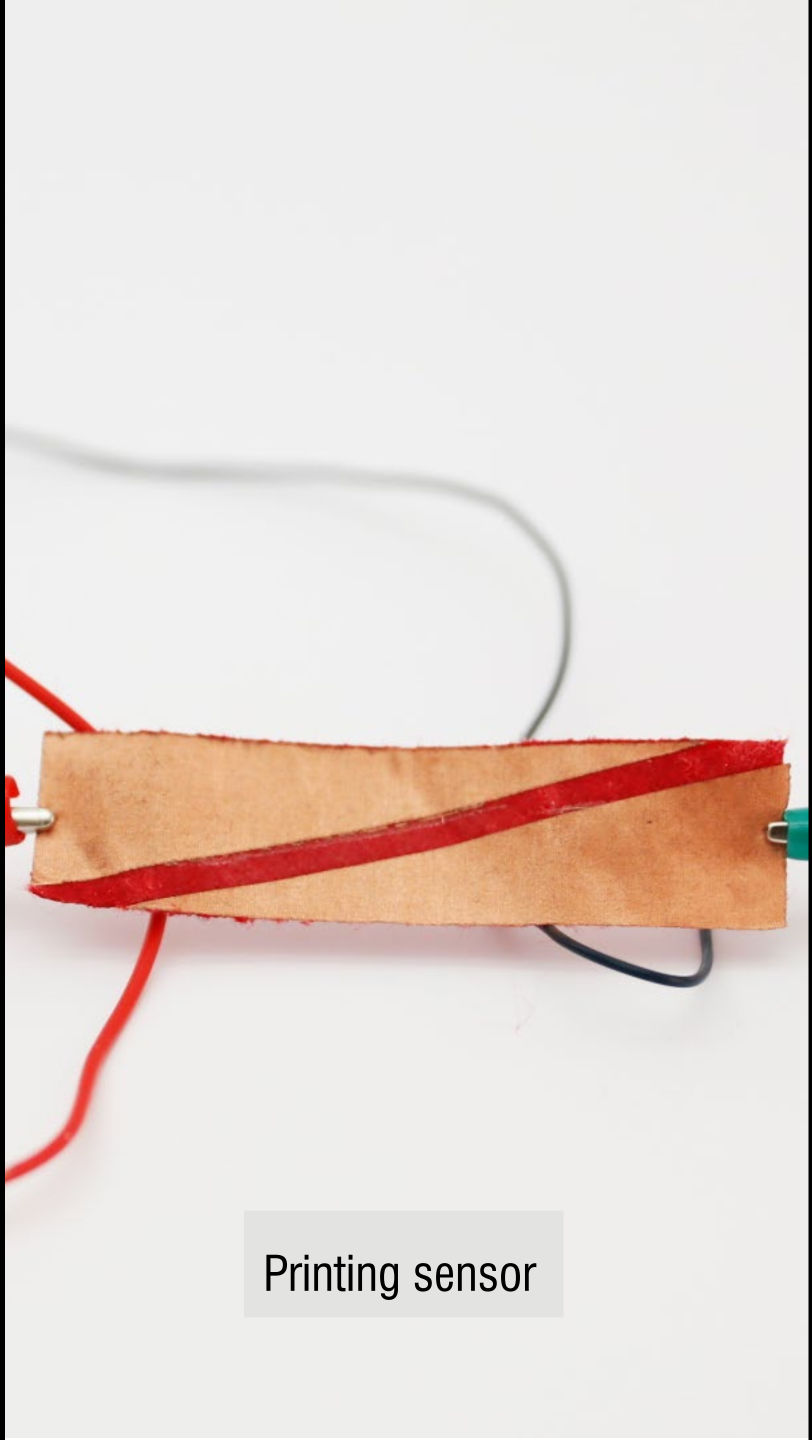
Disney Research
Cornell University
Carnegie Mellon

CHI 2015


Playback x7


Playback x8
© Disney

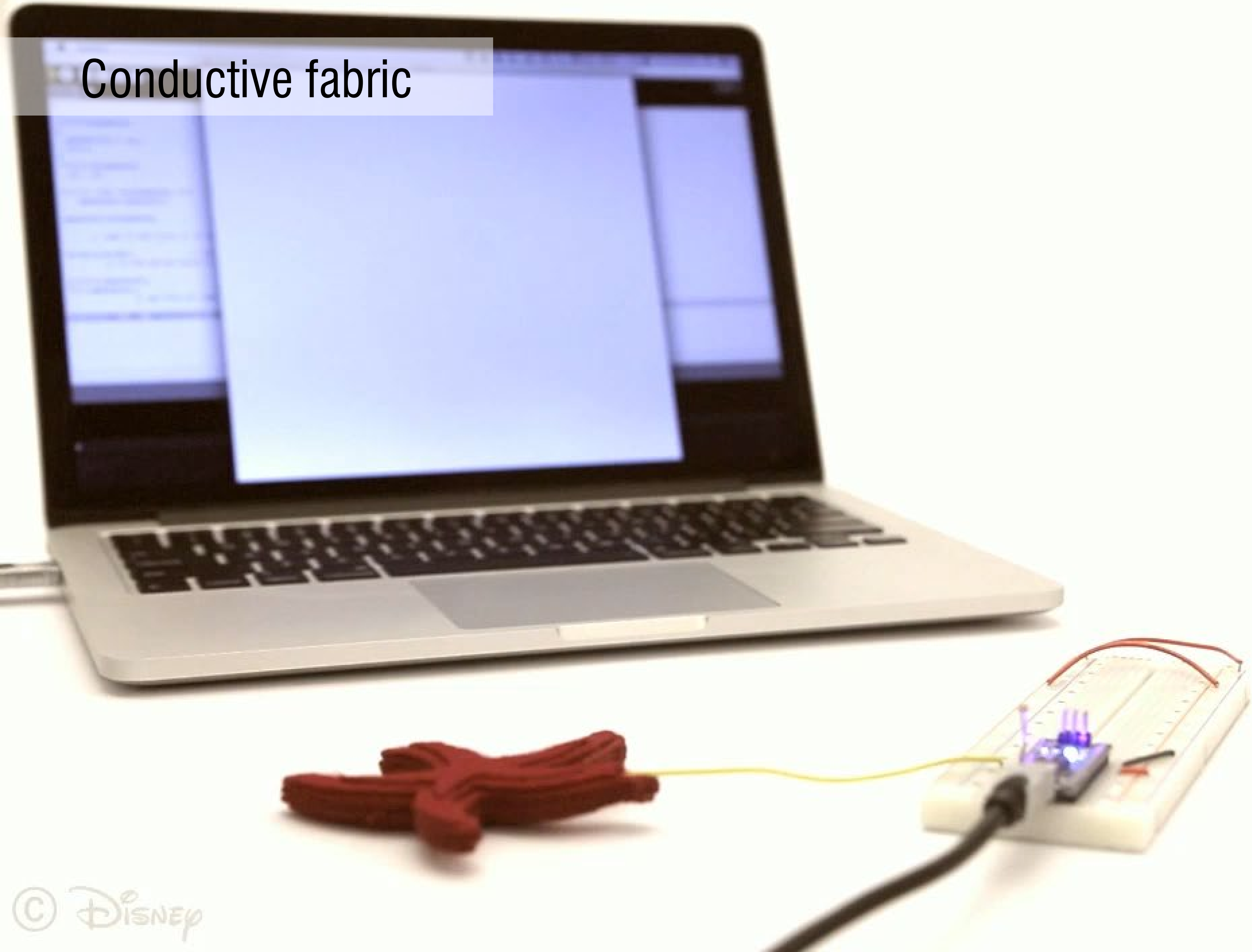

Manipulate deformation


Printing sensor

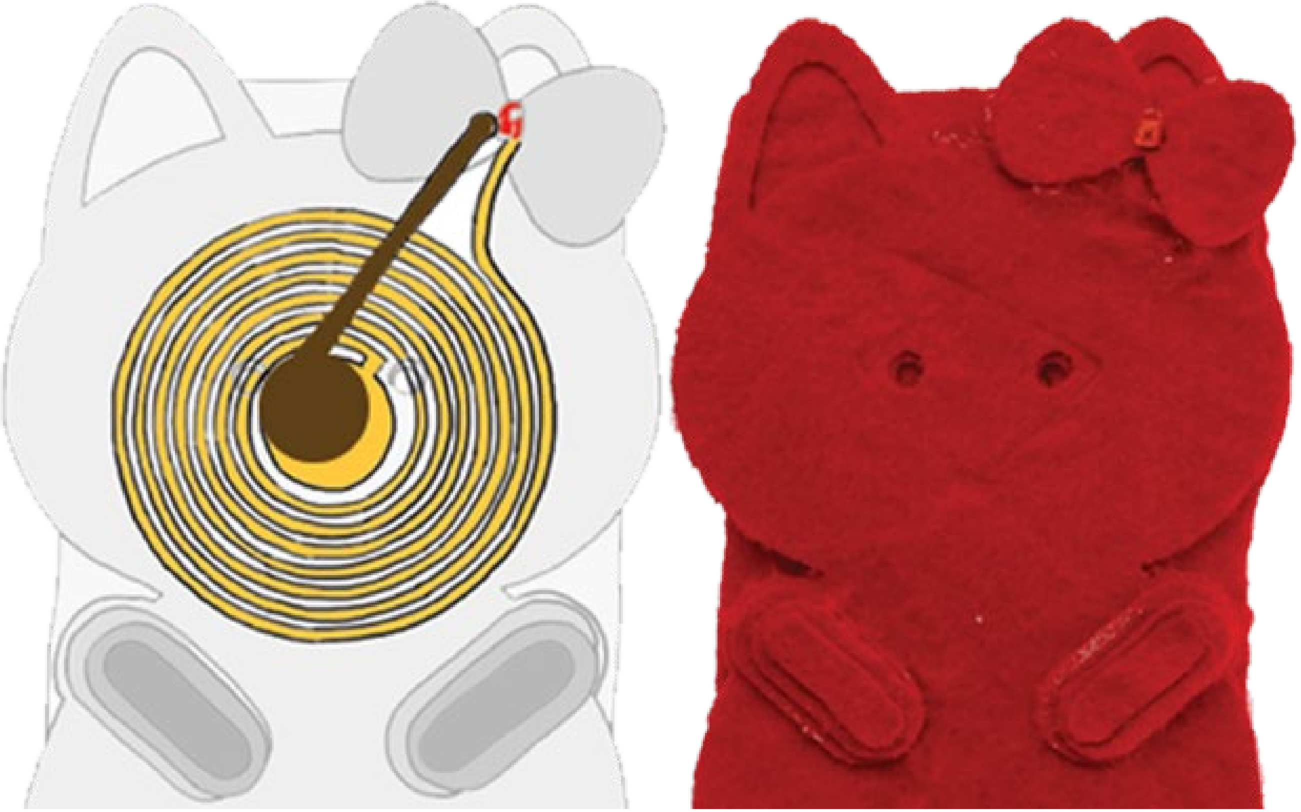

Printing circuit

Deformation manipulation

Conductive fabric



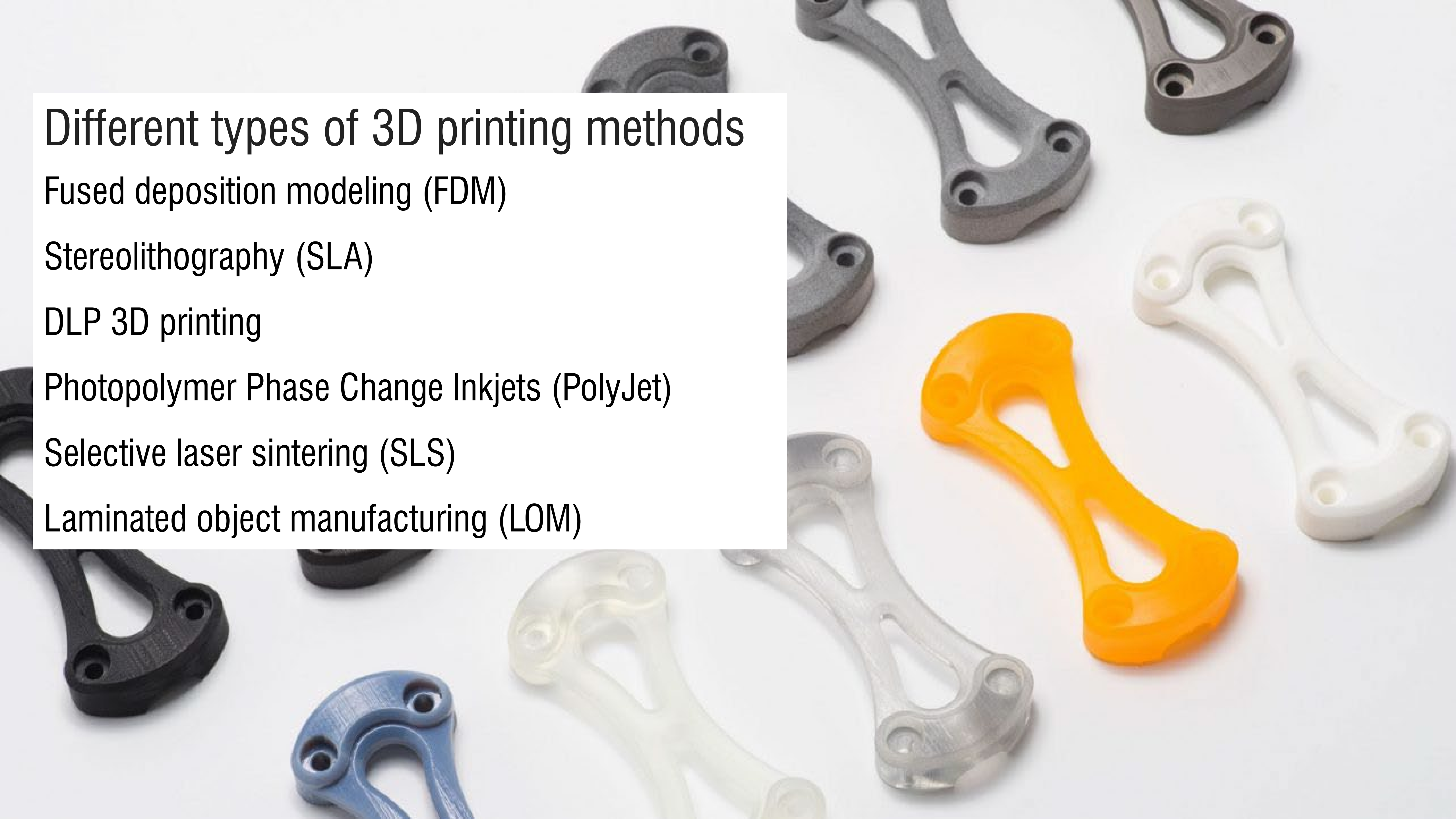
Printing multi-layer circuits



Printing multi-layer circuits

soft material

textile texture
input and sensing



Different types of 3D printing methods

Fused deposition modeling (FDM)

Stereolithography (SLA)

DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)

Recap

3 types of manufacturing methods

Brief history of 3D printing

Examples of printed objects

Varies of printing methods

Thanks to Jon Froehlich and Stefanie Mueller for the slides references

Optional readings

Printed Optics: 3D Printing of Embedded Optical Elements for Interactive Devices

Karl D.D. Willis[1,2] **Eric Brockmeyer**[1] **Scott E. Hudson**[1,3] **Ivan Poupyrev**[1]
Disney Research Pittsburgh[1]
4720 Forbes Avenue
Pittsburgh, PA 15213
{karl, eric.brockmeyer, ivan.poupyrev}
@disneyresearch.com

Computational Design Lab[2], HCI Institute[3]
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
scott.hudson@cs.cmu.edu

Figure 1: Custom optical elements are fabricated with 3D printing and embedded in interactive devices, opening up new possibilities for interaction including: unique display surfaces made from 3D printed 'light pipes' (a), novel internal illumination techniques (b), custom optical sensors (c), and embedded optoelectronics (d).

ABSTRACT

We present an approach to 3D printing custom optical elements for interactive devices labelled *Printed Optics*. *Printed Optics* enable sensing, display, and illumination elements to be directly embedded in the casing or mechanical structure of an interactive device. Using these elements, unique display surfaces, novel illumination techniques, custom optical sensors, and embedded optoelectronic components can be digitally fabricated for rapid, high fidelity, highly customized interactive devices. *Printed Optics* is part of our long term vision for interactive devices that are 3D printed in their entirety. In this paper we explore the possibilities for this vision afforded by fabrication of custom optical elements using today's 3D printing technology.

ACM Classification: H.5.2 [Information Interfaces and Presentation]: User Interfaces.

Keywords: 3D printing; optics; light; sensing; projection; display; rapid prototyping; additive manufacturing.

UIST'12, October 7–10, 2012, Cambridge, Massachusetts, USA.

INTRODUCTION

3D printing is becoming increasingly capable and affordable. We envision a future world where interactive devices can be printed rather than assembled; a world where a device with active components is created as a single object, rather than a case enclosing circuit boards and individually assembled parts (Figure 2). This capability has tremendous potential for rapid high fidelity prototyping, and eventually for production of customized devices tailored to individual needs and/or specific tasks. With these capabilities we envision it will be possible to design highly functional devices in a digital editor — importing components from a library of interactive elements, positioning and customizing them, then pushing 'print' to have them realized in physical form. In this paper we explore some of the possibilities for this vision afforded by today's 3D printing technology. Specifically, we describe an approach for using 3D printed optical elements, *Printed Optics*, as one category of components within a greater library of reusable interactive elements.

Custom optical elements have traditionally been expensive and impractical to produce due to the manufacturing precision and finishing required. Recent developments in 3D printing technology have enabled the fabrication of high resolution transparent plastics with similar optical properties to plexiglas^{TM}. One-off 3D printed optical elements can be designed and fabricated literally within minutes for significantly less cost than conventional manufacturing; greatly increasing accessibility and reducing end-to-end prototyping time. 3D printed optical elements also afford new optical form-factors that were not previously possible, such as fab-

UIST 2012

Willis et.al.

Patching Physical Objects

Alexander Teibrich[1], **Stefanie Mueller**[1], **François Guimbretière**[1,2],
Robert Kovacs[1], **Stefan Neubert**[1], **Patrick Baudisch**[1]
[1]Hasso Plattner Institute
Potsdam, Germany
{firstname.lastname}@hpi.uni-potsdam.de

[2]Cornell University, Information Science
Ithaca, NY 14850, USA
francois@cs.cornell.edu

ABSTRACT

Personal fabrication is currently a one-way process: once an object has been fabricated with a 3D printer, it cannot be changed anymore. Any change requires printing a new version from scratch. The problem is that this approach ignores the nature of design *iteration,* i.e. that in subsequent iterations large parts of an object stay the same and only small parts change. This makes fabricating from scratch feel unnecessary and wasteful.

In this paper, we propose a different approach: instead of re-printing the entire object from scratch, we suggest patching the *existing* object to reflect the next design iteration. We built a system on top of a 3D printer that accomplishes this: Users mount the existing object into the 3D printer, then load both the original and the modified 3D model into our software, which in turn calculates how to patch the object. After identifying which parts to remove and what to add, our system locates the existing object in the printer using the system's built-in 3D scanner. After calibrating the orientation, a mill first removes the outdated geometry, then a print head prints the new geometry in place.

Since only a fraction of the entire object is refabricated, our approach reduces material consumption and plastic waste (for our example objects by 82% and 93% respectively).

Author Keywords: rapid prototyping; 3D printing; sustainability.

ACM Classification Keywords: H.5.2 [Information interfaces and presentation]: User Interfaces.

General Terms: Design; Human Factors.

INTRODUCTION

Personal fabrication machines, such as 3D printers, are on the verge of becoming a mass market [10]. With more people owning a 3D printer, more and more objects will be printed in the future. Many researchers envision a future in which even inexperienced users will create their own designs using software that enables them to create objects through a design-fabricate-test-redesign cycle [4].

Figure 1: To minimize material consumption and to reduce waste during design iteration, we propose *patching* the existing object rather than reprinting it from scratch. (a) First, our software calculates which part changed, then (b) a mill removes outdated geometry, followed by a print head that prints the new geometry.

While we share the excitement about this future evolution, we are worried about potential implications on sustainability: unlike the more "traditional" software-based design process, creating and iterating on physical designs requires actual physical material and creates actual physical waste.

Existing angles on sustainability focus on either reducing print material (e.g. infill material [27], support material [24]) or they try to recycle the already printed material. While a few filament types, such as PLA, are biodegradable, many other materials are not. Filament extruders, such

UIST '15, November 08-11, 2015, Charlotte, NC, USA

DOI: http://dx.doi.org/10.1145/2807442.2807467

UIST 2015

Teibrich et.al.