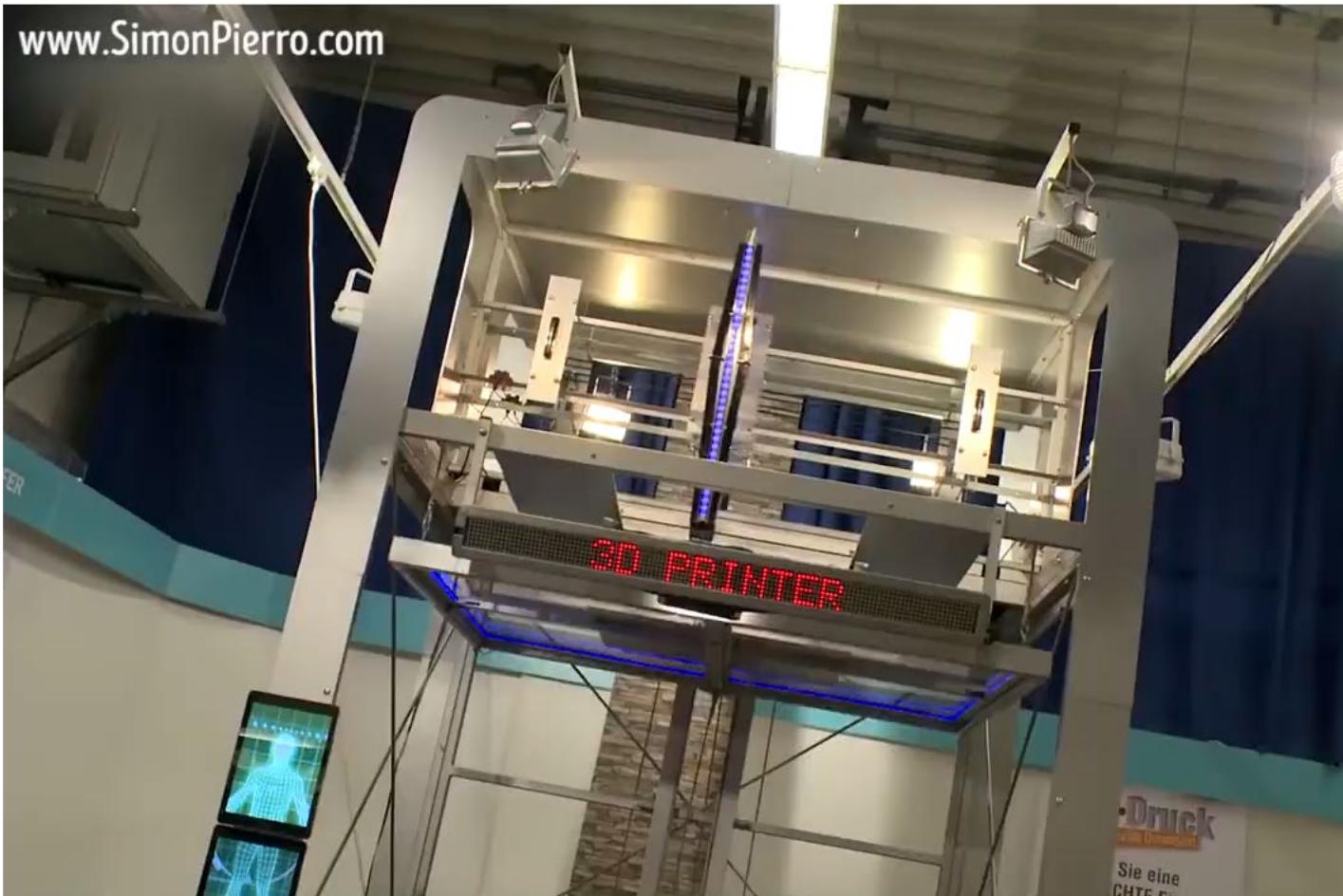
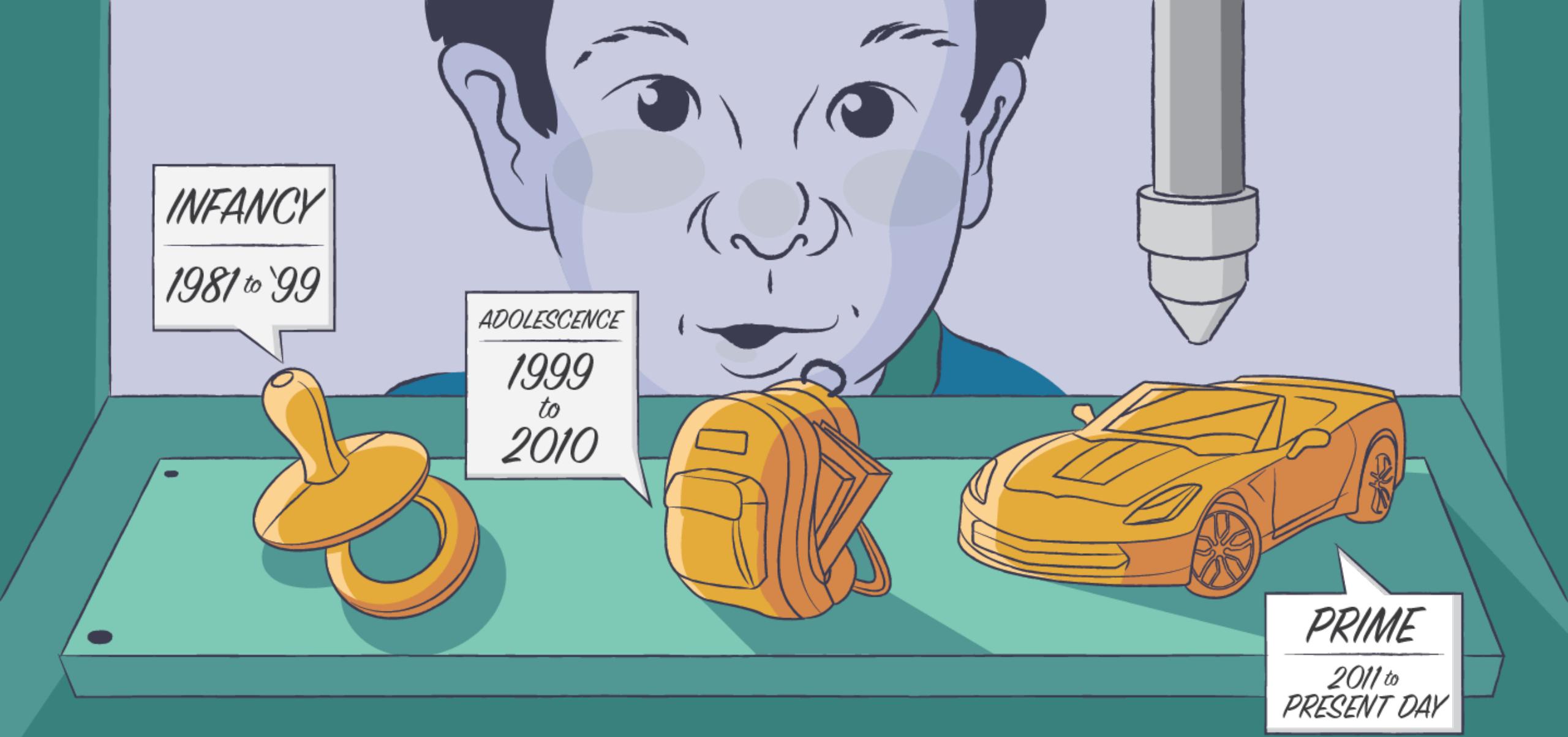


DIGITAL MAGIC XXL

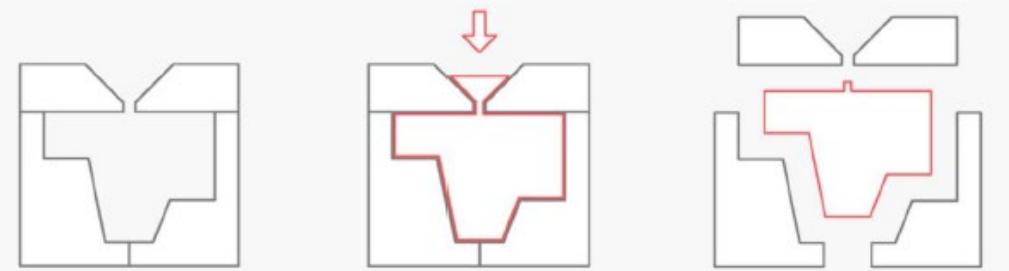


3D PRINTING PEOPLE PRANK

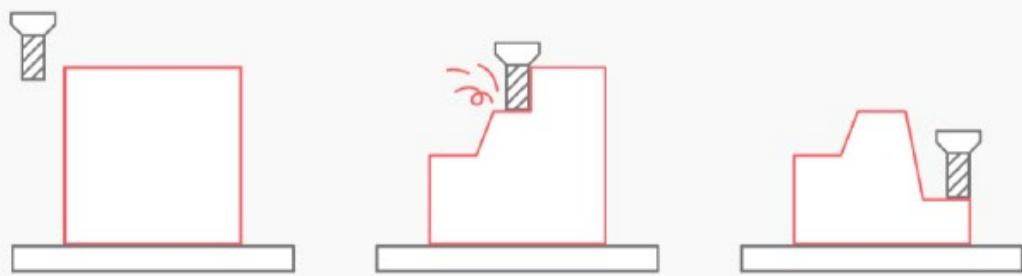


Additive Manufacturing

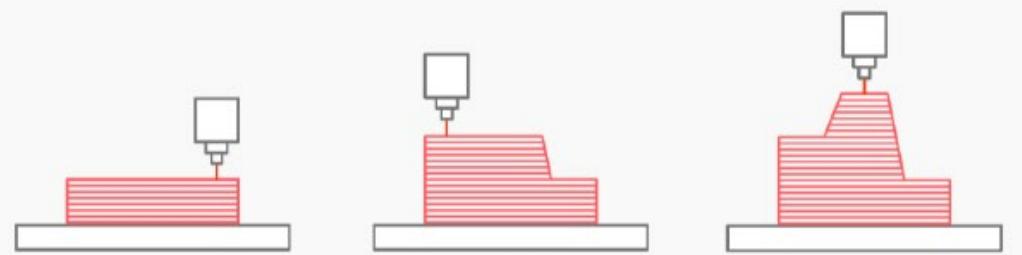
Huaishu Peng | UMD CS | Fall 2022



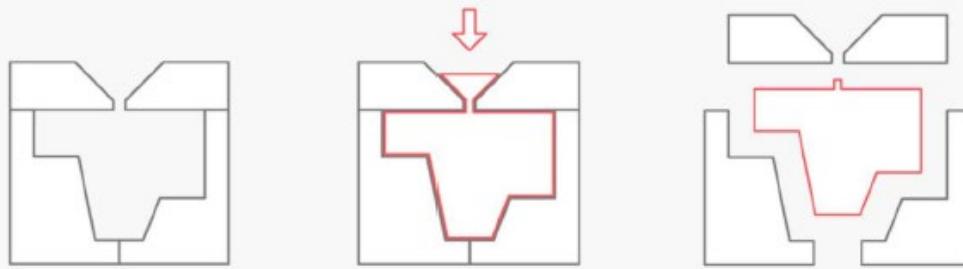
Formative manufacturing



Subtractive manufacturing



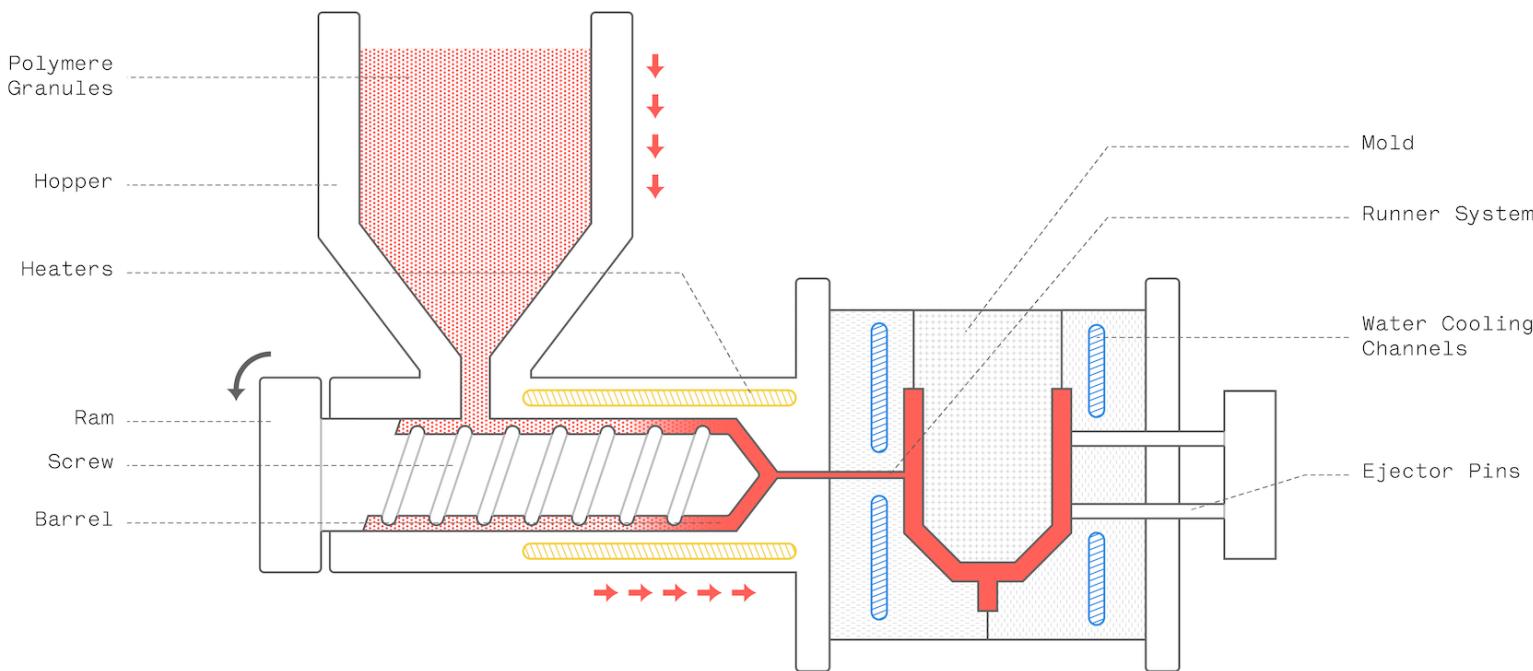
Additive manufacturing

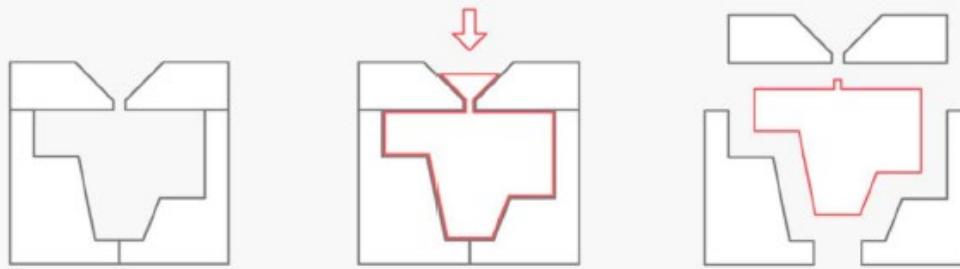


Formative manufacturing

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

Injection Molding



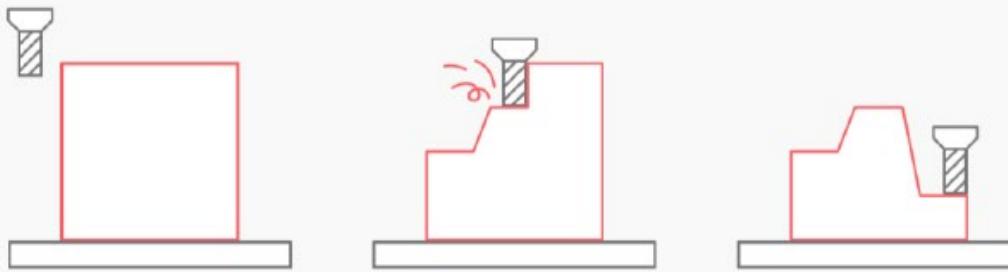


Formative manufacturing

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

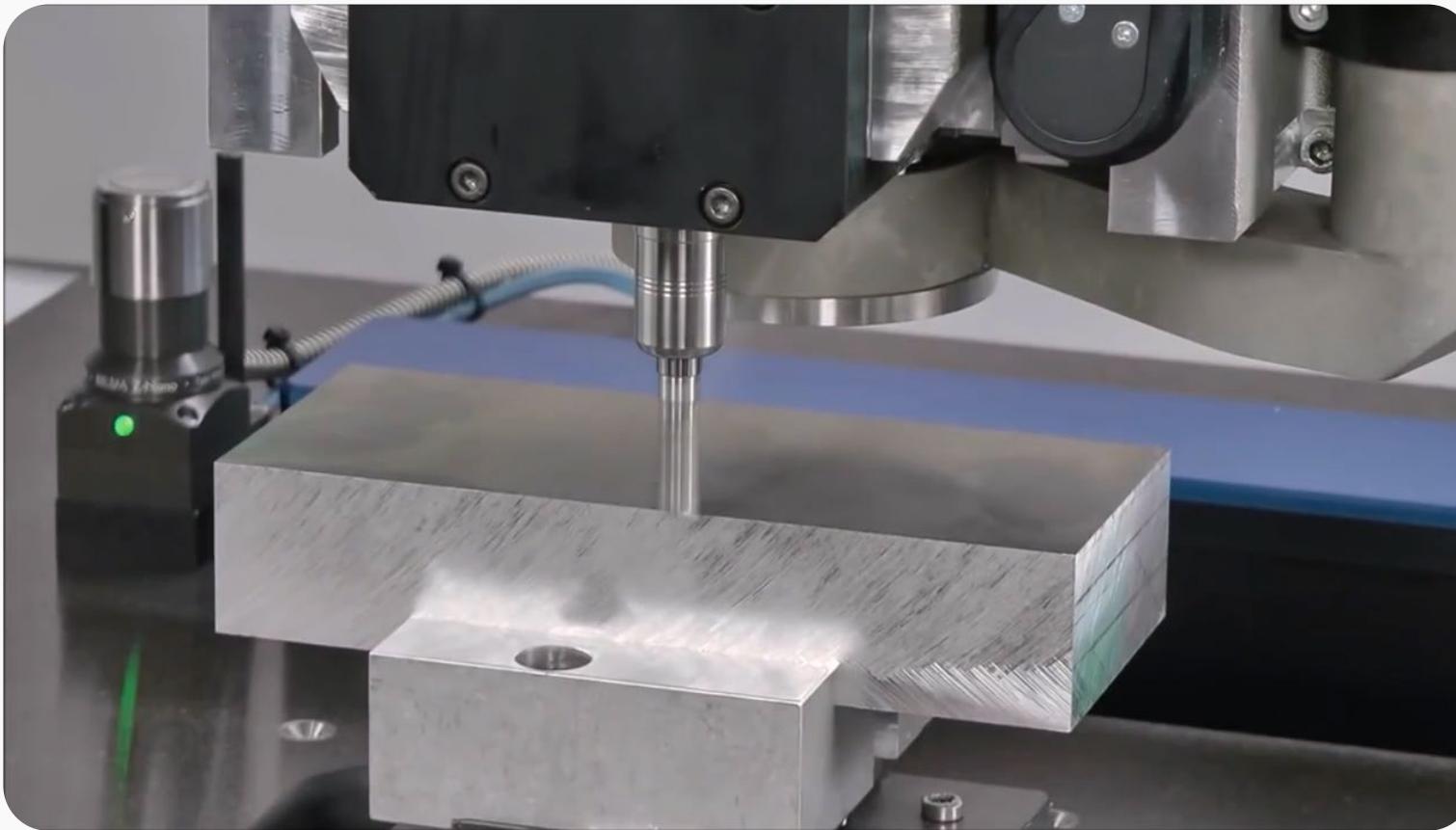


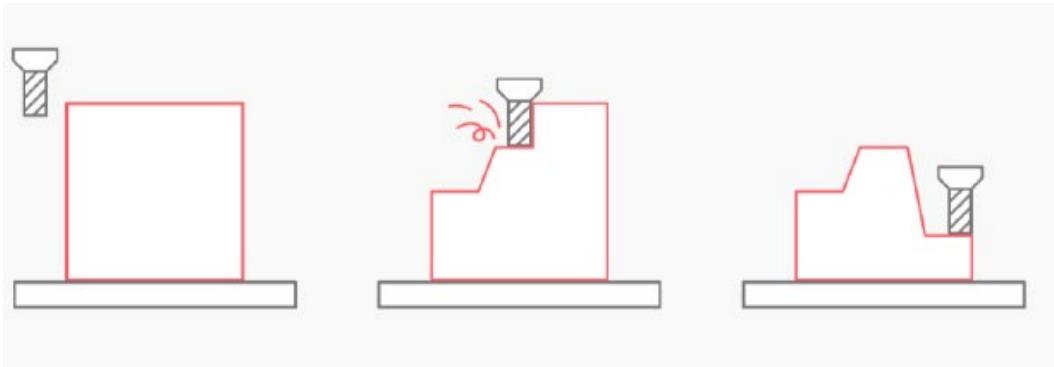
Thermoforming



Subtractive manufacturing

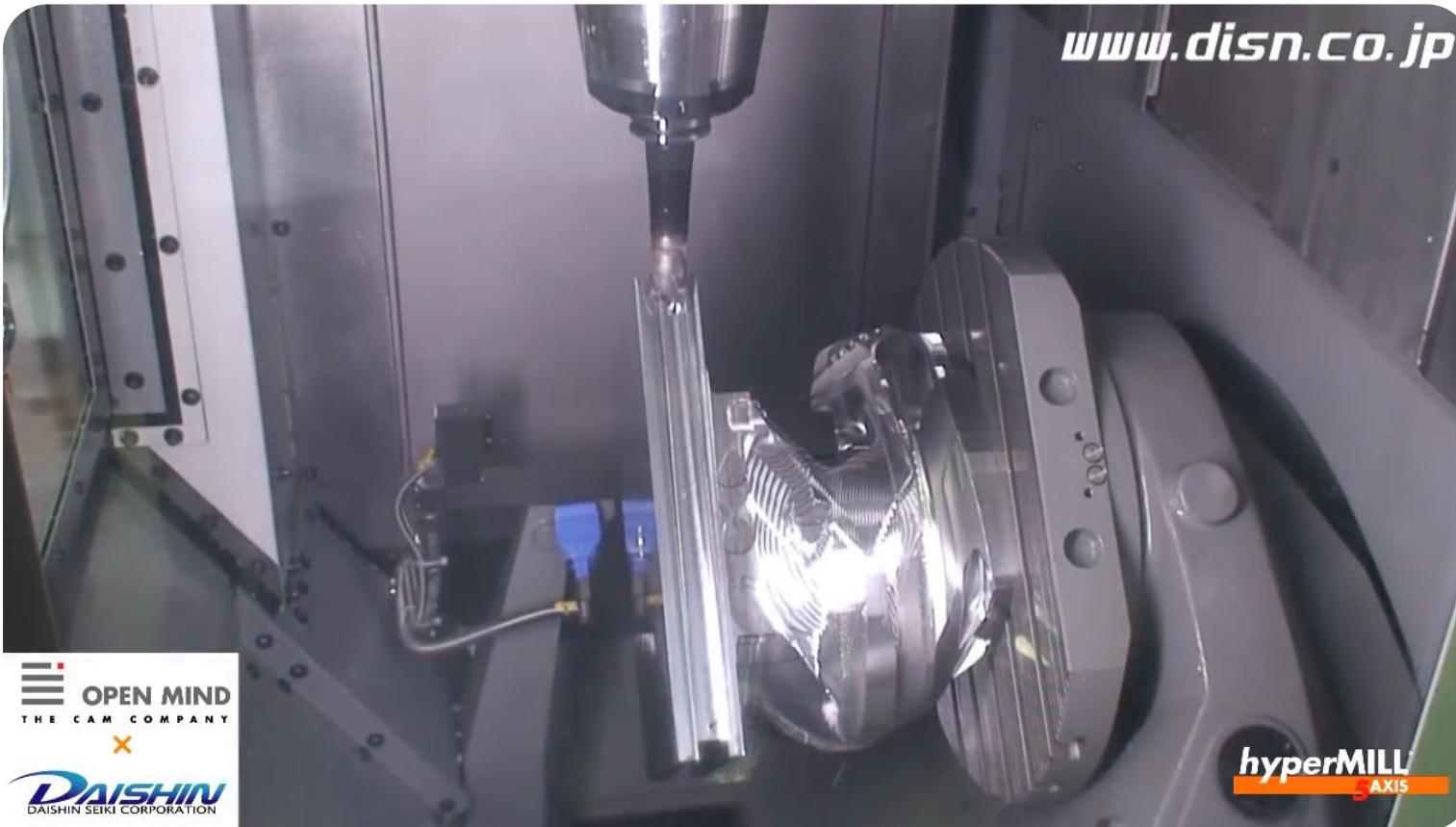
3D objects are constructed by successively cutting material away from a solid block of material.

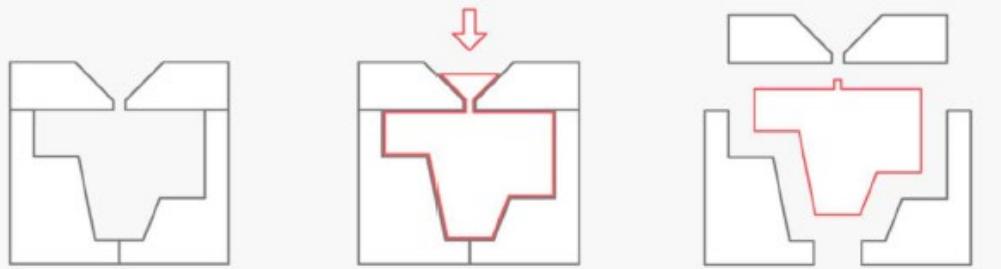




Subtractive manufacturing

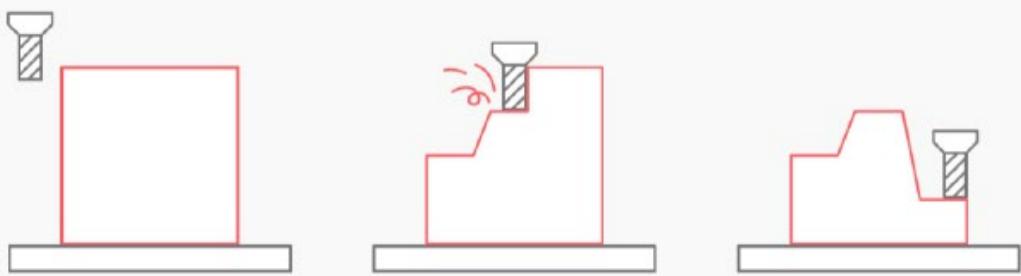
3D objects are constructed by successively cutting material away from a solid block of material.





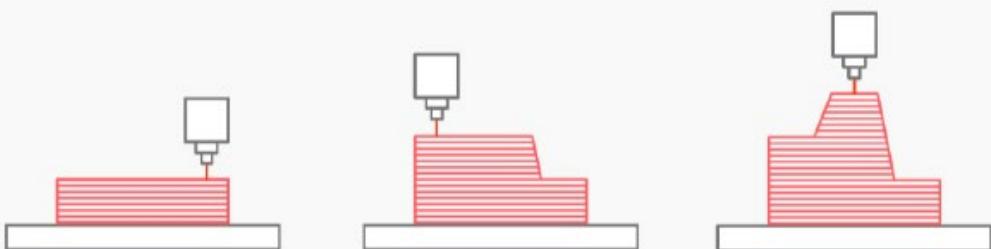
Formative manufacturing

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



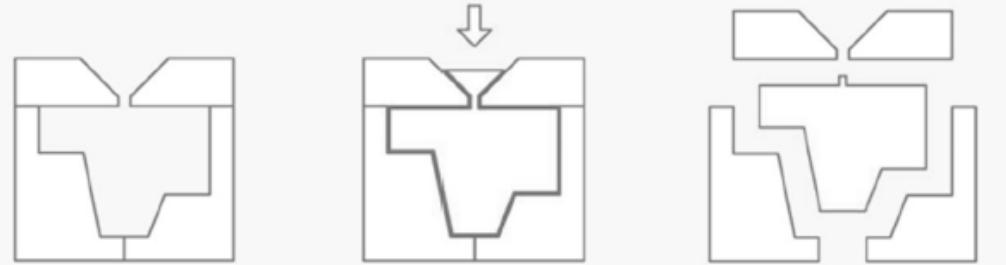
Subtractive manufacturing

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



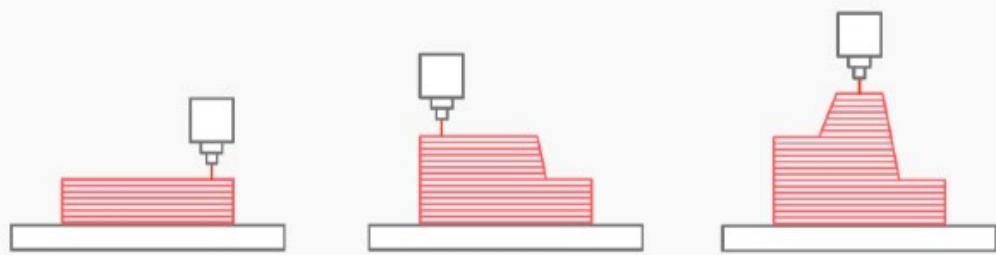
Formative manufacturing

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



Subtractive manufacturing

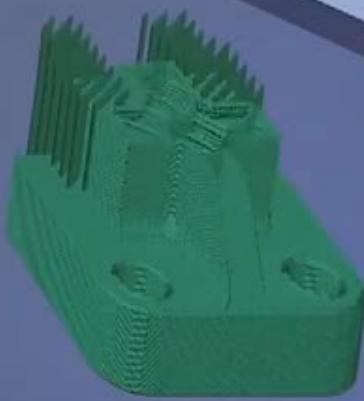
3D objects are constructed by successively cutting material away from a solid block of material.



Additive manufacturing

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

Material Cost: About 20.00g (1.00g
Print Time: About 10.0m



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

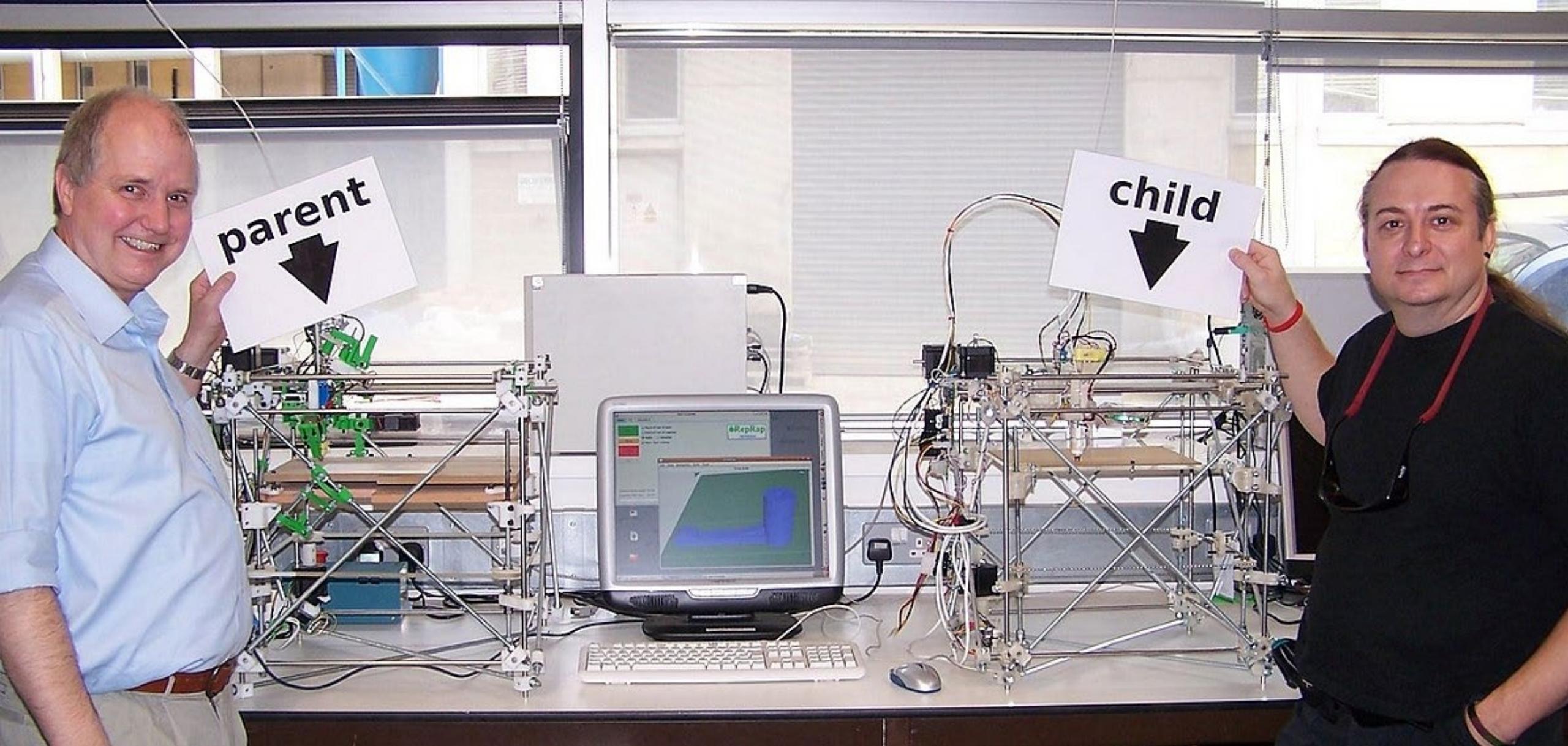


The idea for the technology came to Crump in 1988 when he decided to **make a toy frog for his young daughter using a glue gun** loaded with a mixture of polyethylene and candle wax. He thought of creating the shape layer by layer and of a way to automate the process. In April 1992, Stratasys sold its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

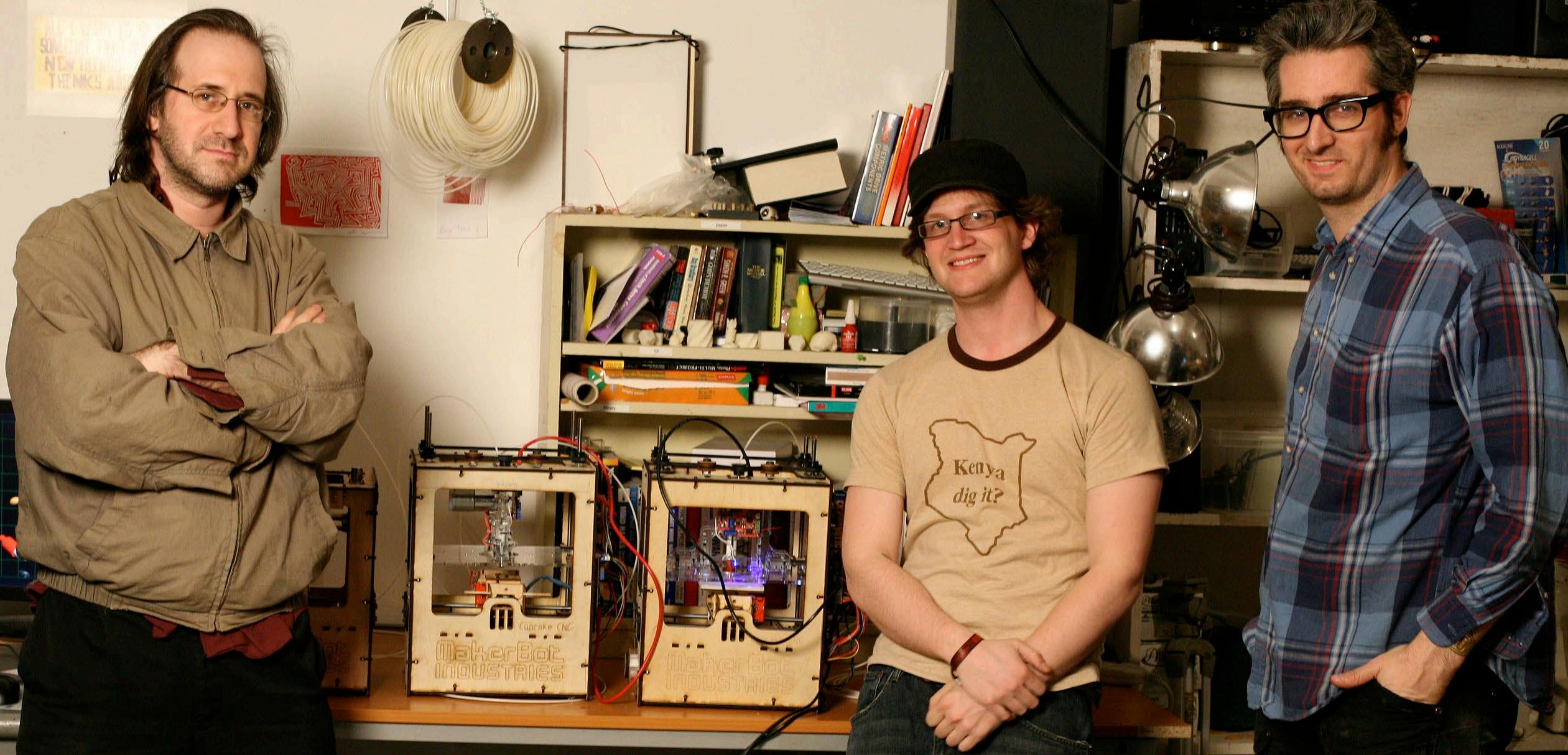


PSH 100

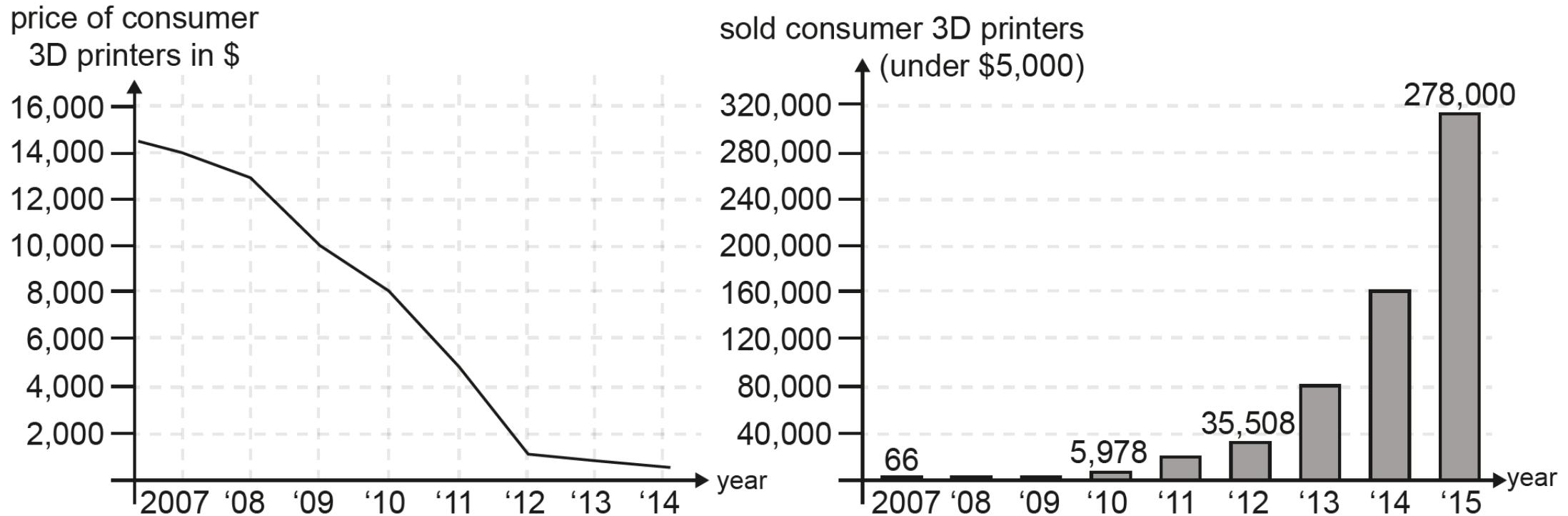
SLM
Solutions Group

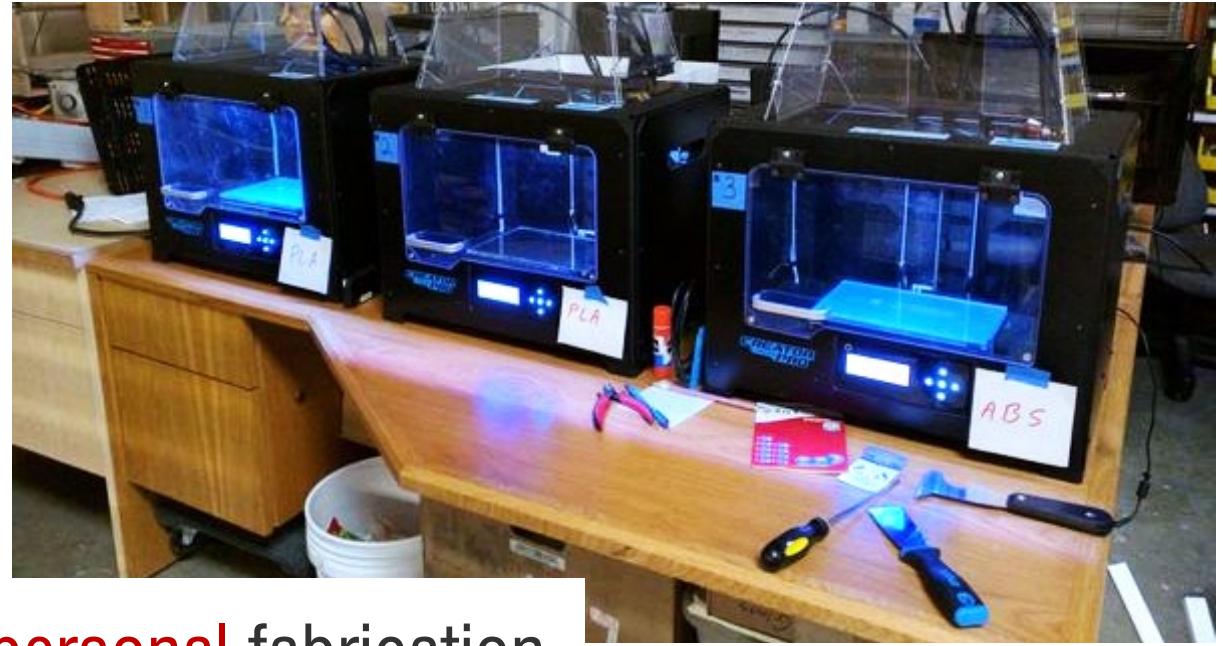


RepRap project started in 2005 at the University of Bath to develop a low-cost 3D-printer that could print most of its components. RepRap stands for **replicating rapid prototype**.



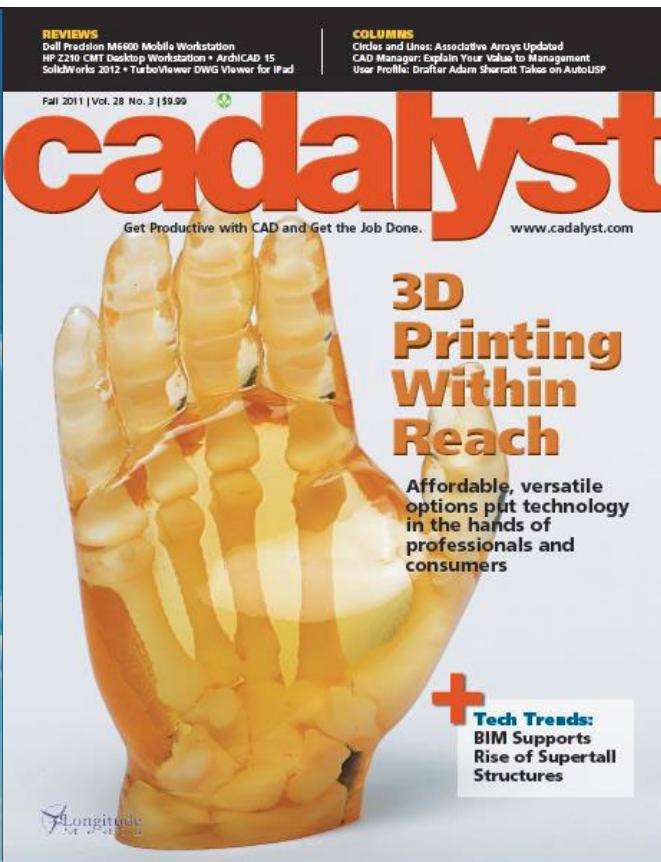
MakerBot founded in **2009** by Adam Mayer, Zach “Hoeken” Smith, and Bre Pettis to build on **RepRap** project.



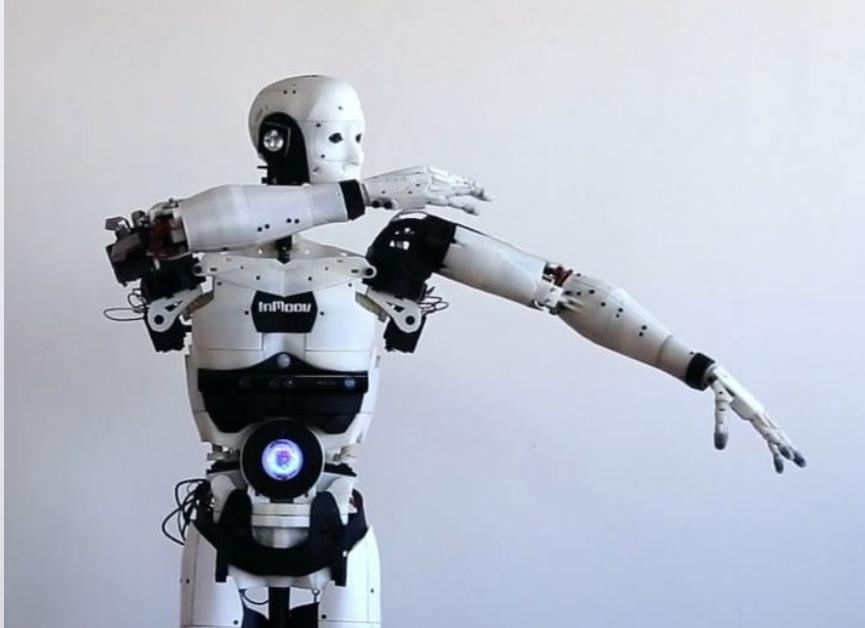
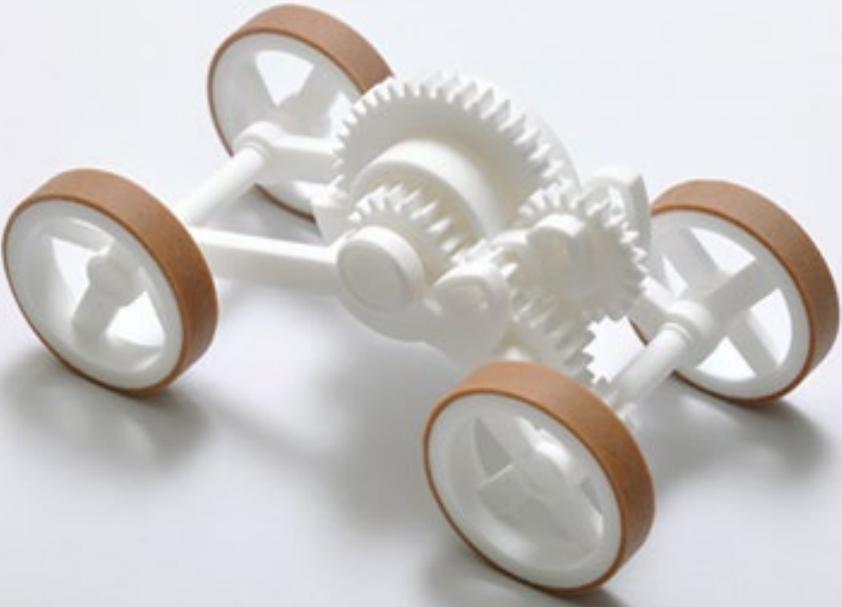


The “new era” of **personal** fabrication

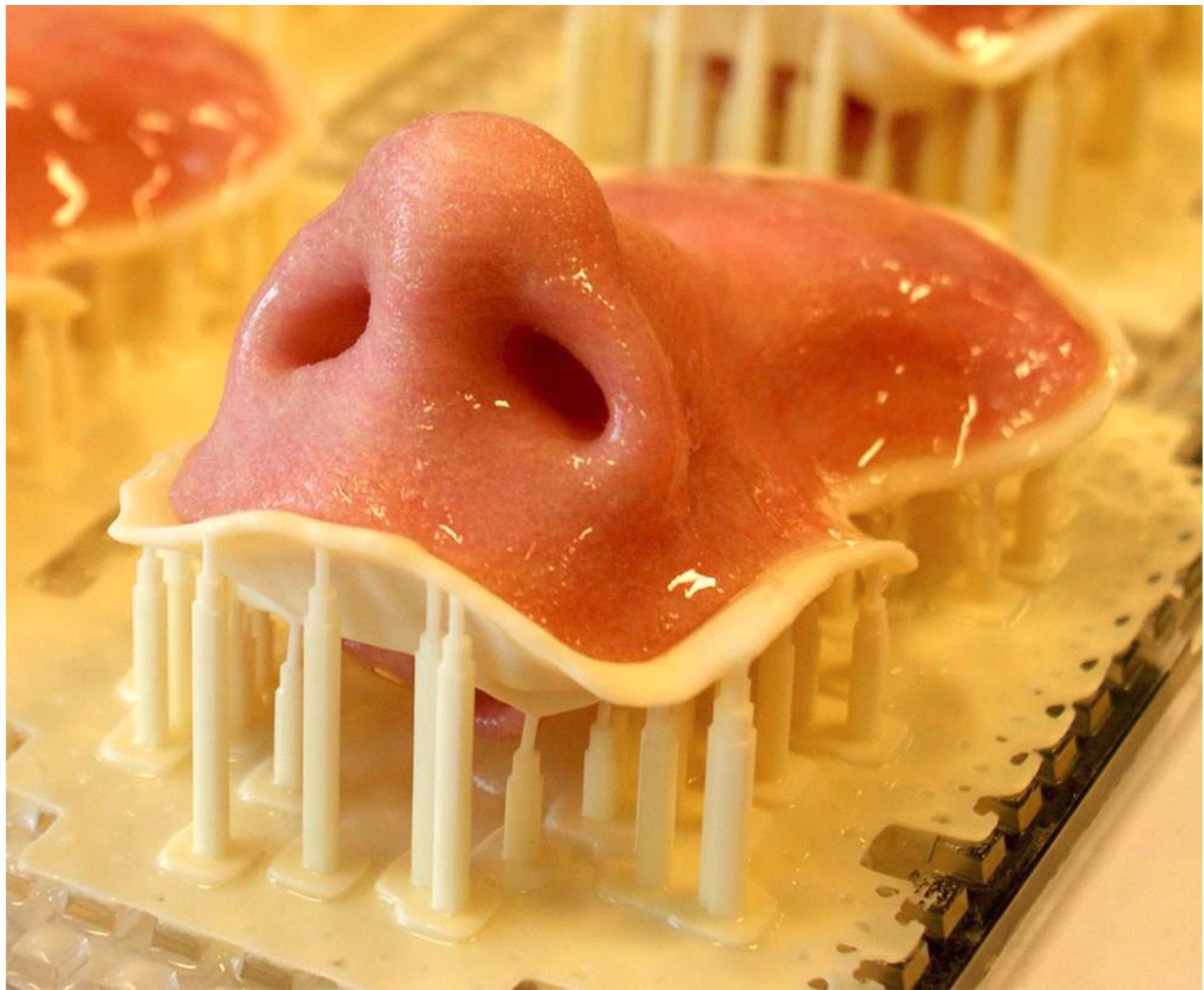
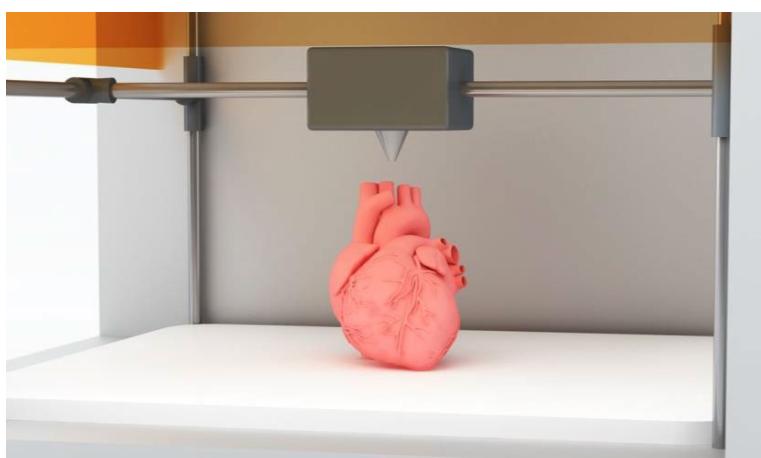
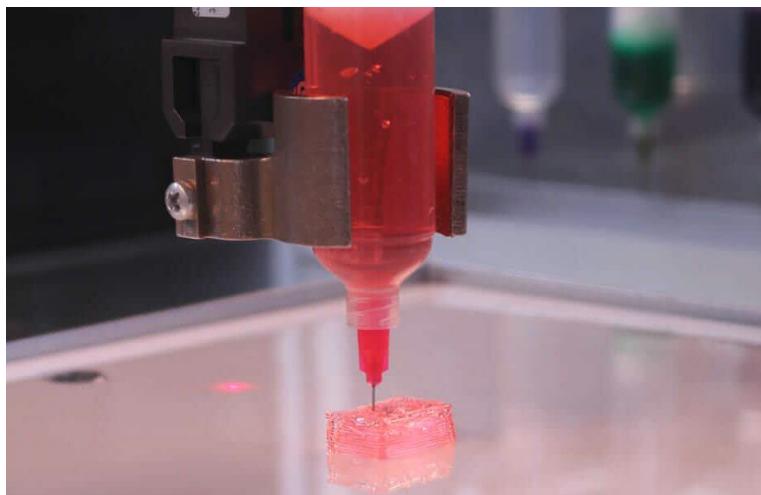




What are the things we know that can be 3D printed?

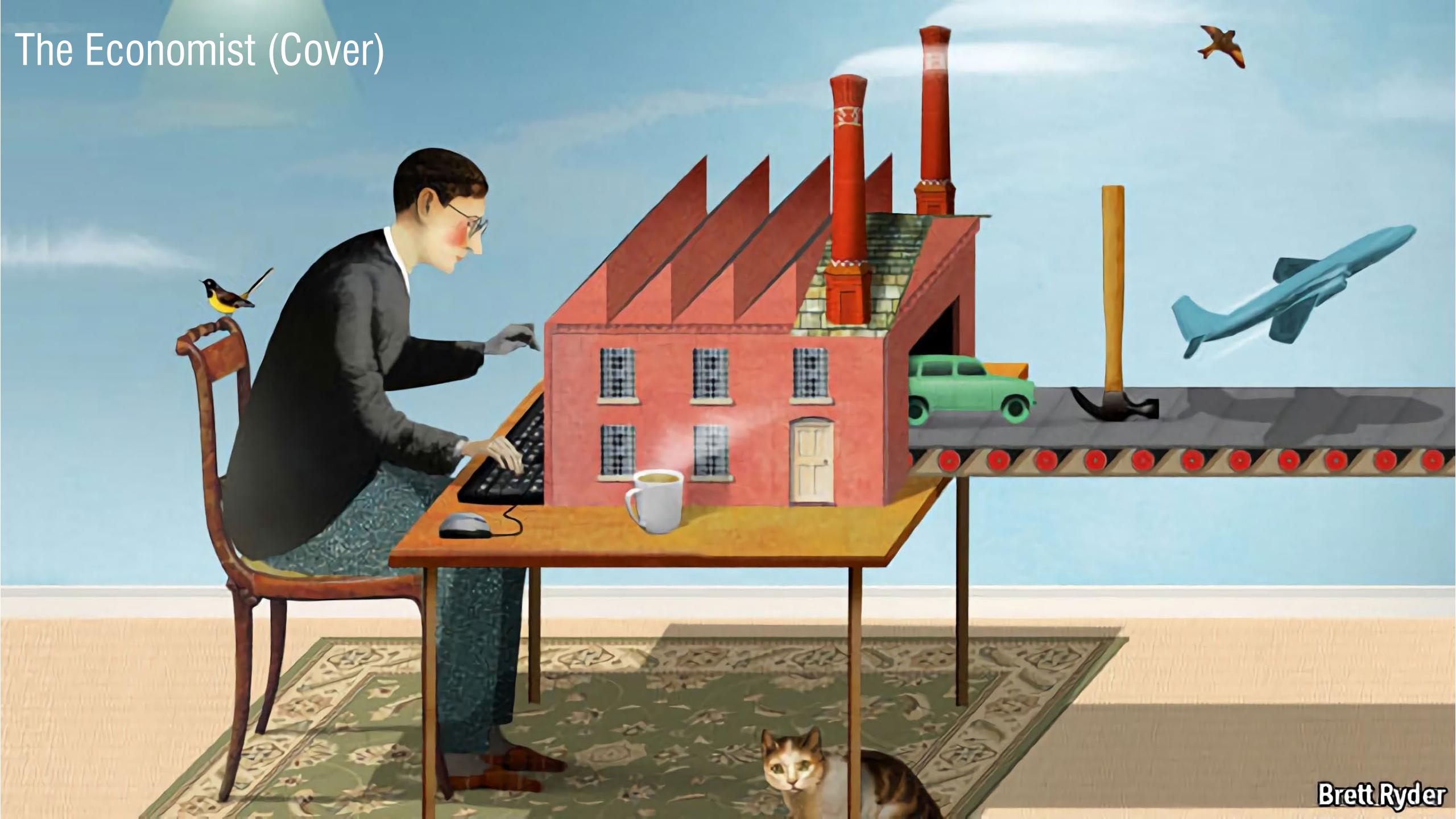


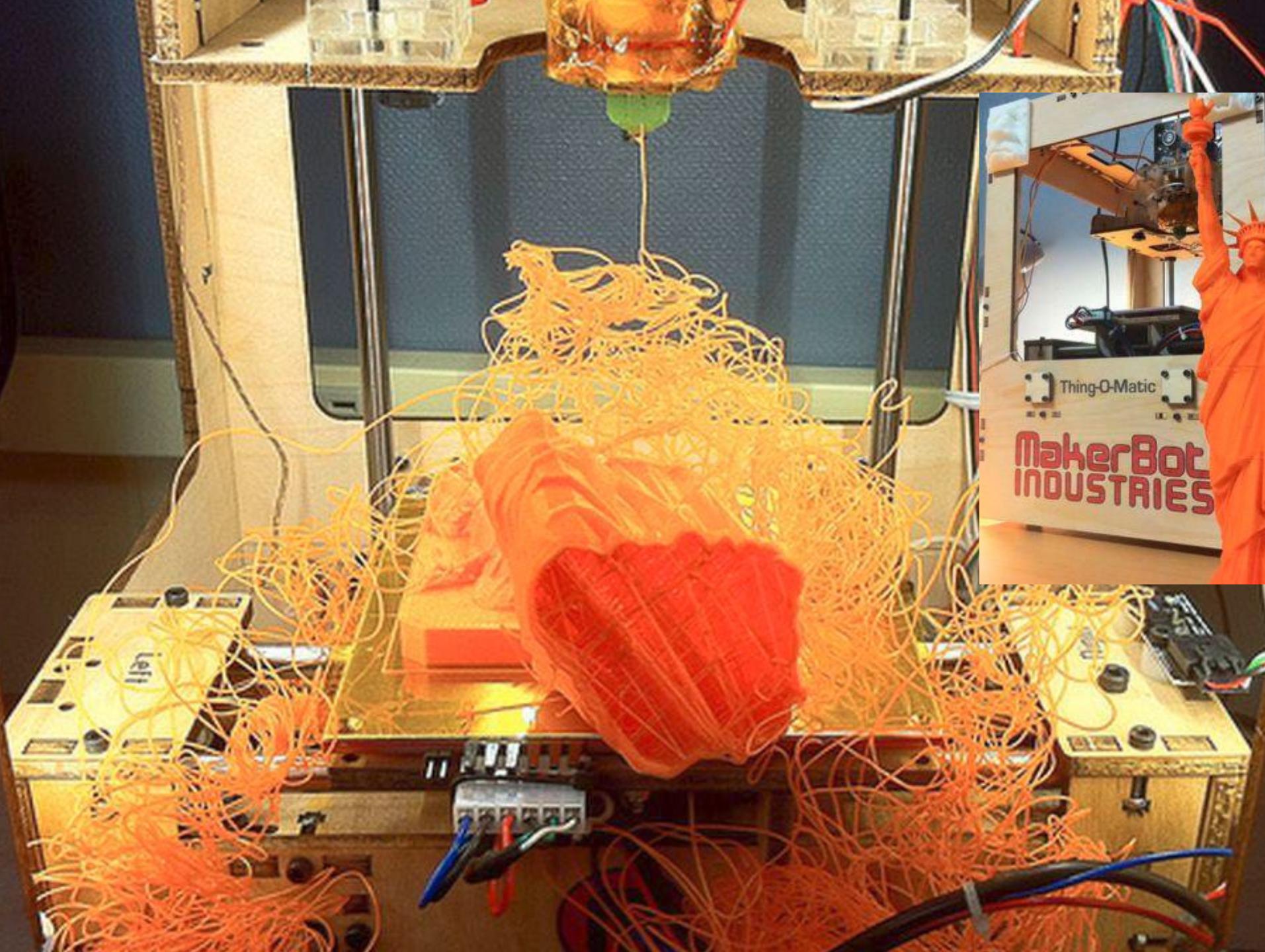




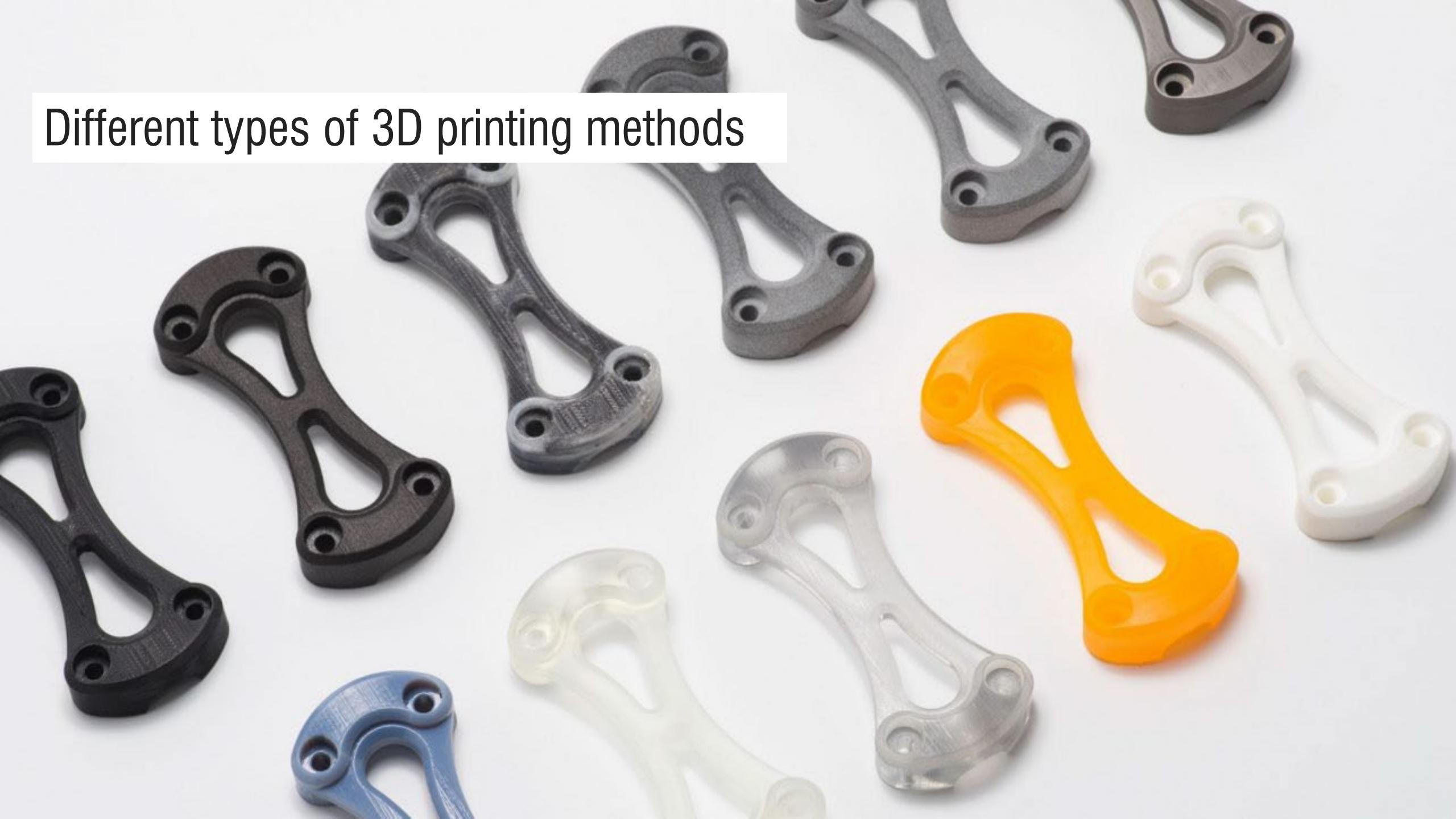


The Economist (Cover)





Different types of 3D printing methods



Different types of 3D printing methods

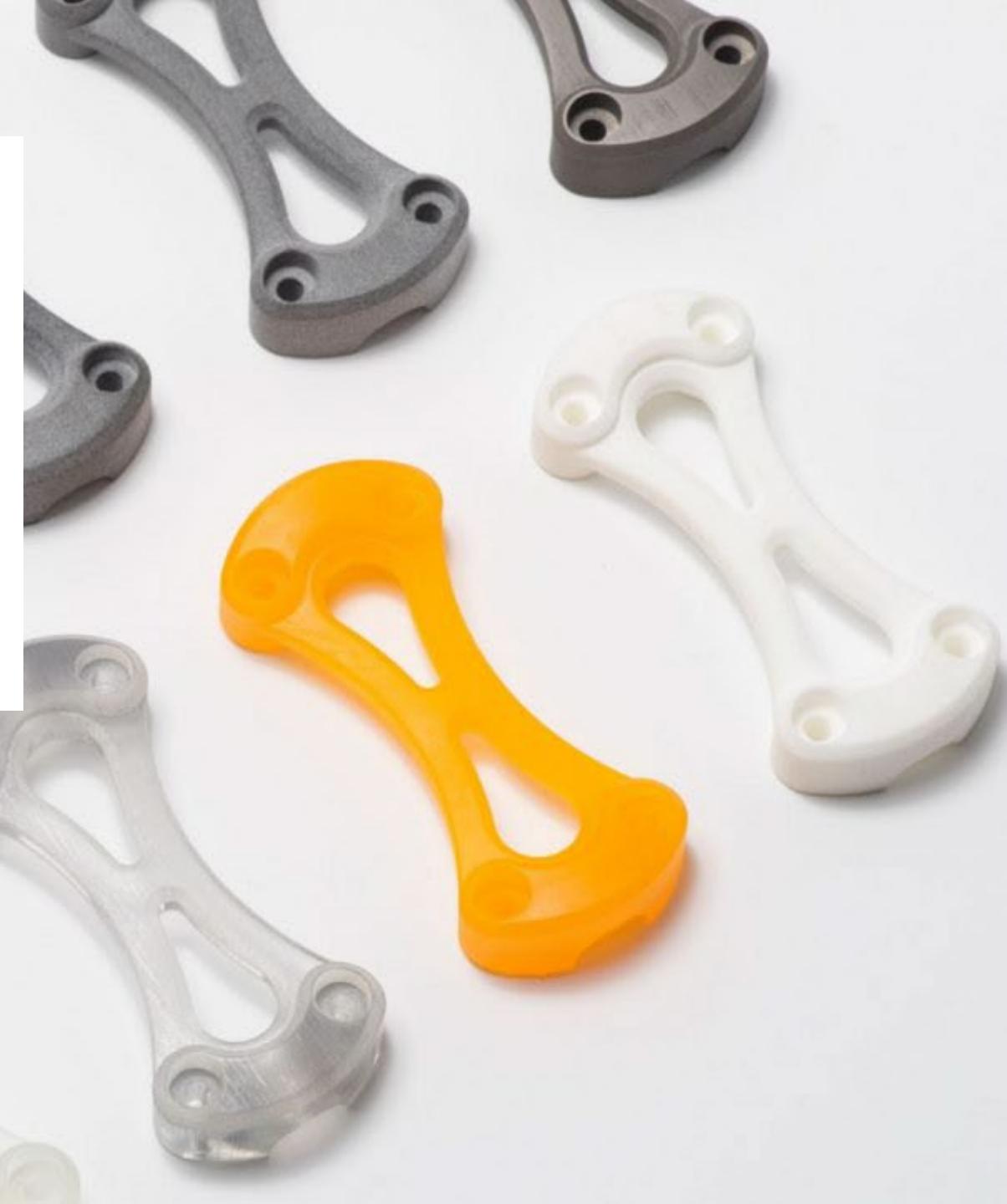
Fused deposition modeling (FDM)

Stereolithography (SLA) / DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)



Different types of 3D printing methods

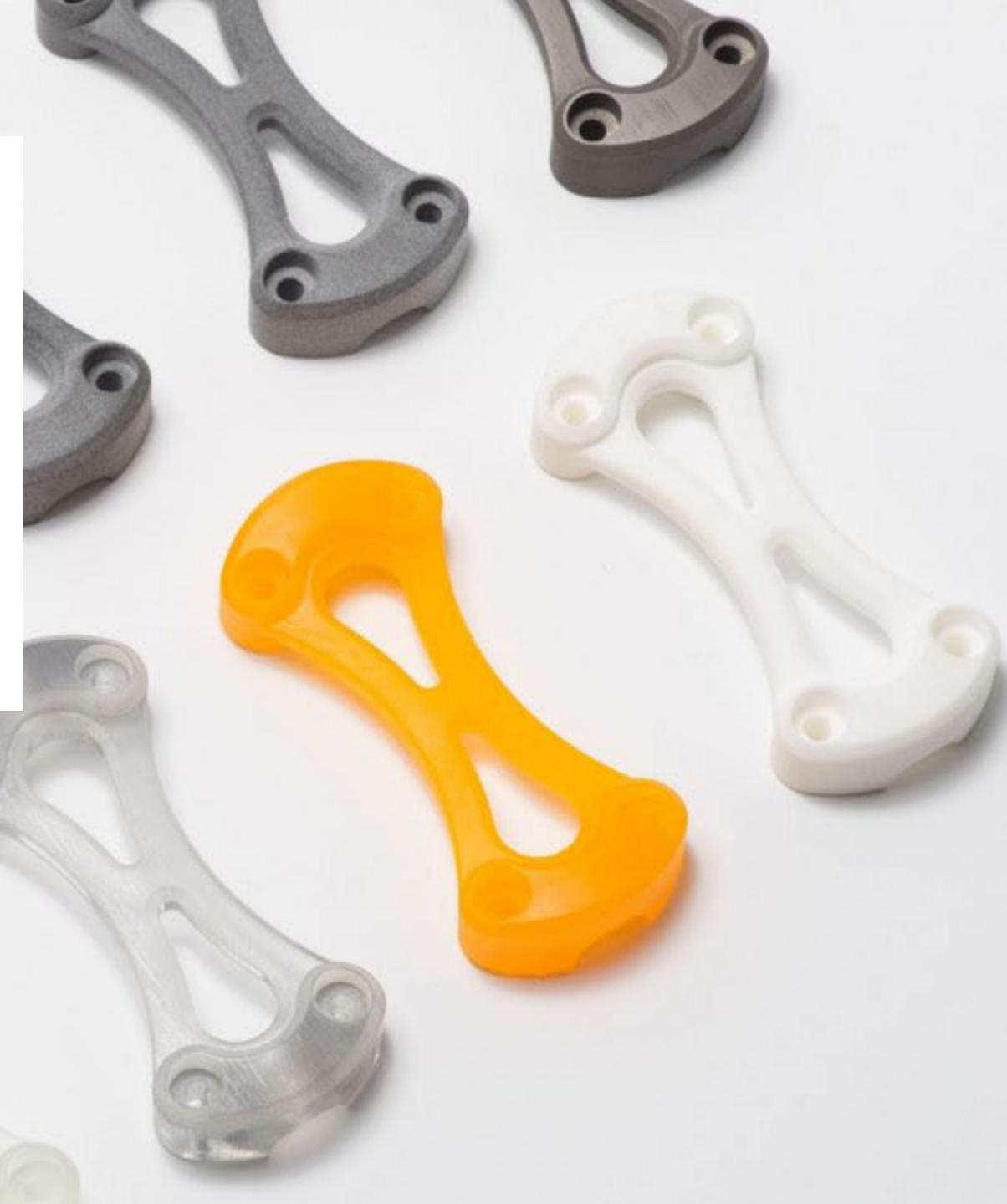
Fused deposition modeling (FDM)

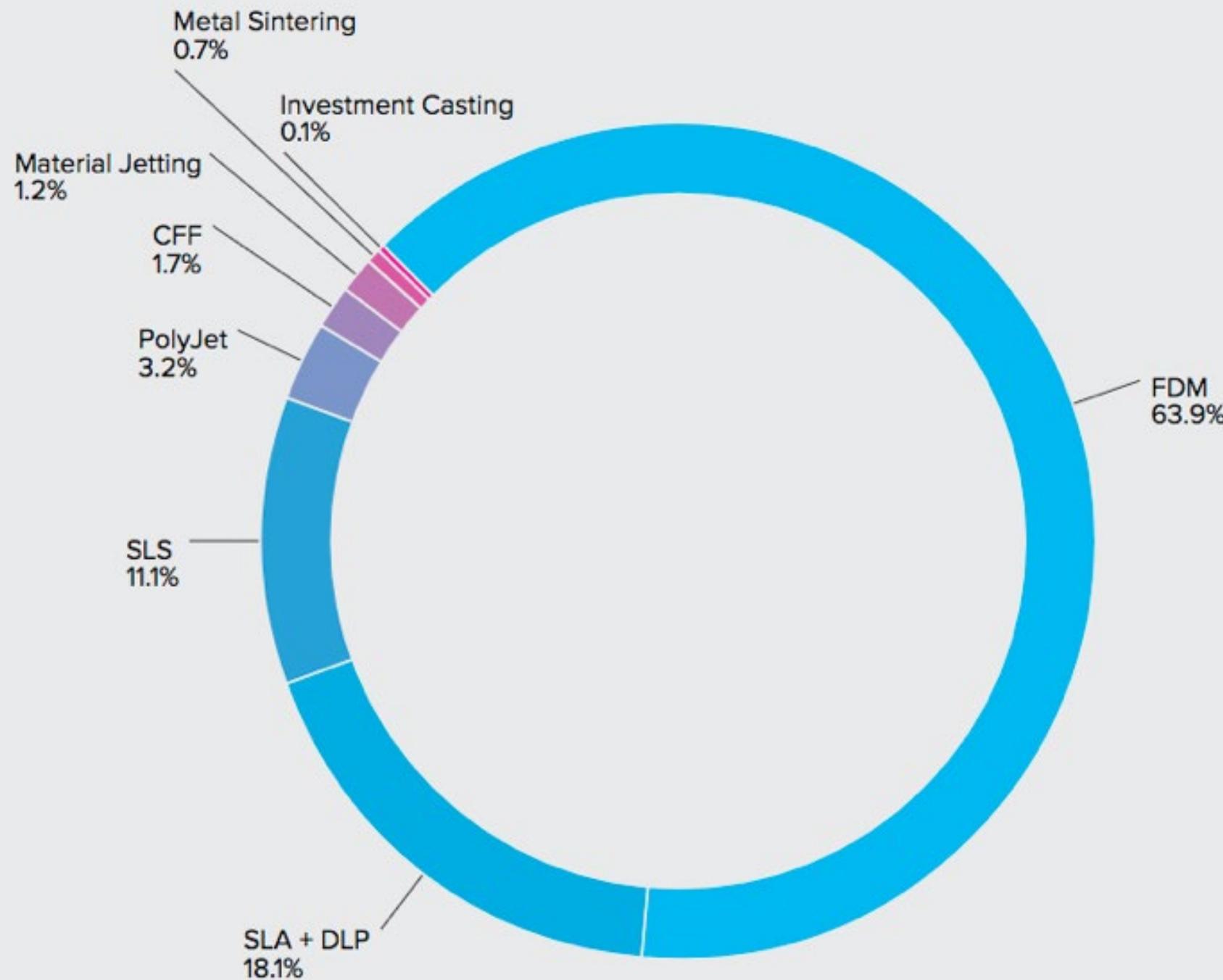
Stereolithography (SLA) / DLP 3D printing

Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

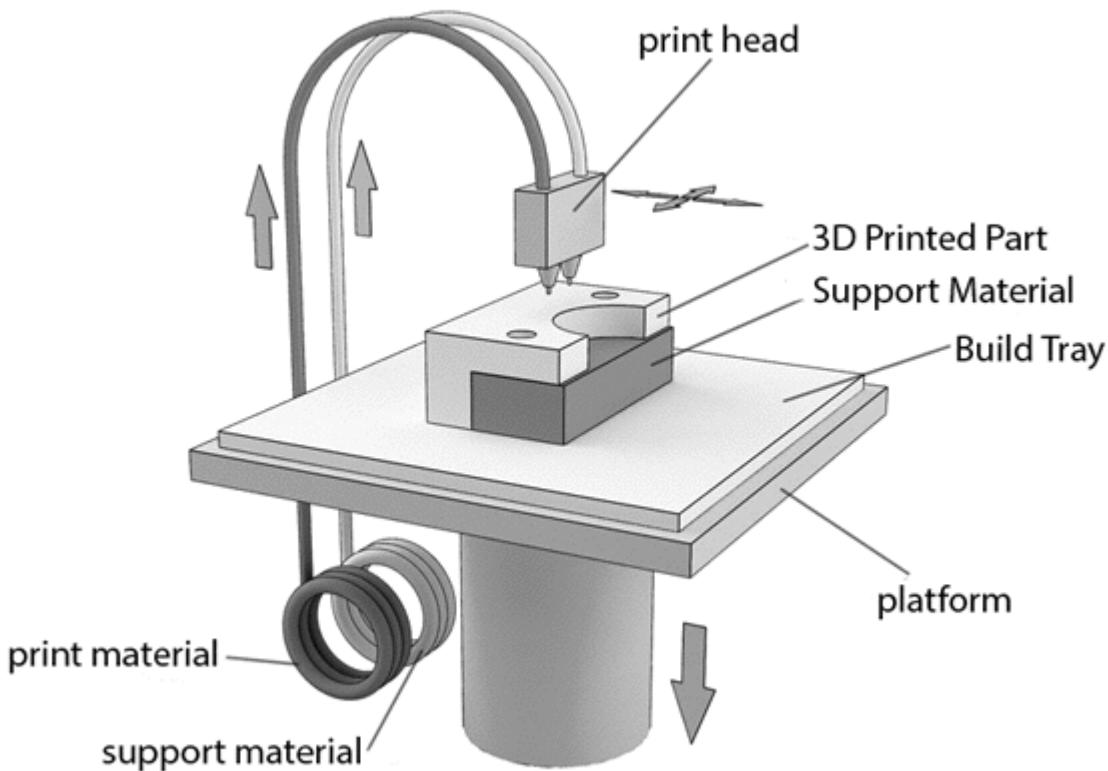
Laminated object manufacturing (LOM)





Fused deposition modeling (FDM)

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



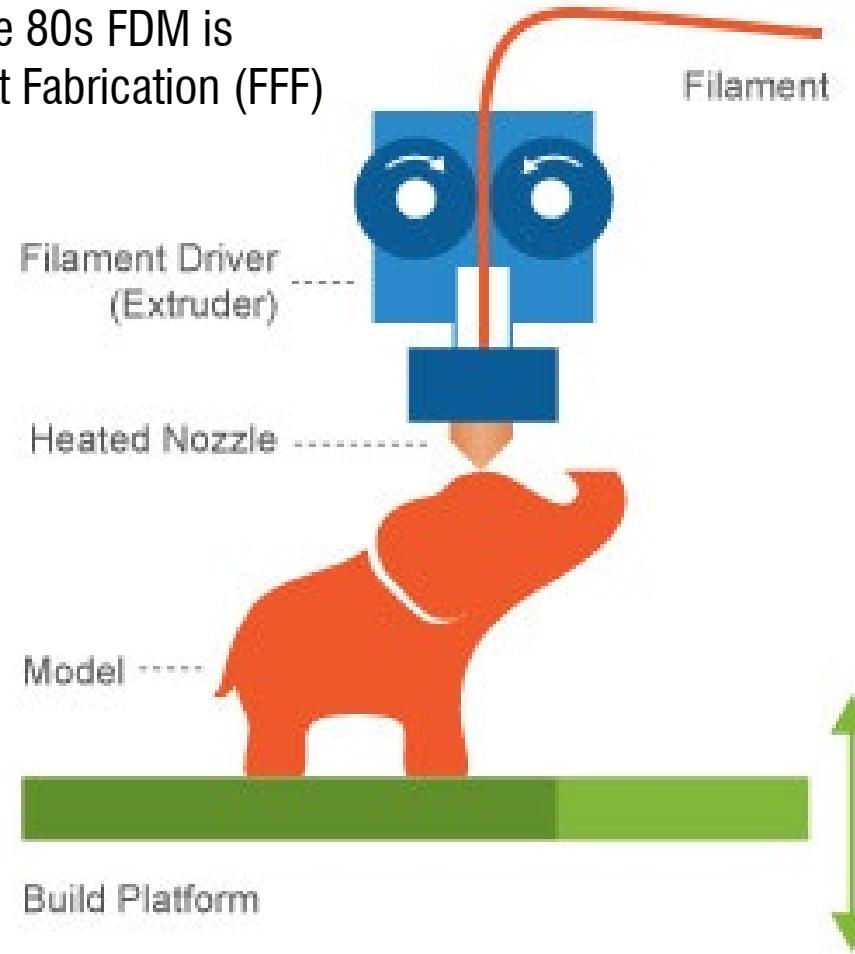
plastic filament on spools

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)

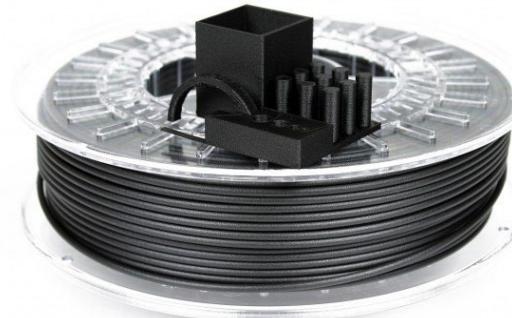


Fused Deposition Modeling (FDM)

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



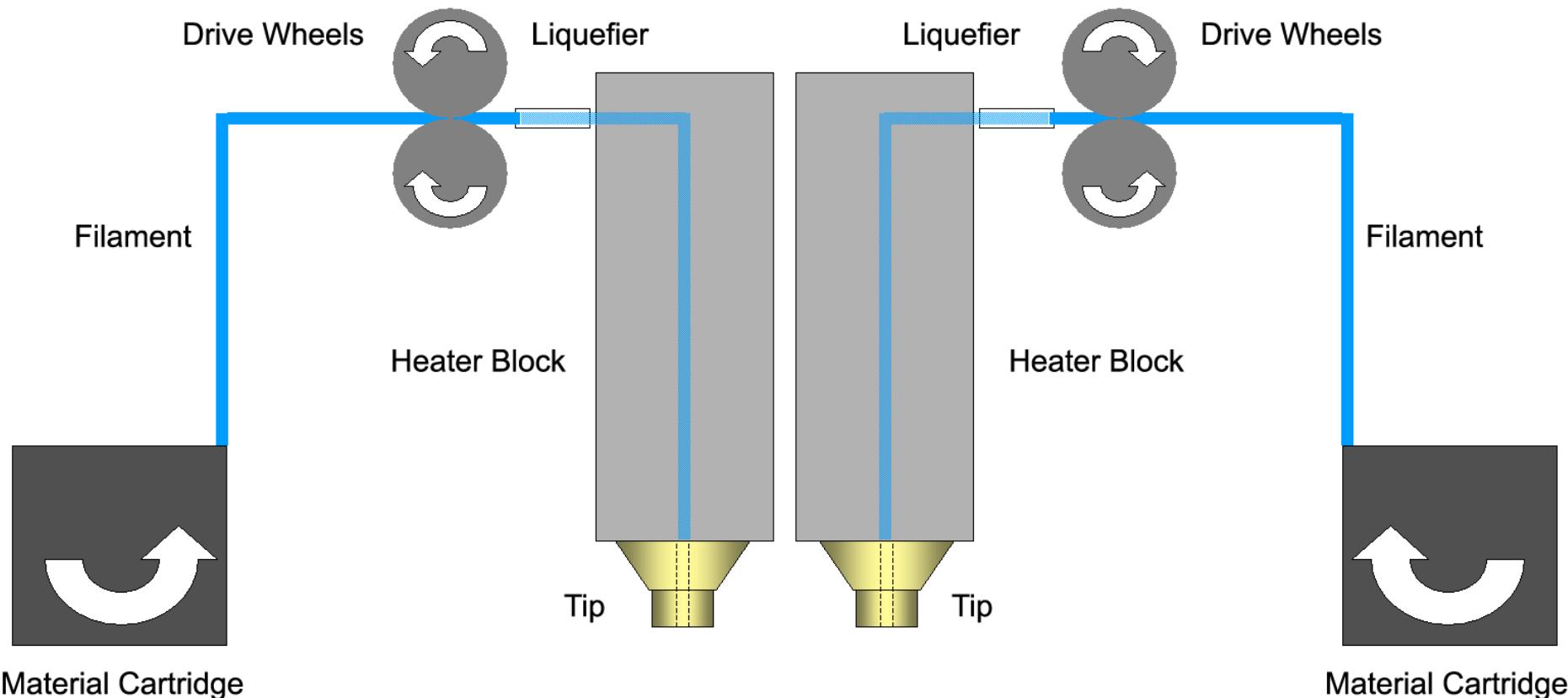
Wood PLA



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

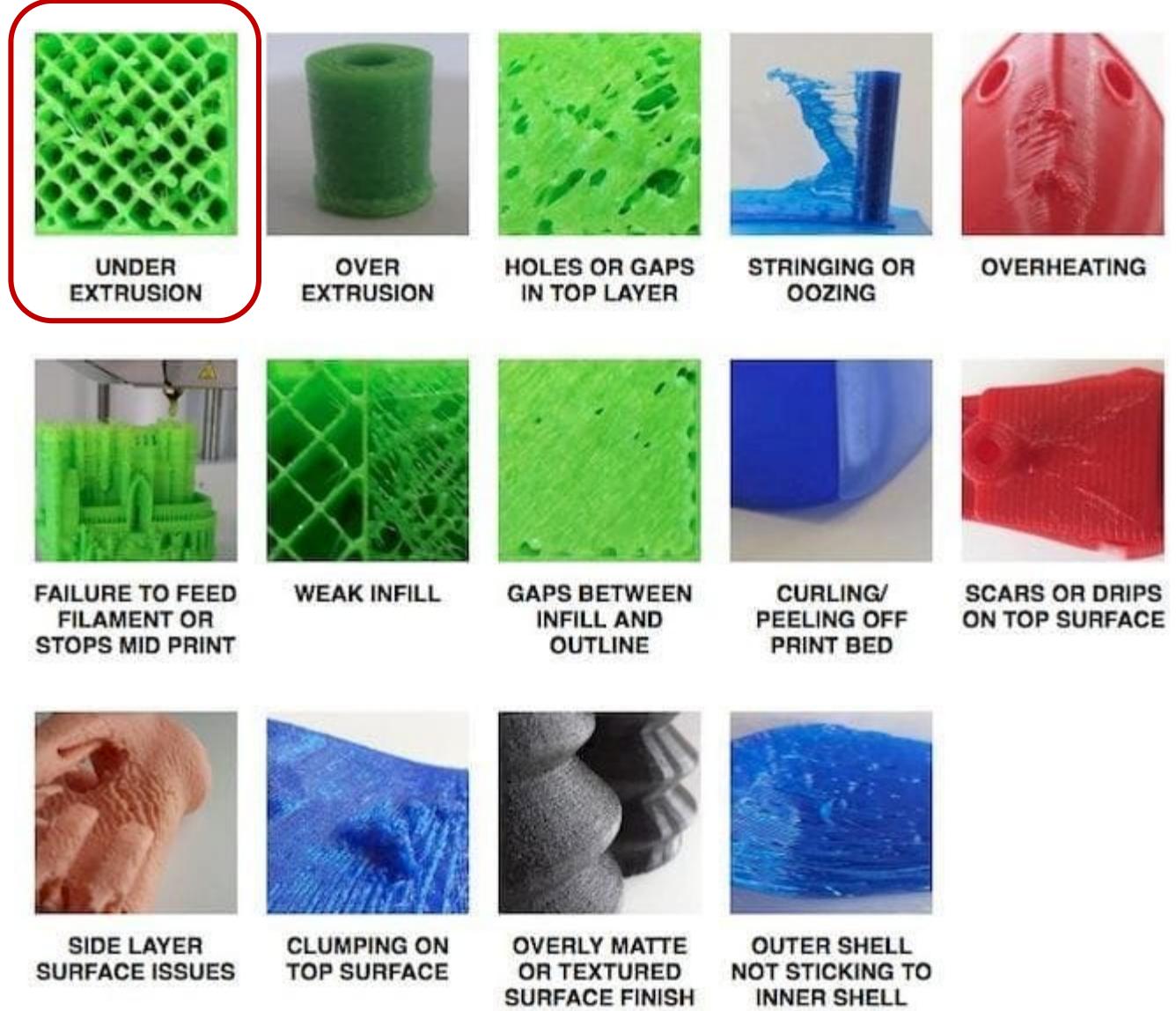
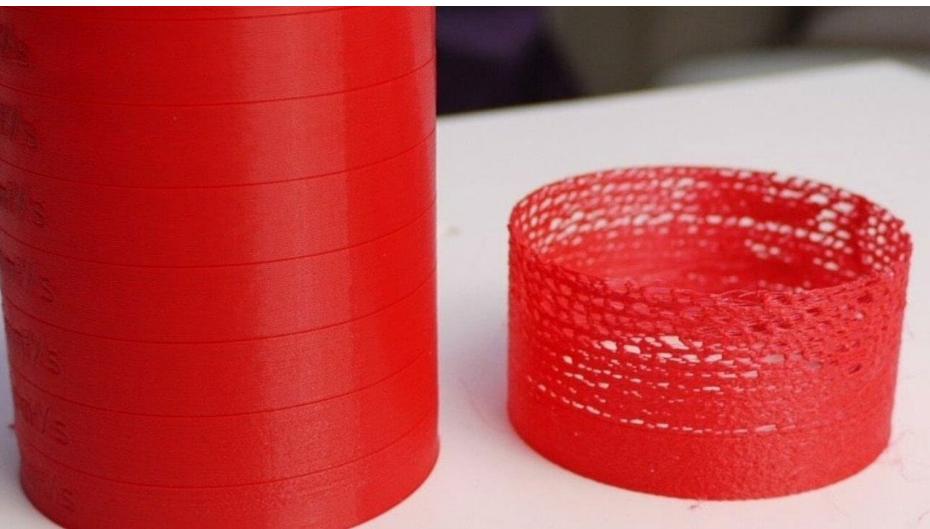
old crushed plastic parts in
new filament out
but: only works a few times, filament
becomes brittle

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

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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 shape a fabric which is then constructed into a 3D object. 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 textures than previous approaches allow. Our approach allows hierarchical control from millimeter structures to decimeter 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 patterns. 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.

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<https://doi.org/10.1145/3373337.3415456>

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Forman et.al.

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 non-traditional production of fully shaped textiles [16, 18]. Despite these advances, the ability to print 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

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

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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 macro-meter structures to decimeter form and is compatible with all common 3D printing.

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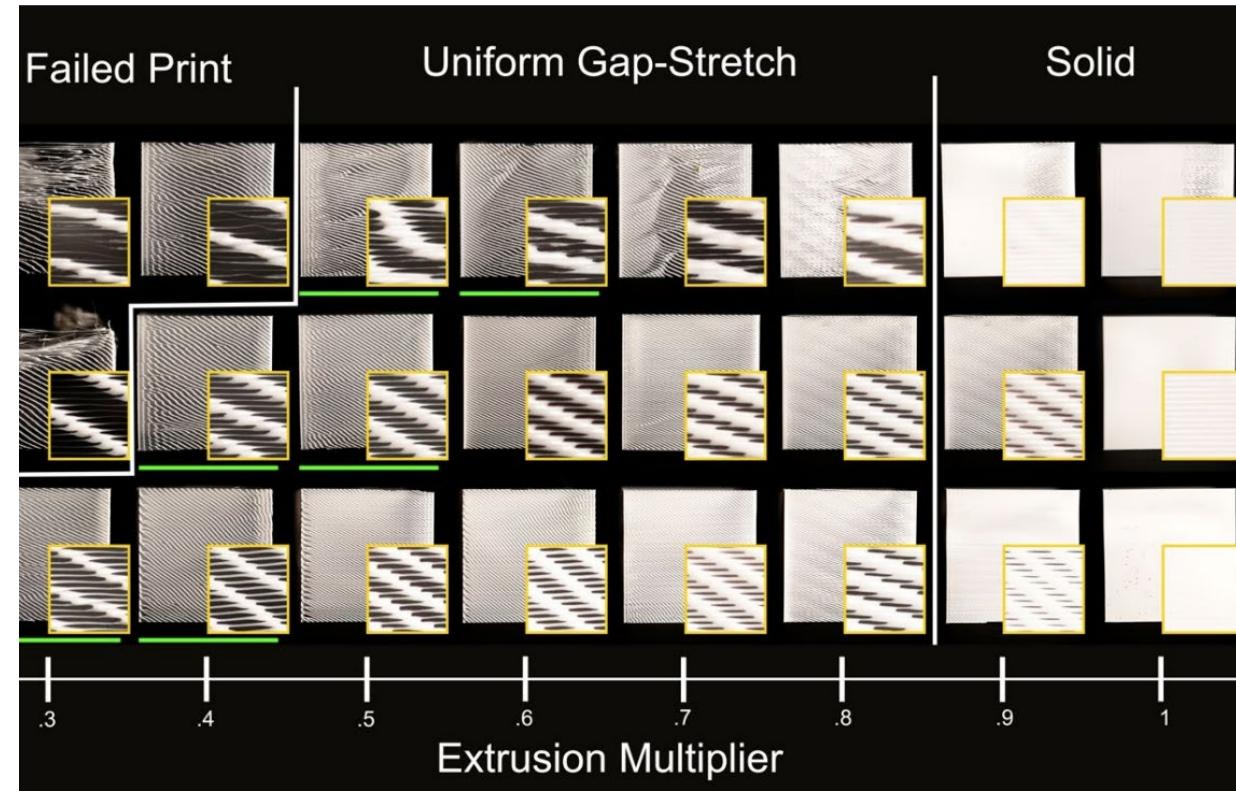
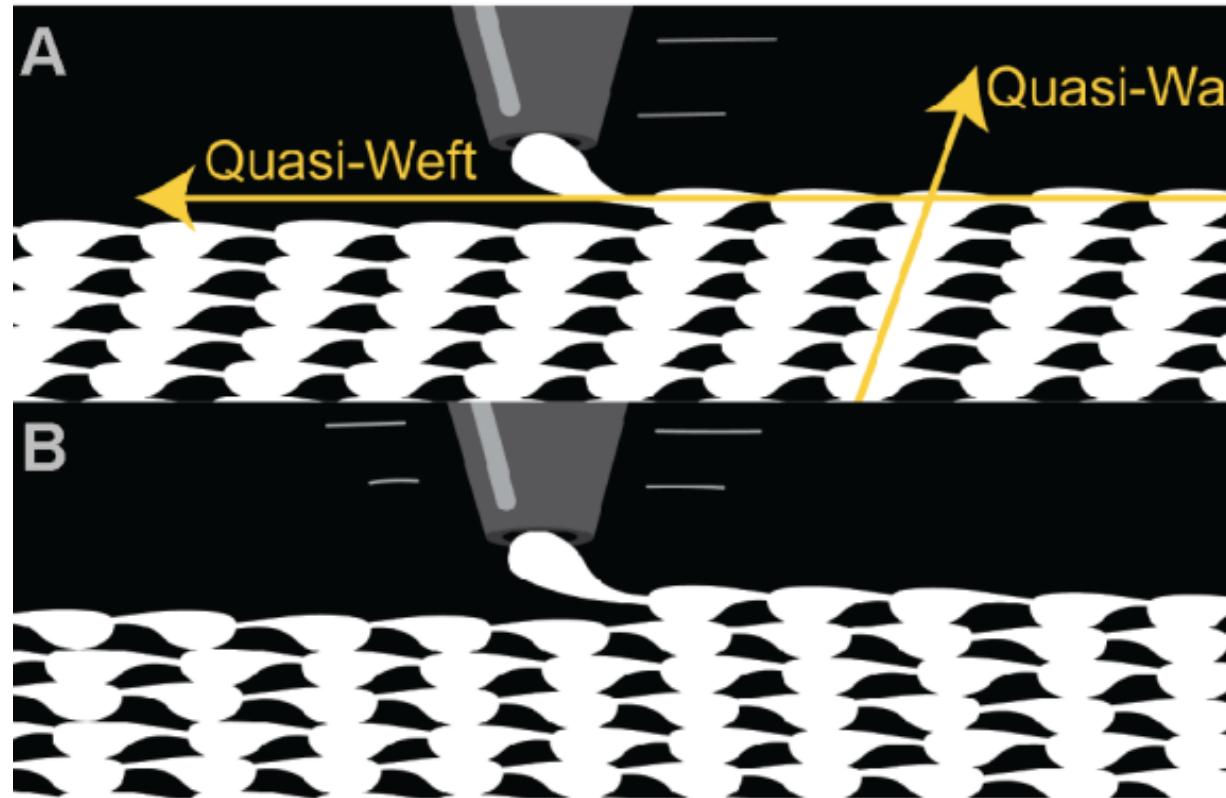
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DefeXtiles: 3D Printing Quasi-Woven Fabric via Under-Extrusion



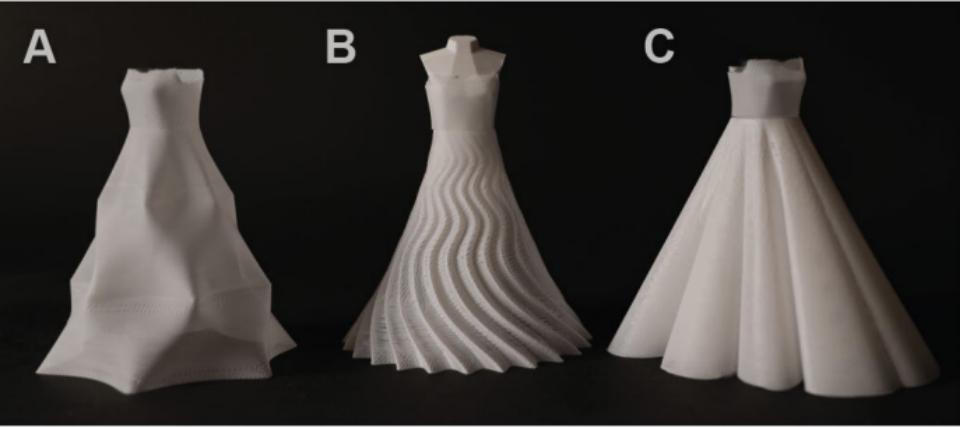


Figure 6: Three miniature dresses printed with PLA all 140cm in height. A) is a dress with a complex non-developable garment. In B) the dress and the dress form are printed simultaneously. C) shows a wedding gown with 3 layers of fabric affording opacity.

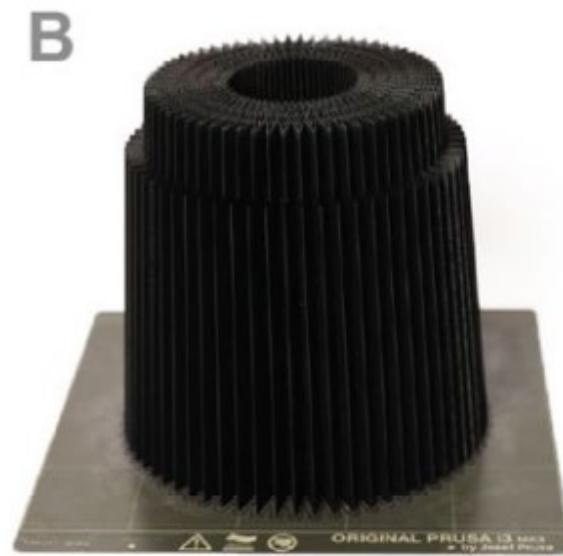
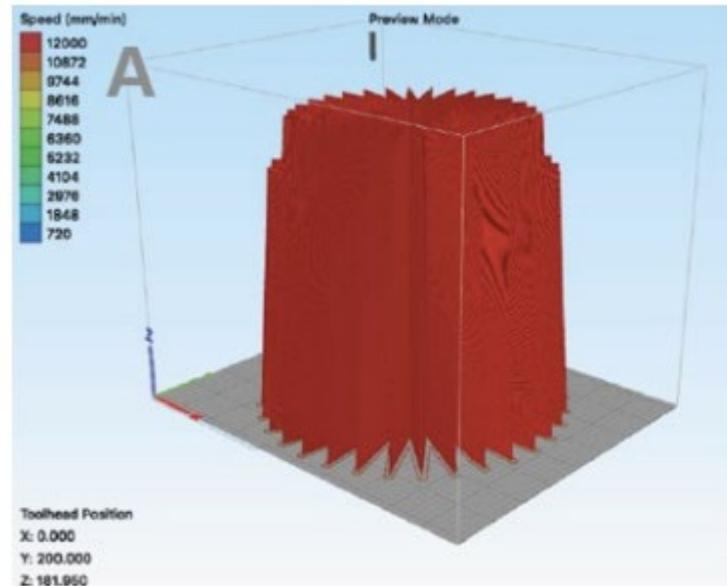


Figure 7: A) The digital version of the pleated skirt design. B) The 3D printed version. C) The unpacked version worn.

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

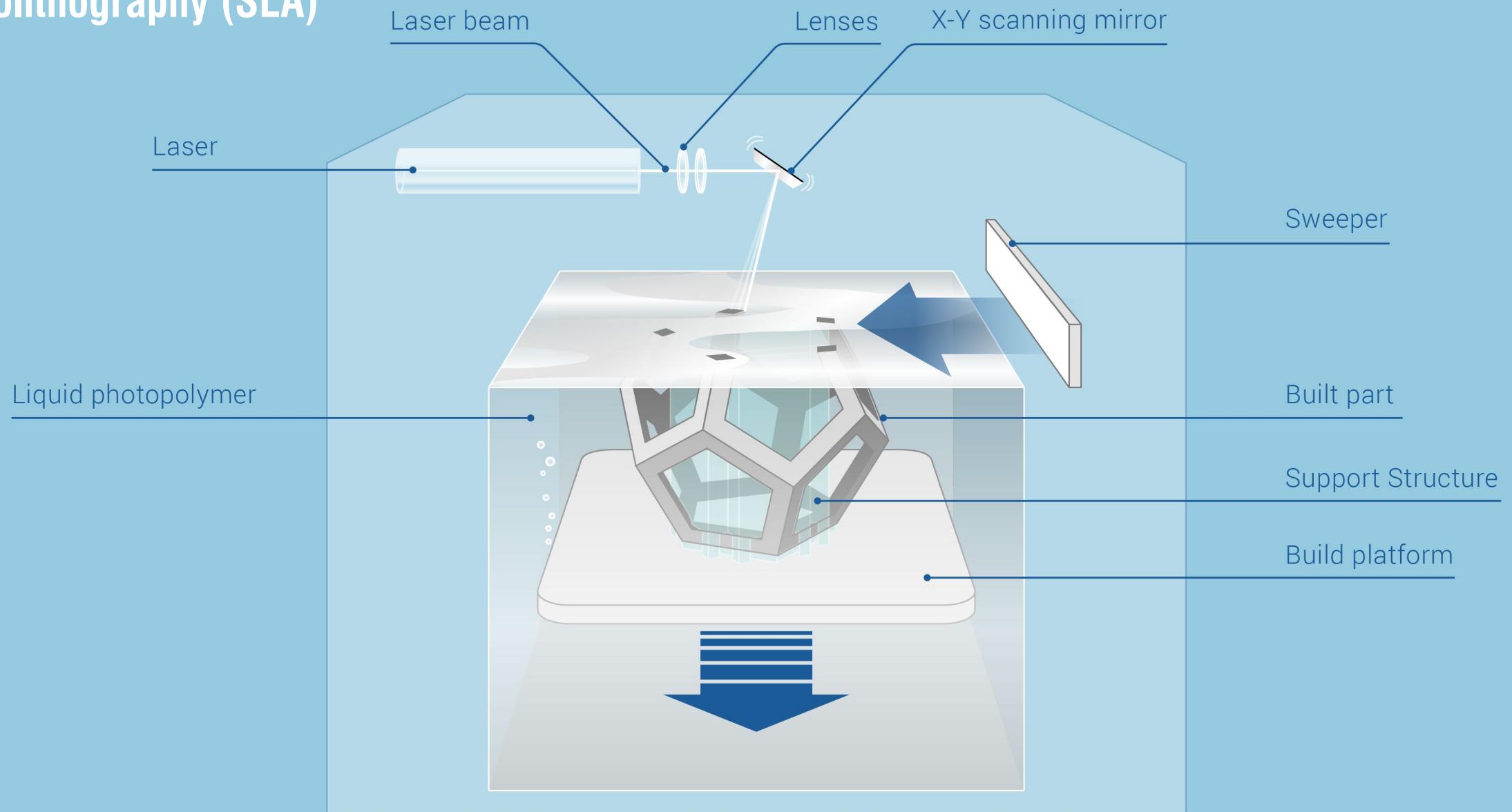
Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

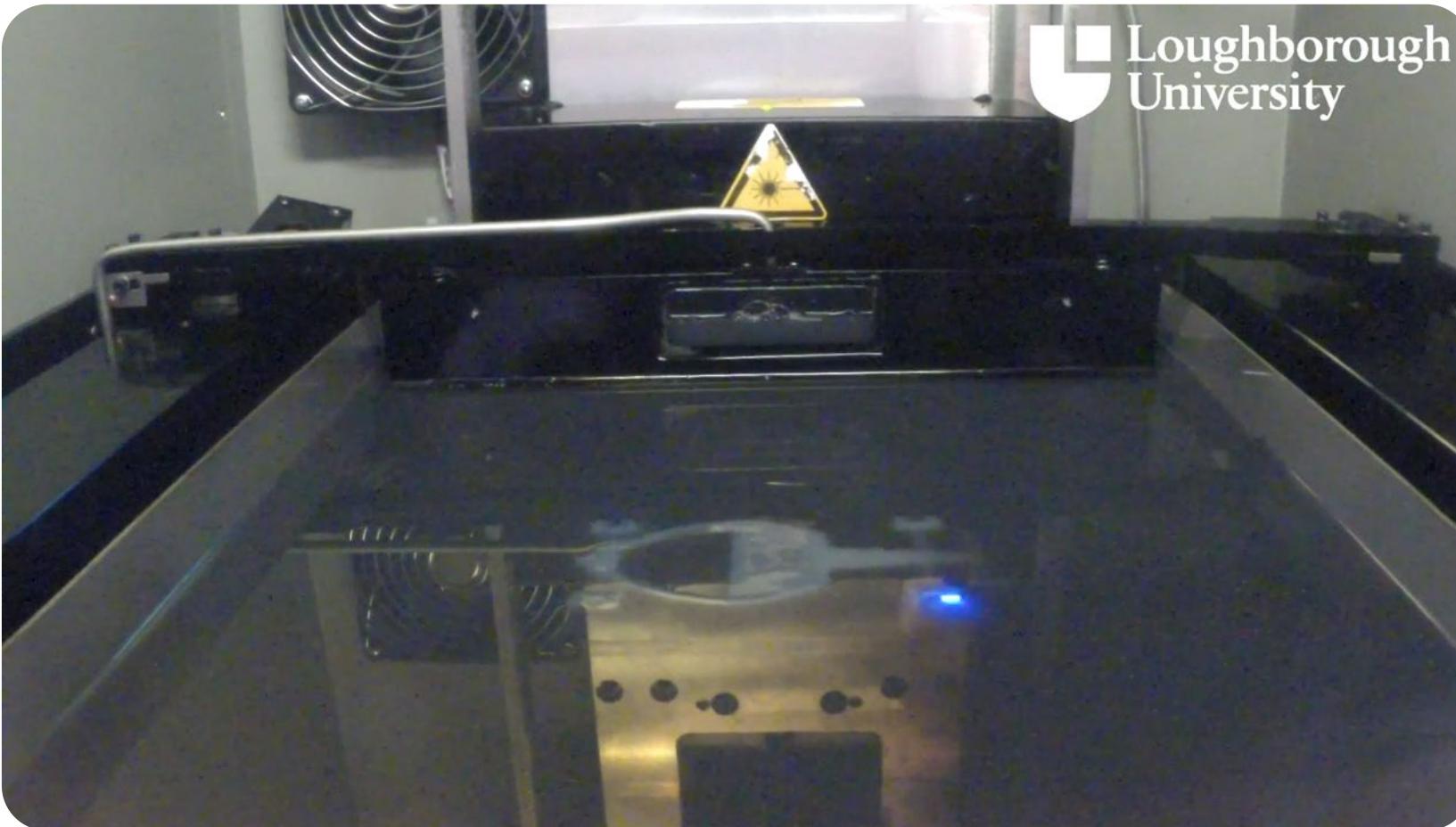
Laminated object manufacturing (LOM)



Stereolithography (SLA)



Stereolithography (SLA)



liquid photo-reactive resin in a tank

laser selectively hardens top layer of resin

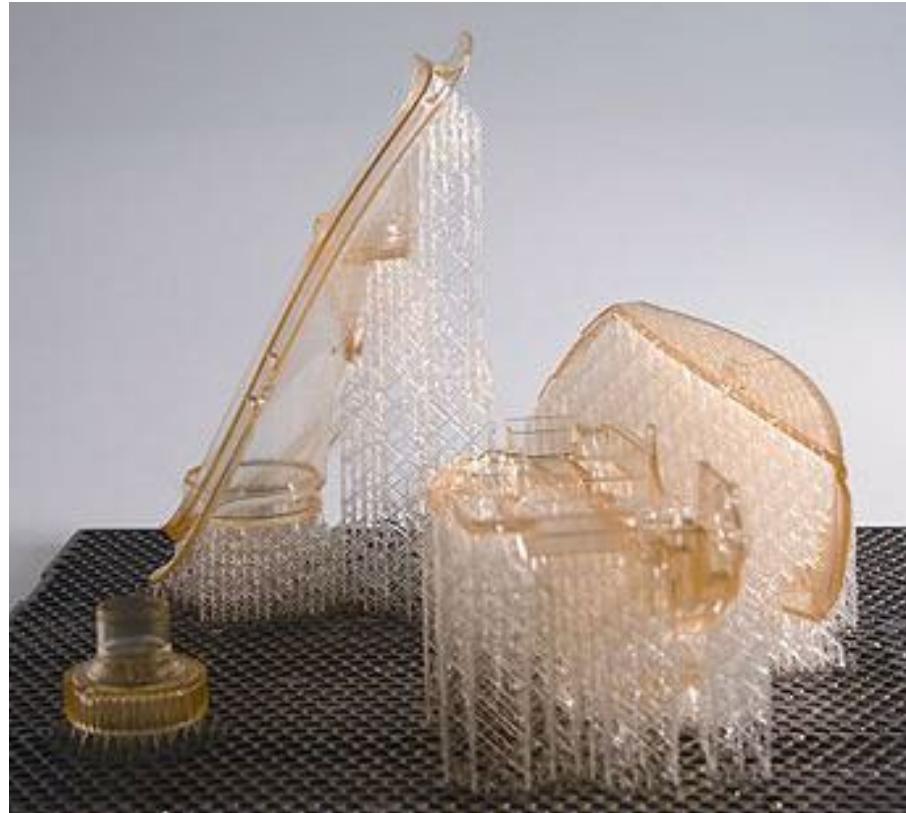
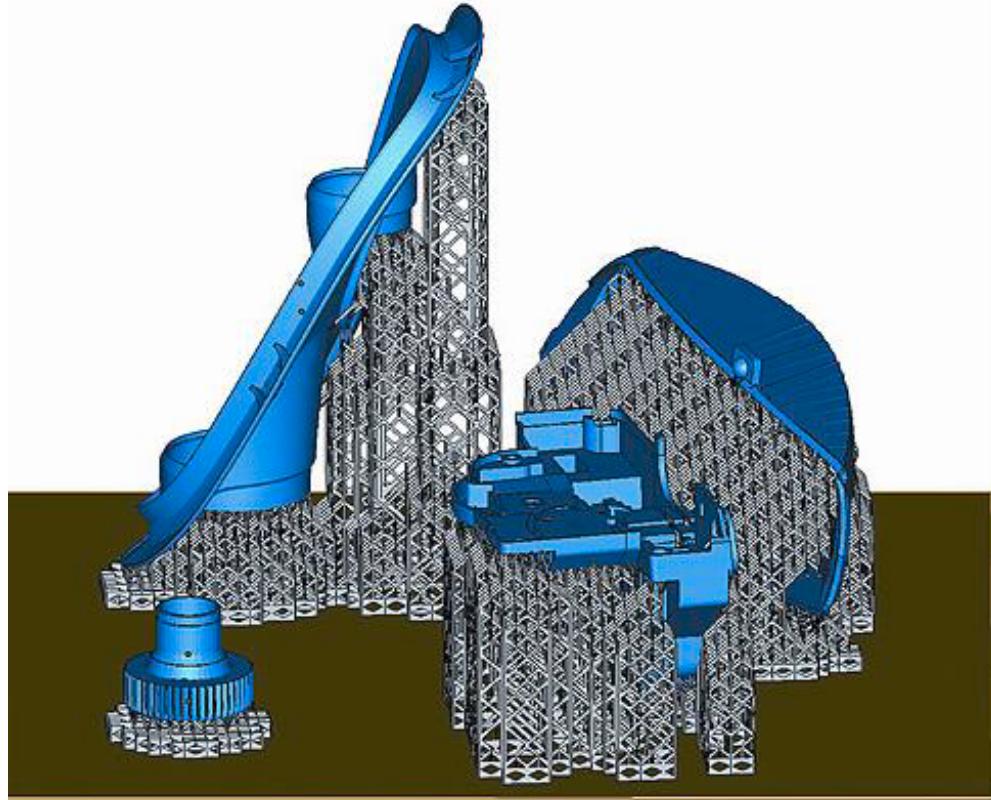
the platform descends by one layer

sweeper equally distributes resin for new layer

Stereolithography (SLA)

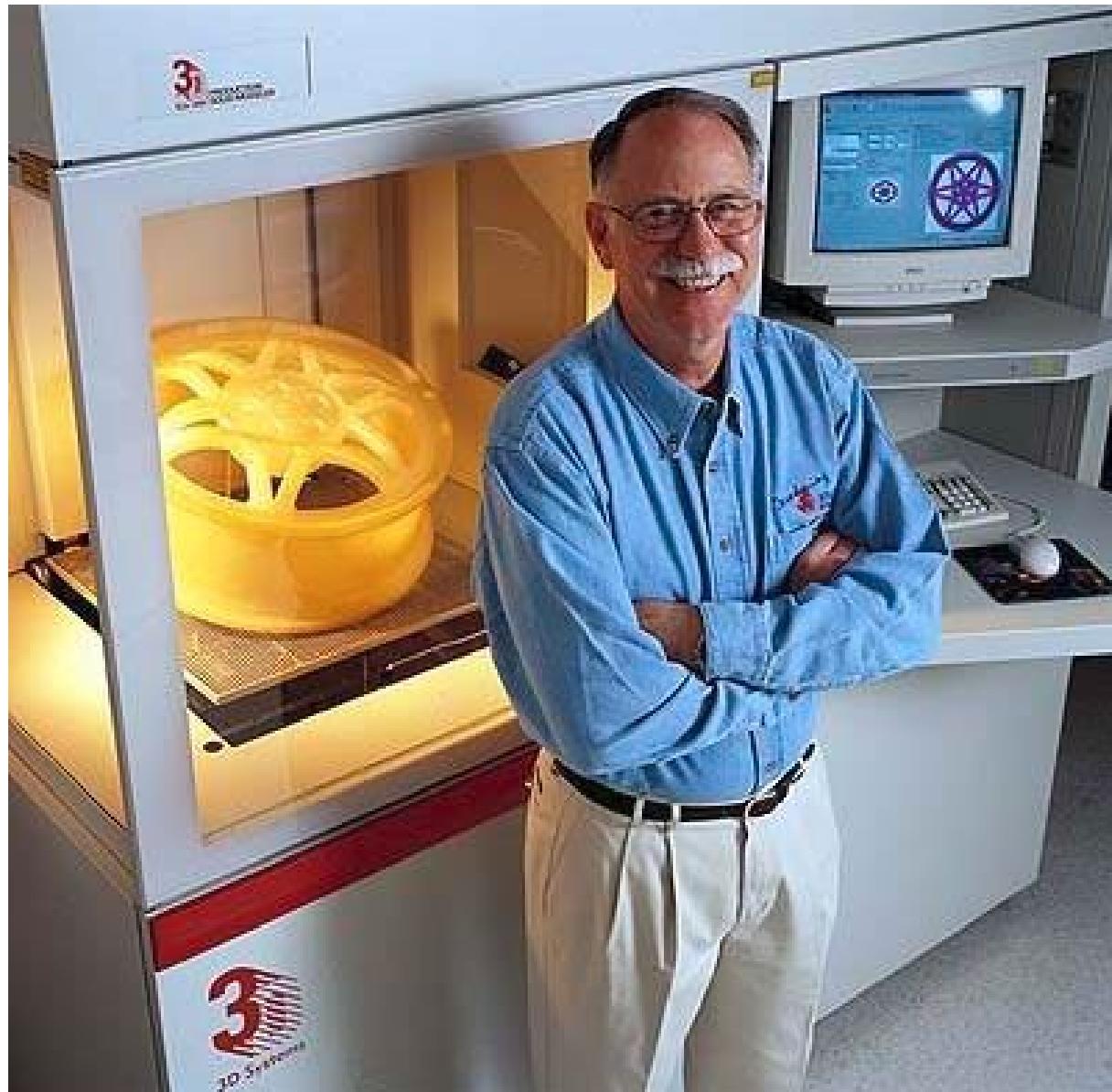
Support structure

–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



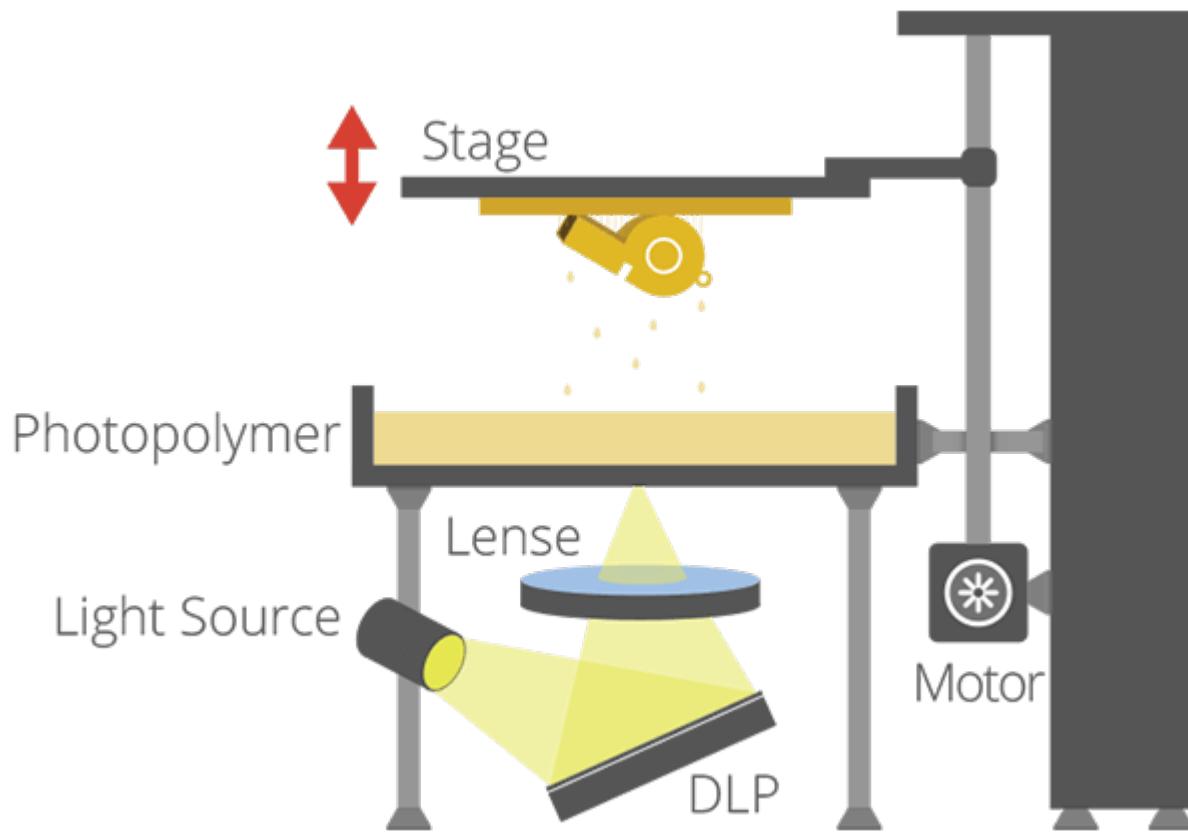
what is a **benefit** of using a laser over an extruder?

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

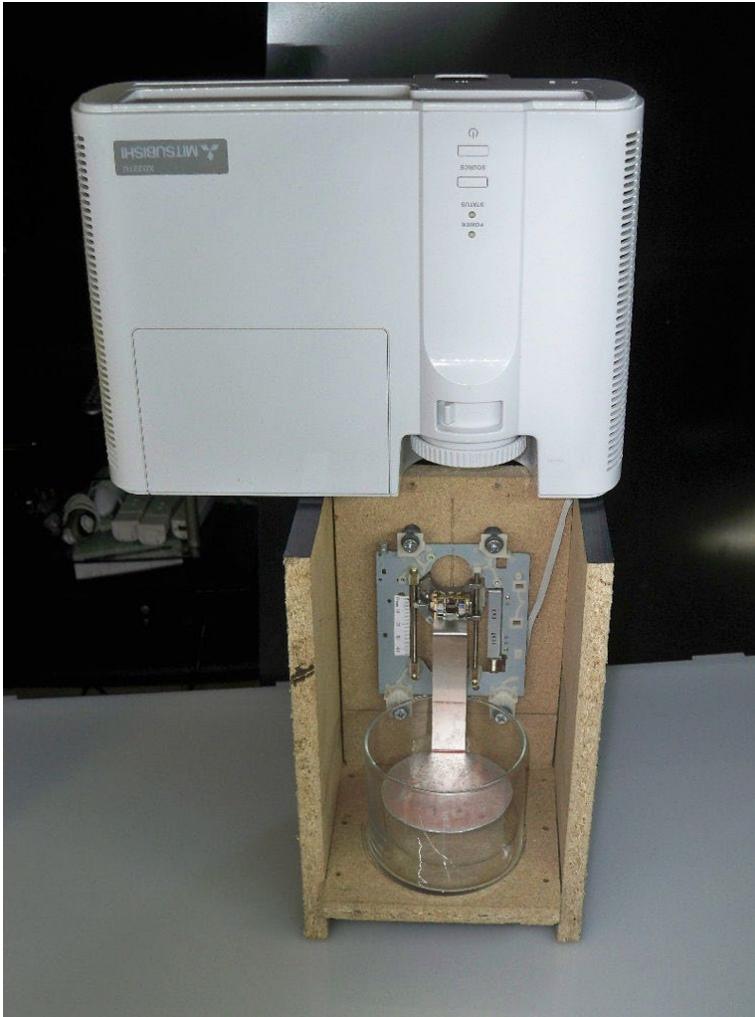
- only one degree of freedom

Faster than SLA

- exposes one layer at a time

Materials

- same as SLA



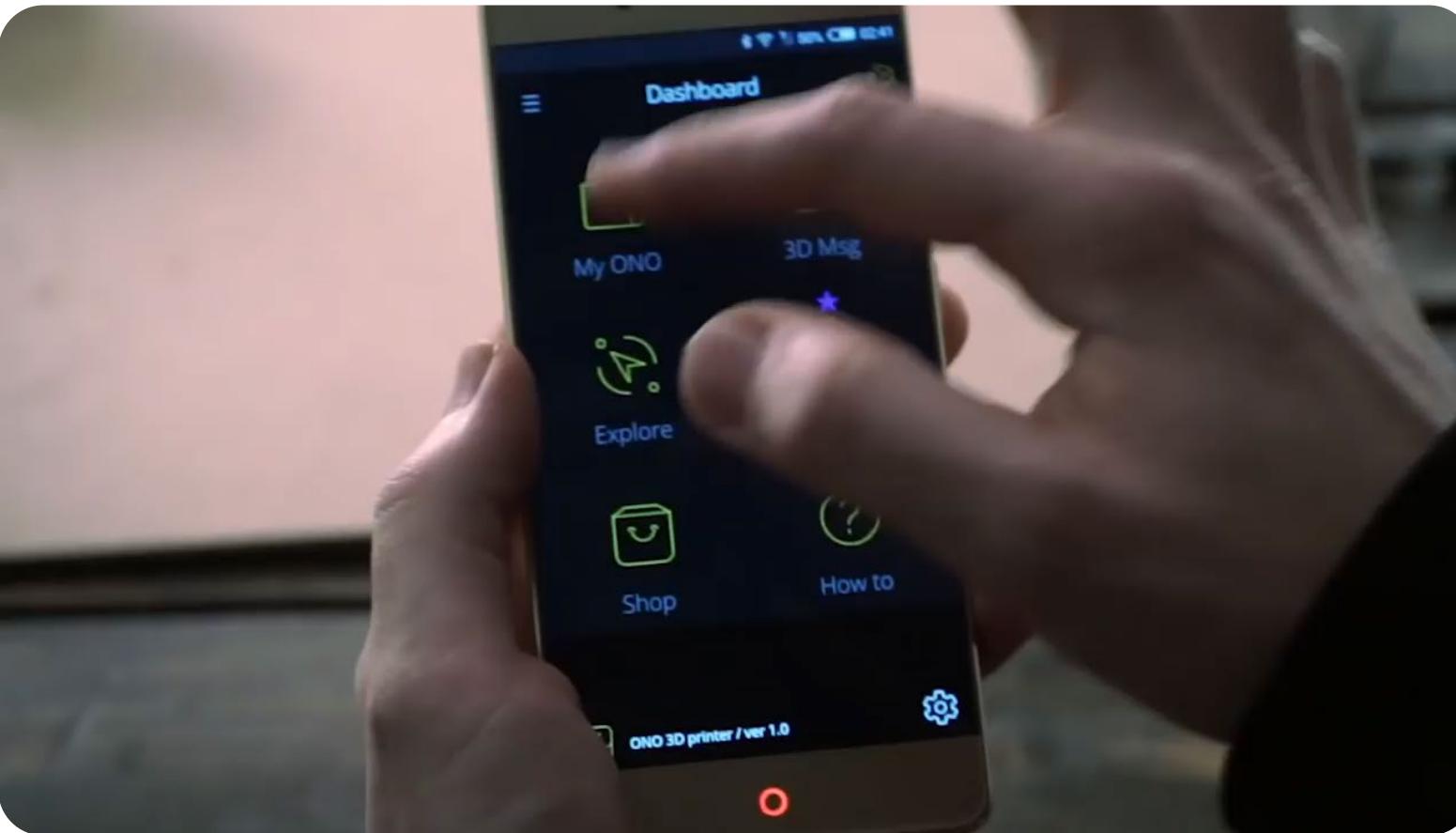
how can you make this a **mobile 3D printer**?



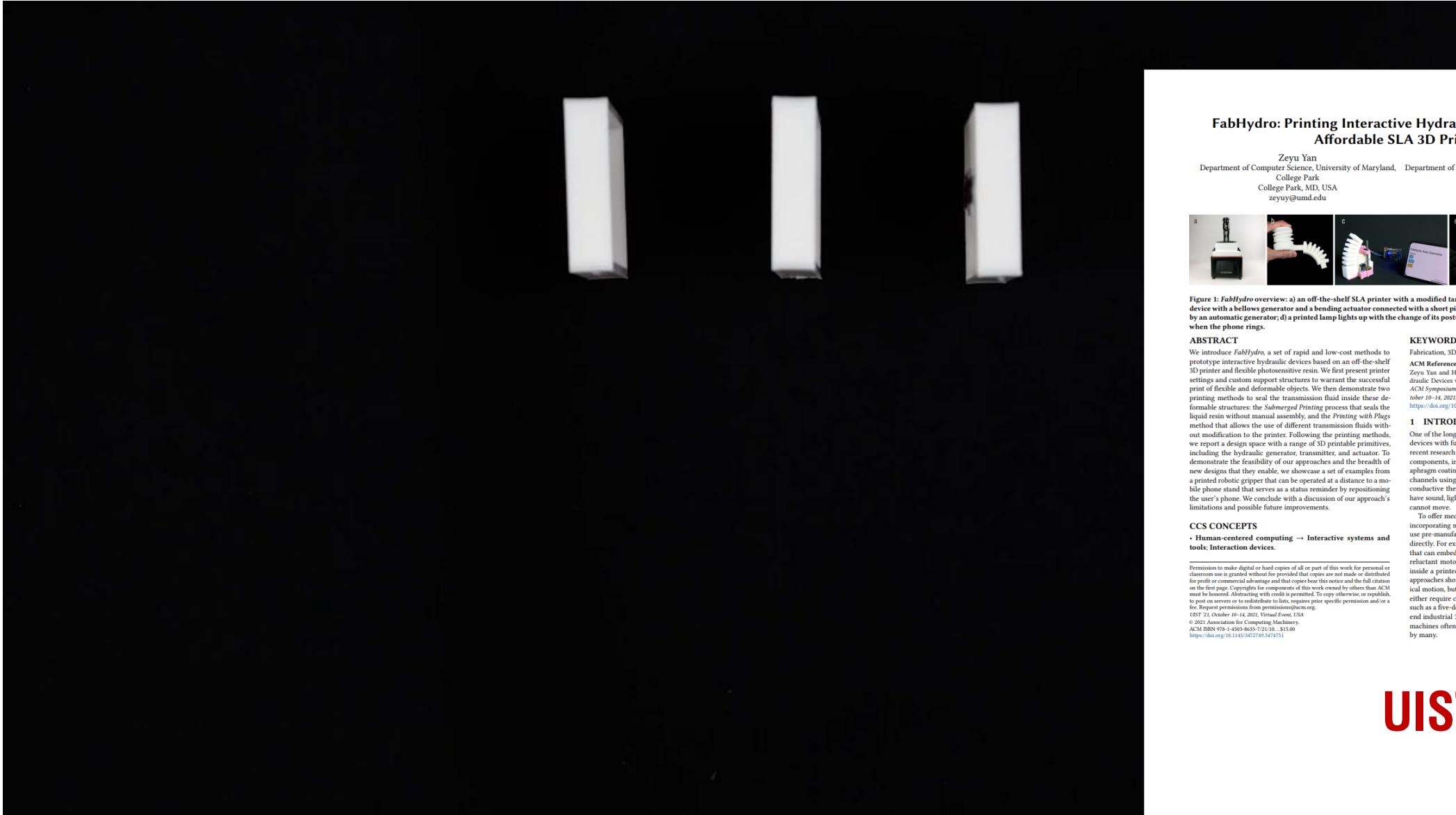
 **T3D**

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

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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* that seals the liquid without any assembly, and the *Printing with Plugs* method that allows the use of different types of sealants and their 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.

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, 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 interactiveness [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 [5], and touch sensors with conductive thermoplastics [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 in the printed object – some use pre-machined actuators [15], others aim to print actuators directly. For example, Peng et al. [42] design a 3D printer that can embed magnetic wires in the printing process to build reluctance motors. McCurdy et al. [35] 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 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 off-the-shelf 3D printer and flexible photosensitive resin.

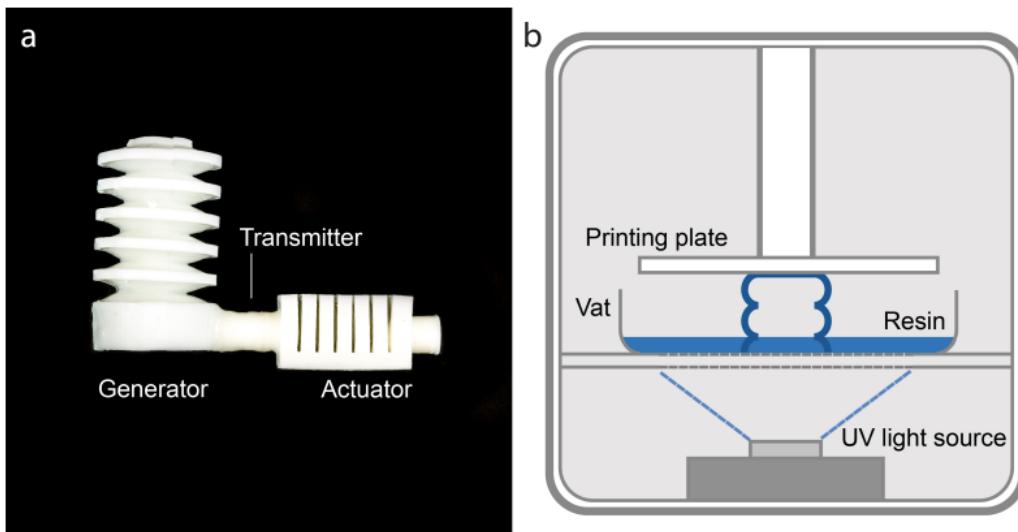


Figure 2: a) An overview of one *FabHydro* device, including a generator, a short piece of tubing, and a bending actuator; b) the conventional SLA printer with single material and an upside-down printing process.

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

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CCS CONCEPTS

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

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ACM ISBN 978-1-4503-8635-7/21/10...\$15.00
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UIST 2021

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

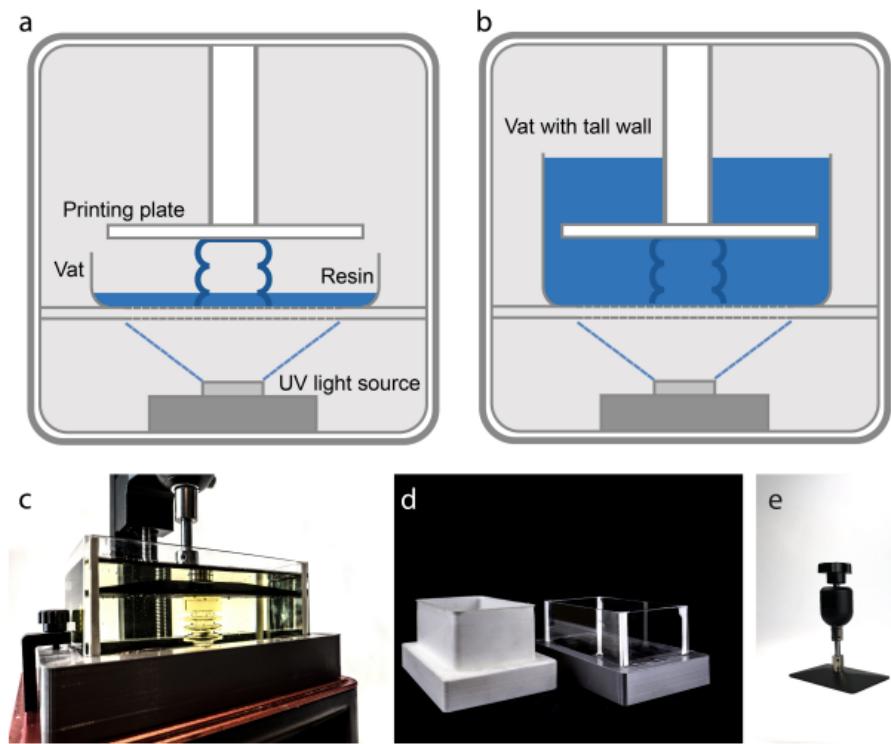


Figure 8: a) The conventional SLA 3D printer structure; b) the *Submerged Printing* process; c) the modified printer assembly filled with standard transparent resin for a clear presentation; and d) the modified vat made with PLA and acrylics; e) the extended printing plate.

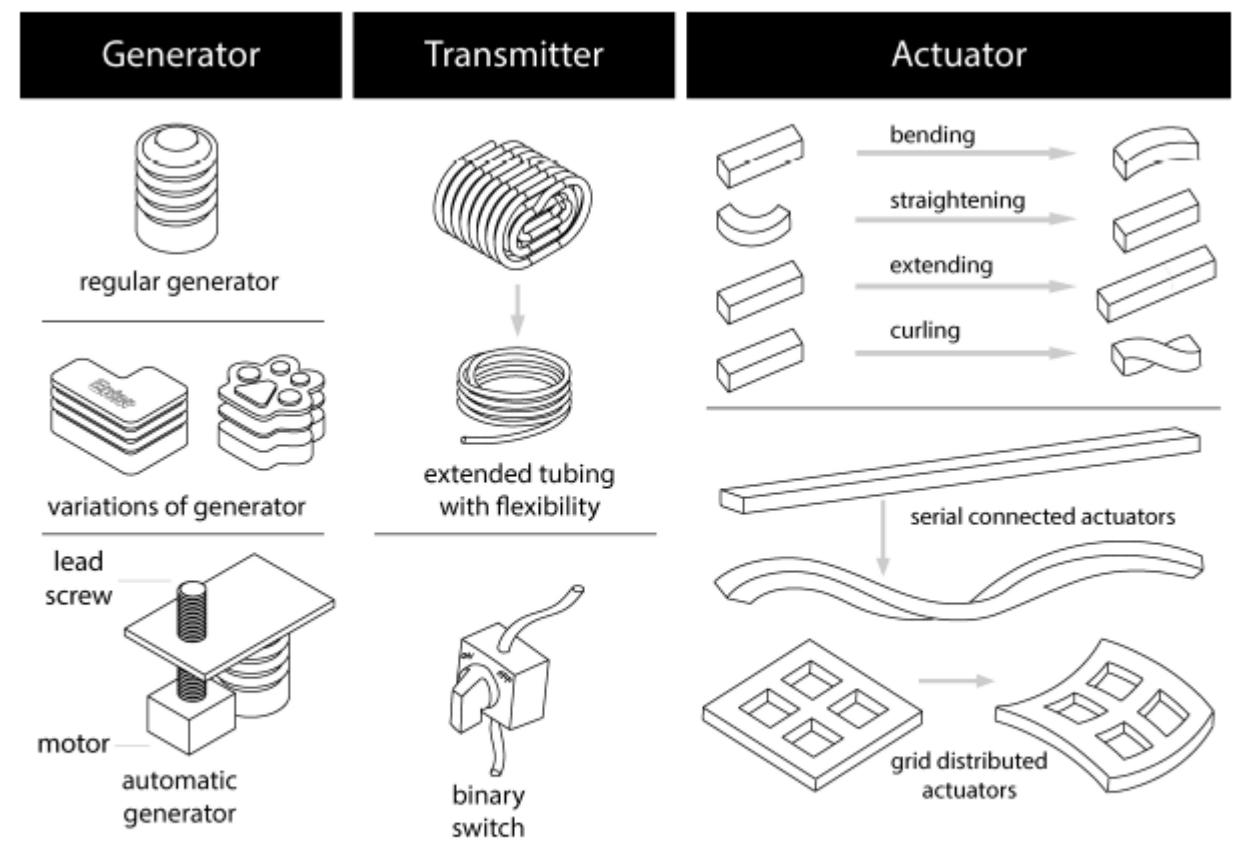
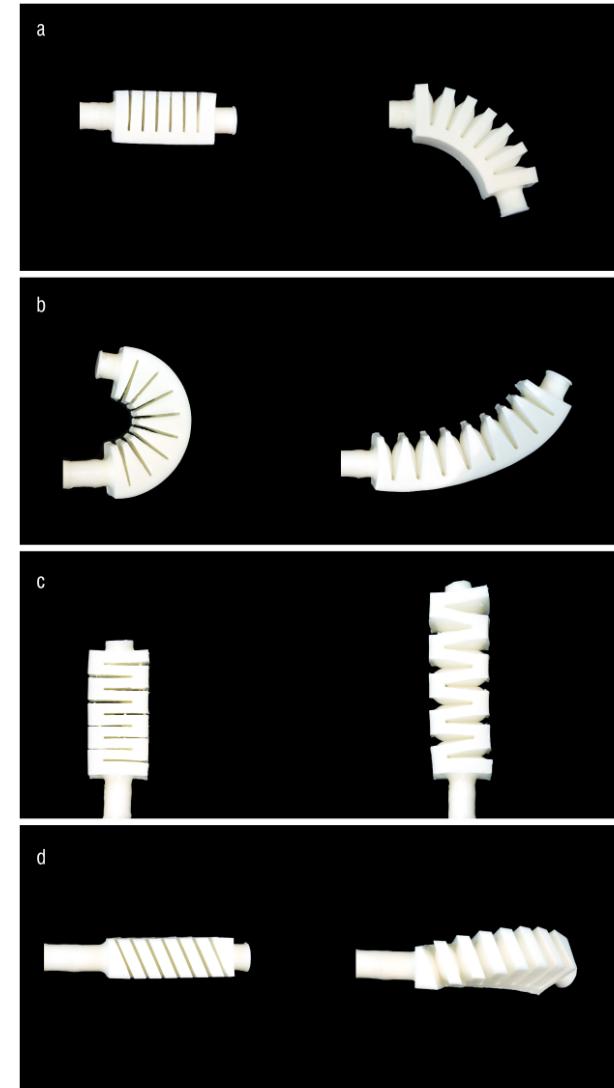
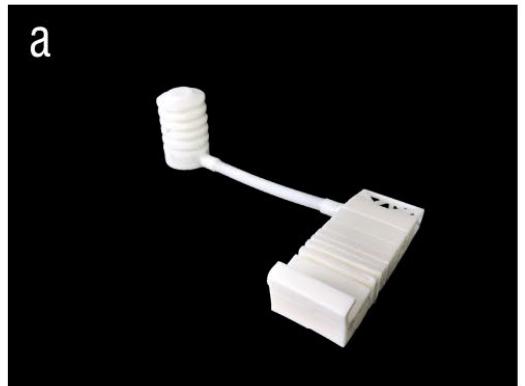


Figure 10: Design space: building blocks of *FabHydro*.

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

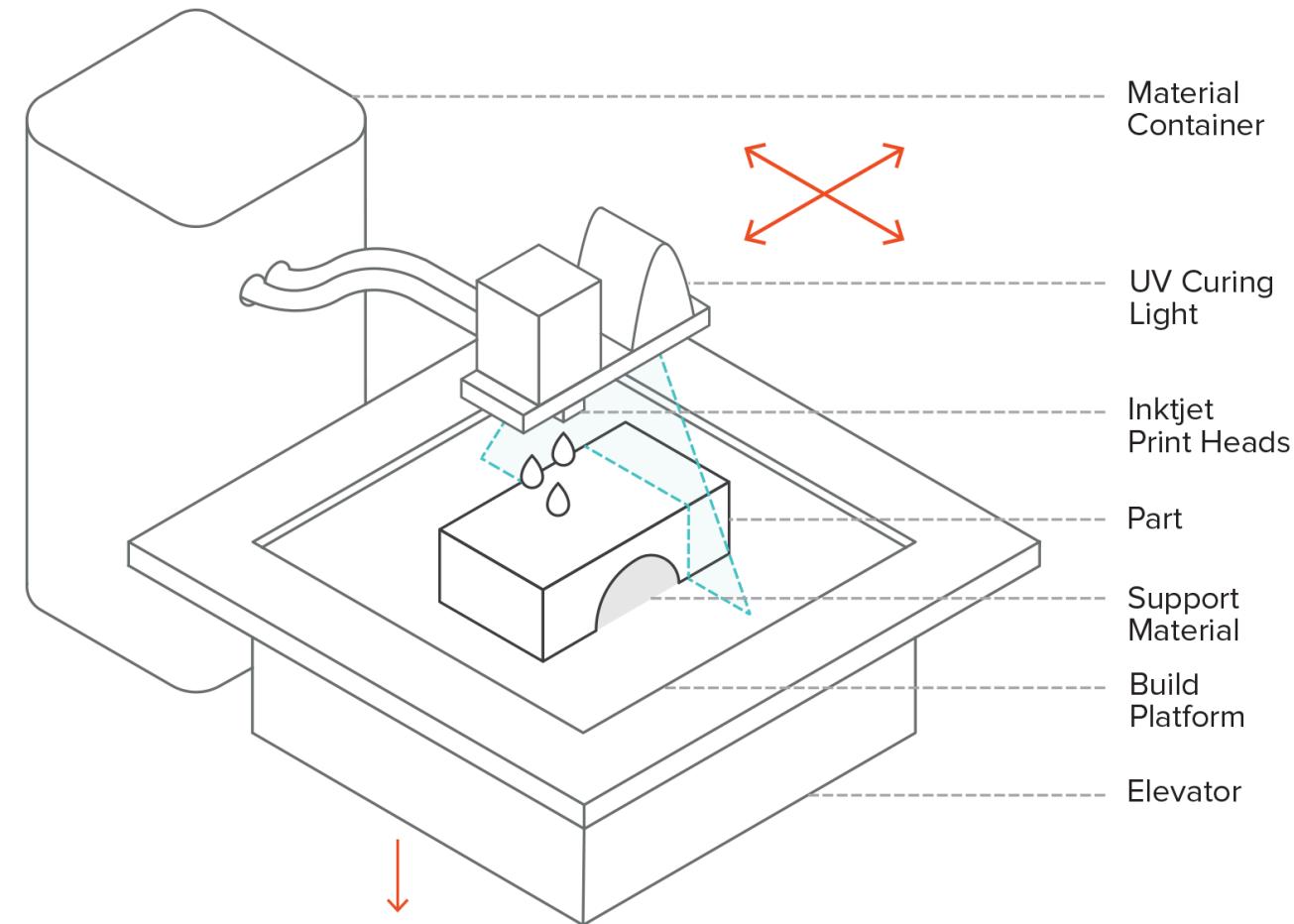
Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)



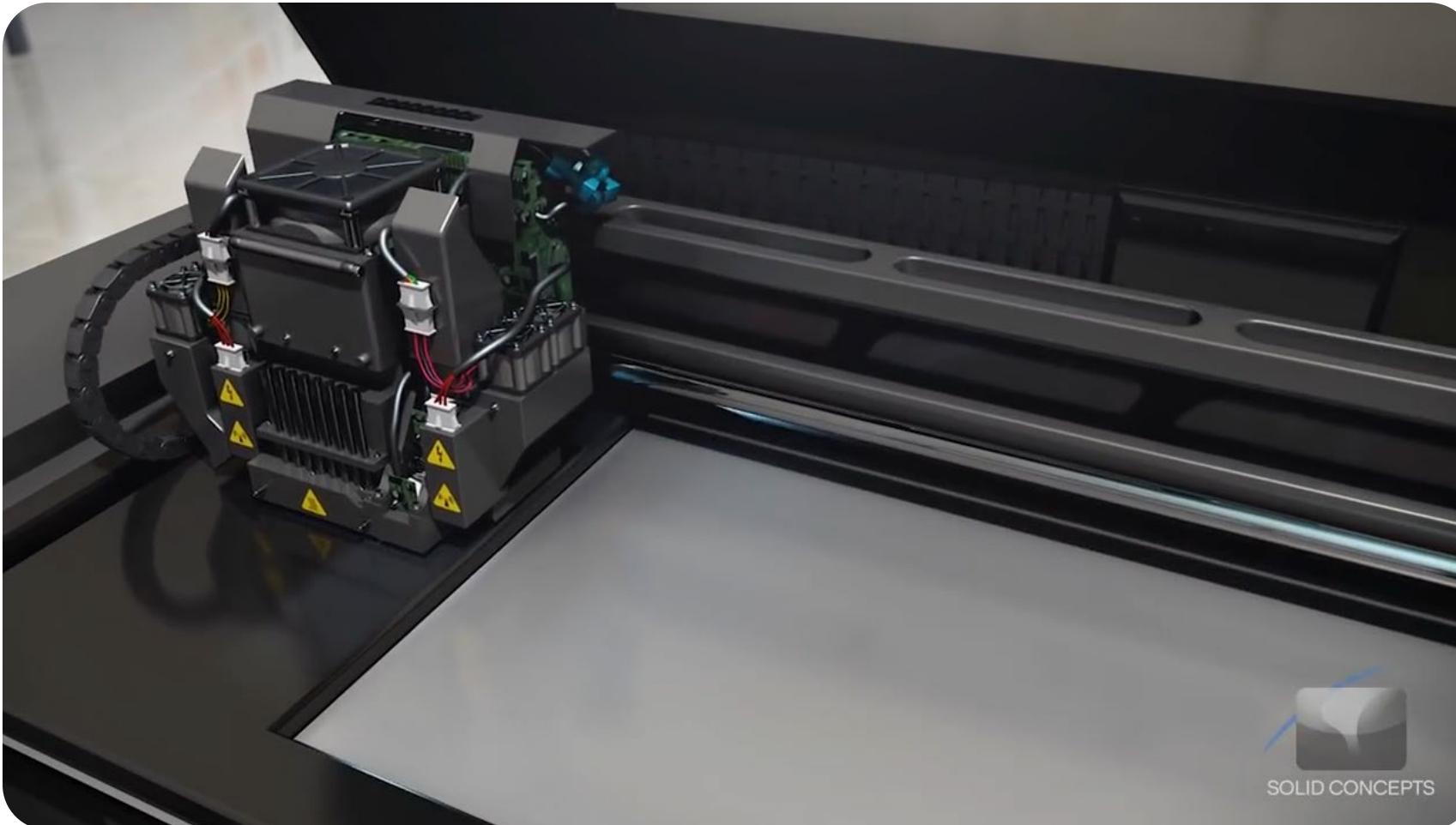
Photopolymer Phase Change Inkjets



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

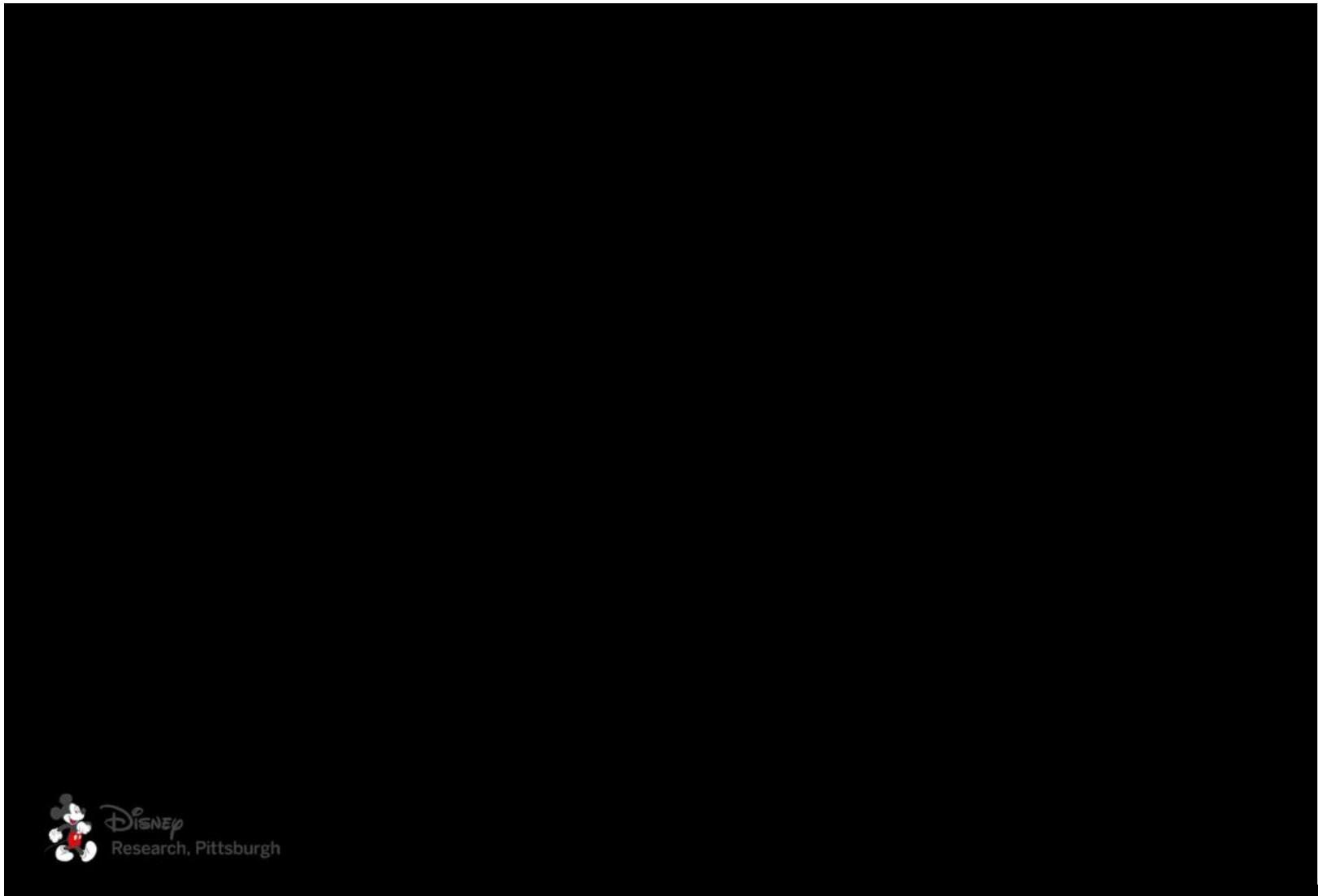
Photopolymers only

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

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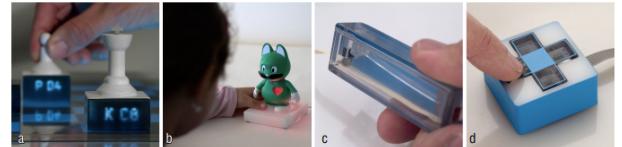


Figure 1: Custom optical elements are fabricated with 3D printing and embedded in interactive devices, opening up new possibilities for interaction including: unique display surfaces made from 3D printed “light pipes” (a), novel internal illumination techniques (b), custom optical sensors (c), and embedded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

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UIST 2012

Willis et.al.



Different types of 3D printing methods

Fused deposition modeling (FDM)

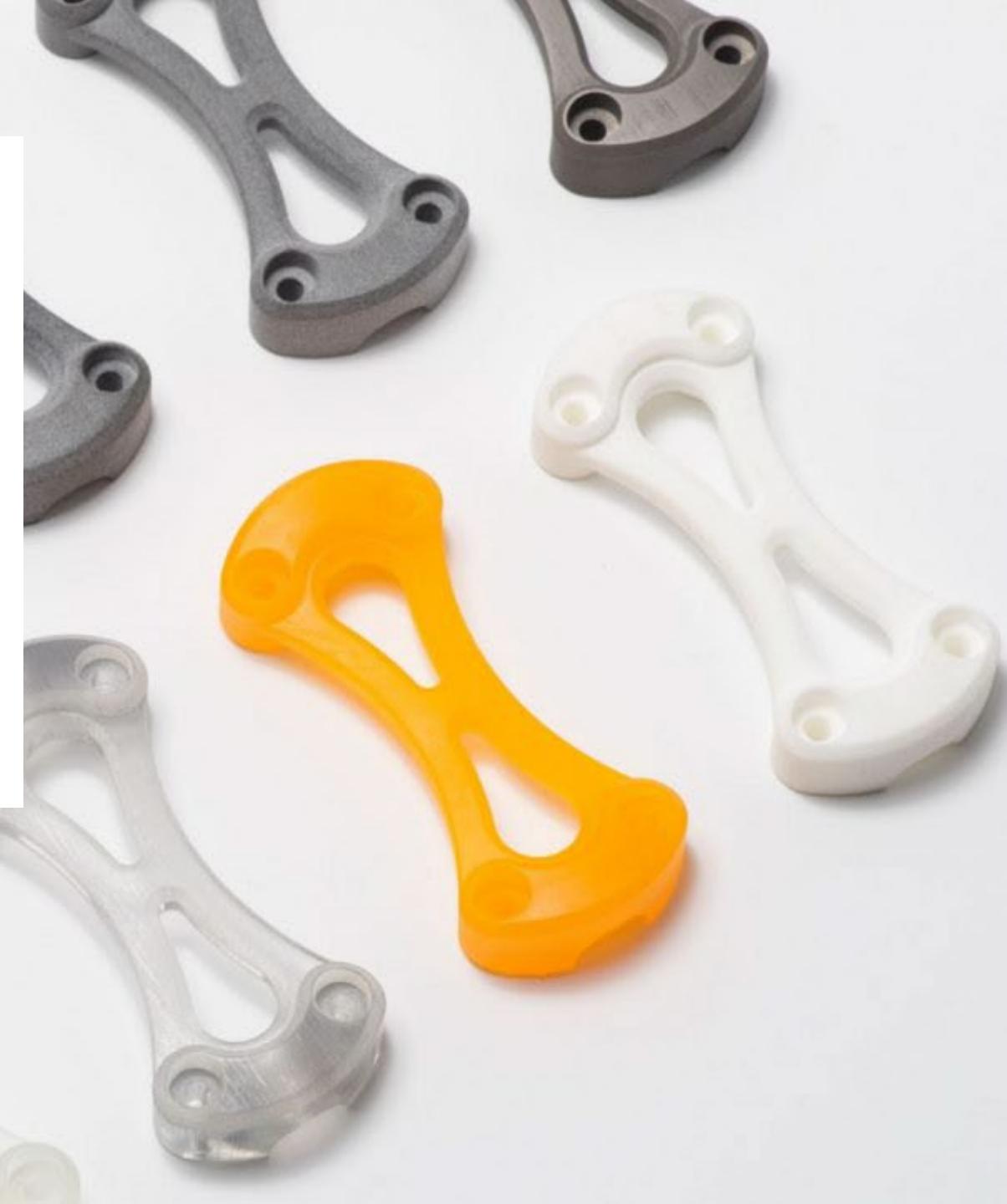
Stereolithography (SLA)

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)

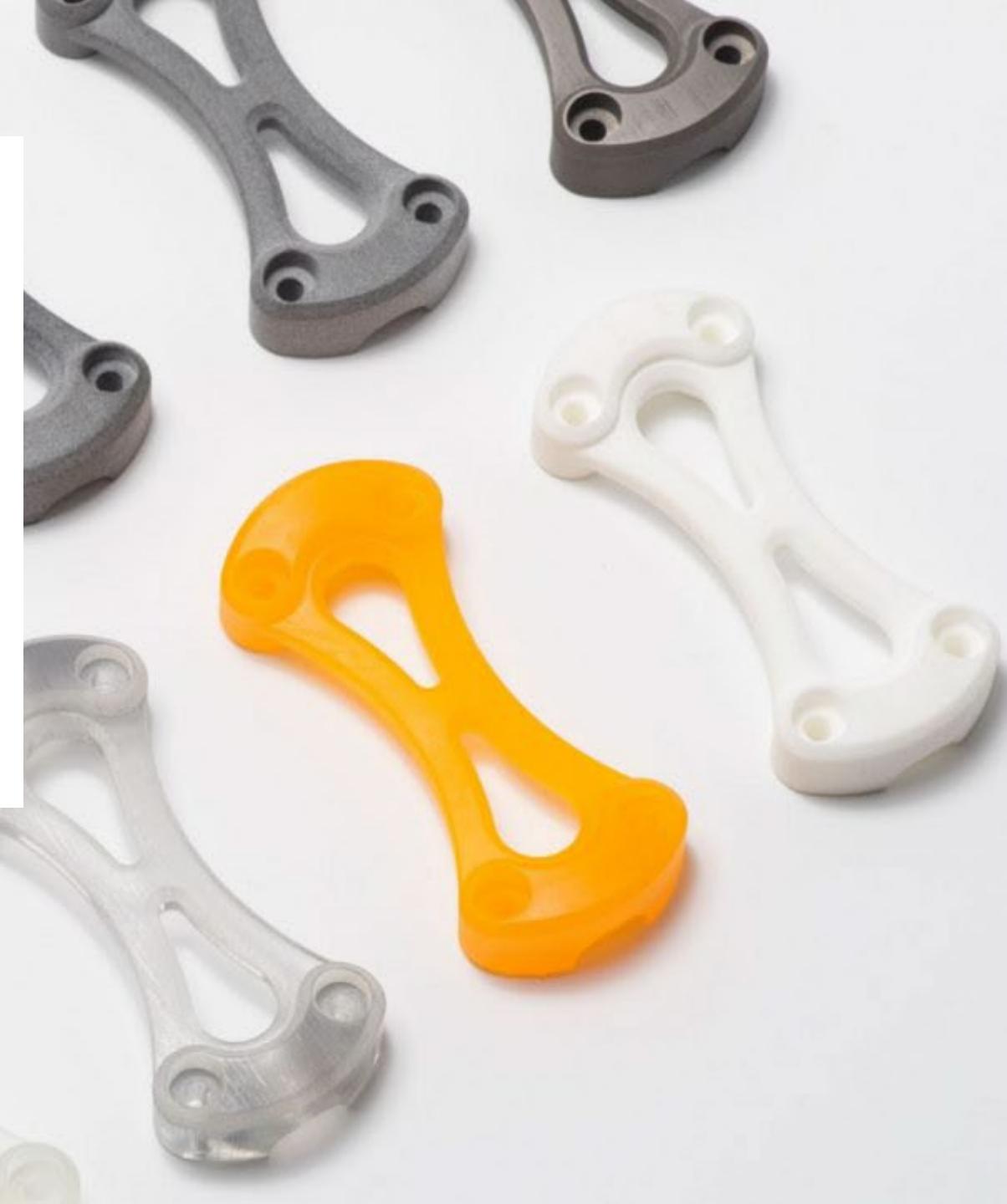
Stereolithography (SLA)

DLP 3D printing

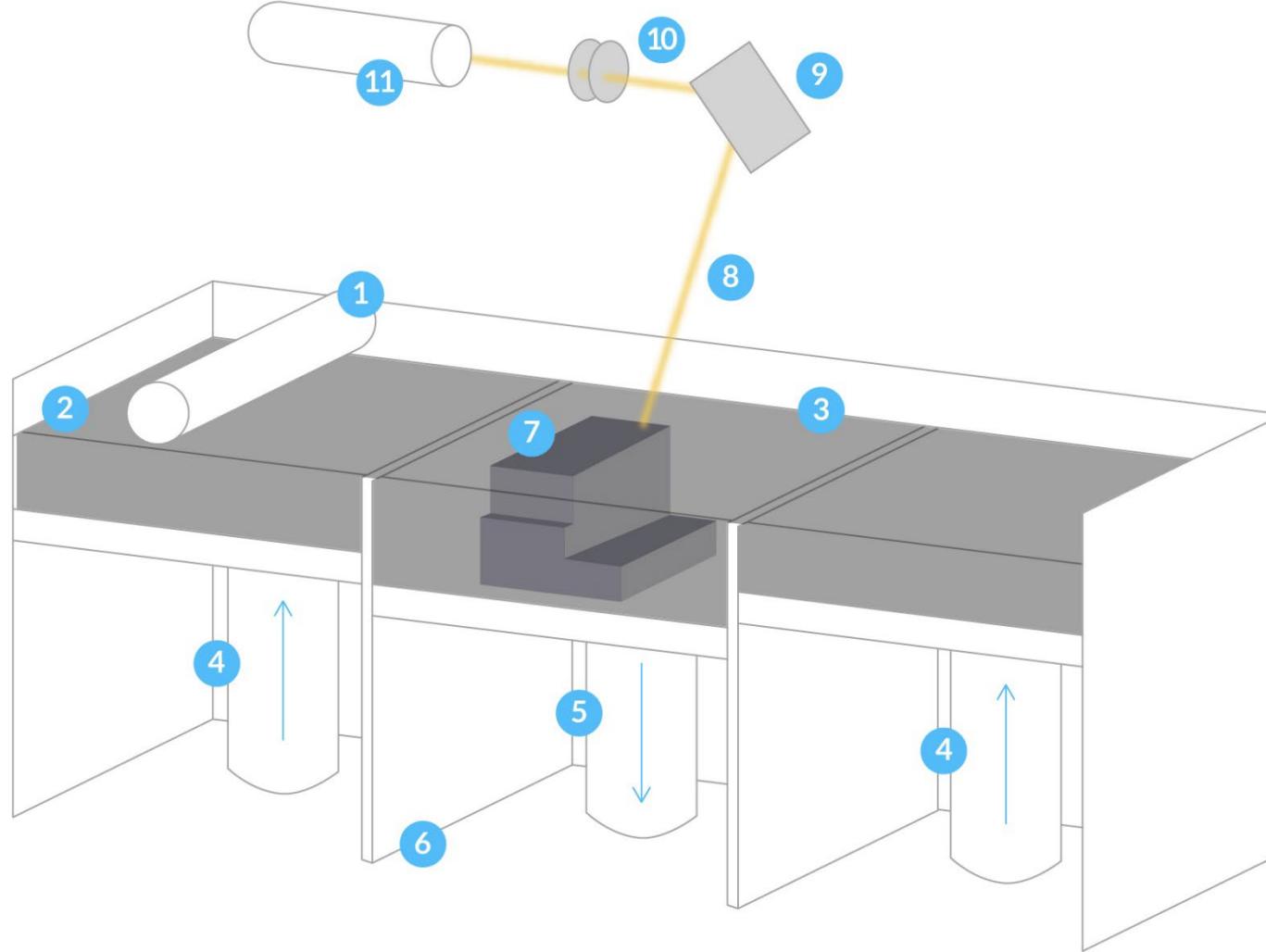
Photopolymer Phase Change Inkjets (PolyJet)

Selective laser sintering (SLS)

Laminated object manufacturing (LOM)



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



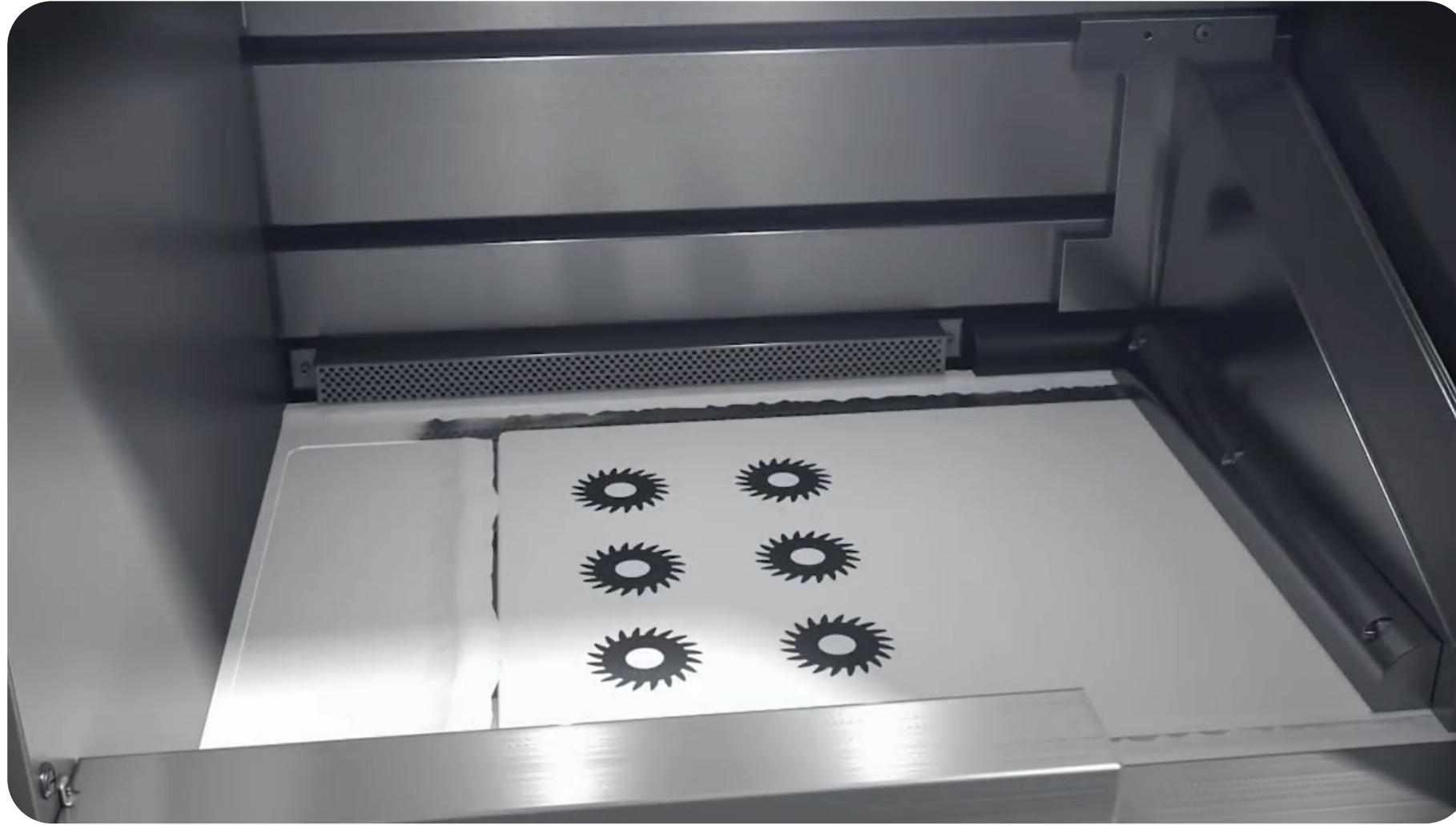
similar to SLA

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 to SLA but laser is more powerful

Bulk material can be preheated

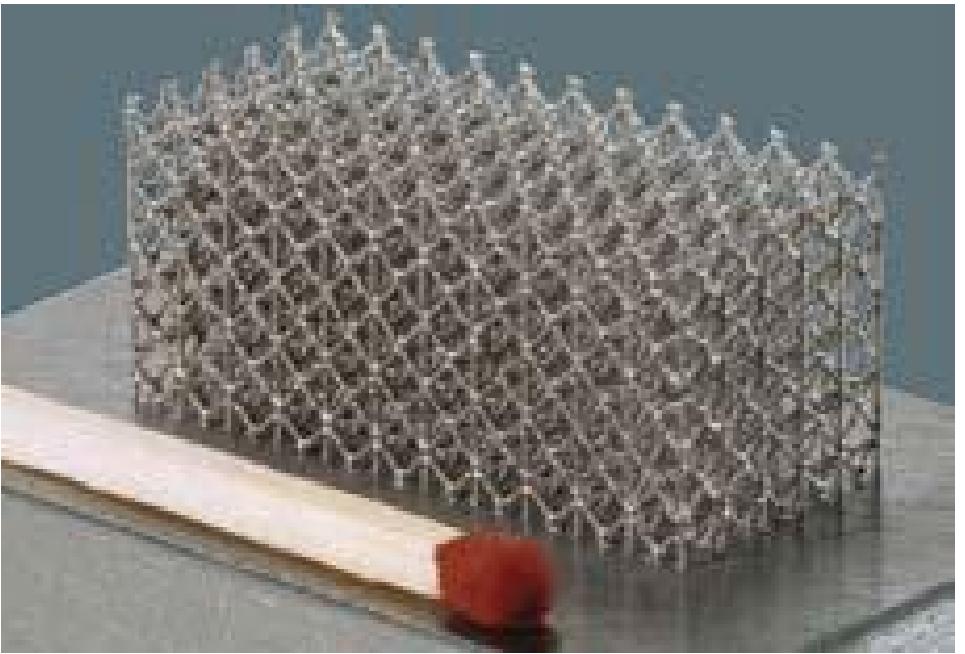
- Reduces the required energy to melt it

Materials

- One material at a time
- Glass**, polymers (e.g., nylon, polystyrene), **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)

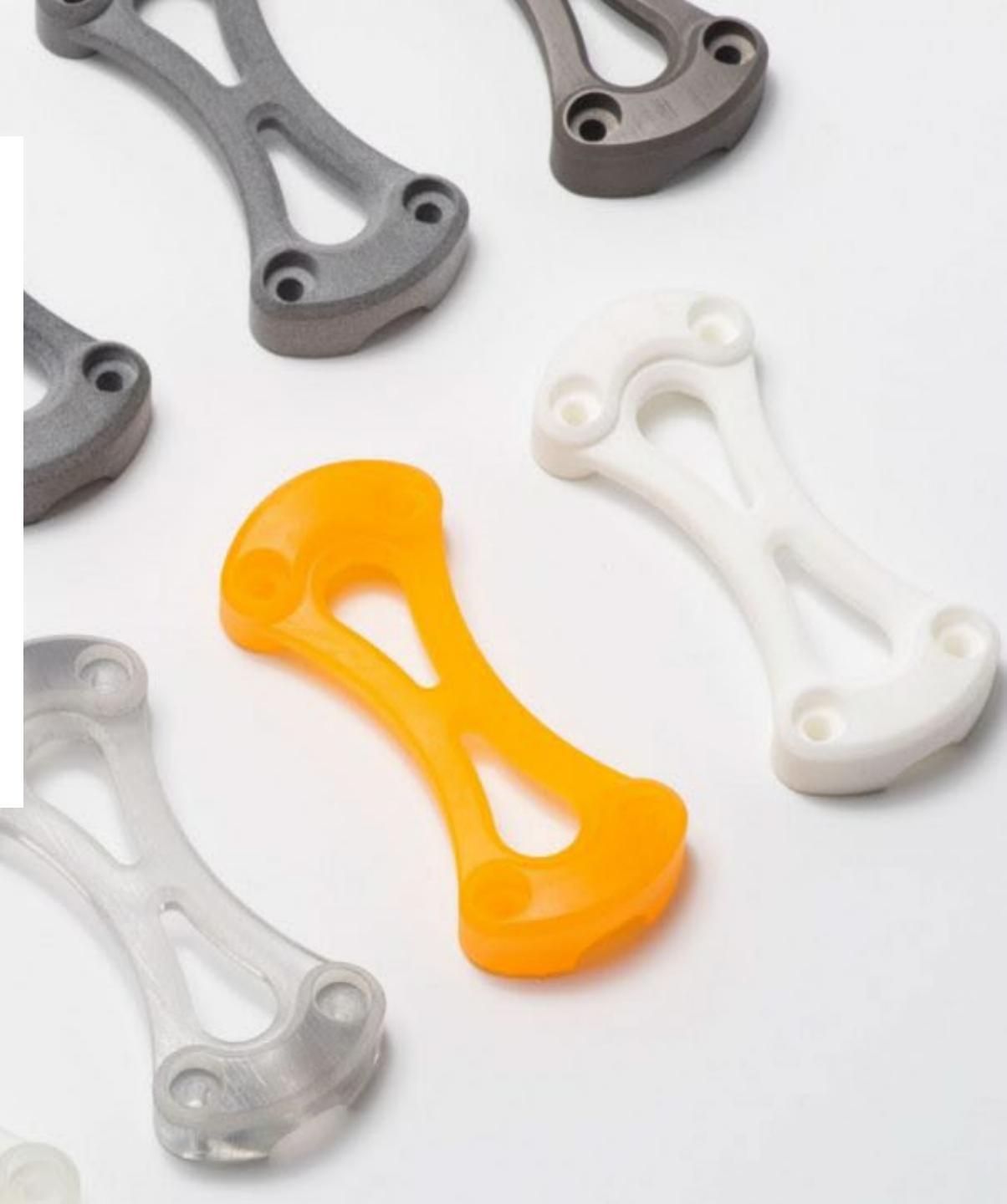
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Different types of 3D printing methods

Fused deposition modeling (FDM)

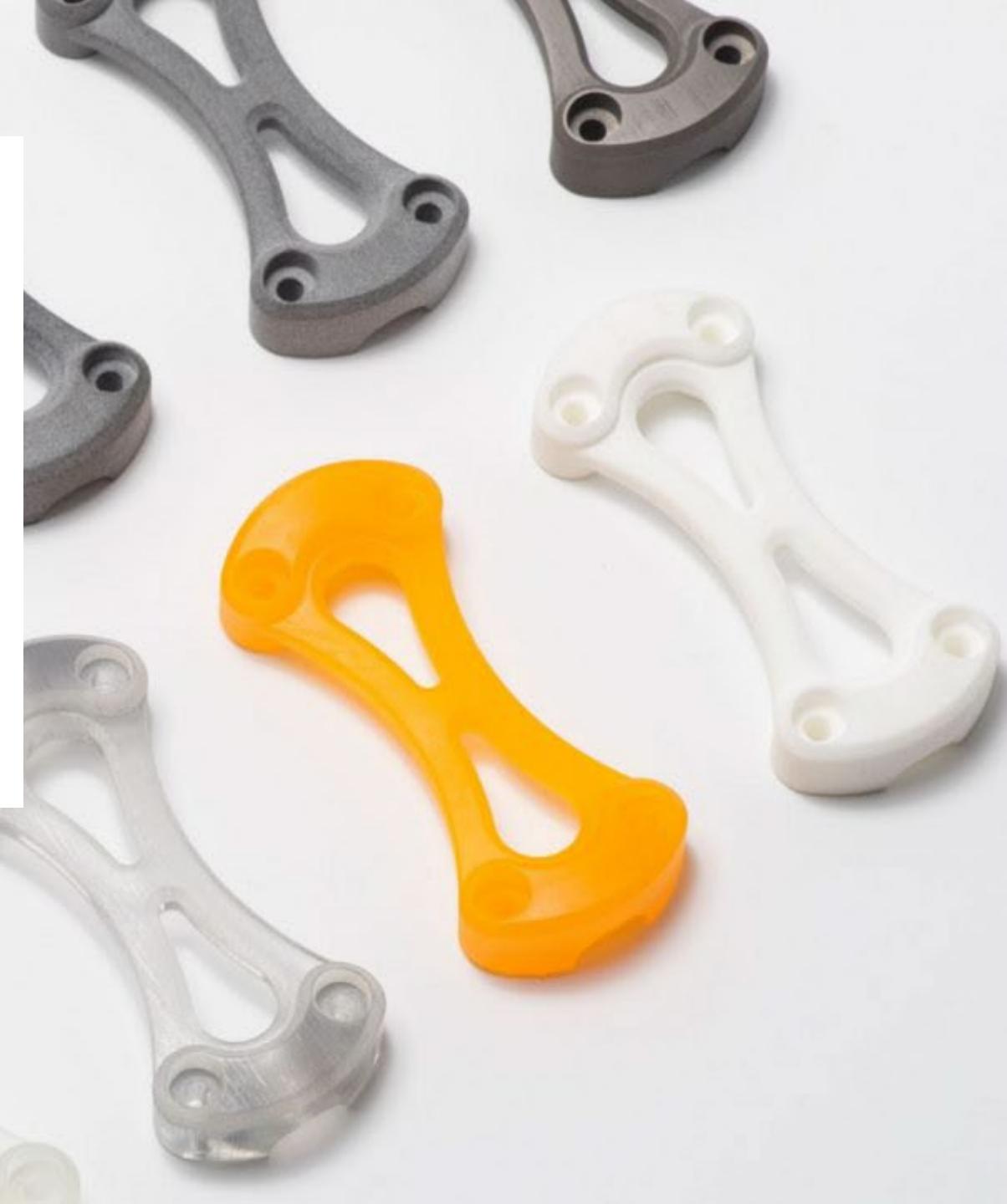
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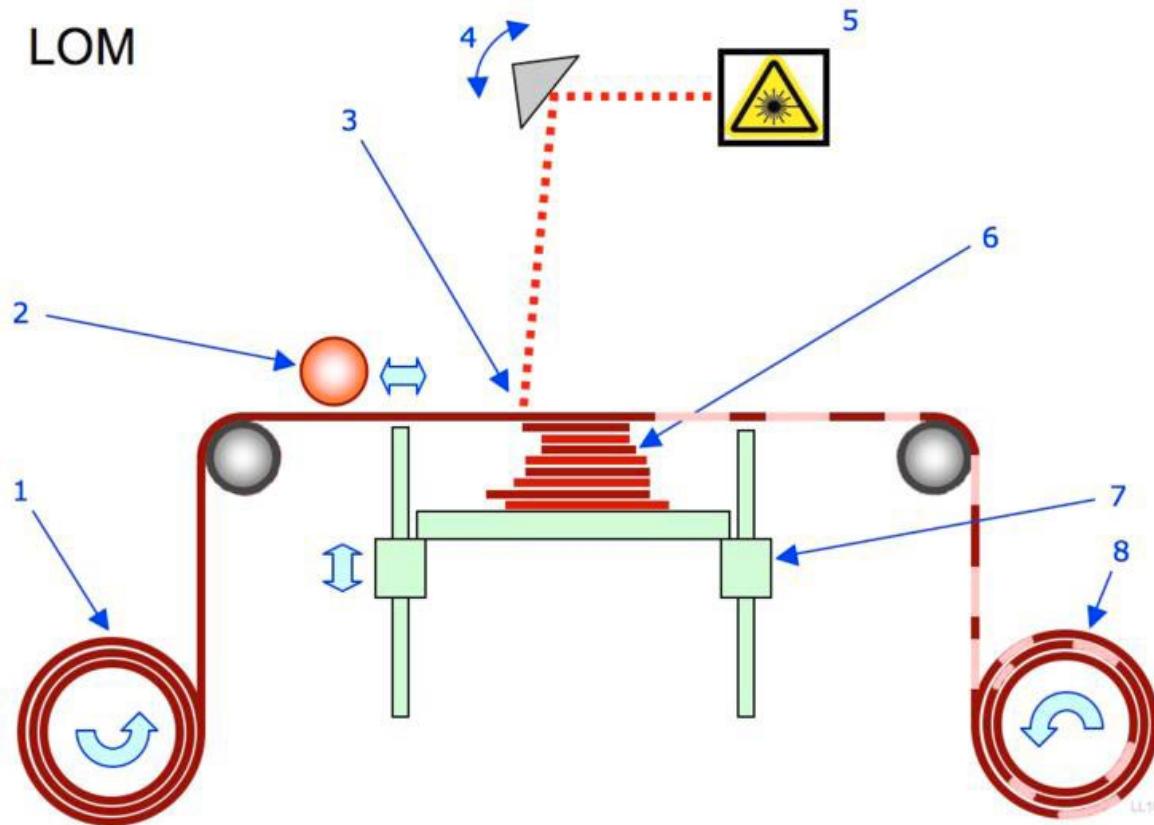


What do you think these are made of?



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

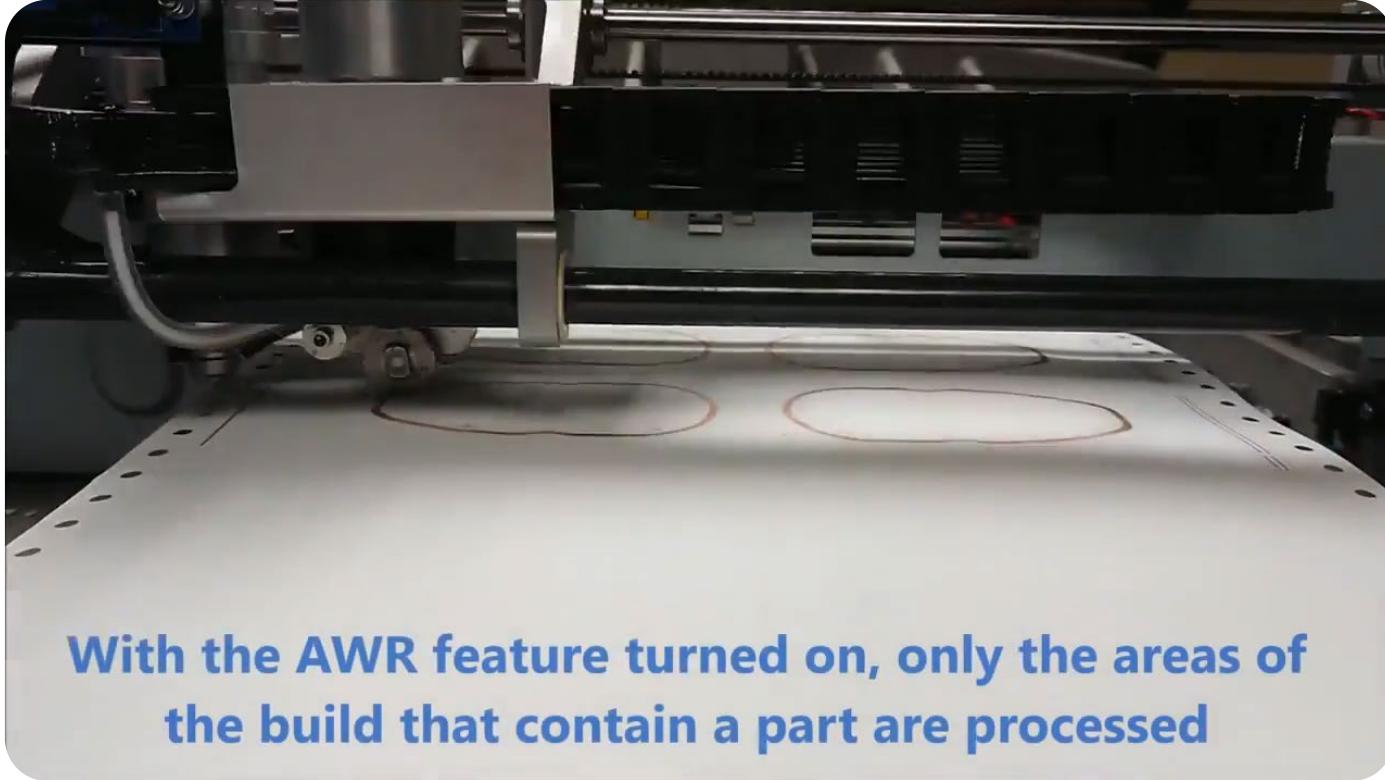
repeat

Laminated Object Manufacturing (LOM)



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

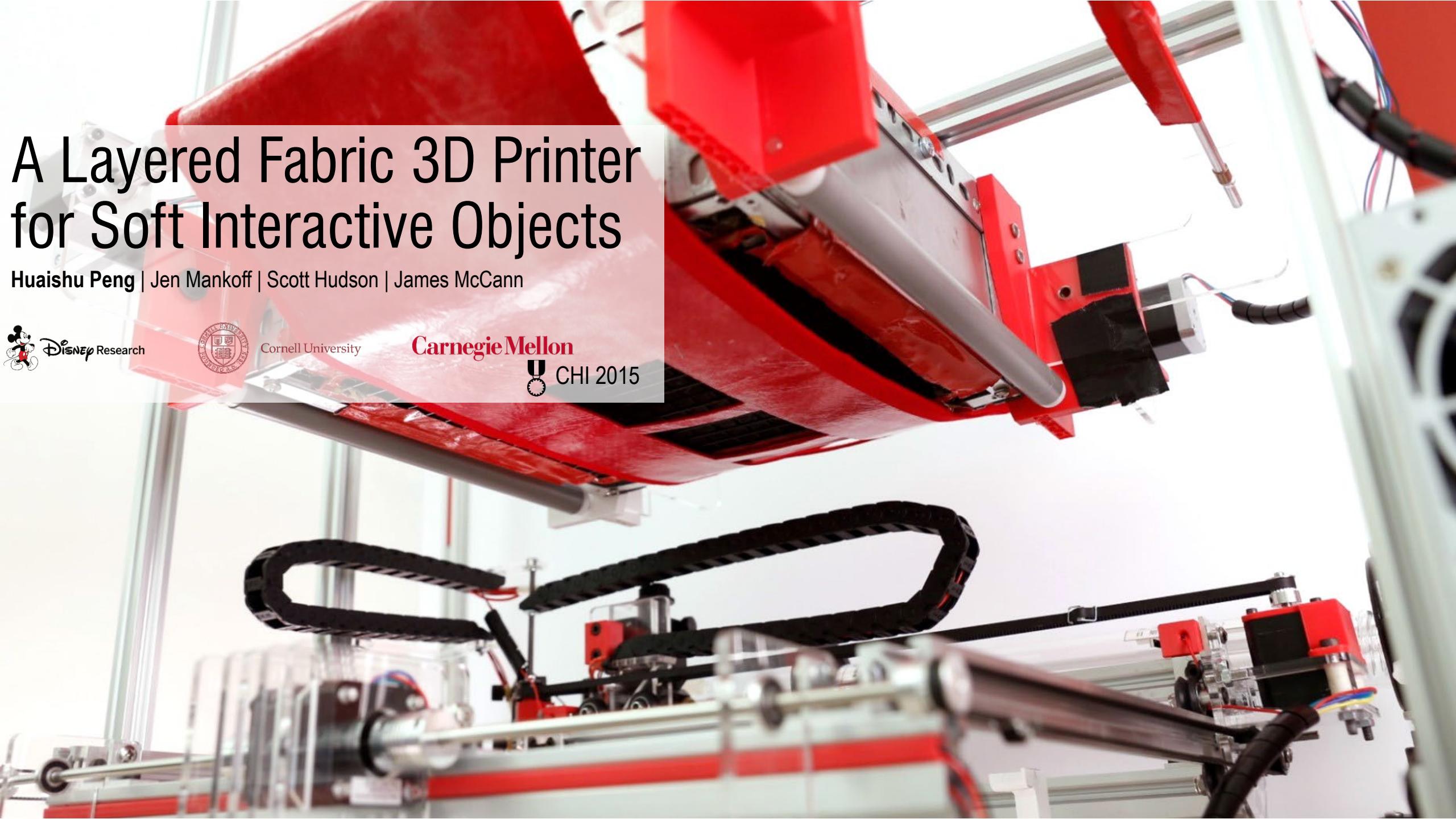
A Layered Fabric 3D Printer for Soft Interactive Objects

Huaishu Peng | Jen Mankoff | Scott Hudson | James McCann



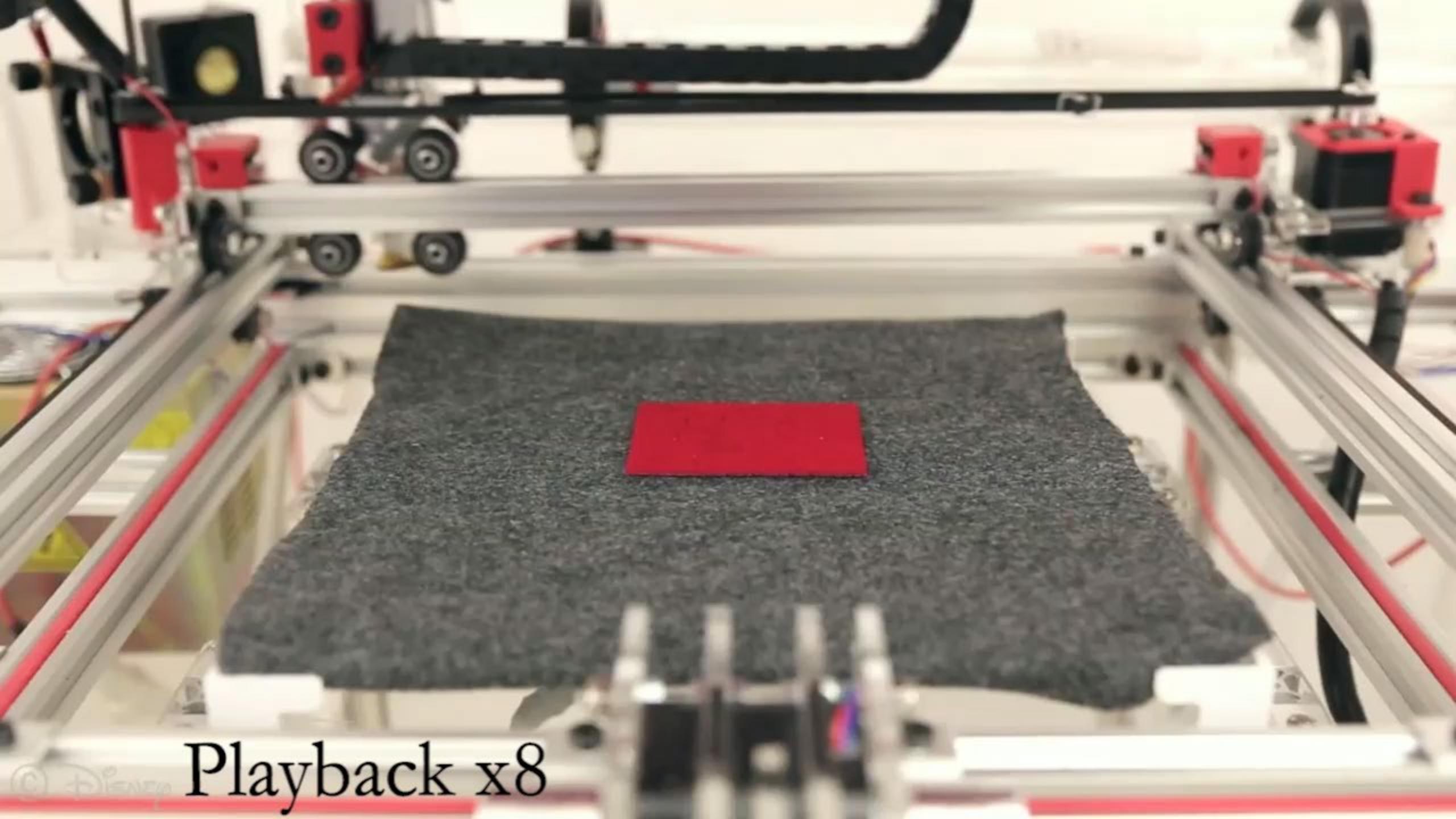
Cornell University

Carnegie Mellon

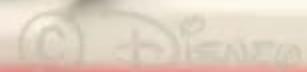




Playback x7



Playback x8



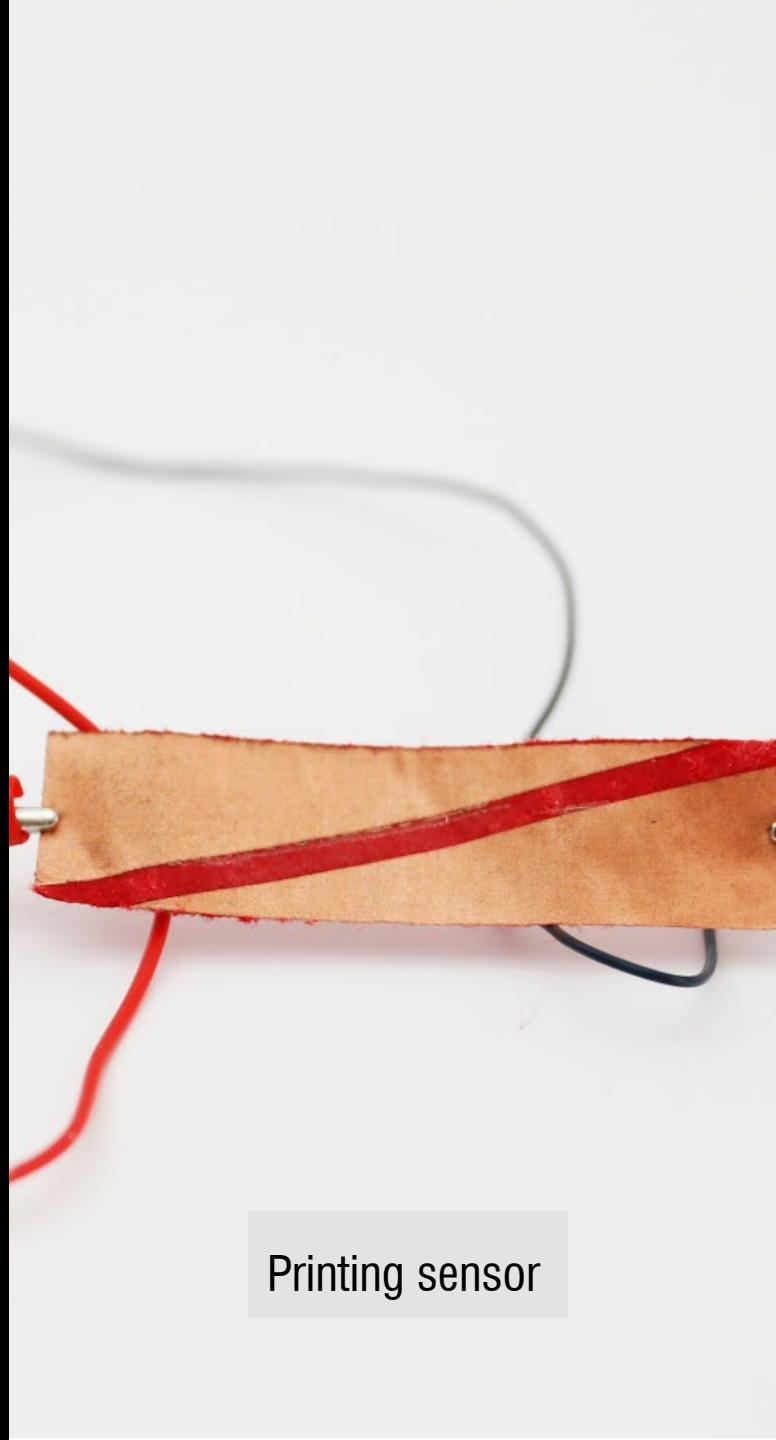


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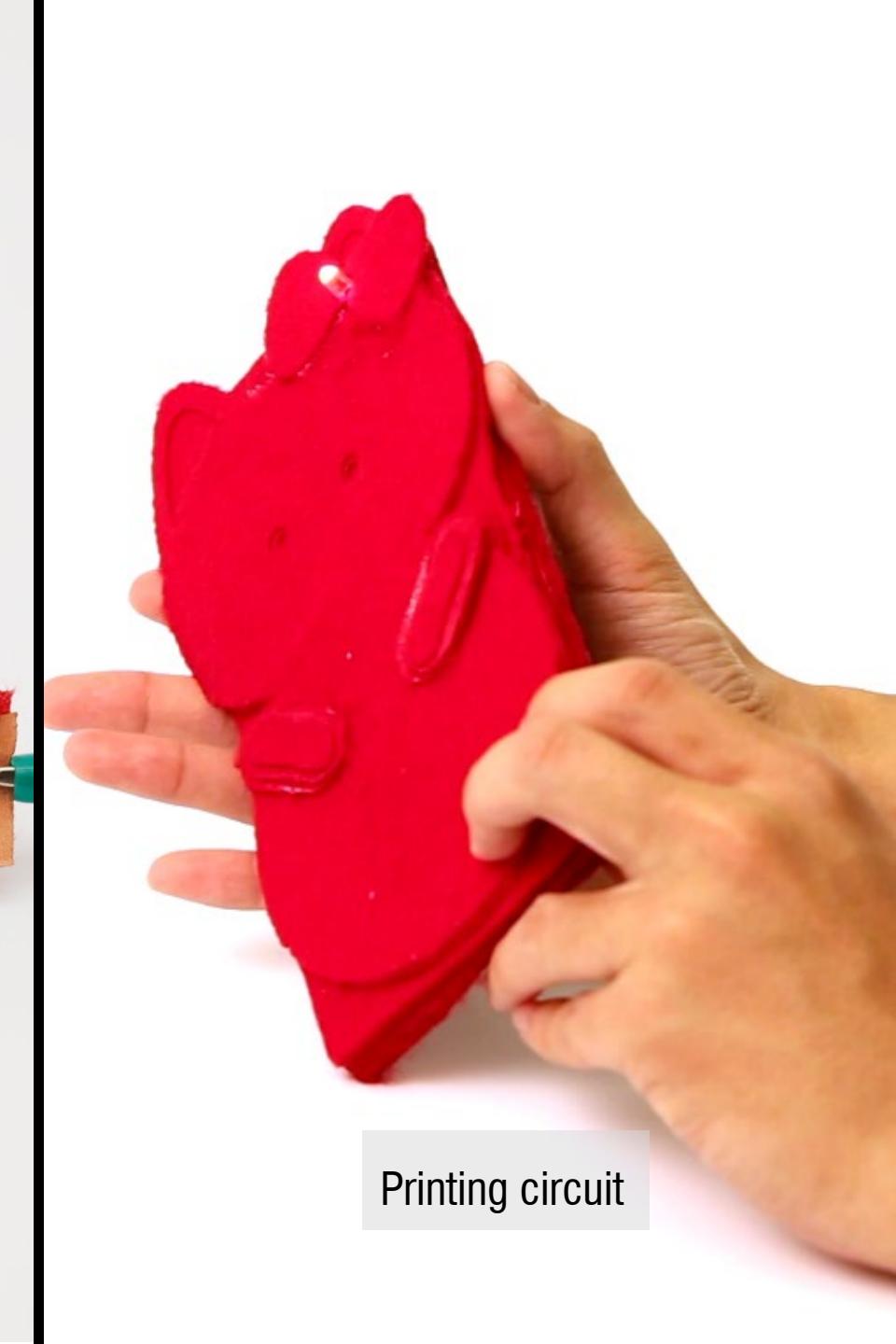




Manipulate deformation



Printing sensor

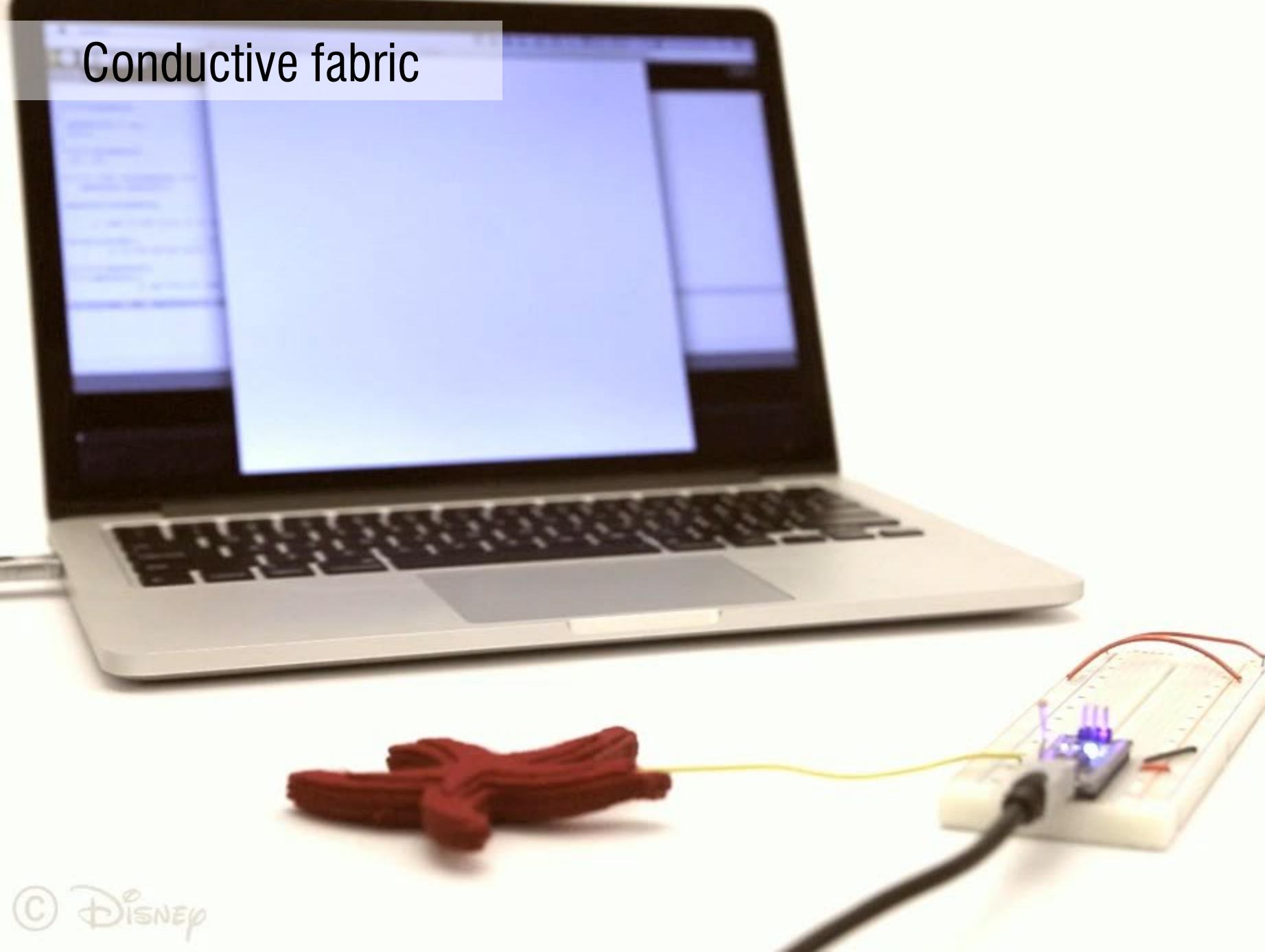


Printing circuit

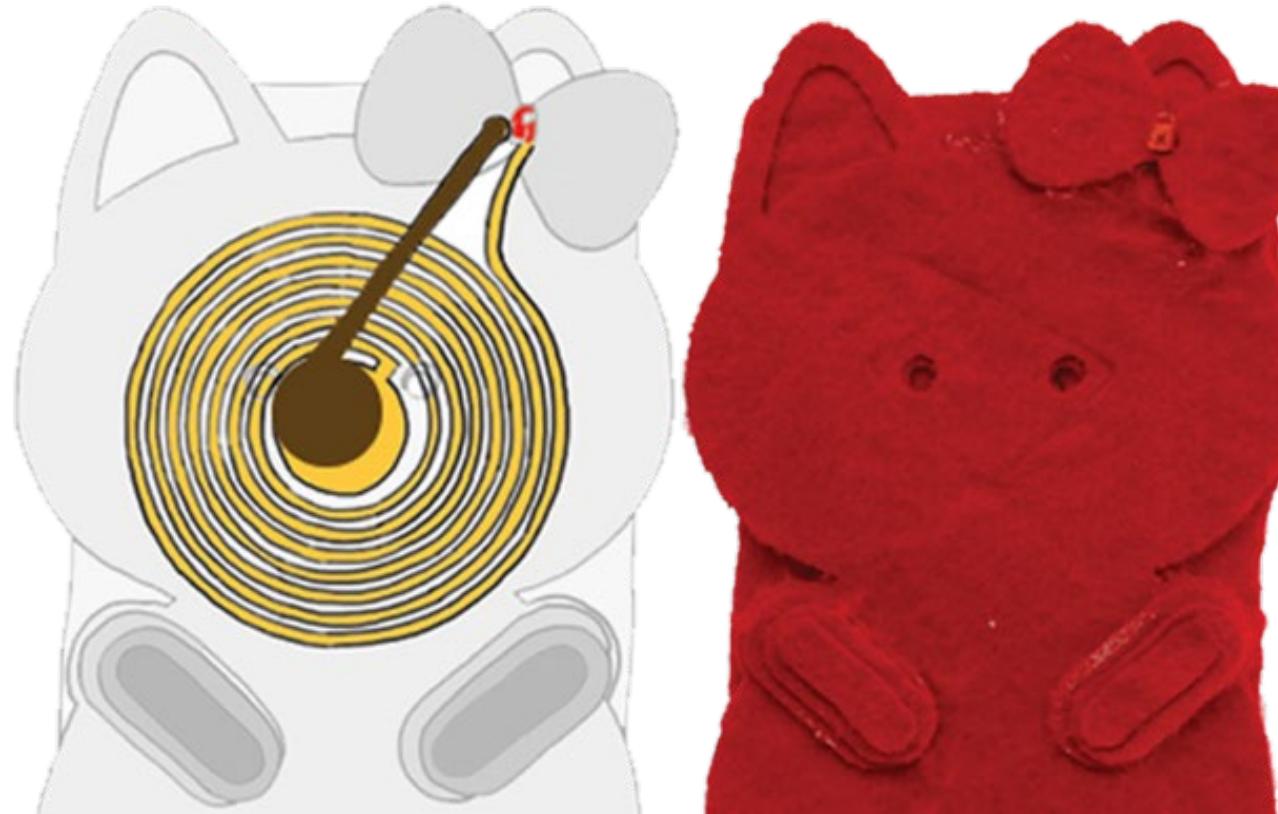
Deformation manipulation



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)

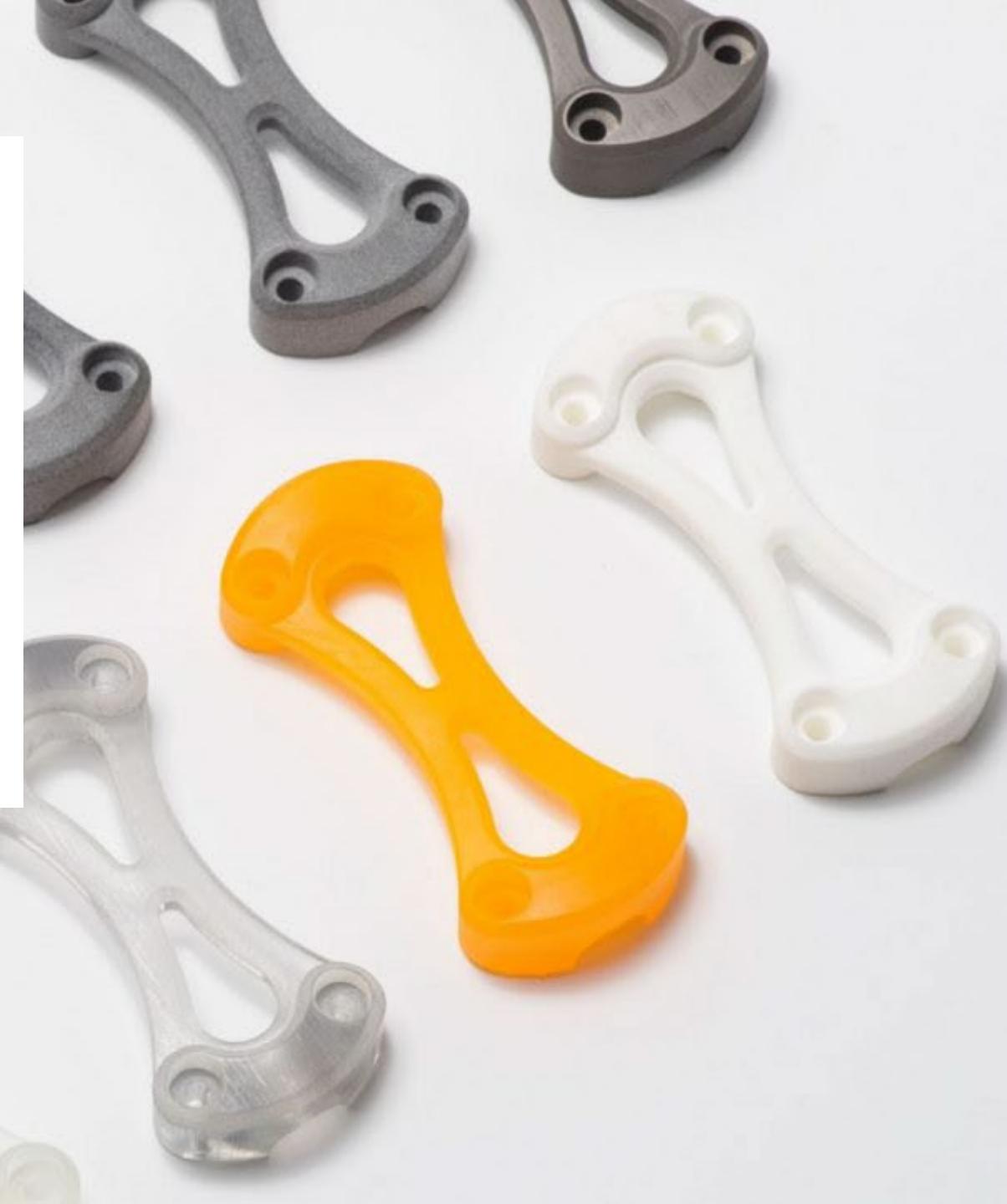
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Photopolymer Phase Change Inkjets (PolyJet)

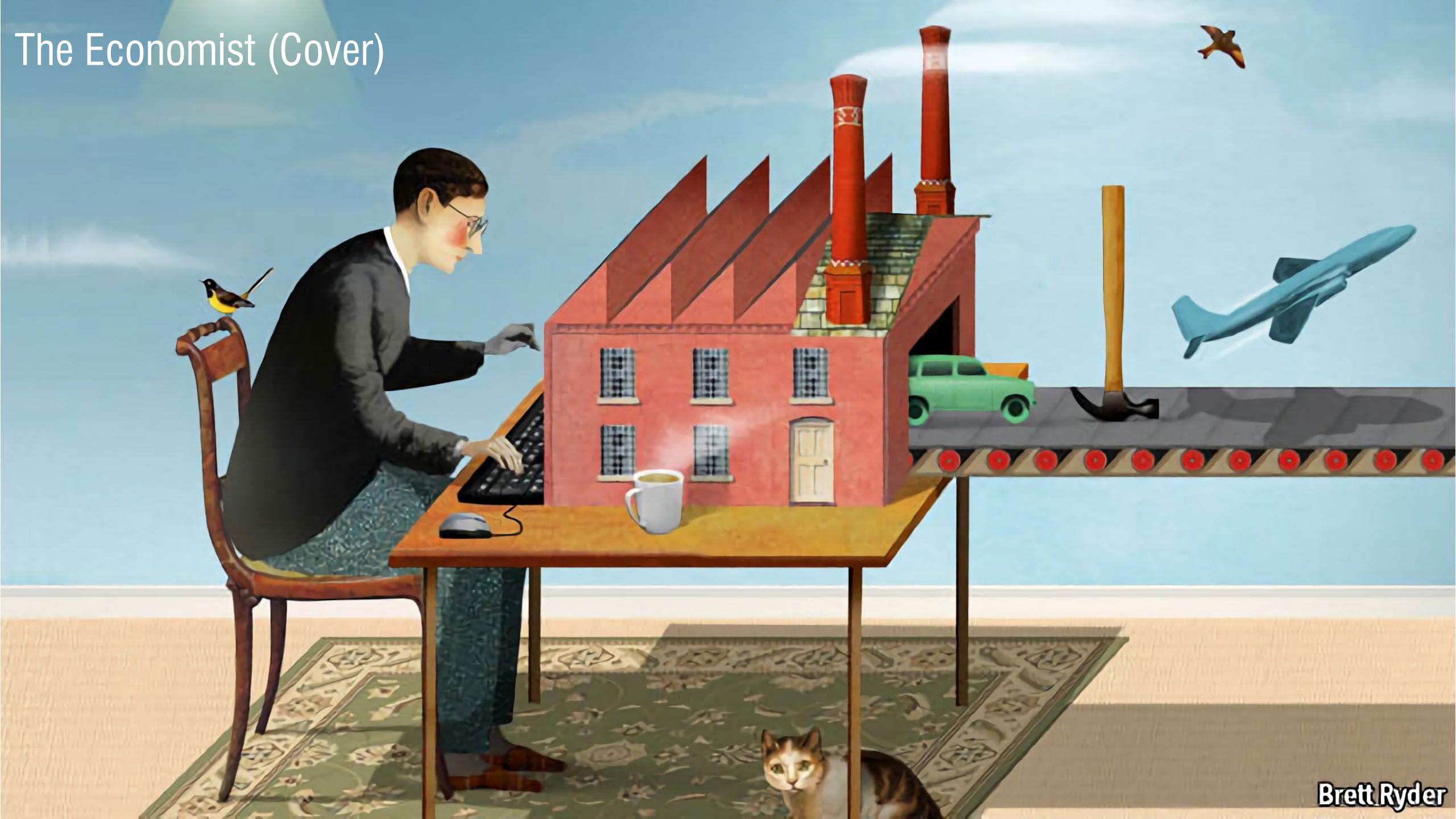
Selective laser sintering (SLS)

Laminated object manufacturing (LOM)

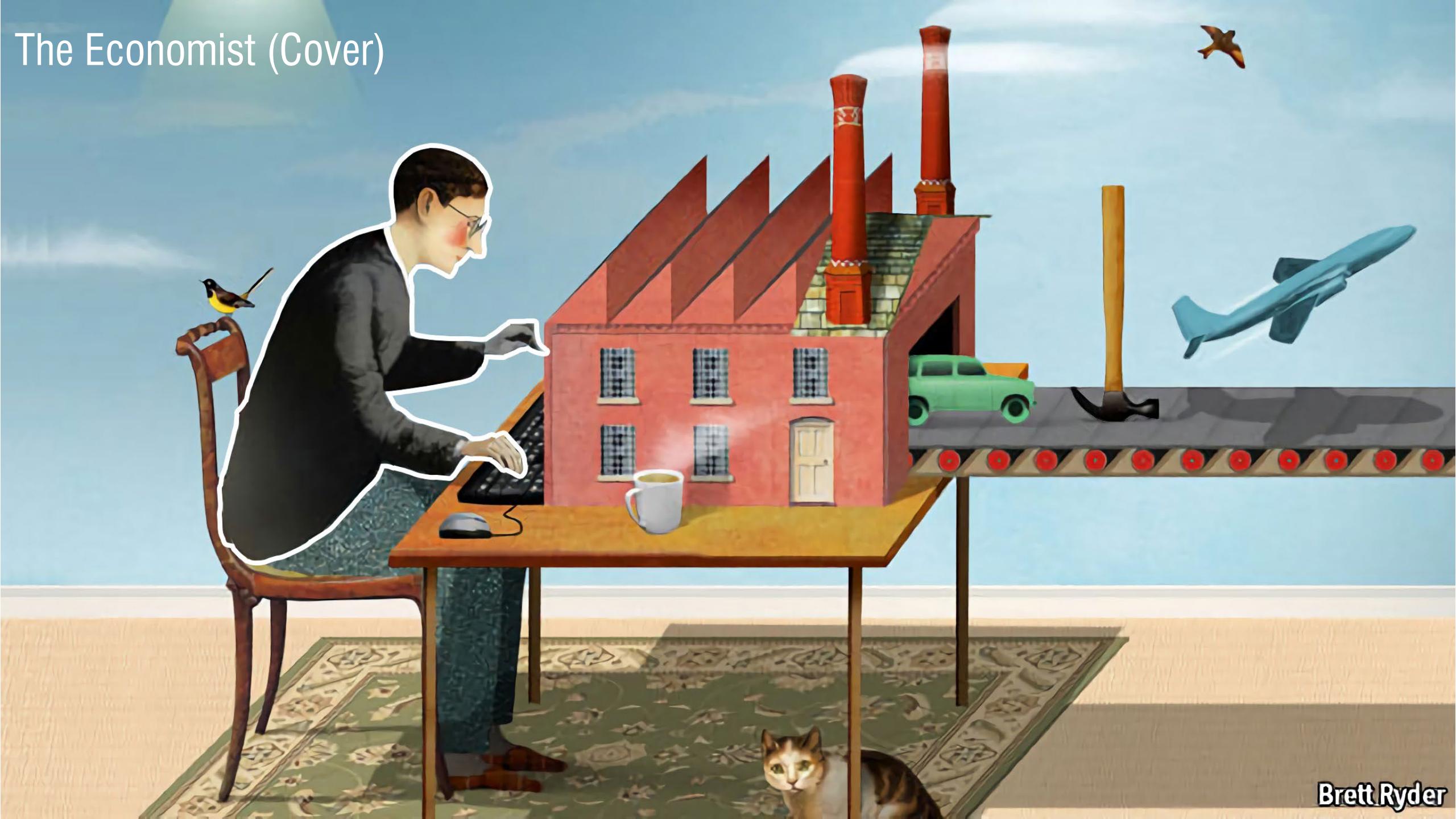


What are the challenges

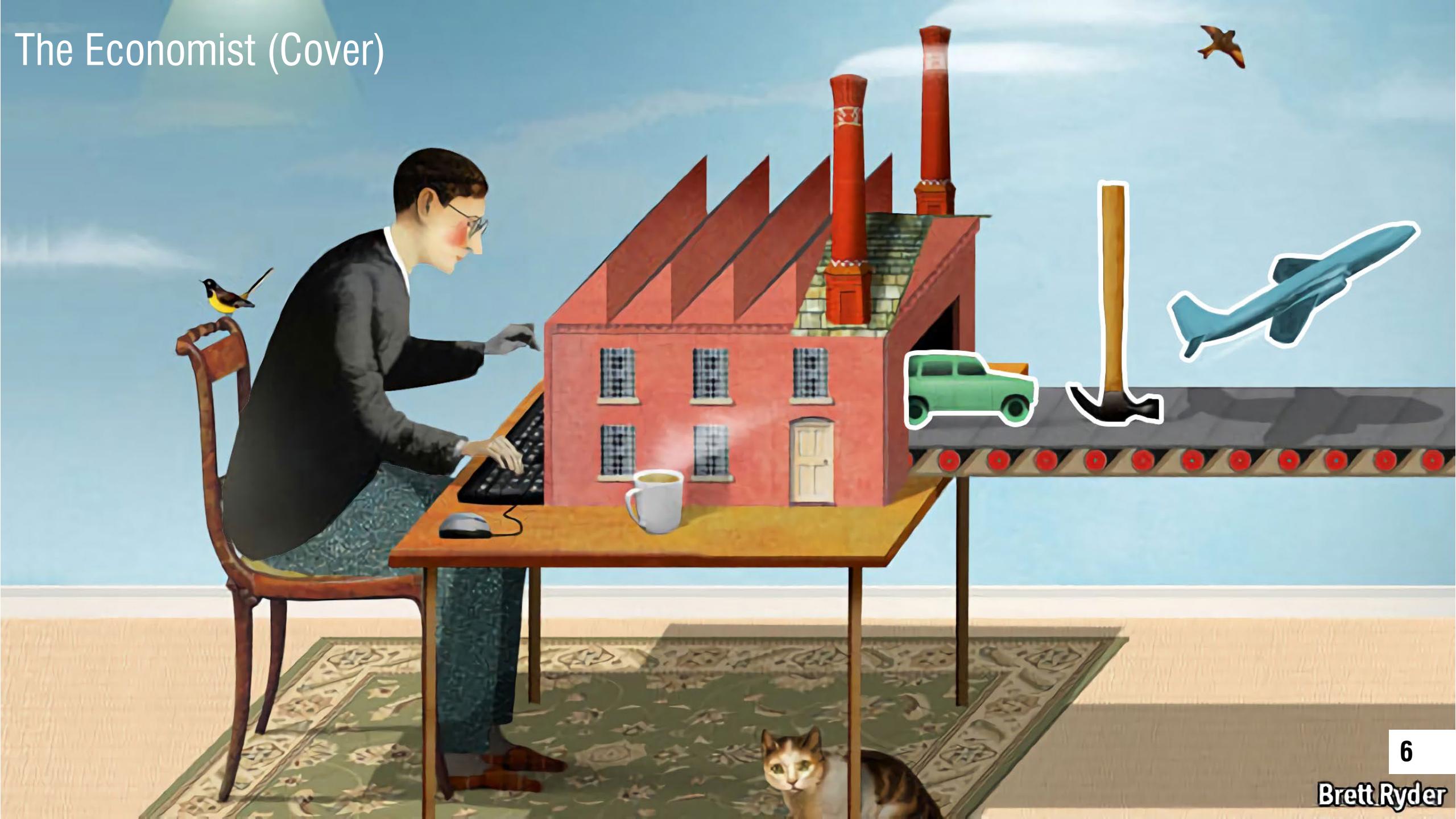
The Economist (Cover)



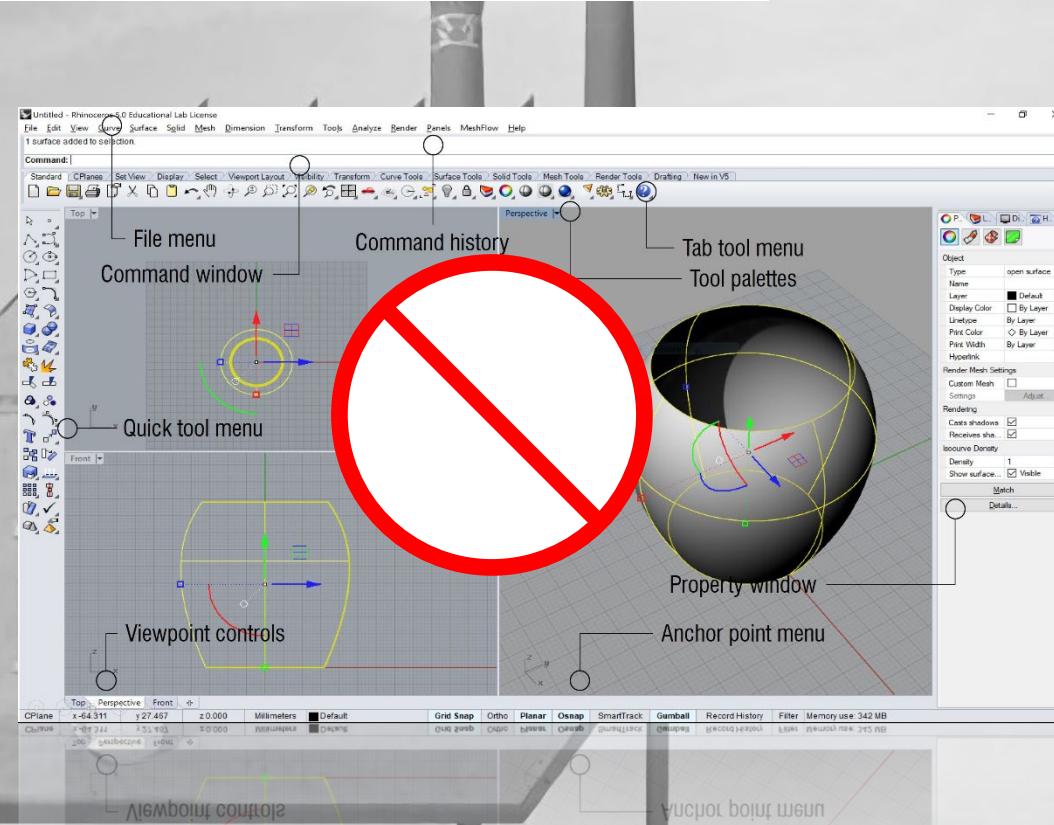
The Economist (Cover)



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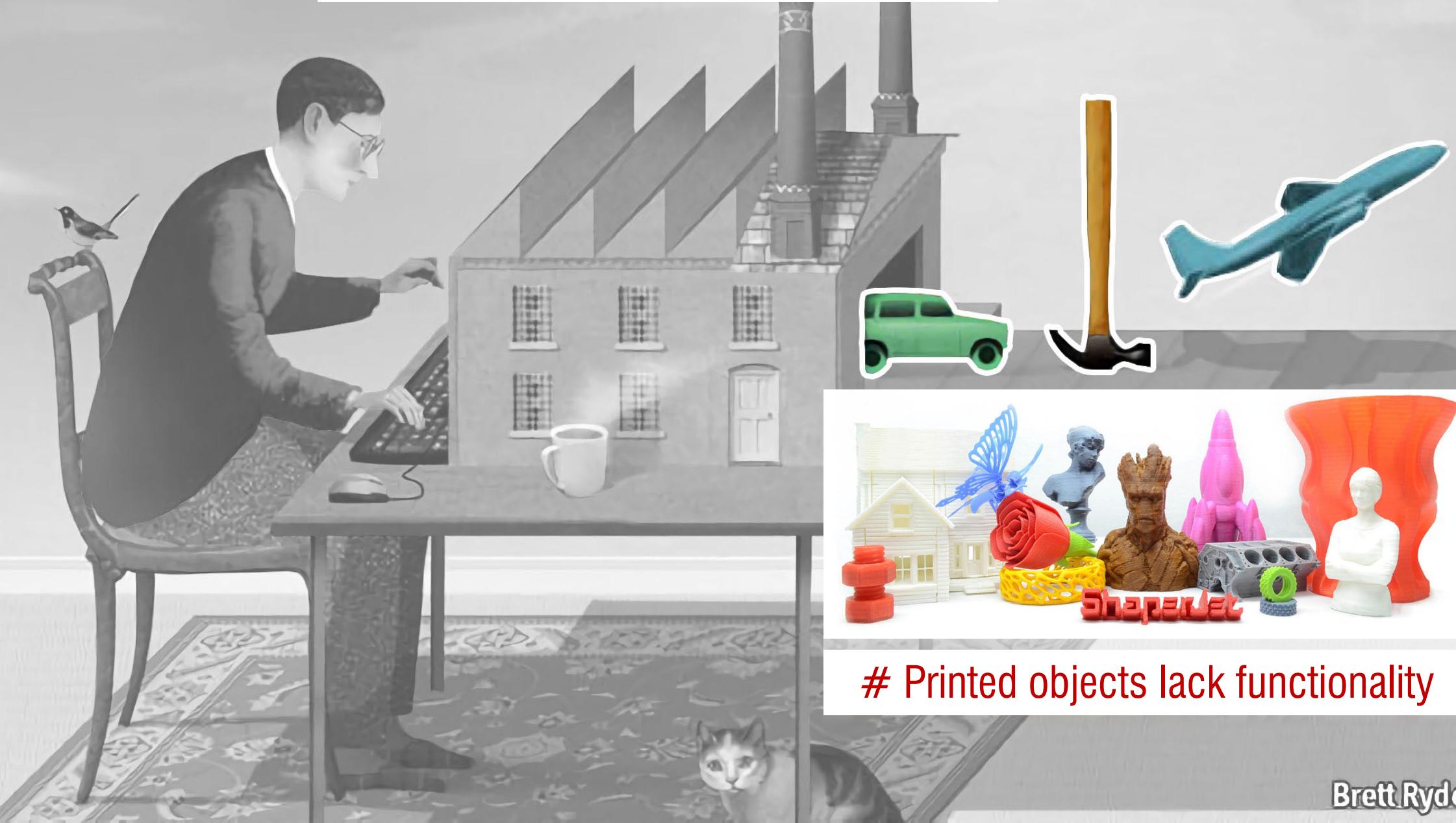


Two challenges for personal fabrication



Design 3D digital models is difficult

Two challenges for Personal Fabrication



Printed objects lack functionality

Brett Ryder

What are the challenges

we will talk about current research that tries to solve many of the challenges later this semester

Recap

3 types of manufacturing methods

Brief history of 3D printing

Examples of printed objects

Varies of printing methods



Optional readings

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

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Scott E. Hudson^{1,3} Ivan Poupyrev¹
Computational Design Lab², HCI Institute³
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
scott.hudson@cs.cmu.edu

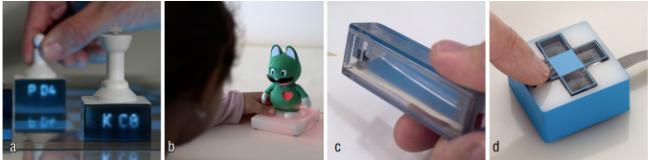


Figure 1: Custom optical elements are fabricated with 3D printing and embedded in interactive devices, opening up new possibilities for interaction including: unique display surfaces made from 3D printed ‘light pipes’ (a), novel internal illumination techniques (b), custom optical sensors (c), and embedded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

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UIST ’12, October 7–10, 2012, Cambridge, Massachusetts, USA.
Copyright 2012 ACM 978-1-4503-1580-7/12/10...\$15.00.

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 enable the fabrication of high resolution transparent plastics with similar optical properties to plexiglas™. 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-

Patching Physical Objects

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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 reprinted, 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].

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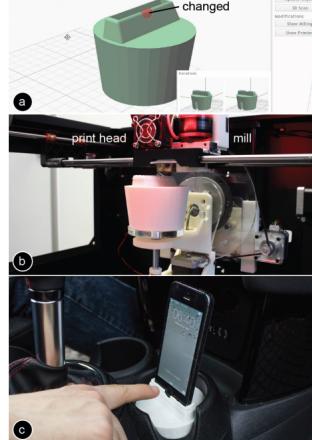


Figure 1: To minimize material consumption and to reduce waste during design iteration, we propose *patching* the existing object rather than reprinting it from scratch. (a) First, our software calculates which part changed, then (b) a mill removes outdated geometry, followed by a print head that prints 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 2012

Willis et.al.

UIST 2015

Teibrich et.al.



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I am an assistant professor in the department of Computer Sciences at the University of Wisconsin-Madison. My research interests include Human-Computer Interaction (HCI), accessibility, augmented and virtual reality (AR/VR), human-centered AI, and mobile interaction. I **design and build intelligent interactive systems to enhance human abilities**. Via my research, I seek to understand the challenges and needs of people with diverse abilities, and design systems and interaction techniques to empower them in both the real life activities and the emerging virtual worlds. My work has been published at many top-tier conferences and journals in the field of Human-Computer Interaction (including three best paper nominees), as well as 3 U.S. and international patents. I received my Ph.D. degree from Cornell Tech, Cornell University, and B.E. degree and M.S. degree with distinction on thesis in Computer Science at Tsinghua University.

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[GOOGLE SCHOLAR](#)

PHD RECRUITMENT

I'm looking for motivated students who are interested in applying AI and AR/VR technology to the accessibility field. Students who have a computer vision/machine learning background will be prioritized.

RECENT TALKS

Designing Augmented Reality Systems to Empower People with Low Vision, A11yVR Meetup, Oct 22, 2020.



Designing Technologies to Make Virtual Reality Accessible for People with Low Vision, DUB Talk, Jan 13, 2019.

[Designing Technologies to Make Virtual Reality Accessible for People with Low Vision](#)

NEWS

◆ 6.17.2022

Two papers on social VR accessibility accepted to ASSETS 2022. So proud of my students, Kexing Zhang, Tiger Ji, and Bri Cochran!

◆ 12.21.2020

One paper conditionally accepted to CHI 2021 (Congrats Yueteng Weng)! Stay tuned for the preprint.

◆ 7.10.2020

Defended my PhD dissertation! Big thanks to my advisor Shiri Azenkot and committee members Serge Belongie and Deborah Estrin for inspiring and supporting my research!

◆ 5.20.2020

Our video presentation for CHI 2020 is out! In this talk, we introduced our user study on comparing the effectiveness of visual and audio wayfinding guidance on smartglasses for people with low vision. Check it out [here](#)!

◆ 12.10. 2019

Two papers got conditionally accepted to CHI 2020! Aloha Hawaii!!!

◆ 11.01. 2019

My journal paper on ForeSee with a whole set of interaction techniques for low vision is accepted by TACCESS!

Guest lecture next Monday On Accessibility + VR

Be there, on zoom.