Take a break and enjoy your holiday time;)

Announcement

Final Exam –

Date: Fri, Dec. 13, 4pm - 6pm

Location: Online

Open book: laptop and digital material – Yes; Chat/ChatGPT/LLM based tools – No

Final Milestone Presentation –

Date: Dec 9th 3:30pm - 5:00pm (Be there at least 15 min ahead of time to setup your ‘booth’)

Location: Sandbox

Live Demo! Bring your setup to Sandbox early, and prepare to give a live demonstration, walkthrough key features/iterations you’ve made throughout the semester.

Final Milestone Summary –

Date: Dec 15 EOD (Sun)

Format: 2 options.

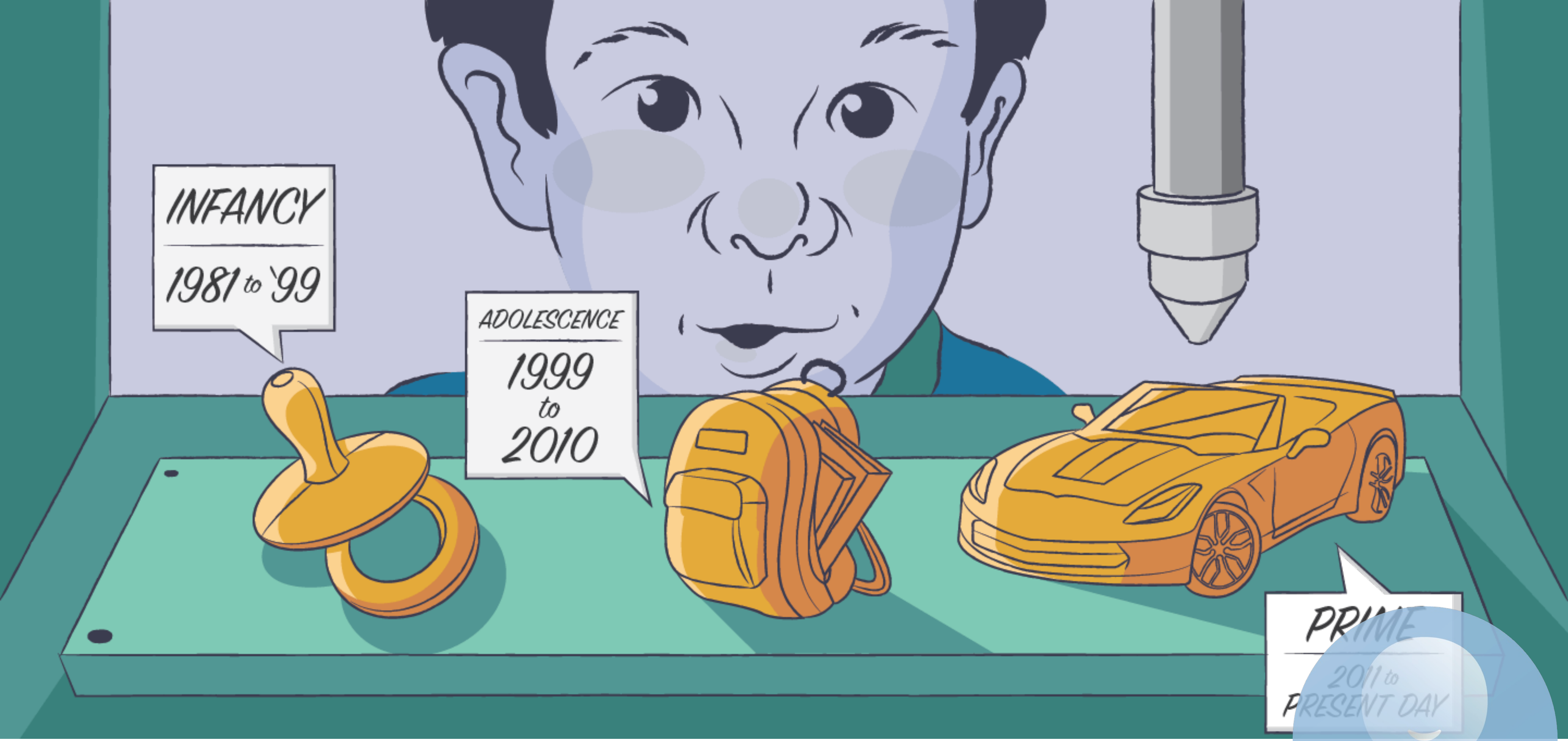
1) Online https://www.hackster.io/smartlab/projects with Documentation + simple video.
2) UIST paper format. https://uist.acm.org/2024/author-guide/

More details on ELMS.

Team Eval Survey –

Date: Dec 15 EOD

https://forms.gle/TtPvygMeq9VXvVPs5

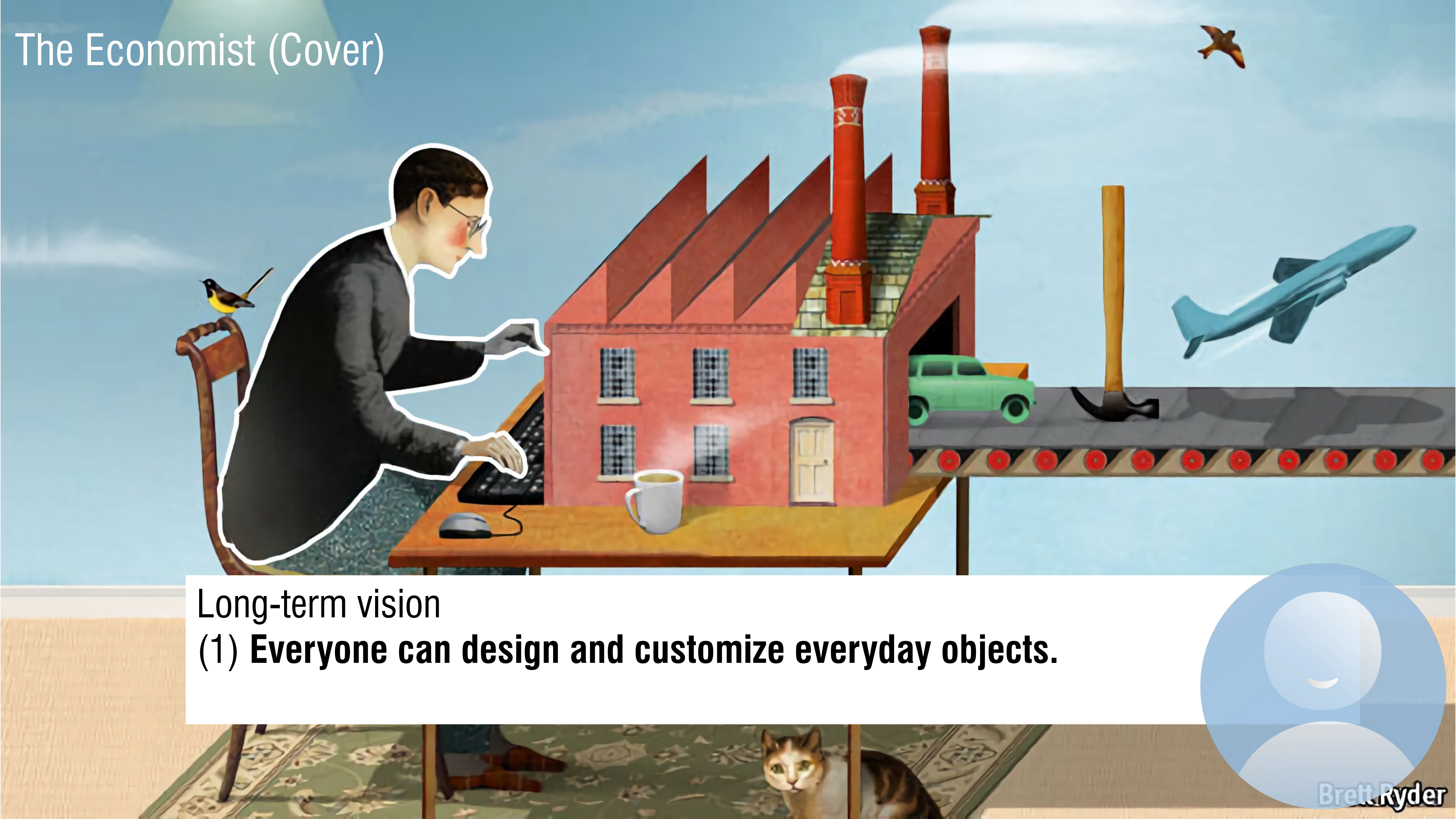


Personal Fabrication

CMSC730 | Huaishu Peng | UMD CS

Industrial 3D Printer

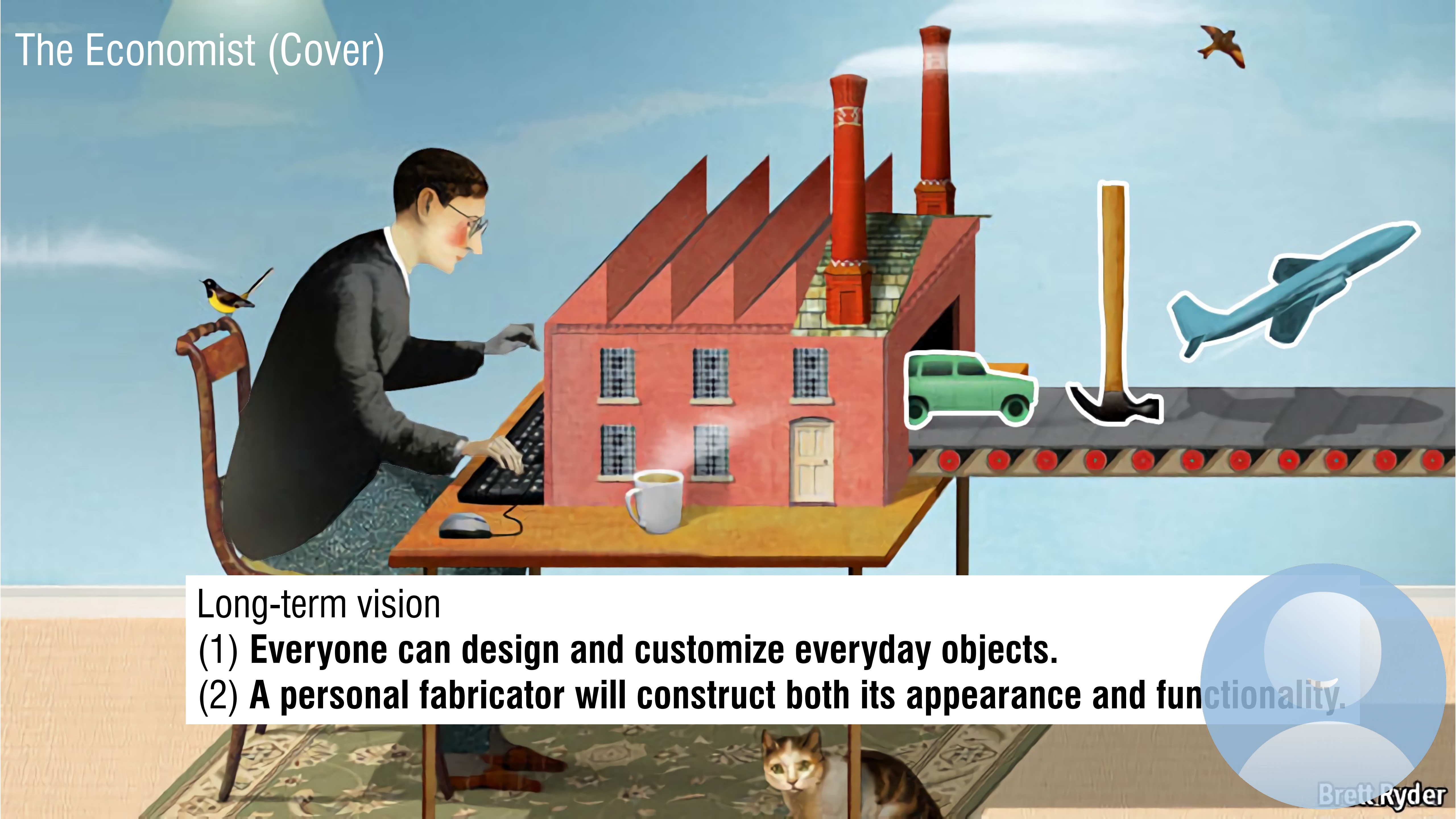
The Economist (Cover)



Long-term vision

(1) **Everyone can design and customize everyday objects.**

The Economist (Cover)



Long-term vision

(1) **Everyone can design and customize everyday objects.**

(2) **A personal fabricator will construct both its appearance and functionality.**

Design 3D digital models is difficult

What are the drawbacks of CAD design tools?

Implicit design commands
Complex interface
No fast physical feedback (intimacy between the designer and the raw material)

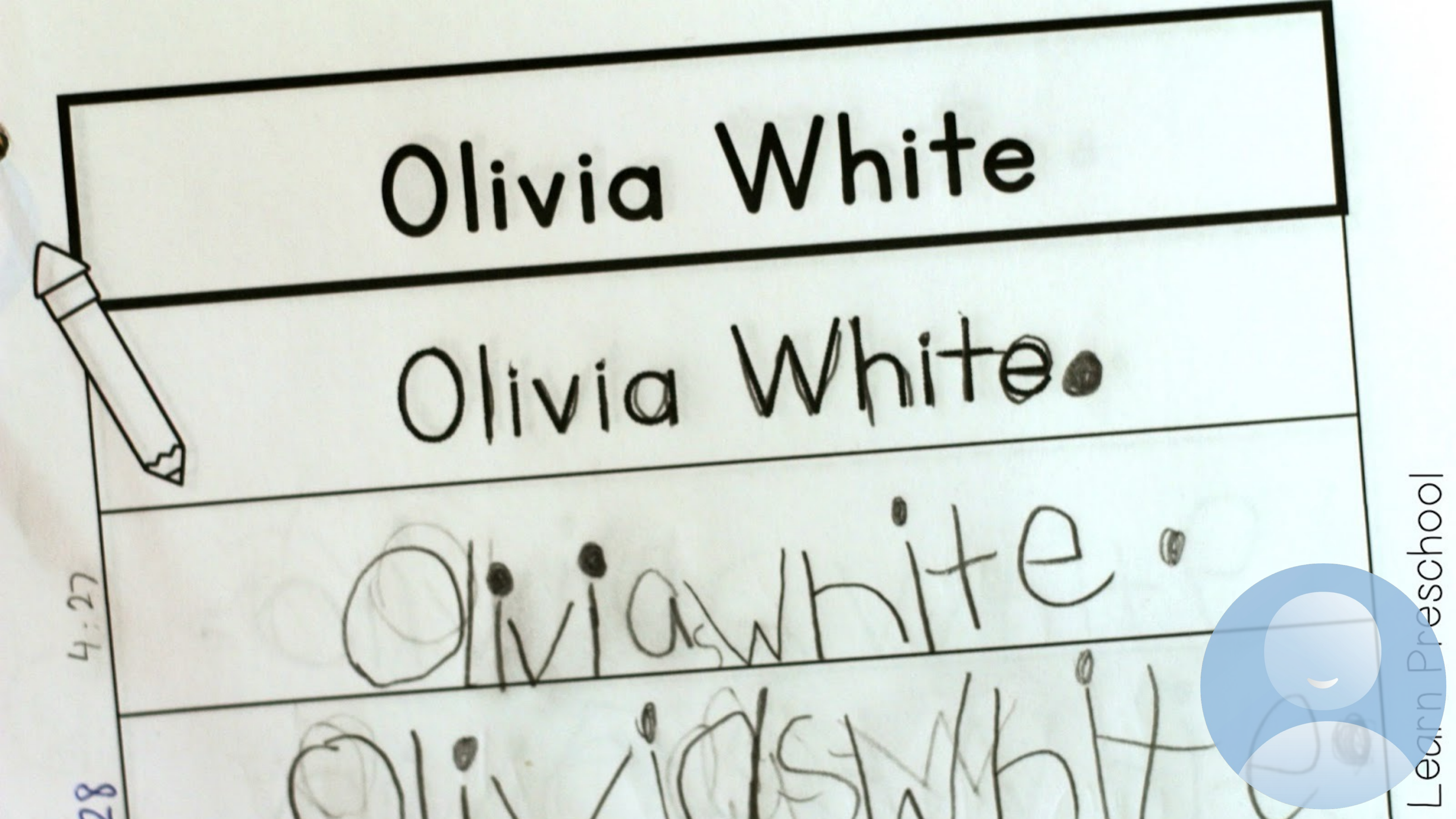
(a) Target 3D model

Input: 3D digital model

?

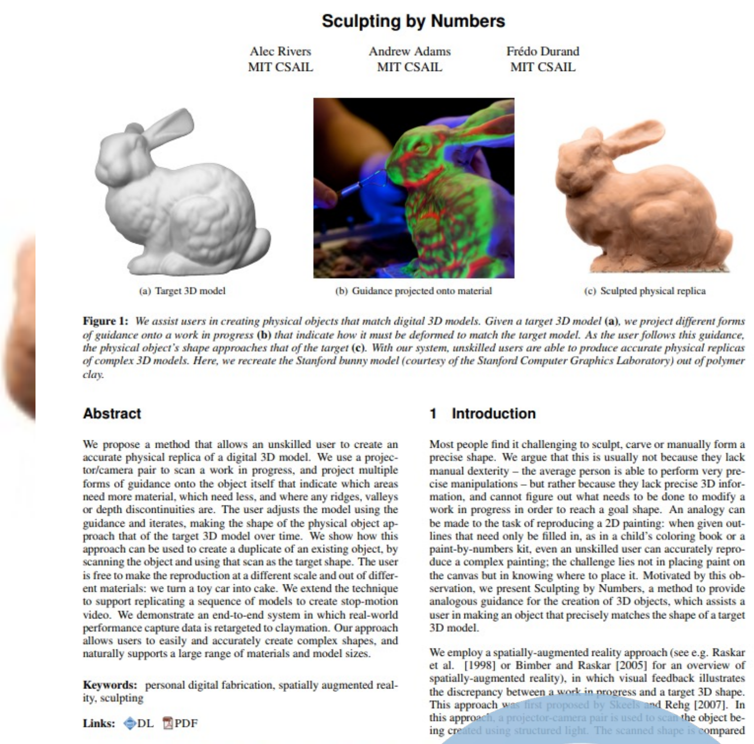
(c) Sculpted physical replica

Output: 3D clay model


Olivia White
Olivia White
4:27
Learn Preschool

(a) Target 3D model

(b) Guidance projected onto material



Sculpting by Numbers

Alec Rivers
MIT CSAIL

Andrew Adams
MIT CSAIL

Frédo Durand
MIT CSAIL

(a) Target 3D model (b) Guidance projected onto material (c) Sculpted physical replica

Figure 1: *We assist users in creating physical objects that match digital 3D models. Given a target 3D model* **(a)**, *we project different forms of guidance onto a work in progress* **(b)** *that indicate how it must be deformed to match the target model. As the user follows this guidance, the physical object's shape approaches that of the target* **(c)**. *With our system, unskilled users are able to produce accurate physical replicas of complex 3D models. Here, we recreate the Stanford bunny model (courtesy of the Stanford Computer Graphics Laboratory) out of polymer clay.*

Abstract

We propose a method that allows an unskilled user to create an accurate physical replica of a digital 3D model. We use a projector/camera pair to scan a work in progress, and project multiple forms of guidance onto the object itself that indicate which areas need more material, which need less, and where any ridges, valleys or depth discontinuities are. The user adjusts the model using the guidance and iterates, making the shape of the physical object approach that of the target 3D model over time. We show how this approach can be used to create a duplicate of an existing object, by scanning the object and using that scan as the target shape. The user is free to make the reproduction at a different scale and out of different materials: we turn a toy car into cake. We extend the technique to support replicating a sequence of models to create stop-motion video. We demonstrate an end-to-end system in which real-world performance capture data is retargeted to claymation. Our approach allows users to easily and accurately create complex shapes, and naturally supports a large range of materials and model sizes.

Keywords: personal digital fabrication, spatially augmented reality, sculpting

Links: DL PDF

1 Introduction

Most people find it challenging to sculpt, carve or manually form a precise shape. We argue that this is usually not because they lack manual dexterity – the average person is able to perform very precise manipulations – but rather because they lack precise 3D information, and cannot figure out what needs to be done to modify a work in progress in order to reach a goal shape. An analogy can be made to the task of reproducing a 2D painting: when given outlines that need only be filled in, as in a child's coloring book or a paint-by-numbers kit, even an unskilled user can accurately reproduce a complex painting; the challenge lies not in placing paint on the canvas but in knowing where to place it. Motivated by this observation, we present Sculpting by Numbers, a method to provide analogous guidance for the creation of 3D objects, which assists a user in making an object that precisely matches the shape of a target 3D model.

We employ a spatially-augmented reality approach (see e.g. Raskar et al. [1998] or Bimber and Raskar [2005] for an overview of spatially-augmented reality), in which visual feedback illustrates the discrepancy between a work in progress and a target 3D shape. This approach was first proposed by Skeels and Rehg [2007]. In this approach, a projector-camera pair is used to scan the object being created using structured light. The scanned shape is compared

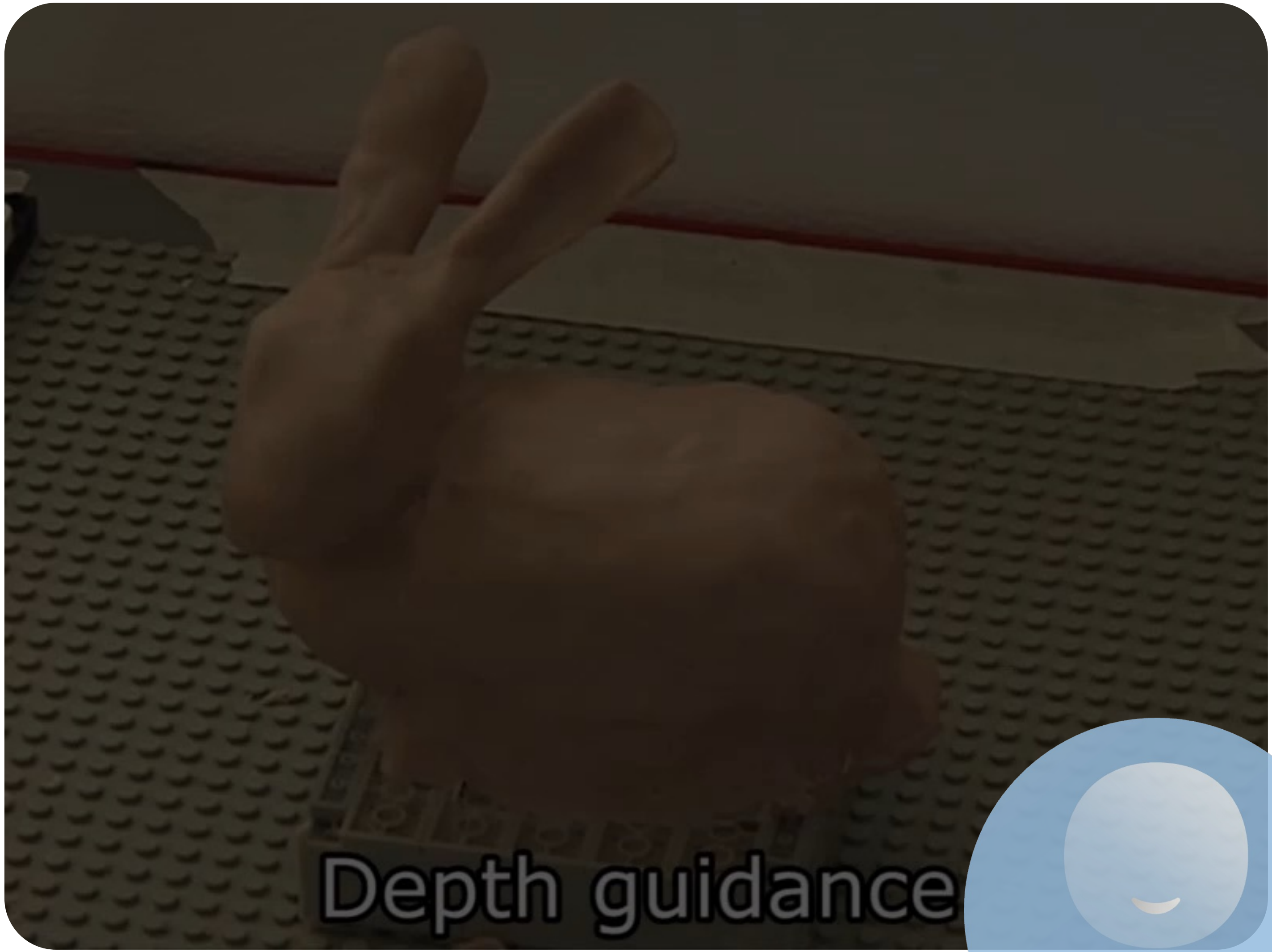
(c) Sculpted physical replica

Rivers et.al. from MIT
2012

Structured light 3D scanning

Compare the scanning result with the 3D digital model

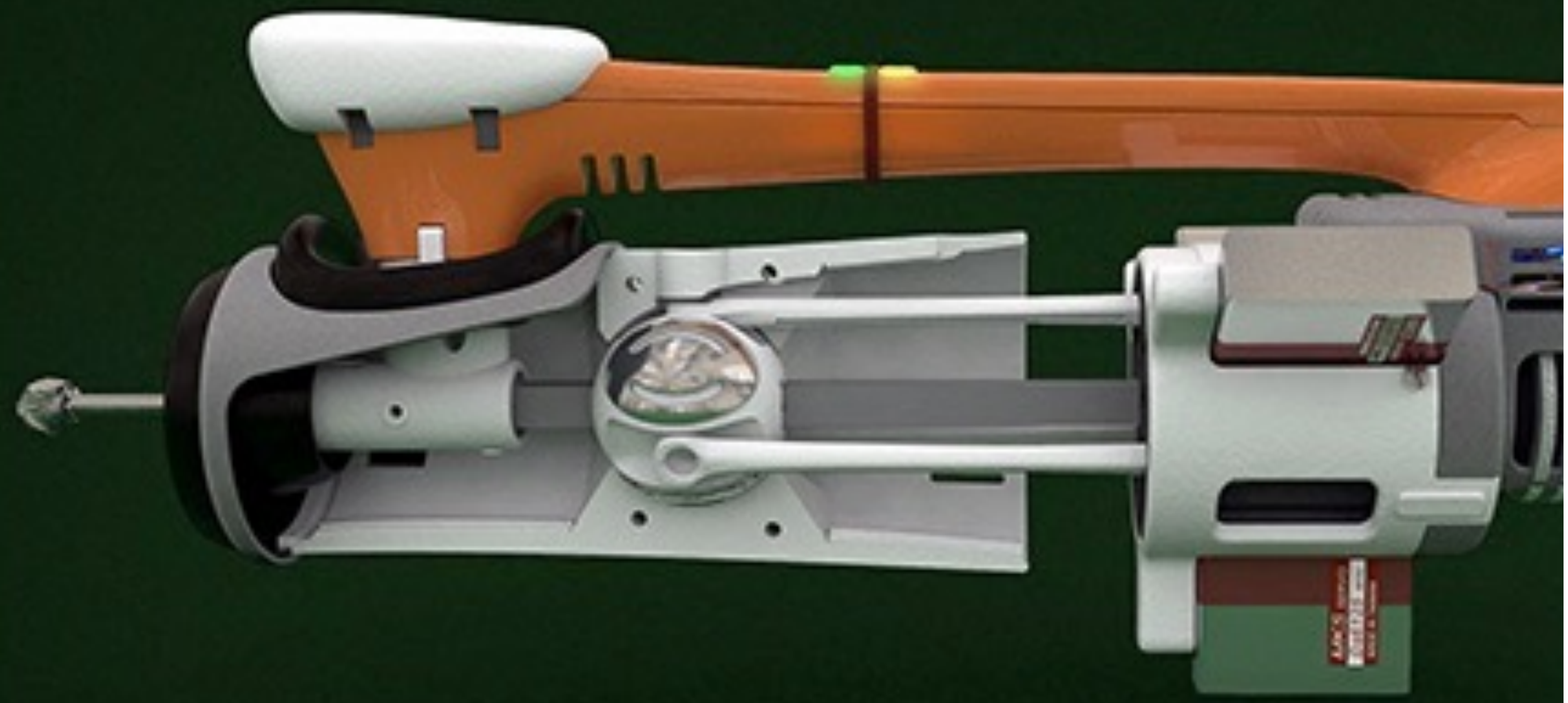
Differences are projected at each step with green/red colors



Limitations of this light guidance idea?

Turn-taking (scan at each of the ‘step’)
Would be hard to do with other material such as wood/foam (because there is no additive process for such material)

Possible solutions?



FreeD – A Freehand Digital Sculpting Tool

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ABSTRACT
In this paper, we present an approach to combining digital fabrication and craft, emphasizing the user experience. While many researchers strive to enable makers to design and produce 3D objects, our research seeks to present a new fabrication approach to make unique, one-of-a-kind artifacts. To that end, we developed the FreeD, a hand-held digital milling device. The system is guided and monitored by a computer while preserving the maker's freedom to sculpt and carve, and to manipulate the work in many creative ways. Relying on a predesigned 3D model, the computer gets into action only when the milling bit risks the object's integrity, by slowing down the spindle's speed or by drawing back the shaft, while the rest of the time it allows complete gestural freedom. We describe the key concepts of our work and its motivation, present the FreeD's architecture and technology, and discuss two projects made with the tool.

Author Keywords
Computer-Aided Design (CAD); Craft; Digital Fabrication; Carving; Milling.

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

INTRODUCTION
Over the last several years, digital fabrication technologies have altered many disciplines [4]. Today's designers can easily create, download, or modify a Computer-Aided Design (CAD) model of their desired object, and fabricate it directly using a digital process. In developing new manufacturing technologies, engineers seek an optimal solution, reducing the process to as few parameters as possible, and separating design from fabrication. Ease of use, accessibility, proliferation and efficacy grow as technology matures. However, qualities such as creative engagment in the experience itself are lost. The nature of interaction with the fabricated artifact is rarely the focus of new developments.

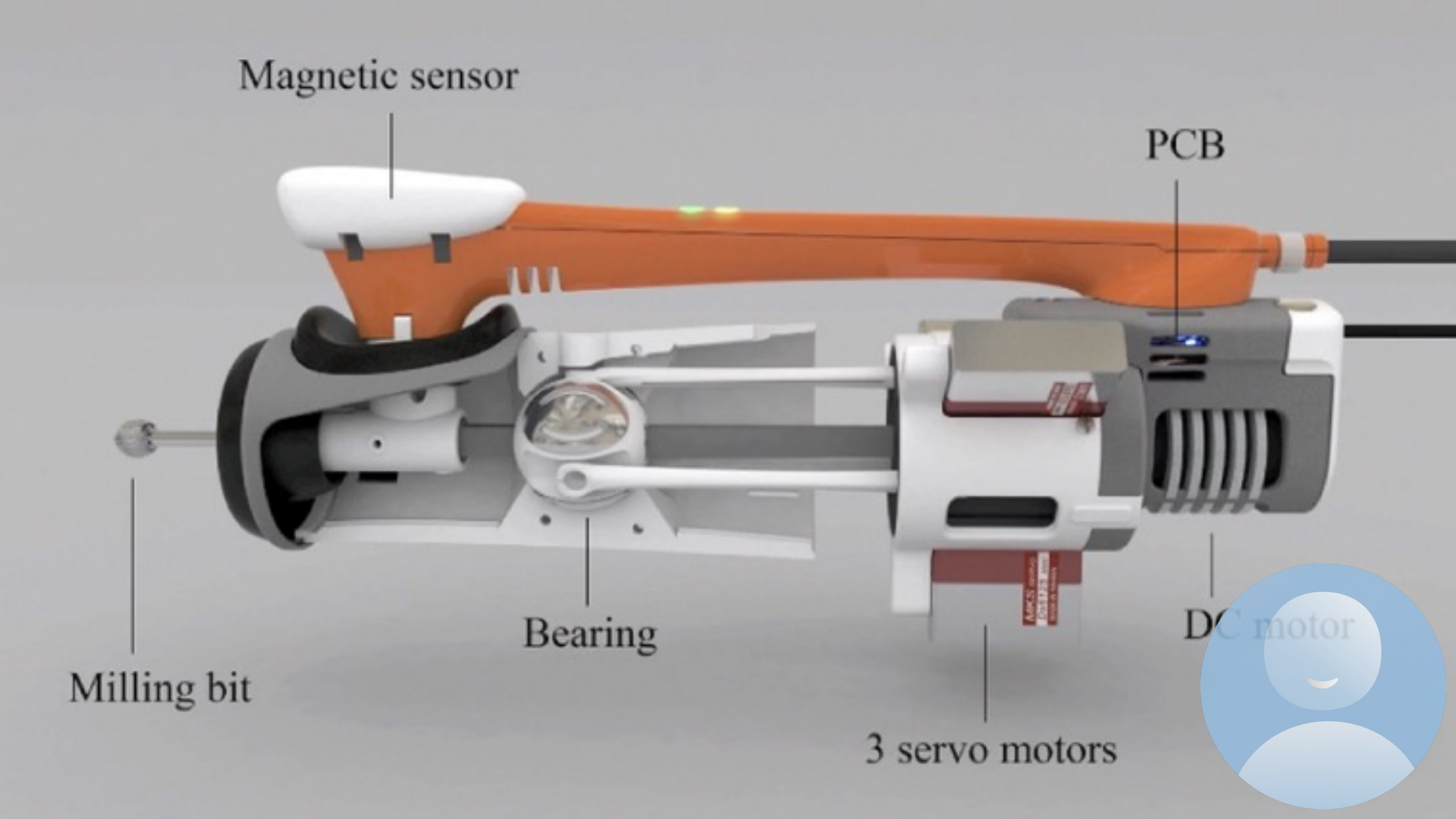
While the process of engineering minimizes risks, seeks efficiency, and enables automation and repetition, craft is about involvment and engagement, uniqueness of the final products, and authenticity of the experience [7]. Engaging in an intimate fabrication process and enjoying the experience of shaping raw material are inherent values of traditional craft. As a result of this engagement, handcrafted products are unique and carry personal narratives [10].

Our research interest lies in the cross-section between digital fabrication and the study of the craft experience. We wish to allow designers to engage with the physical material, not only the CAD environment. We hope to encourage the exploration of an intimate digital fabrication approach, introducing craft qualities into the digital domain. Our contribution is a system merging qualities of both traditions: minimizing fabrication risk by using a small degree of digital control and automation while allowing authentic engagement with raw material to achieve unique results.

The *FreeD* is a freehand digitally controlled milling device (Figure 1). With the FreeD we harness CAD abilities in 3D design while keeping the user involved in the milling process. A computer monitors this 3D location-aware tool while preserving the maker's gestural freedom. The computer intervenes only when the milling bit approaches the 3D model. In such a case, it will either slow down the spindle, or draw back the shaft; the rest of the time it allows the user to freely shape the work. Our hope is to substantiate the importance of engaging in a discourse that posits a new hybrid territory for investigation and discovery - a territory of artifacts produced by both machine and man.

Figure 1: (A) The FreeD and (B-C) the process of making a bowl from polyethylene foam.

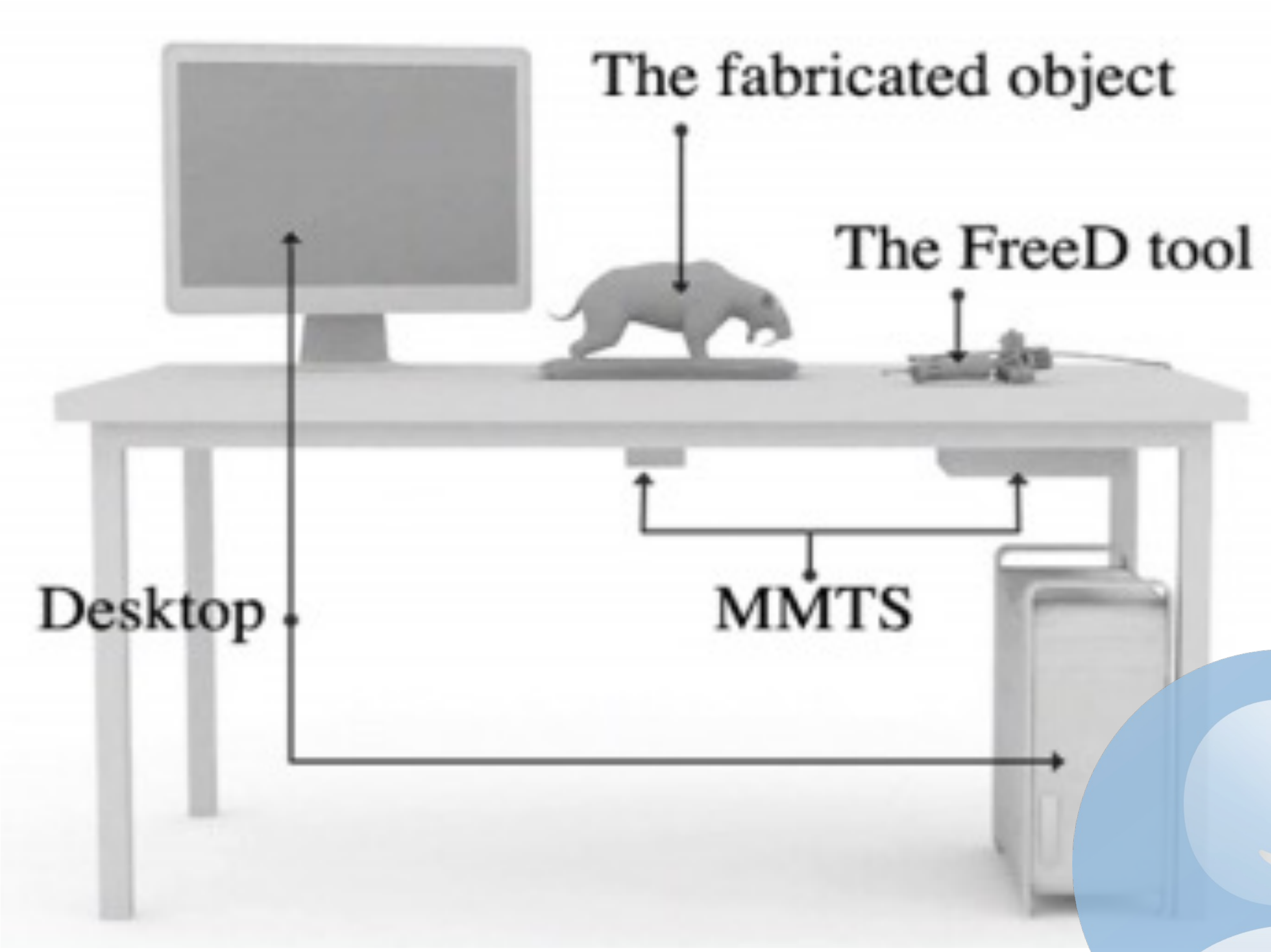
CHI 13 and UIST 13
Zoran et.al. from MIT


Magnetic sensor
PCB
Bearing
Milling bit
3 servo motors
DC motor

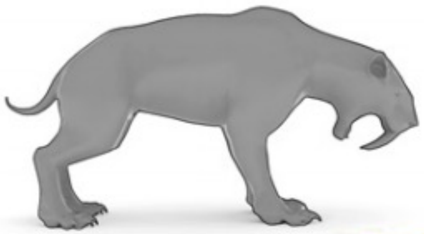
Tracking: 6DOF Magnetic tracking

Control: stop milling at the edge of the digital model

Control can be overridden with manual control



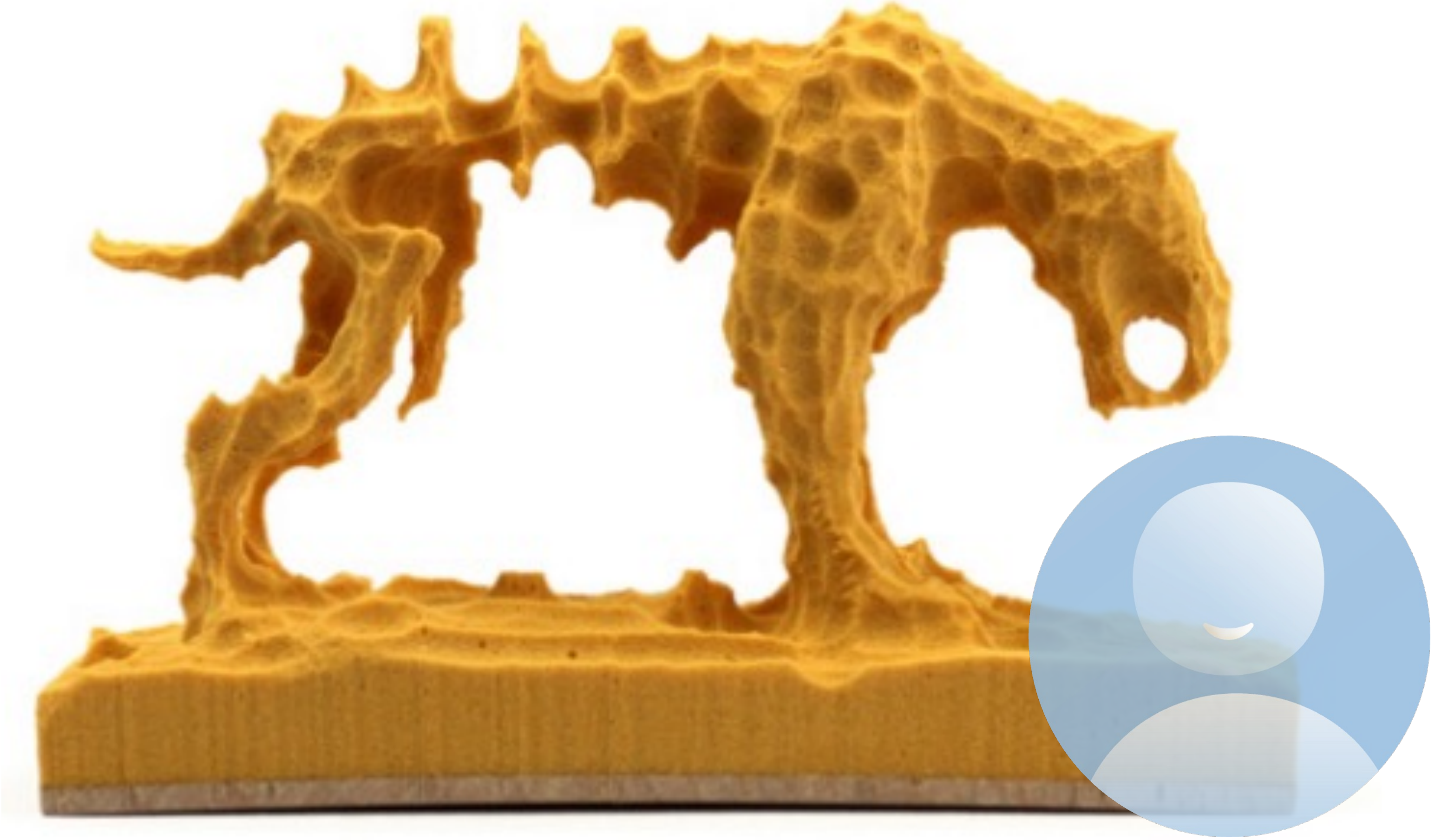
What can this do that the previous project cannot?



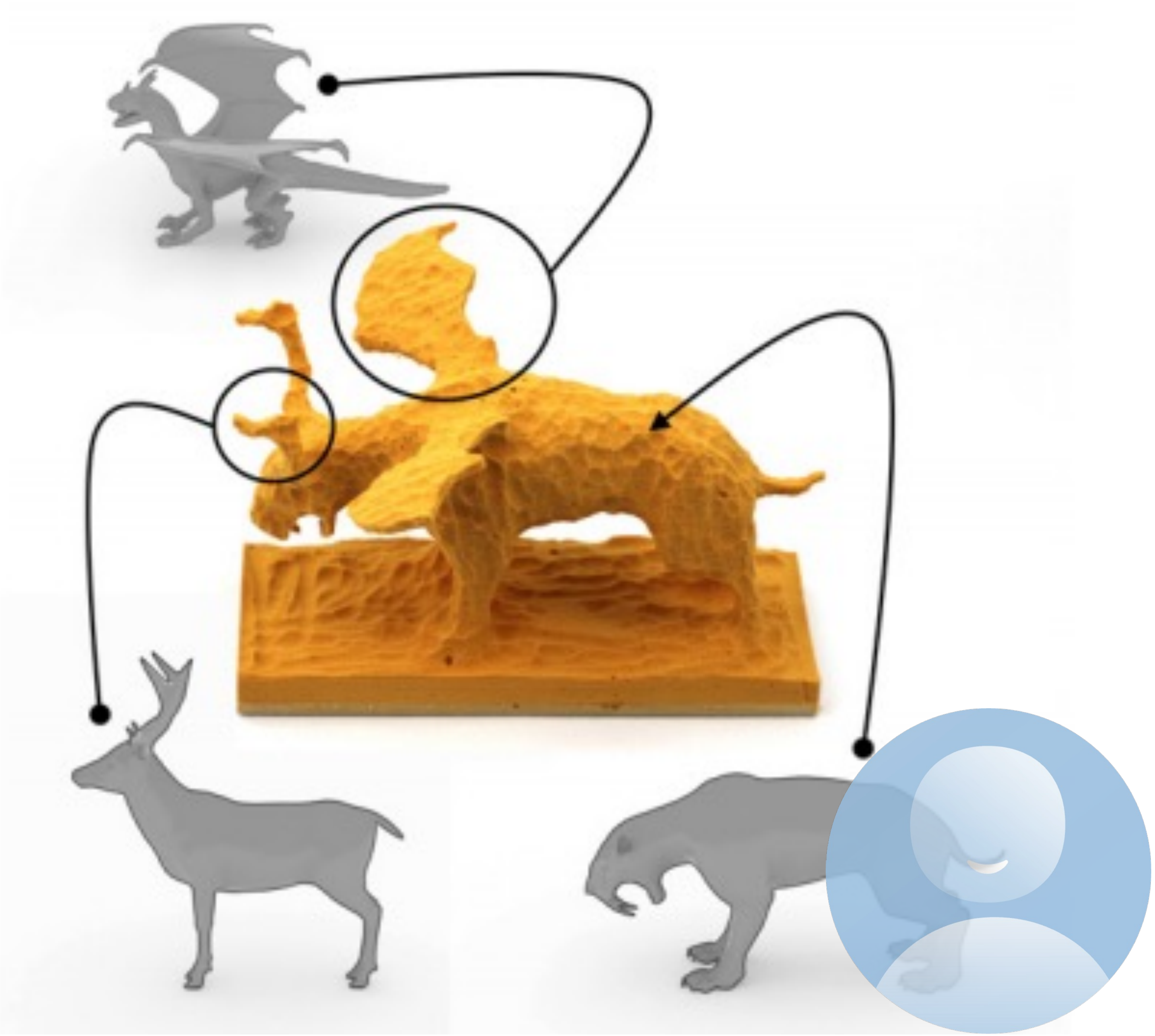
(a)

(b)

Manual override

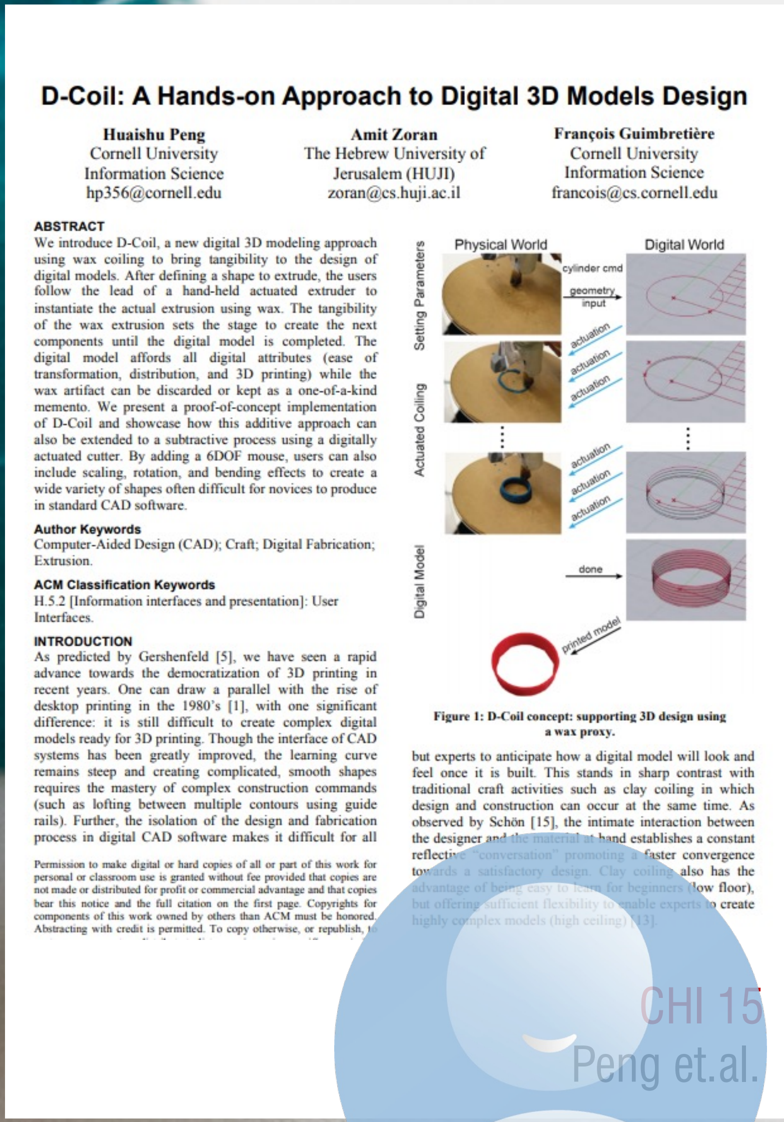


user can manually switch between
different reference virtual models during the work



Physical merging

What if we have no digital model at the beginning?
What if we hope to design a 3D model **from scratch**?



D-Coil: A Hands-on Approach to Digital 3D Models Design

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François Guimbretière
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Information Science
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ABSTRACT

We introduce D-Coil, a new digital 3D modeling approach using wax coiling to bring tangibility to the design of digital models. After defining a shape to extrude, the users follow the lead of a hand-held actuated extruder to instantiate the actual extrusion using wax. The tangibility of the wax extrusion sets the stage to create the next components until the digital model is completed. The digital model affords all digital attributes (ease of transformation, distribution, and 3D printing) while the wax artifact can be discarded or kept as a one-of-a-kind memento. We present a proof-of-concept implementation of D-Coil and showcase how this additive approach can also be extended to a subtractive process using a digitally actuated cutter. By adding a 6DOF mouse, users can also include scaling, rotation, and bending effects to create a wide variety of shapes often difficult for novices to produce in standard CAD software.

Author Keywords

Computer-Aided Design (CAD); Craft; Digital Fabrication; Extrusion.

ACM Classification Keywords

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

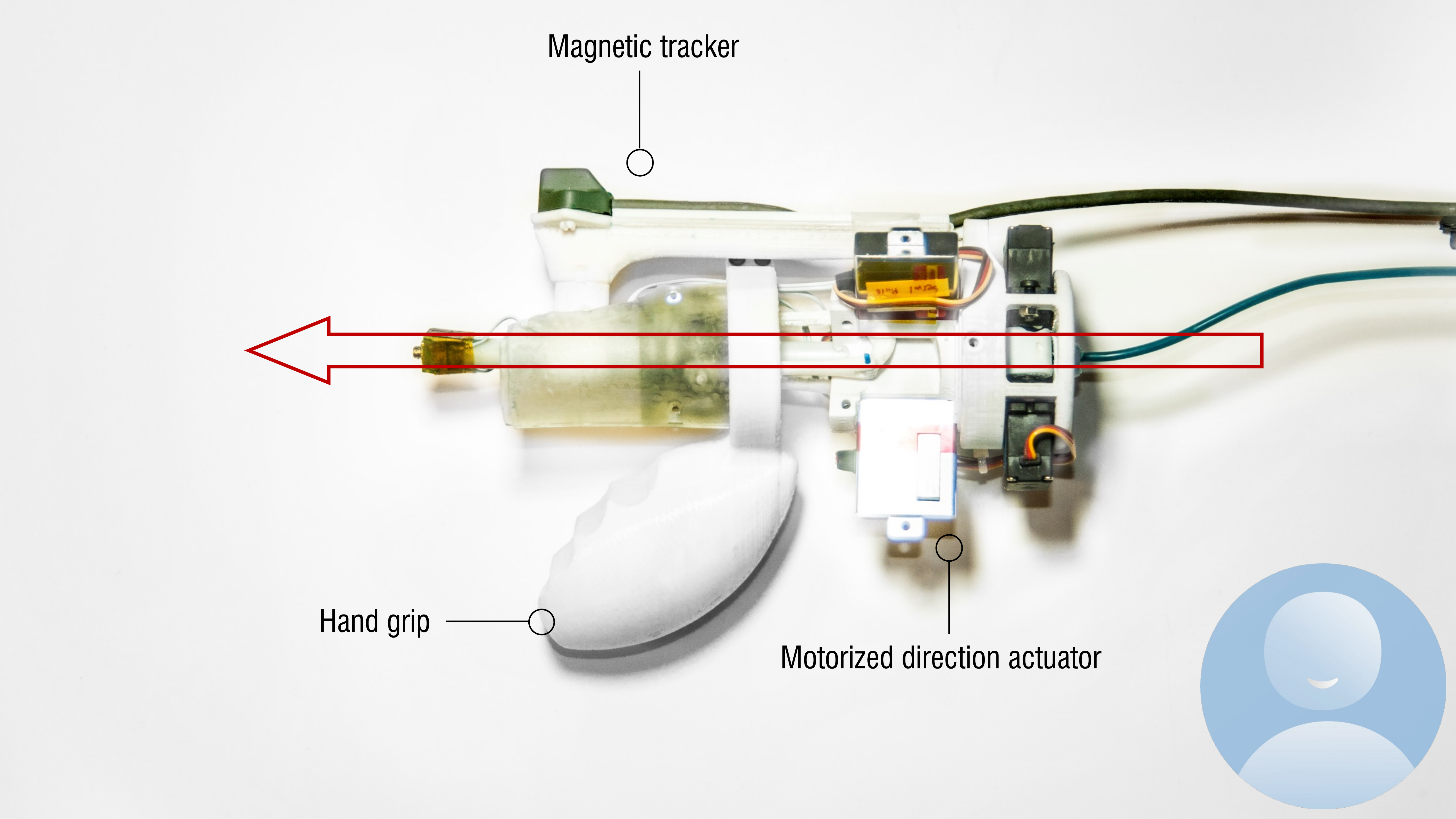
INTRODUCTION

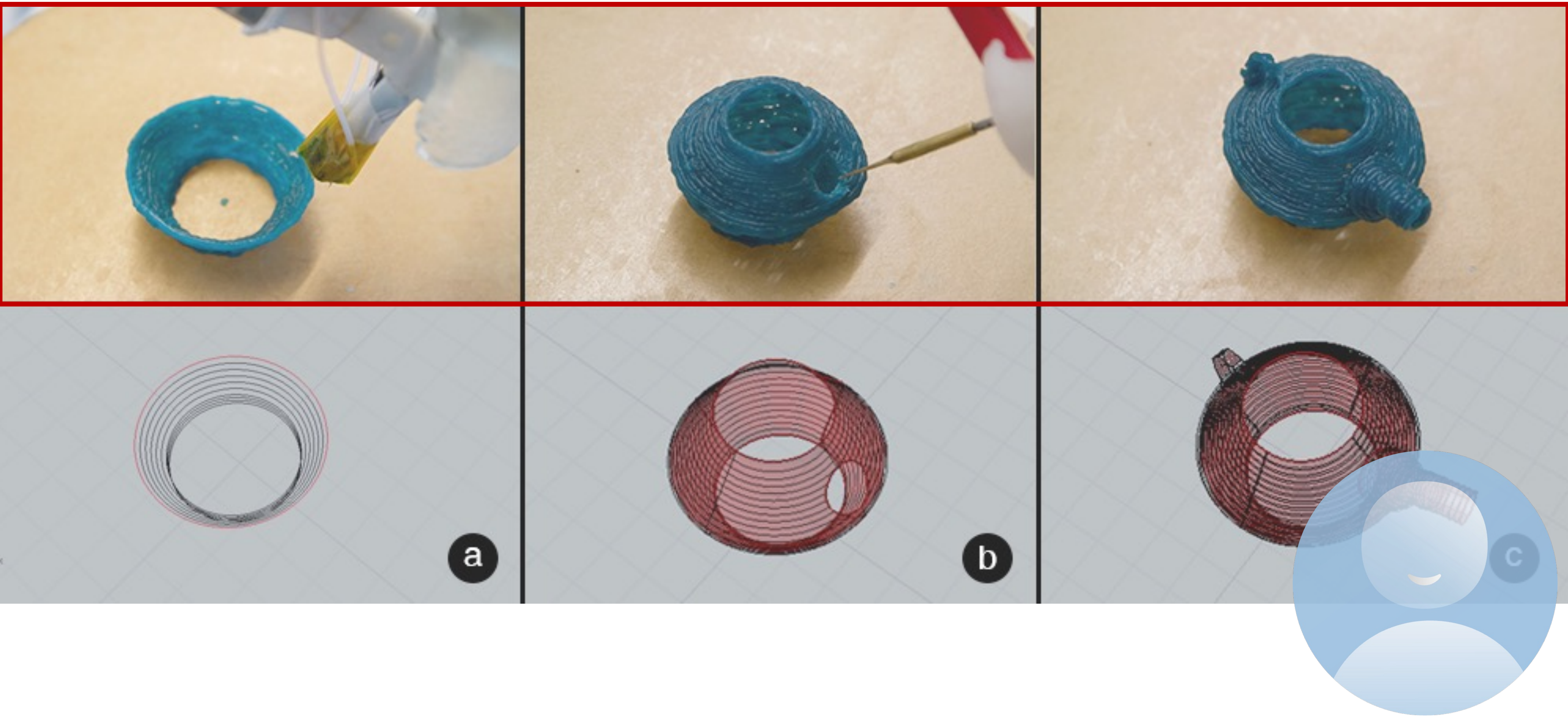
As predicted by Gershenfeld [5], we have seen a rapid advance towards the democratization of 3D printing in recent years. One can draw a parallel with the rise of desktop printing in the 1980's [1], with one significant difference: it is still difficult to create complex digital models ready for 3D printing. Though the interface of CAD systems has been greatly improved, the learning curve remains steep and creating complicated, smooth shapes requires the mastery of complex construction commands (such as lofting between multiple contours using guide rails). Further, the isolation of the design and fabrication process in digital CAD software makes it difficult for all

Figure 1: D-Coil concept: supporting 3D design using a wax proxy.

but experts to anticipate how a digital model will look and feel once it is built. This stands in sharp contrast with traditional craft activities such as clay coiling in which design and construction can occur at the same time. As observed by Schön [15], the intimate interaction between the designer and the material at hand establishes a constant reflective "conversation" promoting a faster convergence towards a satisfactory design. Clay coiling also has the advantage of being easy to learn for beginners (low floor), but offering sufficient flexibility to enable experts to create highly complex models (high ceiling) [13].

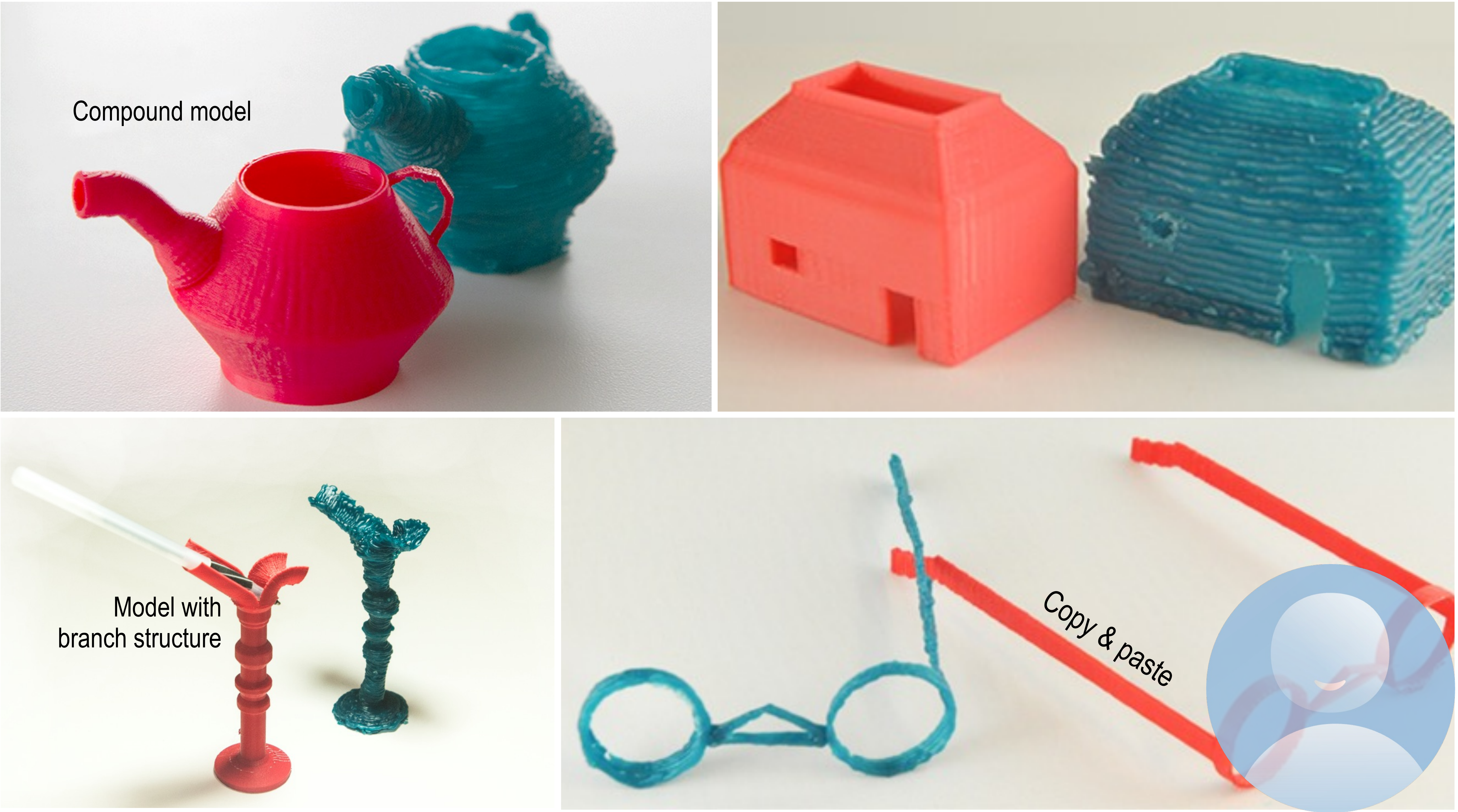
CHI 15
Peng et.al.


Magnetic tracker
Hand grip
Motorized direction actuator


a
b
c

3D modeling with no CAD interface

- No CAD Interface
- No implicit building commands
- Constant tangible feedback

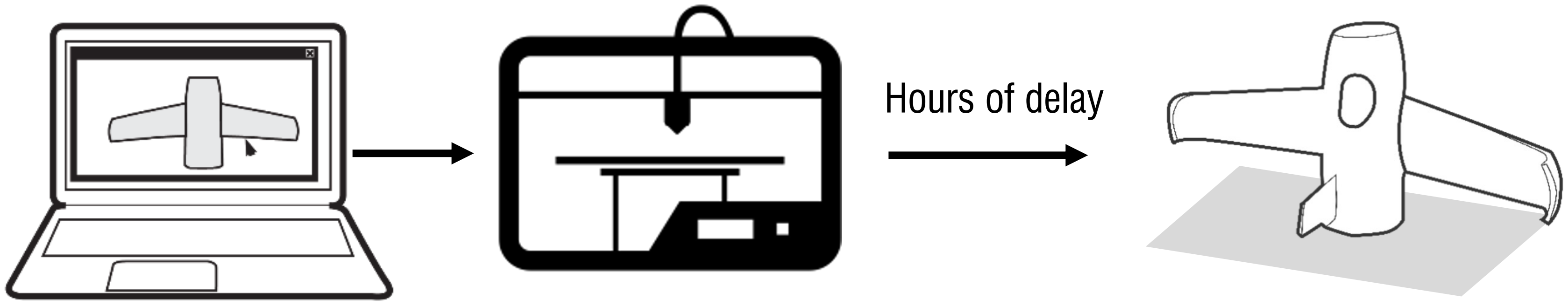

Compound model
Model with
branch structure
Copy & paste

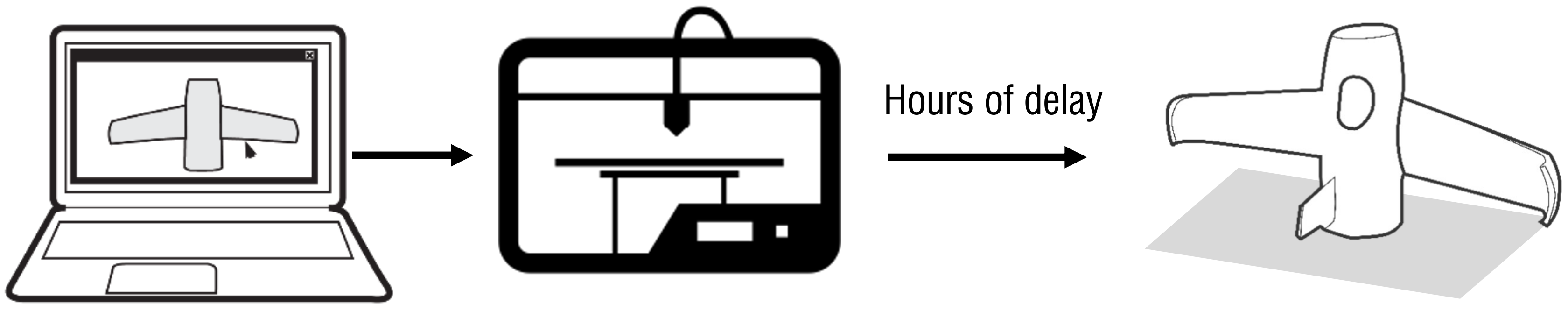
D-Coil

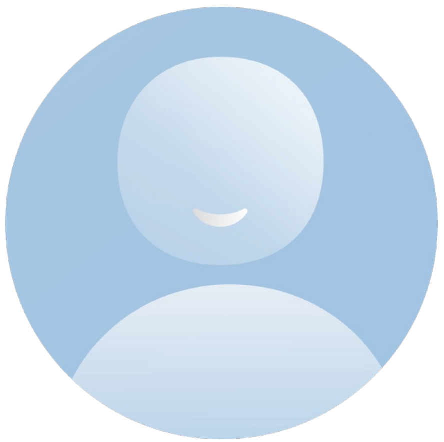
No CAD interface
Digitalization

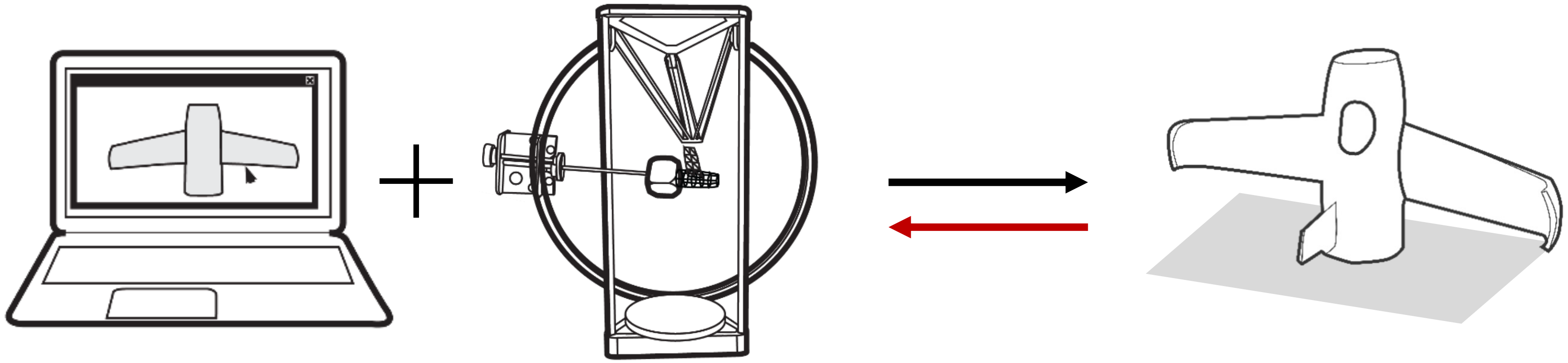
Slow in building speed
Not for CAD users

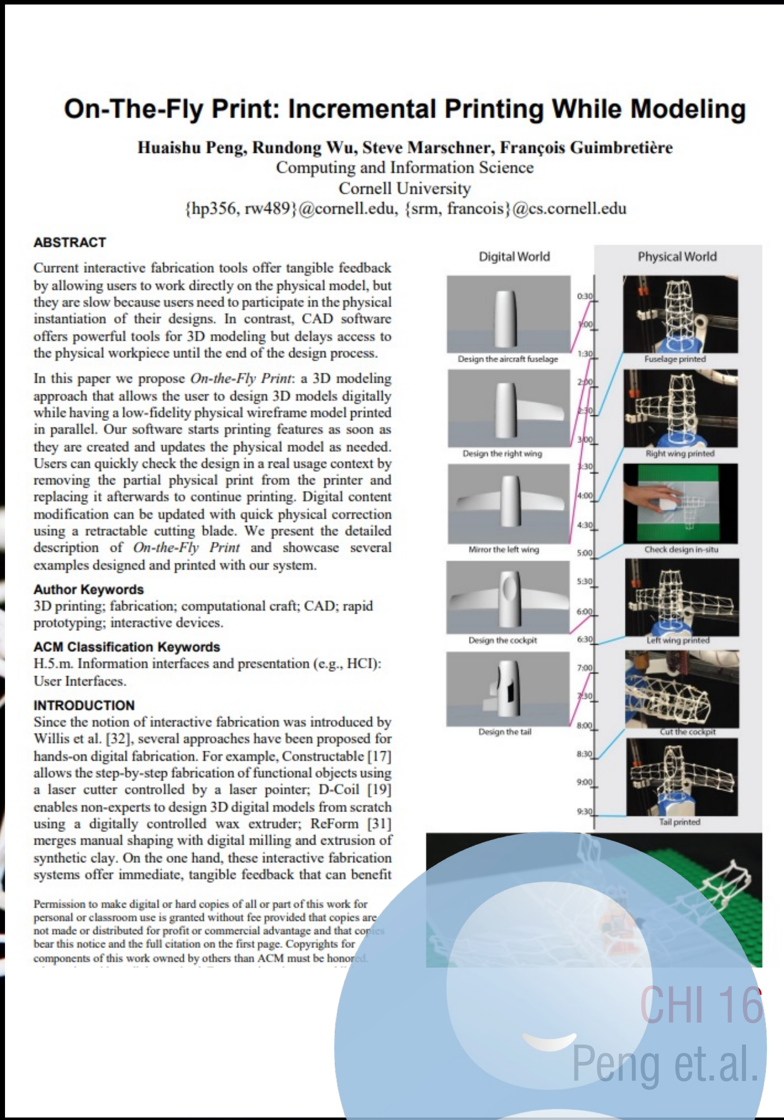
What if we can have a system **for CAD users**
but with timely **physical feedback**?




Hours of delay







On-The-Fly Print: Incremental Printing While Modeling

Huaishu Peng, Rundong Wu, Steve Marschner, François Guimbretière
Computing and Information Science
Cornell University
{hp356, rw489}@cornell.edu, {srm, francois}@cs.cornell.edu

ABSTRACT

Current interactive fabrication tools offer tangible feedback by allowing users to work directly on the physical model, but they are slow because users need to participate in the physical instantiation of their designs. In contrast, CAD software offers powerful tools for 3D modeling but delays access to the physical workpiece until the end of the design process.

In this paper we propose *On-the-Fly Print*: a 3D modeling approach that allows the user to design 3D models digitally while having a low-fidelity physical wireframe model printed in parallel. Our software starts printing features as soon as they are created and updates the physical model as needed. Users can quickly check the design in a real usage context by removing the partial physical print from the printer and replacing it afterwards to continue printing. Digital content modification can be updated with quick physical correction using a retractable cutting blade. We present the detailed description of *On-the-Fly Print* and showcase several examples designed and printed with our system.

Author Keywords
3D printing; fabrication; computational craft; CAD; rapid prototyping; interactive devices.

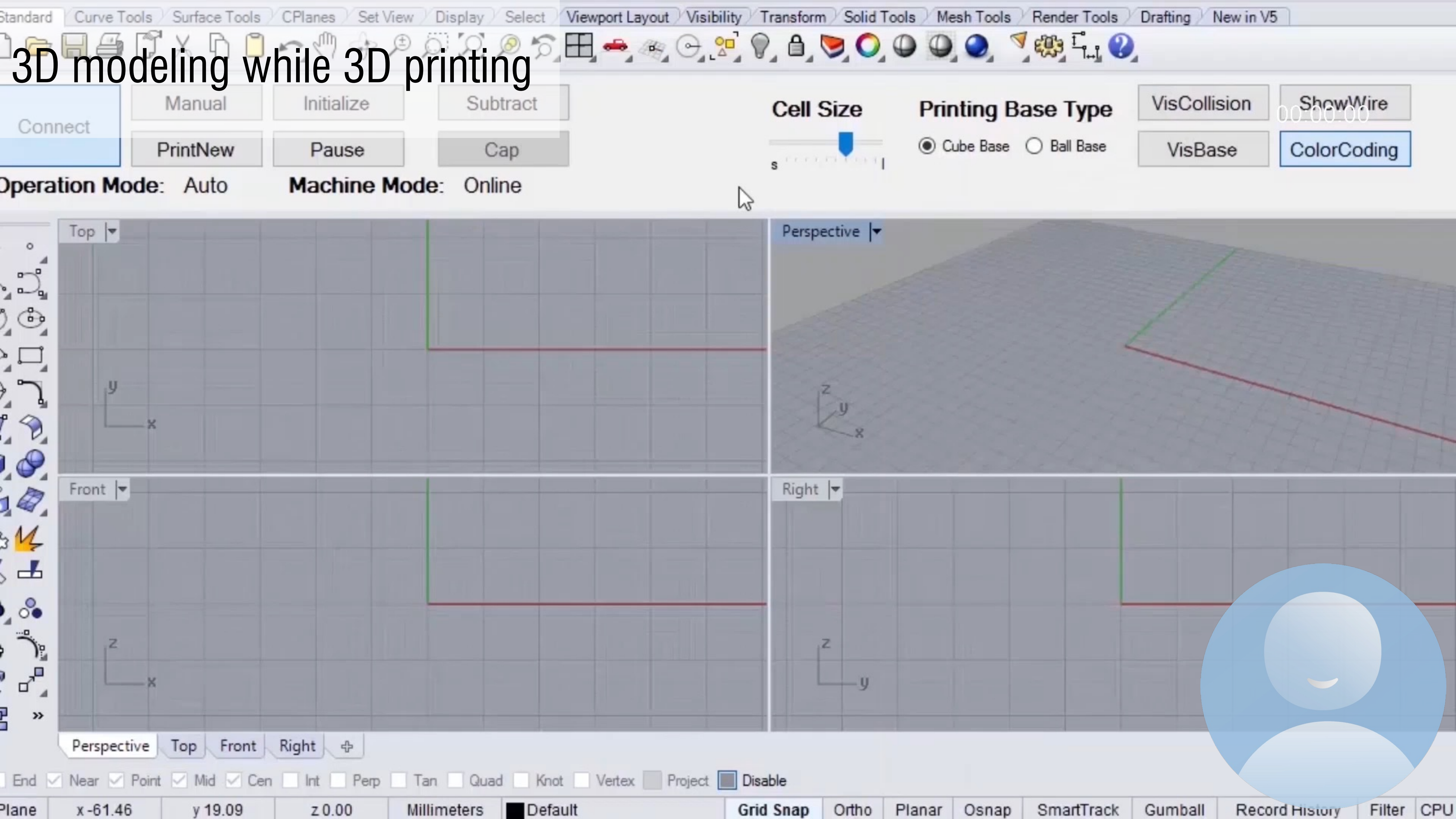
ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): User Interfaces.

INTRODUCTION

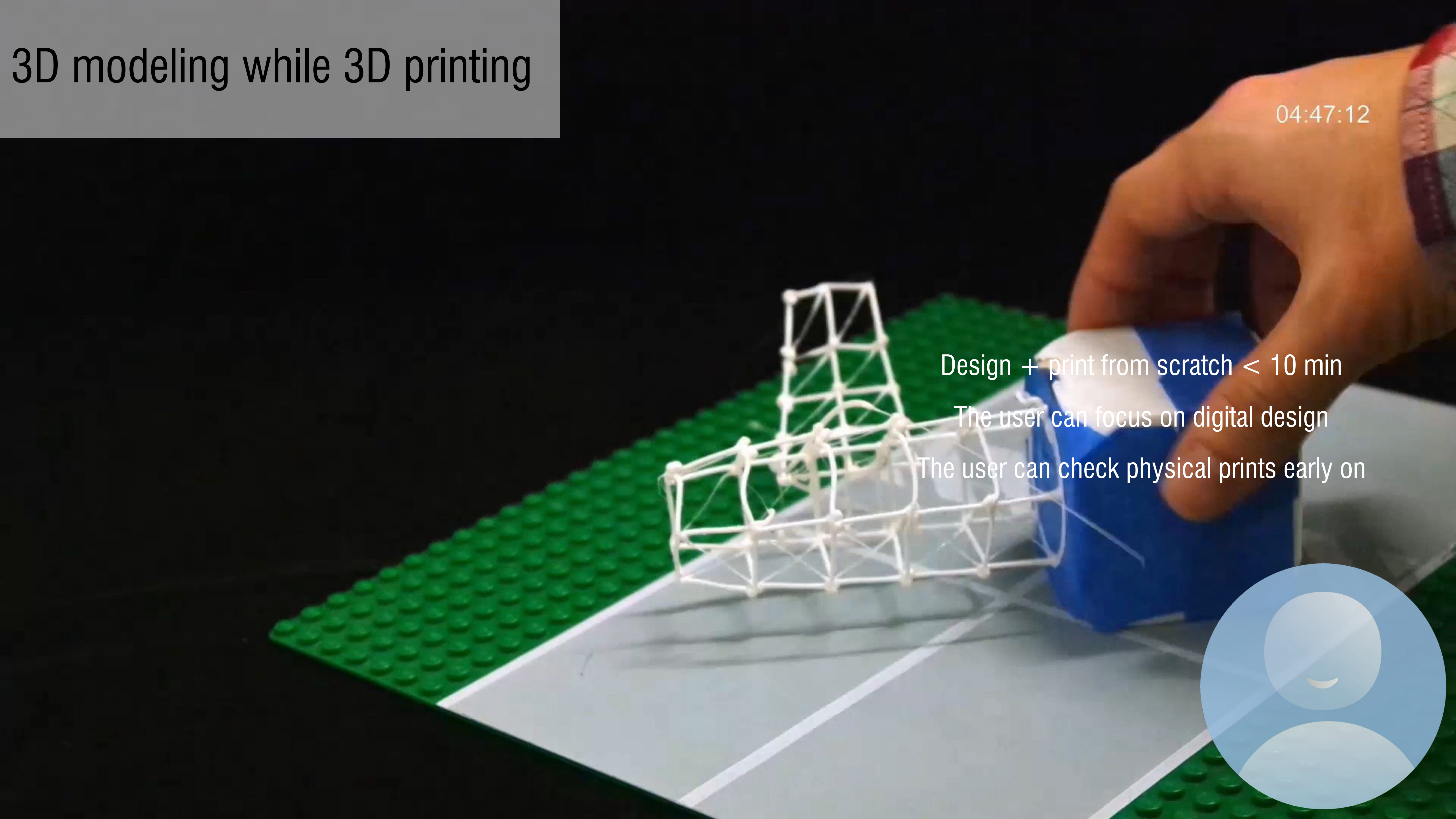
Since the notion of interactive fabrication was introduced by Willis et al. [32], several approaches have been proposed for hands-on digital fabrication. For example, Constructable [17] allows the step-by-step fabrication of functional objects using a laser cutter controlled by a laser pointer; D-Coil [19] enables non-experts to design 3D digital models from scratch using a digitally controlled wax extruder; ReForm [31] merges manual shaping with digital milling and extrusion of synthetic clay. On the one hand, these interactive fabrication systems offer immediate, tangible feedback that can benefit

CHI 16
Peng et.al.

3D modeling while 3D printing



3D modeling while 3D printing



To support design and fab **in parallel**

our machine should be able to

print fast

print incrementally

make subtractive changes

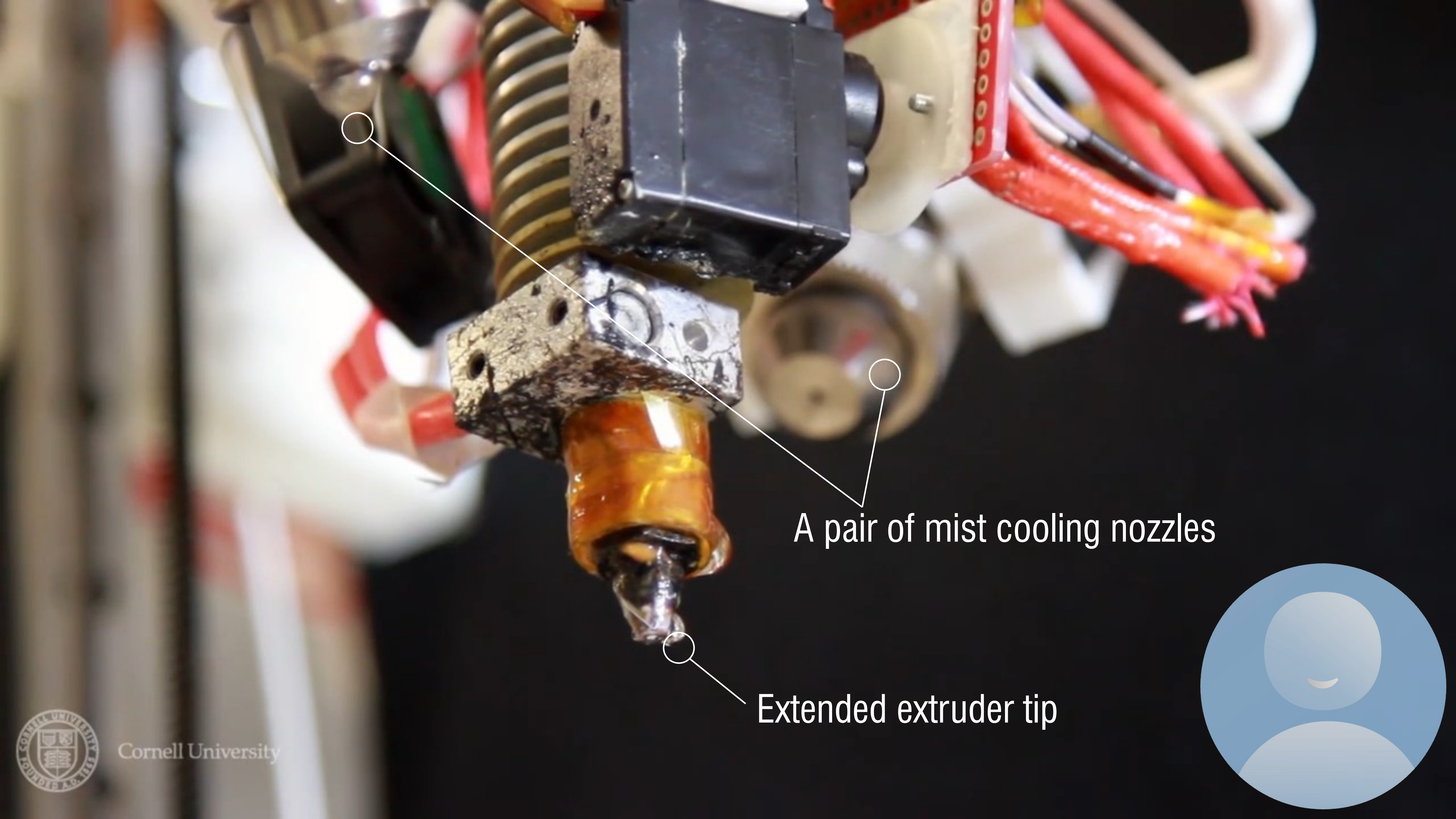
To support design and fab **in parallel**

our machine should be able to

print fast (to catch up the CAD design speed)

print incrementally

make subtractive changes


A pair of mist cooling nozzles
Extended extruder tip
Cornell University

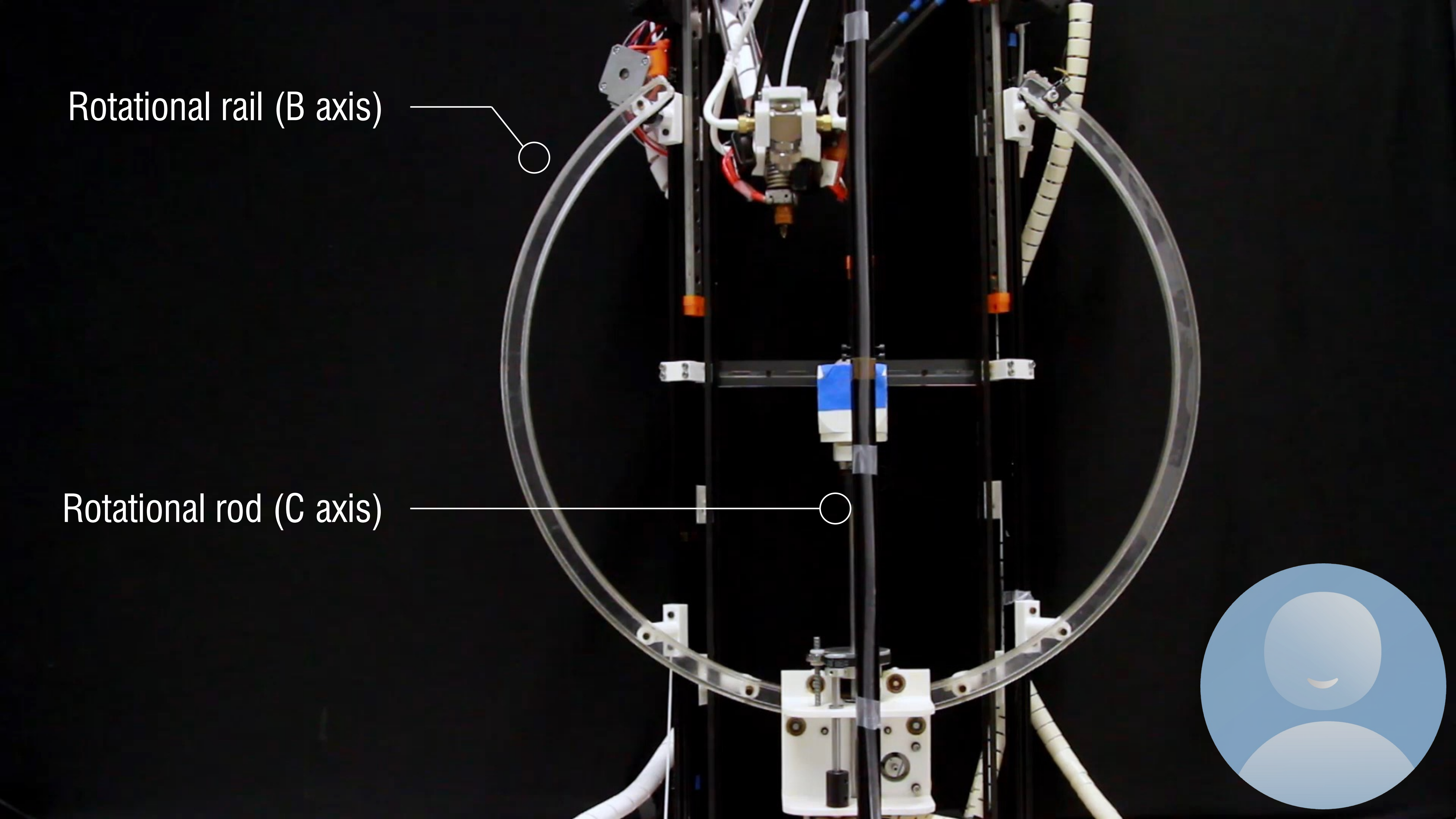
To support design and fab **in parallel**

our machine should be able to

print fast

print incrementally (to avoid reprint every time)

make subtractive changes


Rotational rail (B axis)
Rotational rod (C axis)

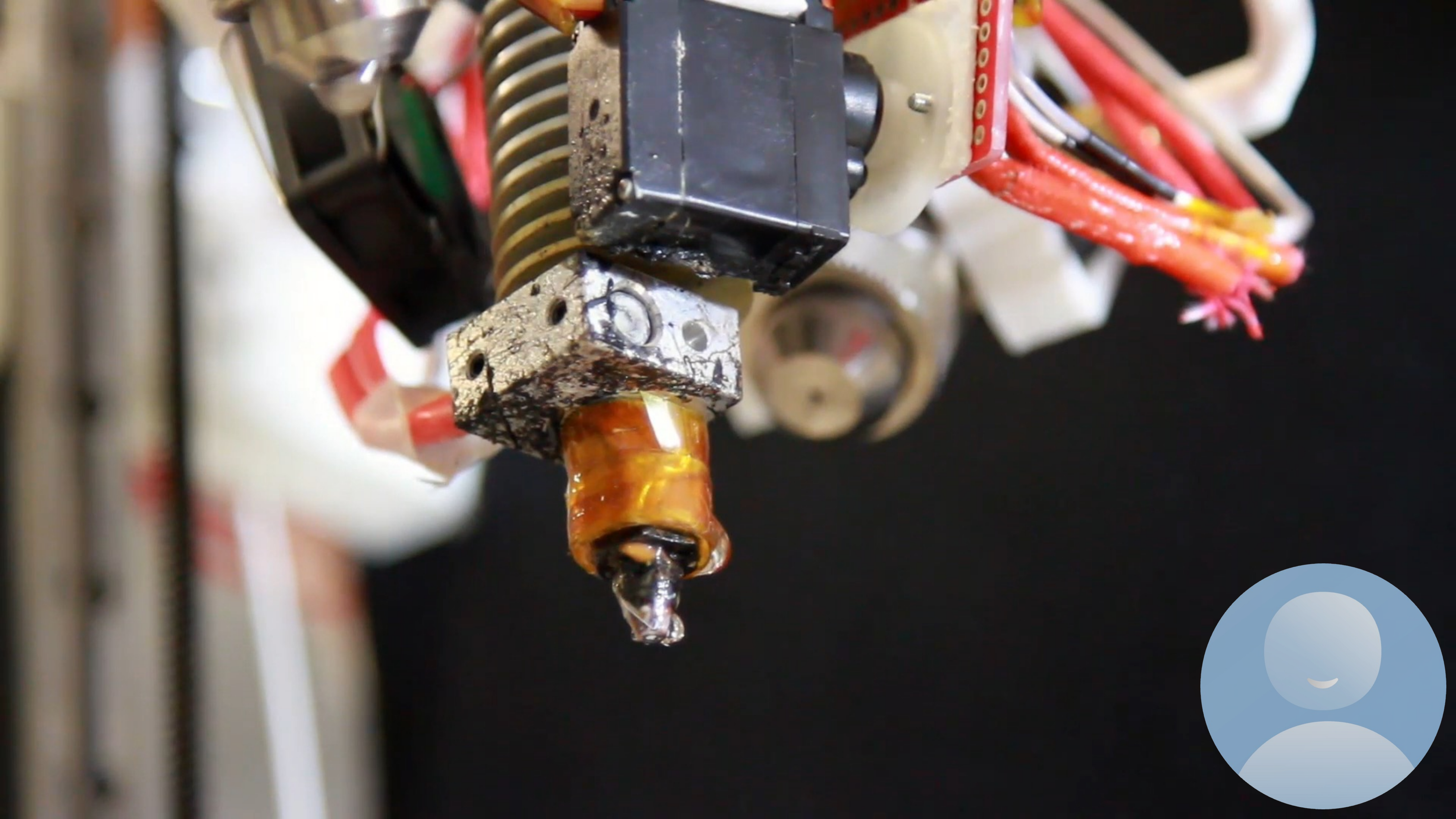
To support design and fab **in parallel**

our machine should be able to

print fast

print incrementally

make subtractive changes (to reflect digital editing)



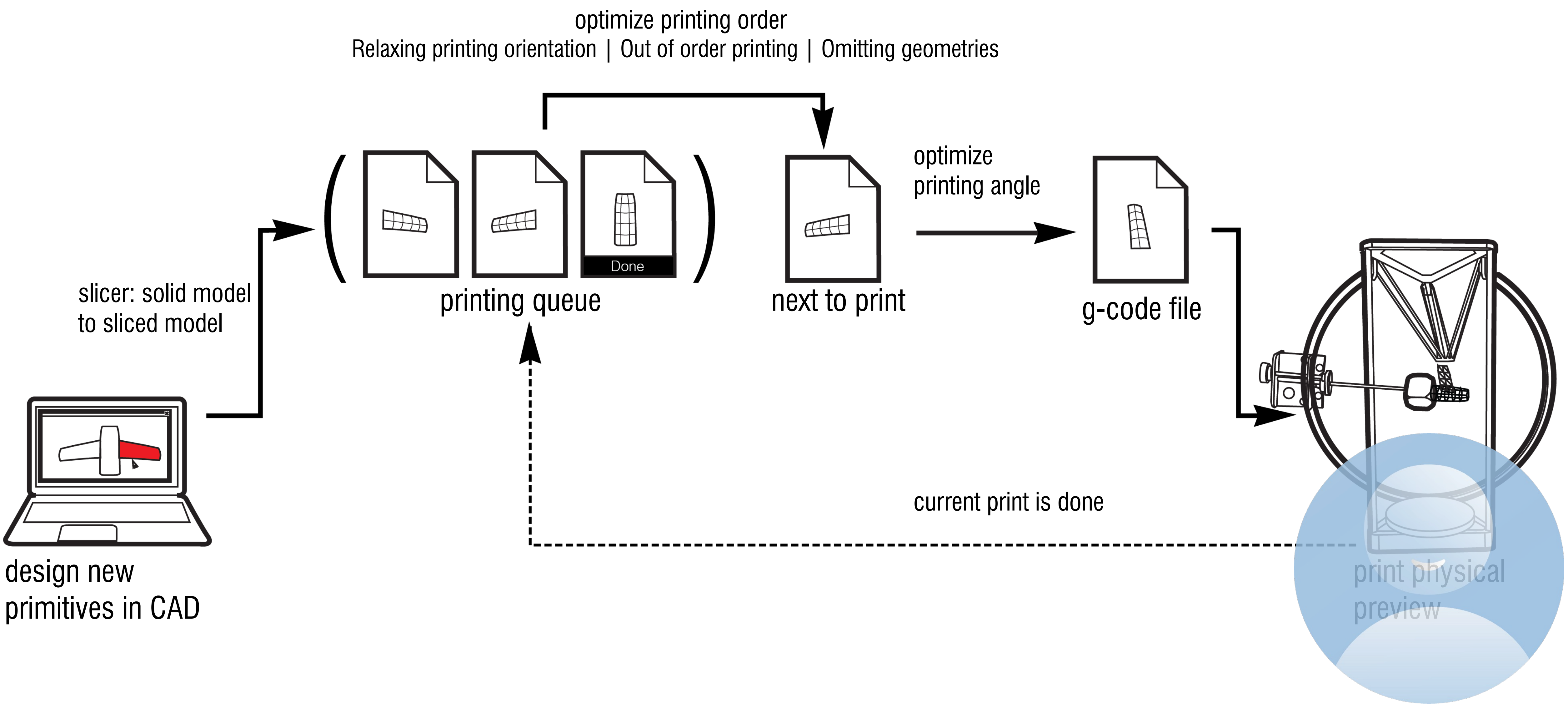
To allow the designer to focus on the design

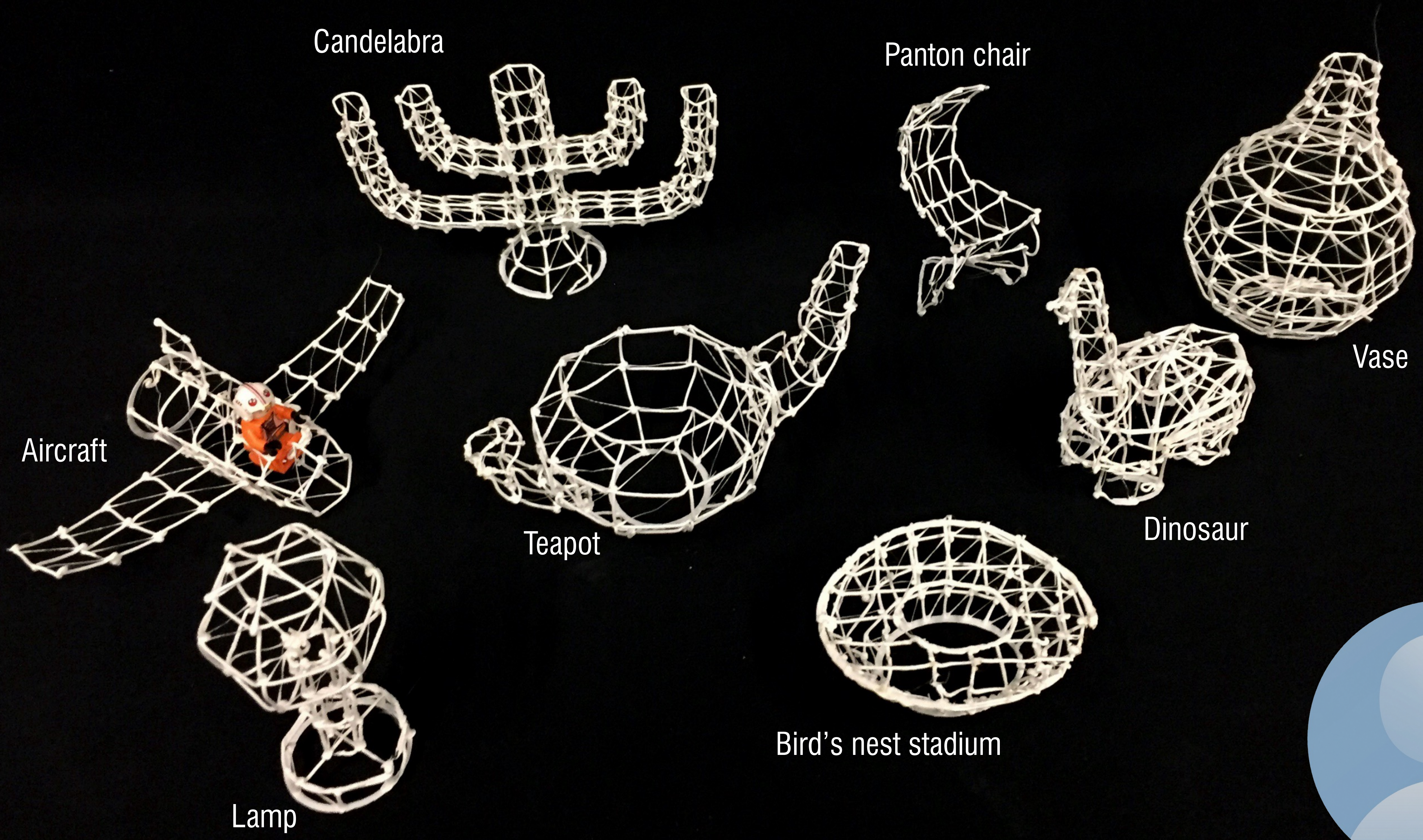
our software should be able to

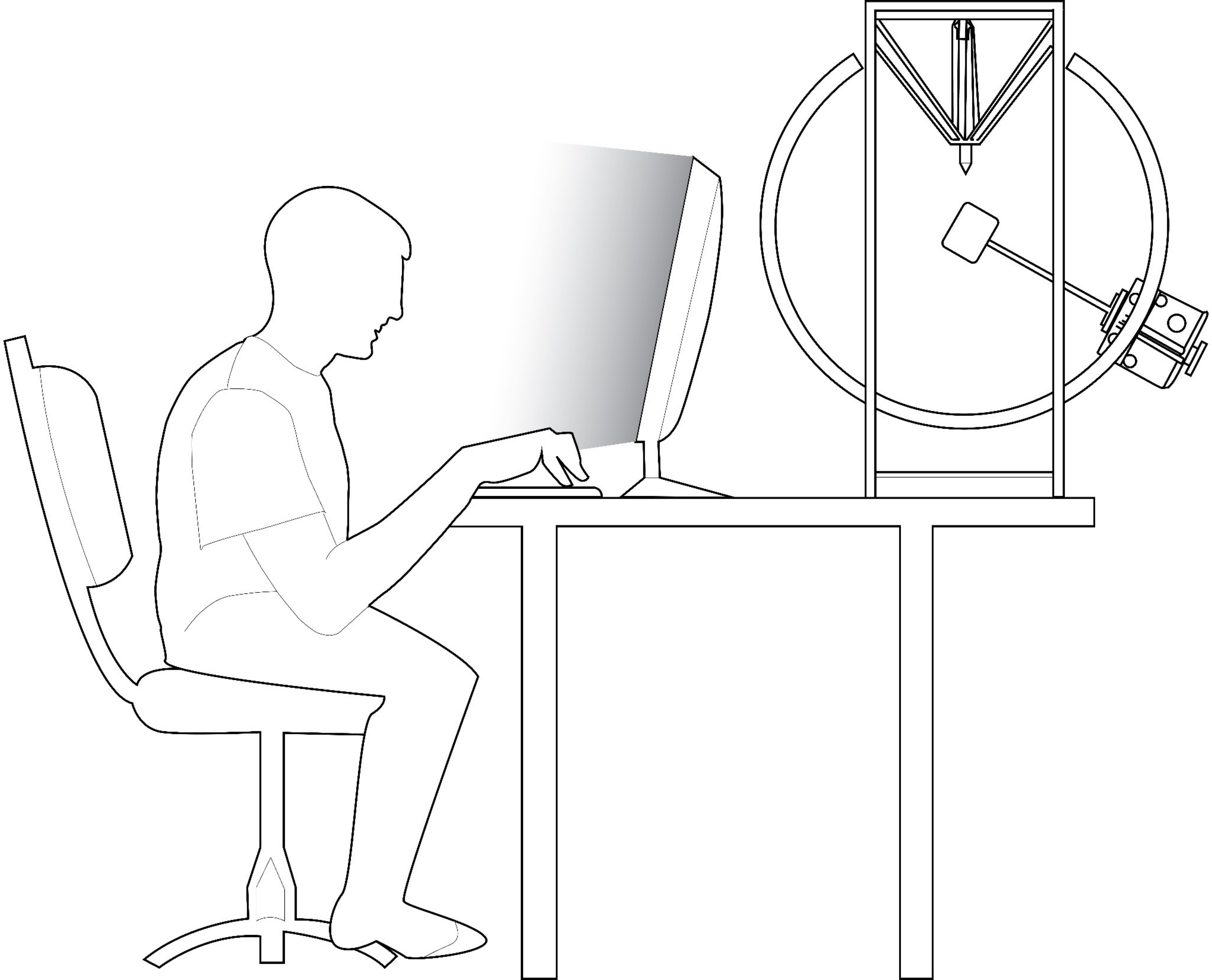
print new primitives automatically

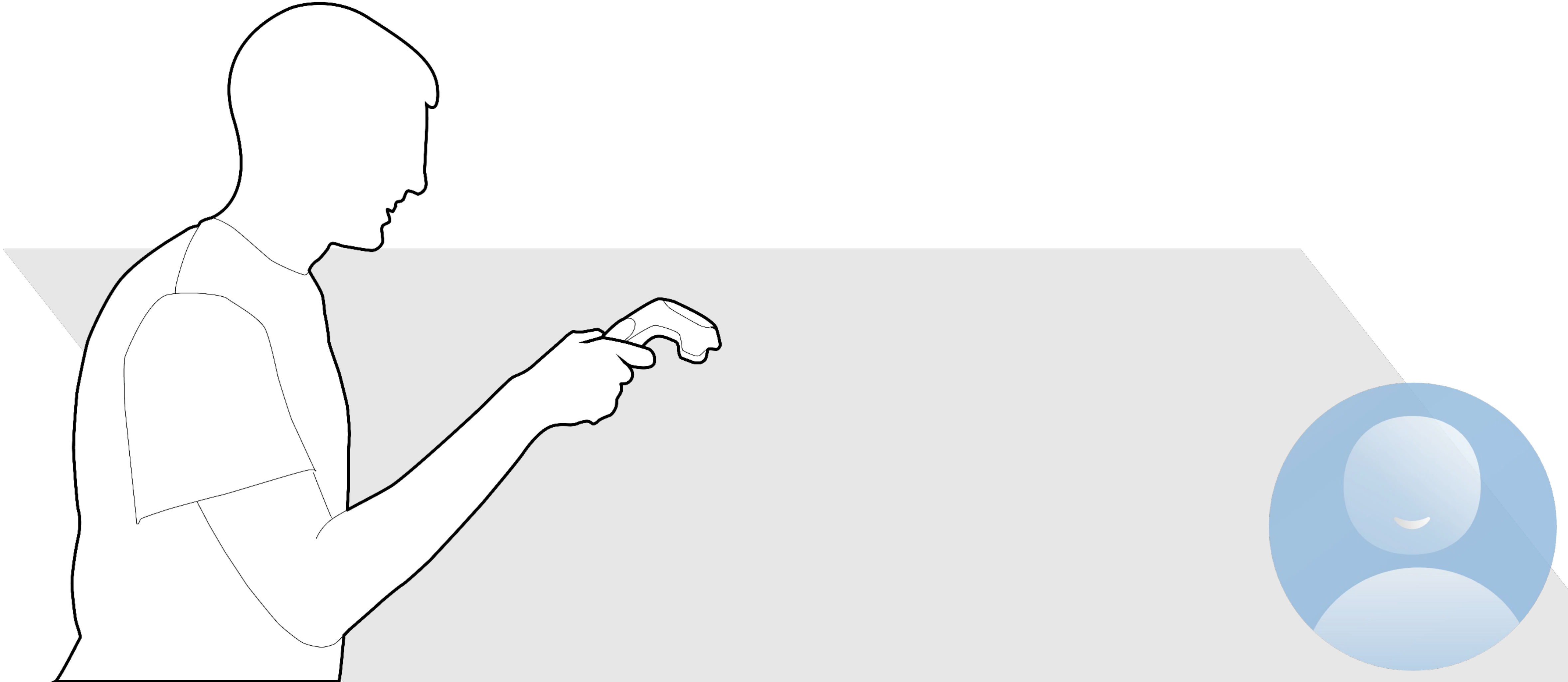
solve potential collisions

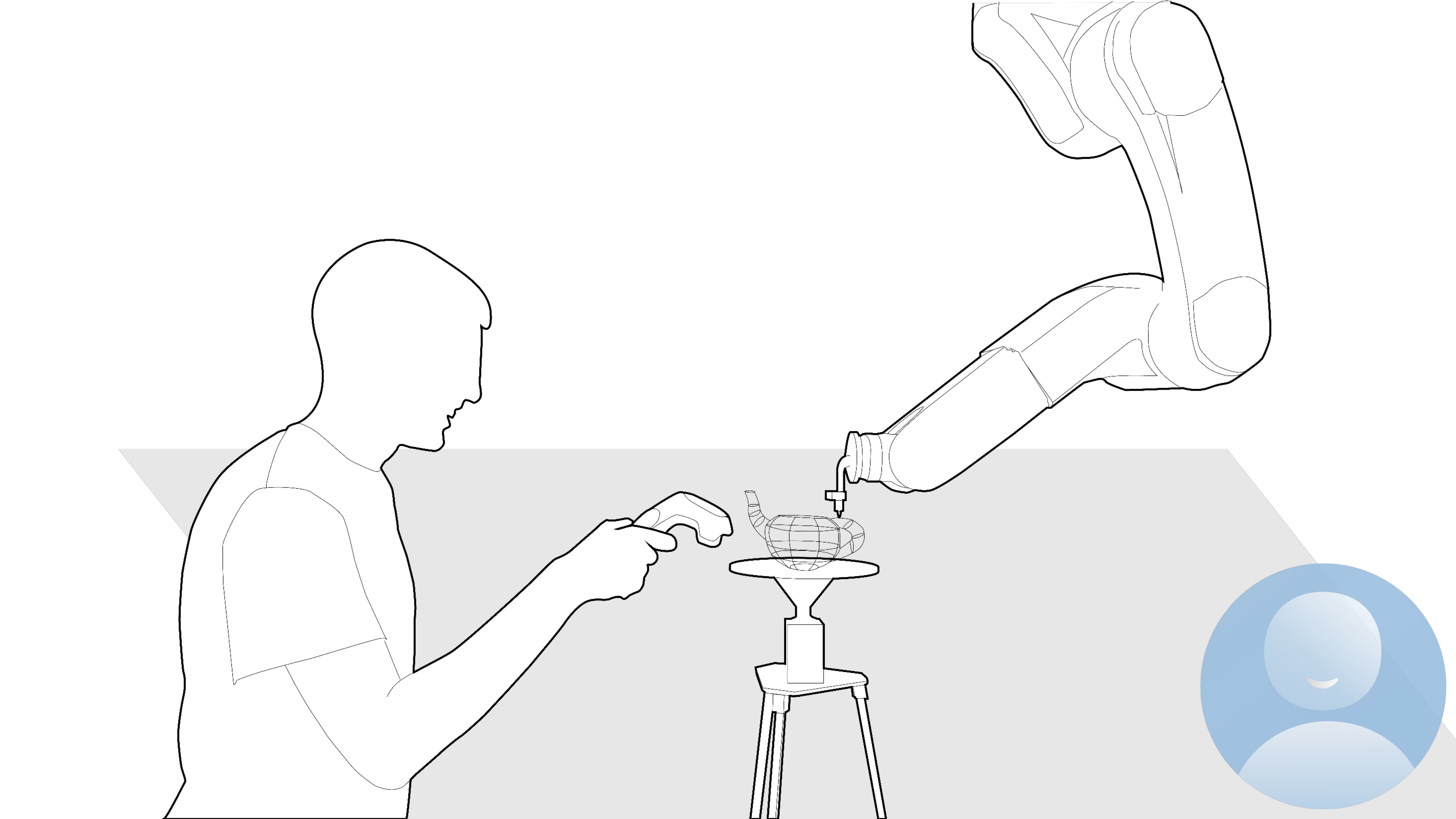
Software Workflow

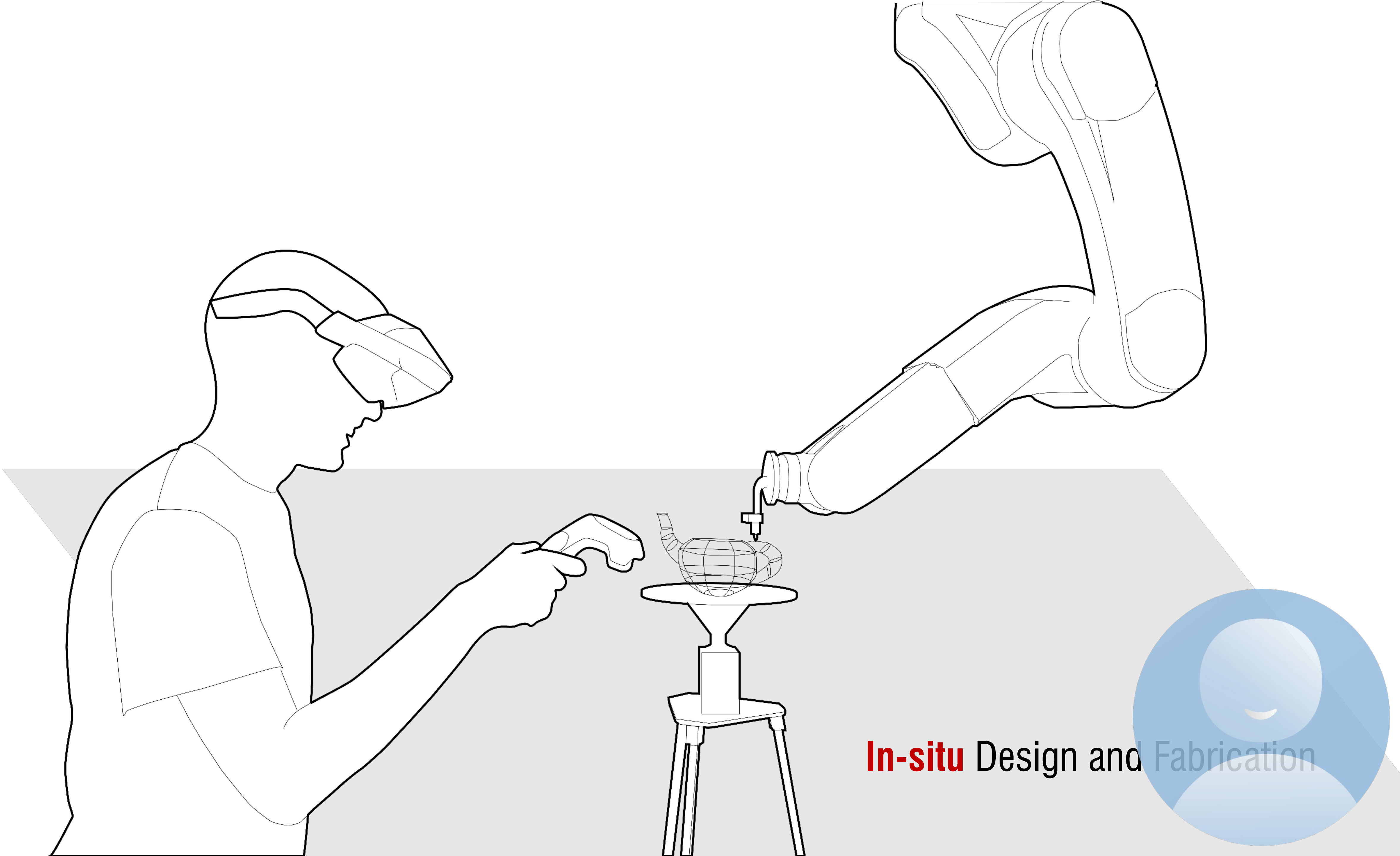


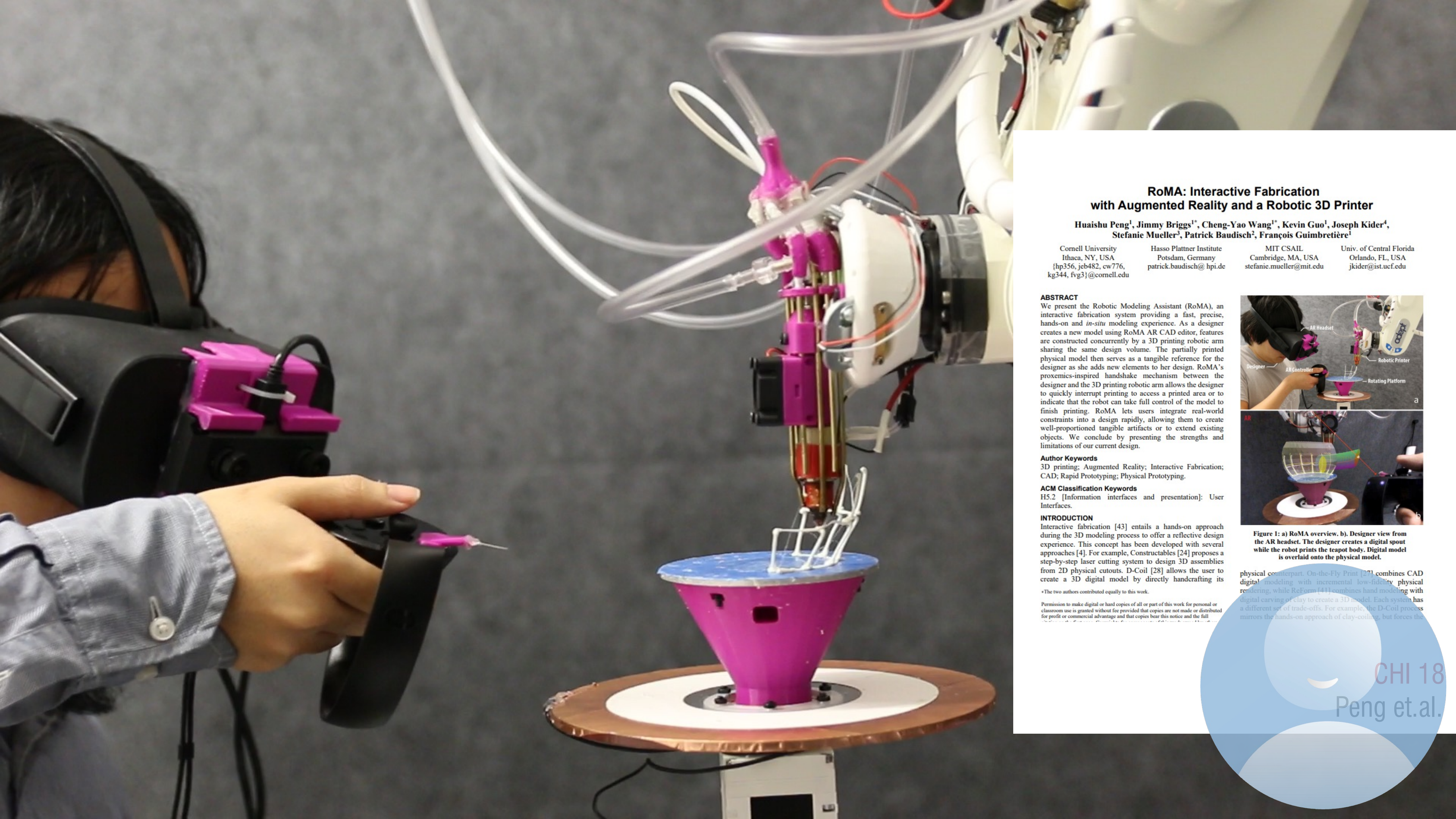

Candelabra
Panton chair
Vase
Aircraft
Teapot
Dinosaur
Bird’s nest stadium
Lamp








In-situ Design and Fabrication



RoMA: Interactive Fabrication with Augmented Reality and a Robotic 3D Printer

Huaishu Peng[1], Jimmy Briggs[1*], Cheng-Yao Wang[1*], Kevin Guo[1], Joseph Kider[4], Stefanie Mueller[3], Patrick Baudisch[2], François Guimbretière[1]

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Univ. of Central Florida, Orlando, FL, USA, jkider@ist.ucf.edu

ABSTRACT

We present the Robotic Modeling Assistant (RoMA), an interactive fabrication system providing a fast, precise, hands-on and *in-situ* modeling experience. As a designer creates a new model using RoMA AR CAD editor, features are constructed concurrently by a 3D printing robotic arm sharing the same design volume. The partially printed physical model then serves as a tangible reference for the designer as she adds new elements to her design. RoMA's proxemics-inspired handshake mechanism between the designer and the 3D printing robotic arm allows the designer to quickly interrupt printing to access a printed area or to indicate that the robot can take full control of the model to finish printing. RoMA lets users integrate real-world constraints into a design rapidly, allowing them to create well-proportioned tangible artifacts or to extend existing objects. We conclude by presenting the strengths and limitations of our current design.

Author Keywords

3D printing; Augmented Reality; Interactive Fabrication; CAD; Rapid Prototyping; Physical Prototyping.

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces.

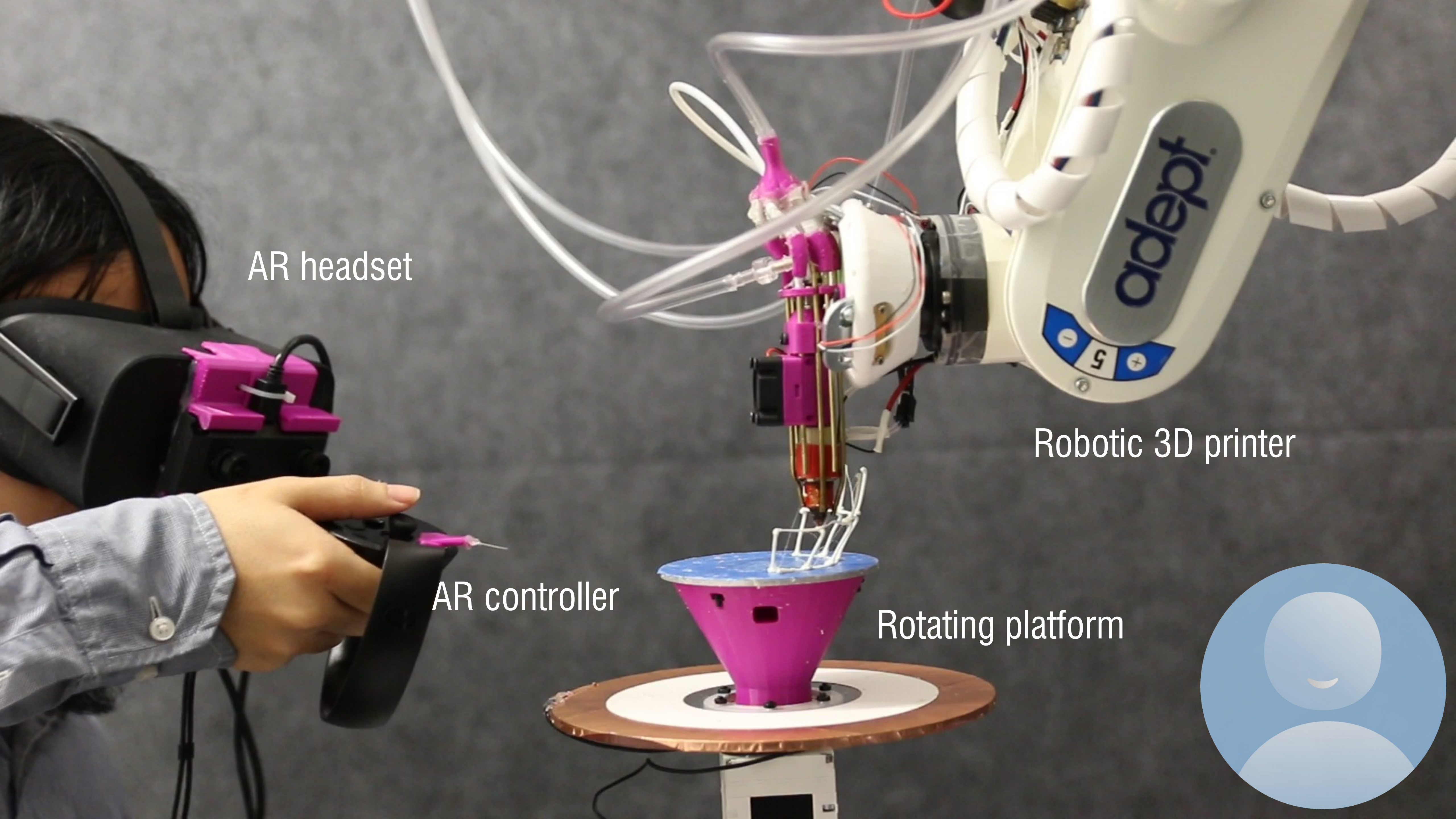
INTRODUCTION

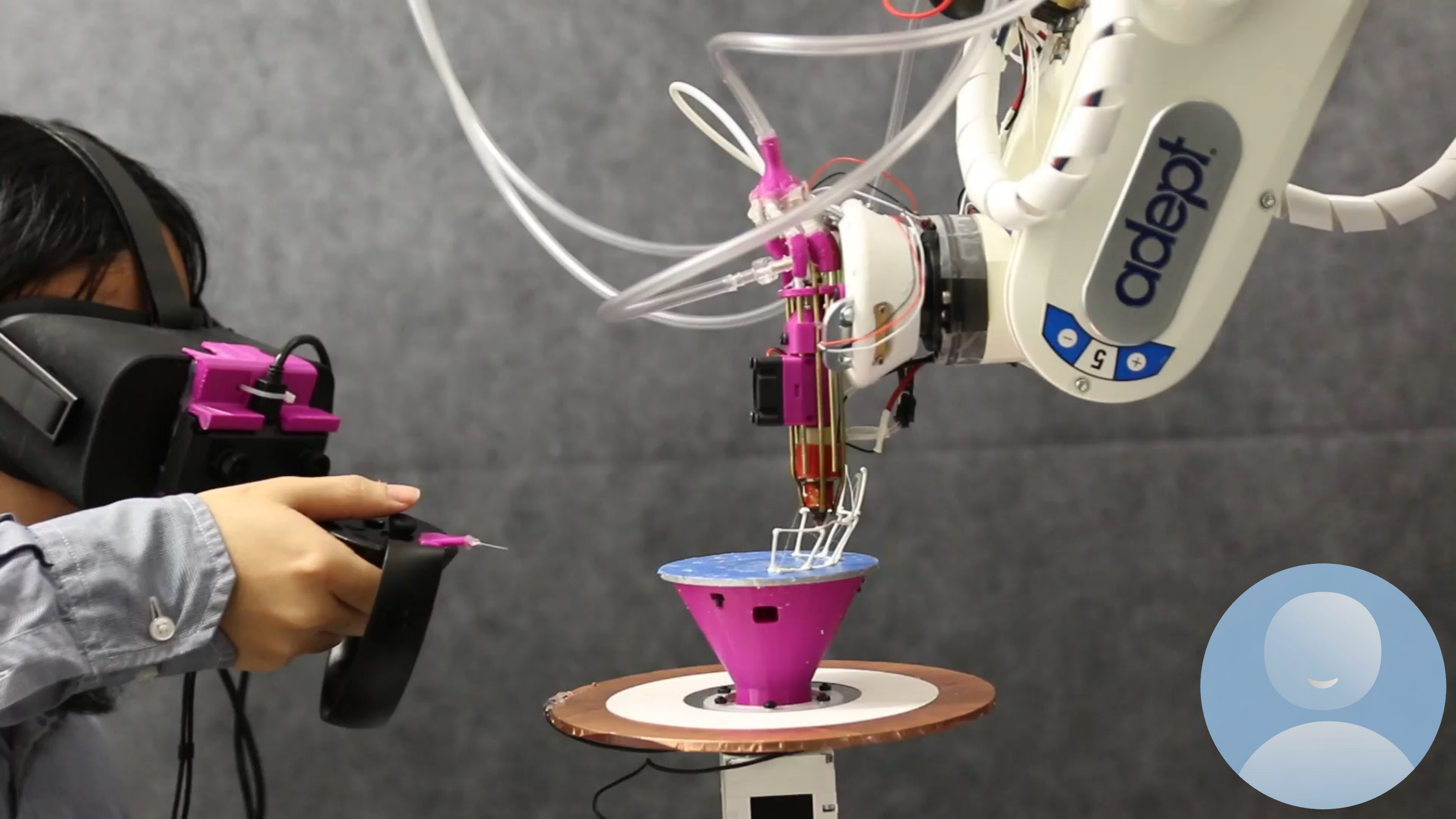
Interactive fabrication [43] entails a hands-on approach during the 3D modeling process to offer a reflective design experience. This concept has been developed with several approaches [4]. For example, Constructables [24] proposes a step-by-step laser cutting system to design 3D assemblies from 2D physical cutouts. D-Coil [28] allows the user to create a 3D digital model by directly handcrafting its

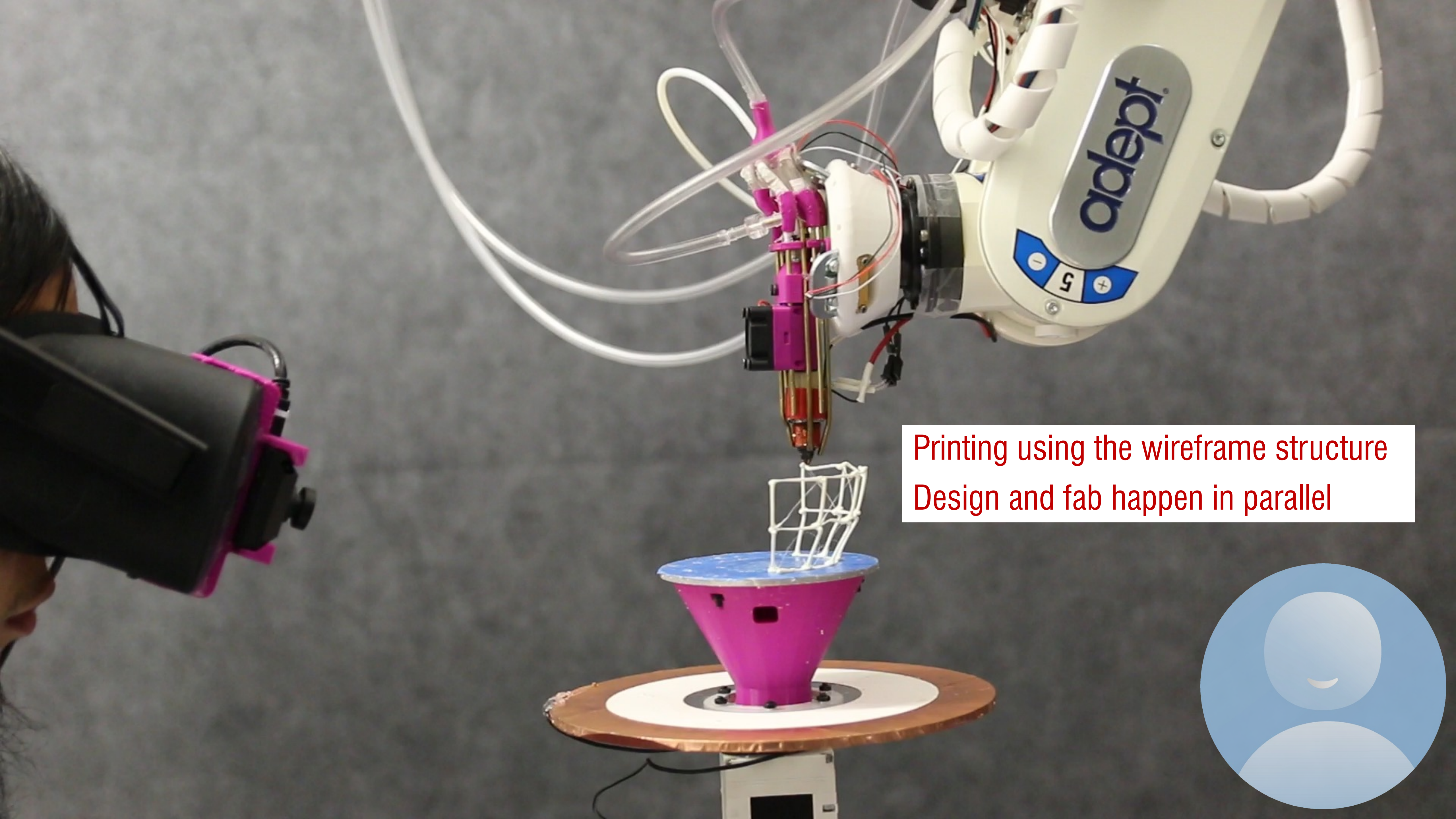
Figure 1: a) RoMA overview. b). Designer view from the AR headset. The designer creates a digital spout while the robot prints the teapot body. Digital model is overlaid onto the physical model.

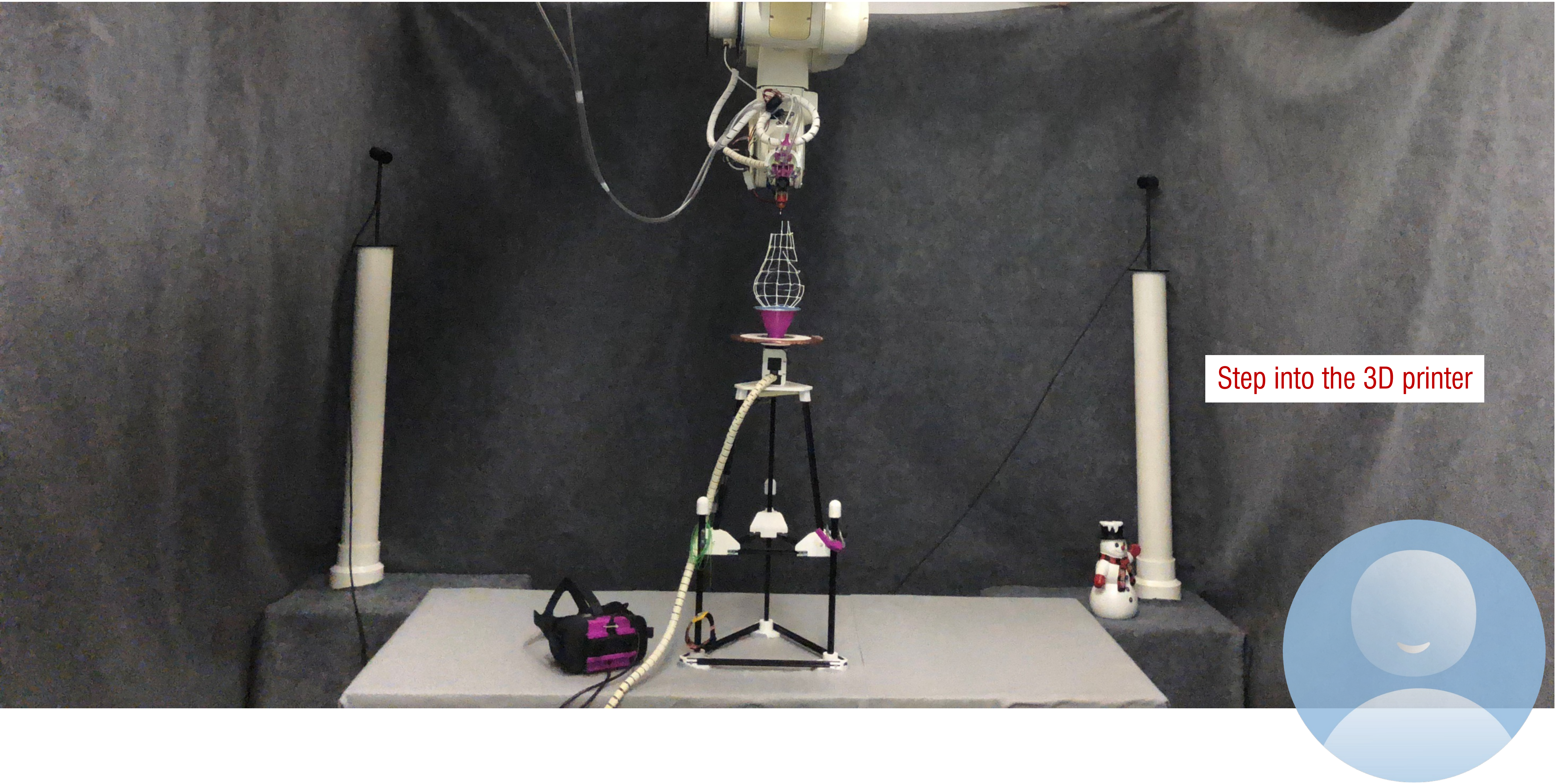
physical counterpart. On-the-Fly Print [27] combines CAD digital modeling with incremental low-fidelity physical rendering, while ReForm [41] combines hand modeling with digital carving of clay to create a 3D model. Each system has a different set of trade-offs. For example, the D-Coil process mirrors the hands-on approach of clay-coiling, but forces the

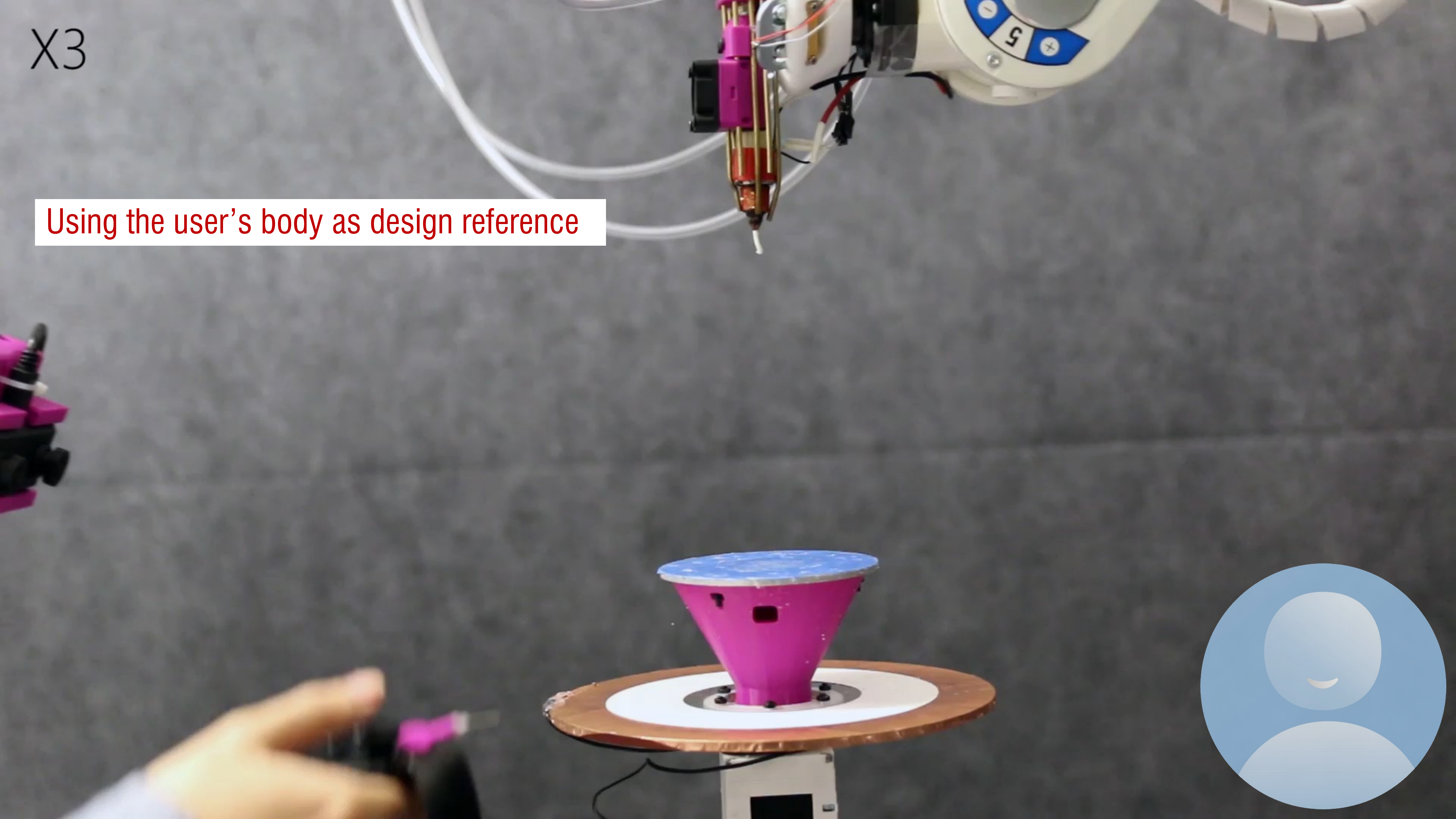
*The two authors contributed equally to this work.

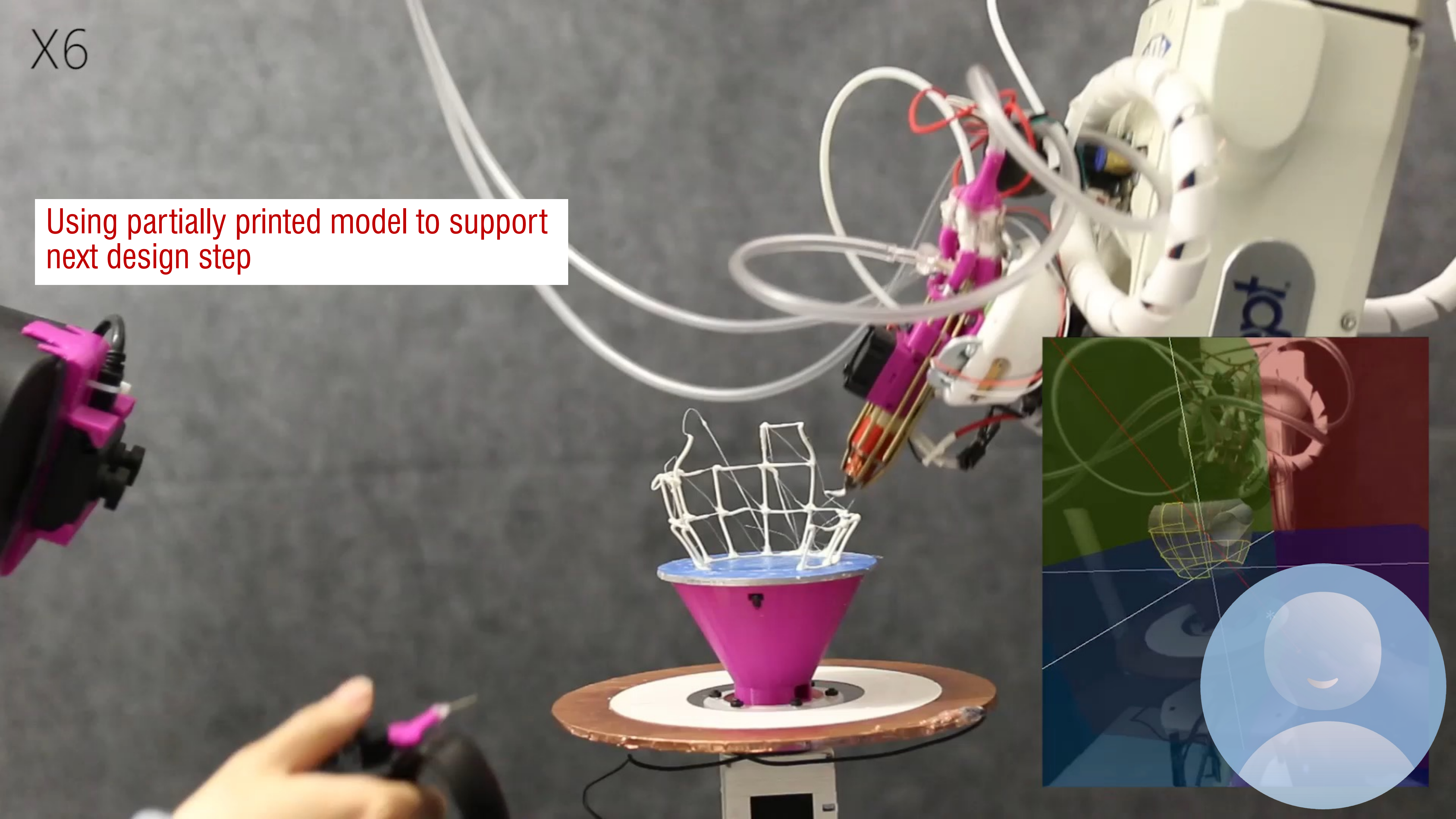

AR headset
Robotic 3D printer
AR controller
Rotating platform
adept


adept
5


Printing using the wireframe structure
Design and fab happen in parallel
adept

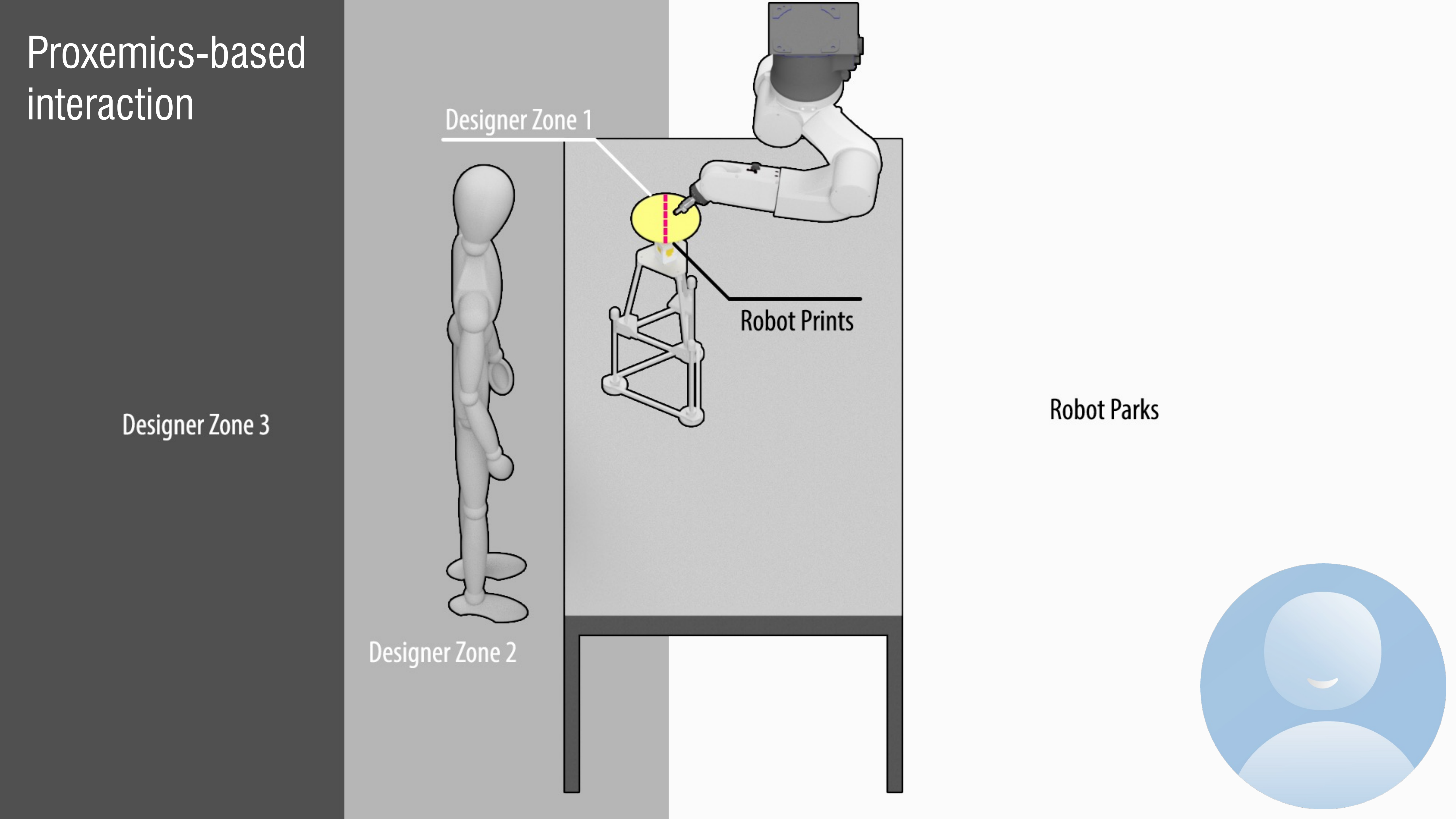

Step into the 3D printer

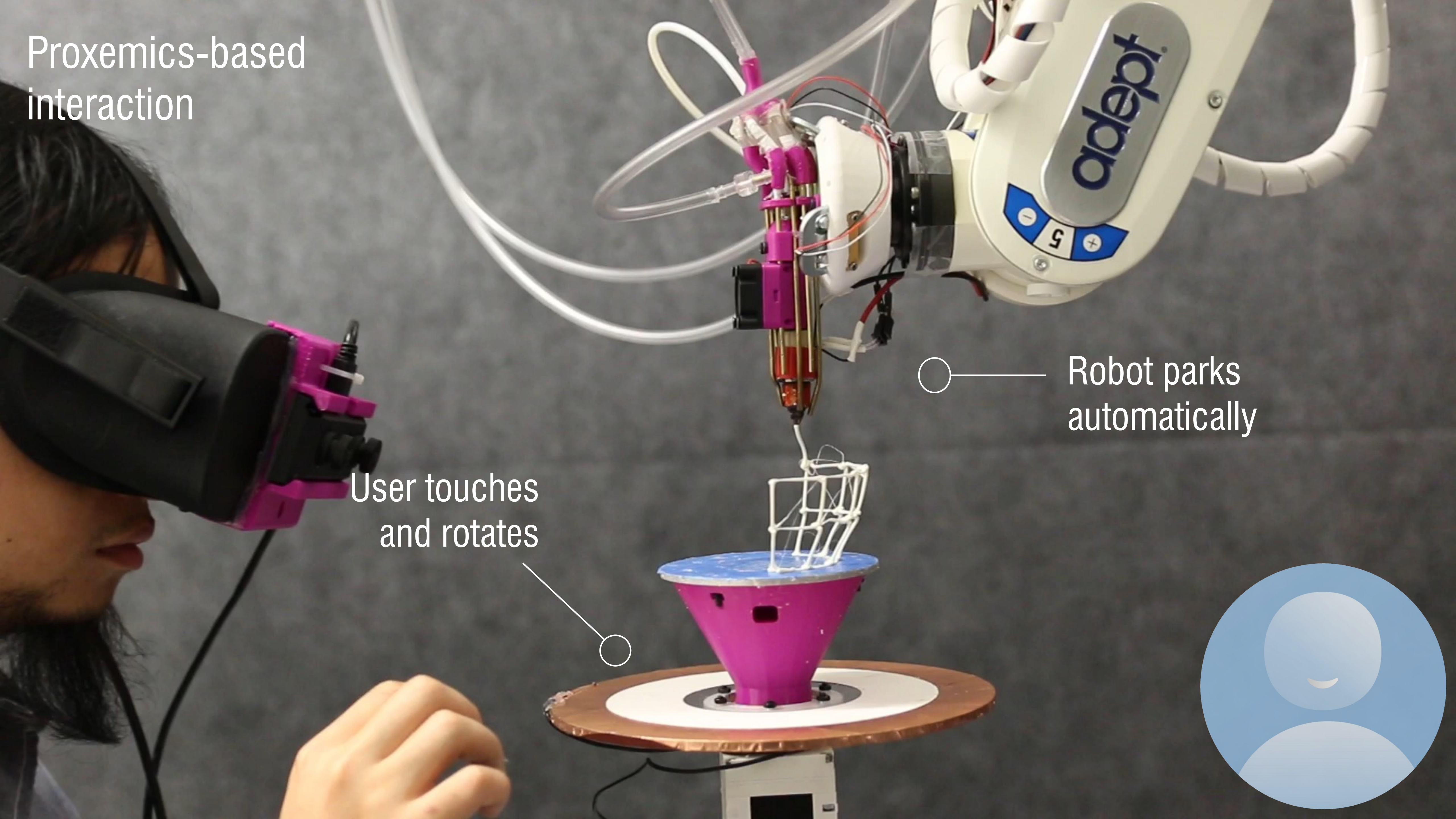

X3
Using the user’s body as design reference

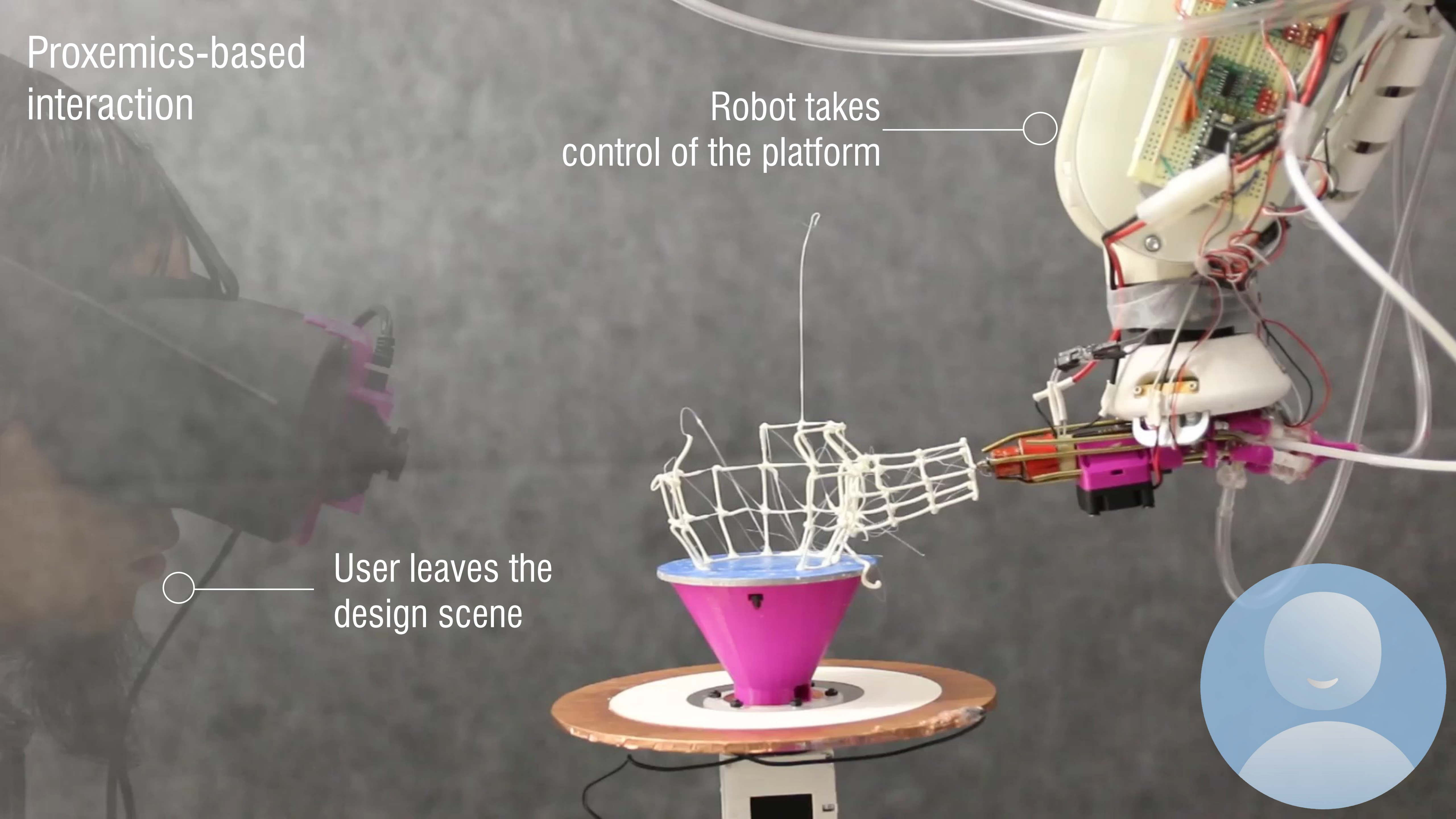

X6
Using partially printed model to support next design step

Design and fabrication directly
ON a physical object

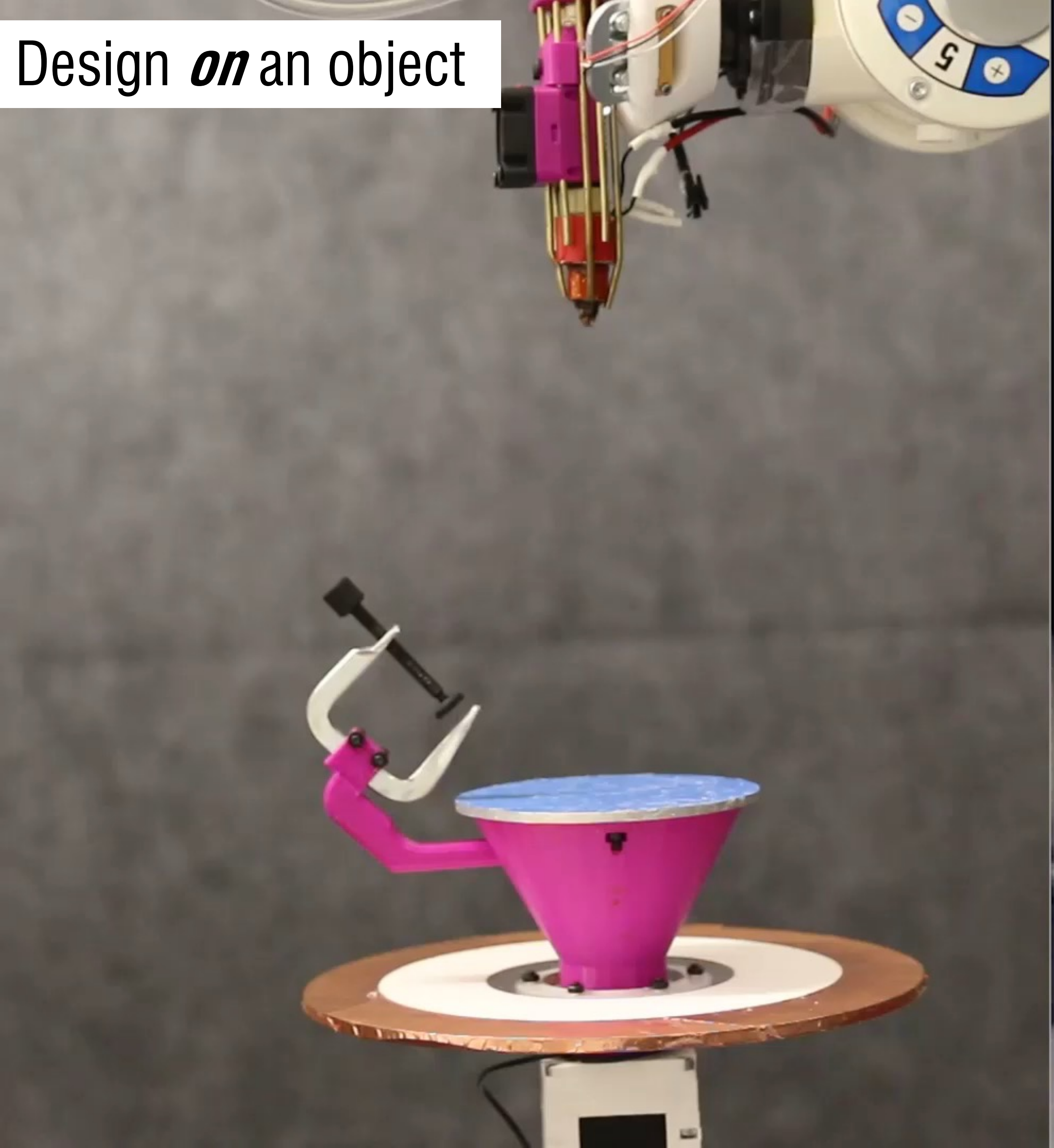
Proxemics-based interaction

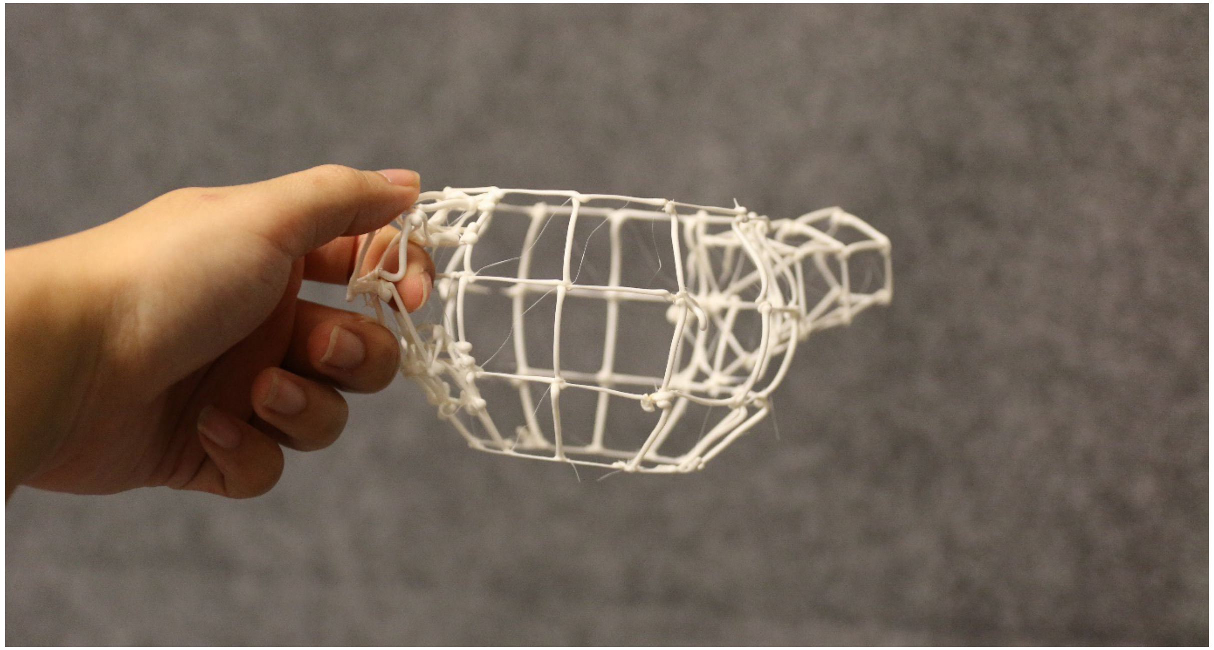



Proxemics-based interaction
Robot parks automatically
User touches and rotates
adept


Proxemics-based
interaction
Robot takes
control of the platform
User leaves the
design scene

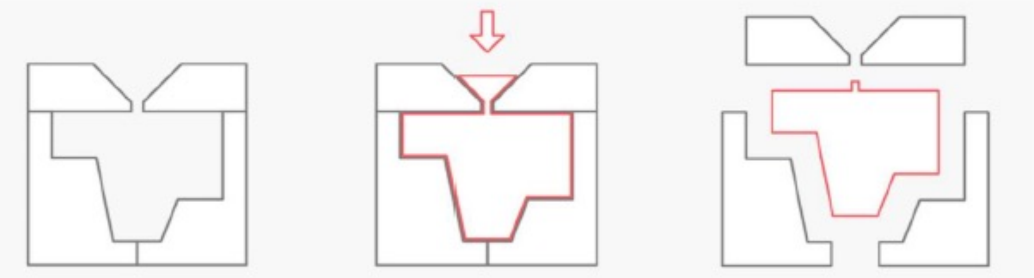
Design *on* an object



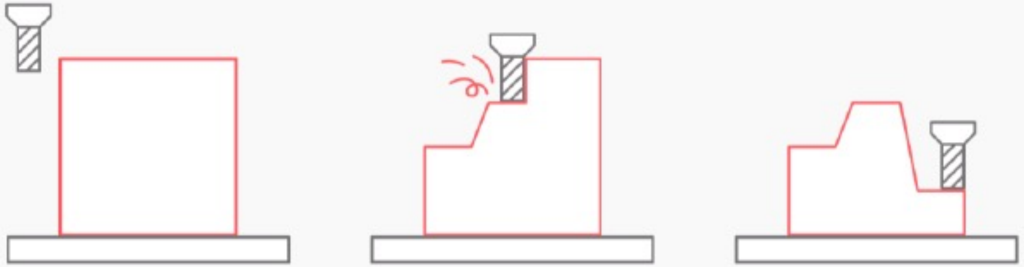


Adding and removing material is still very slow

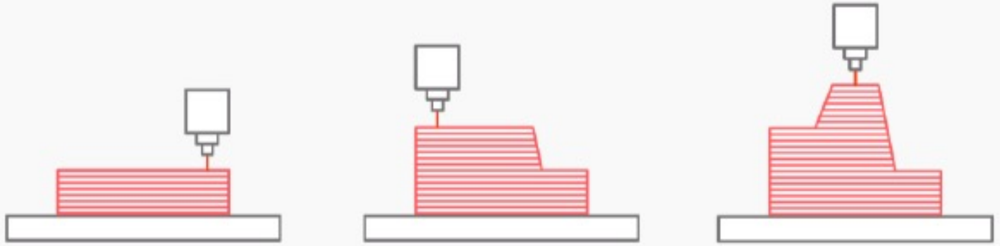
Can we **directly reshape** the material?



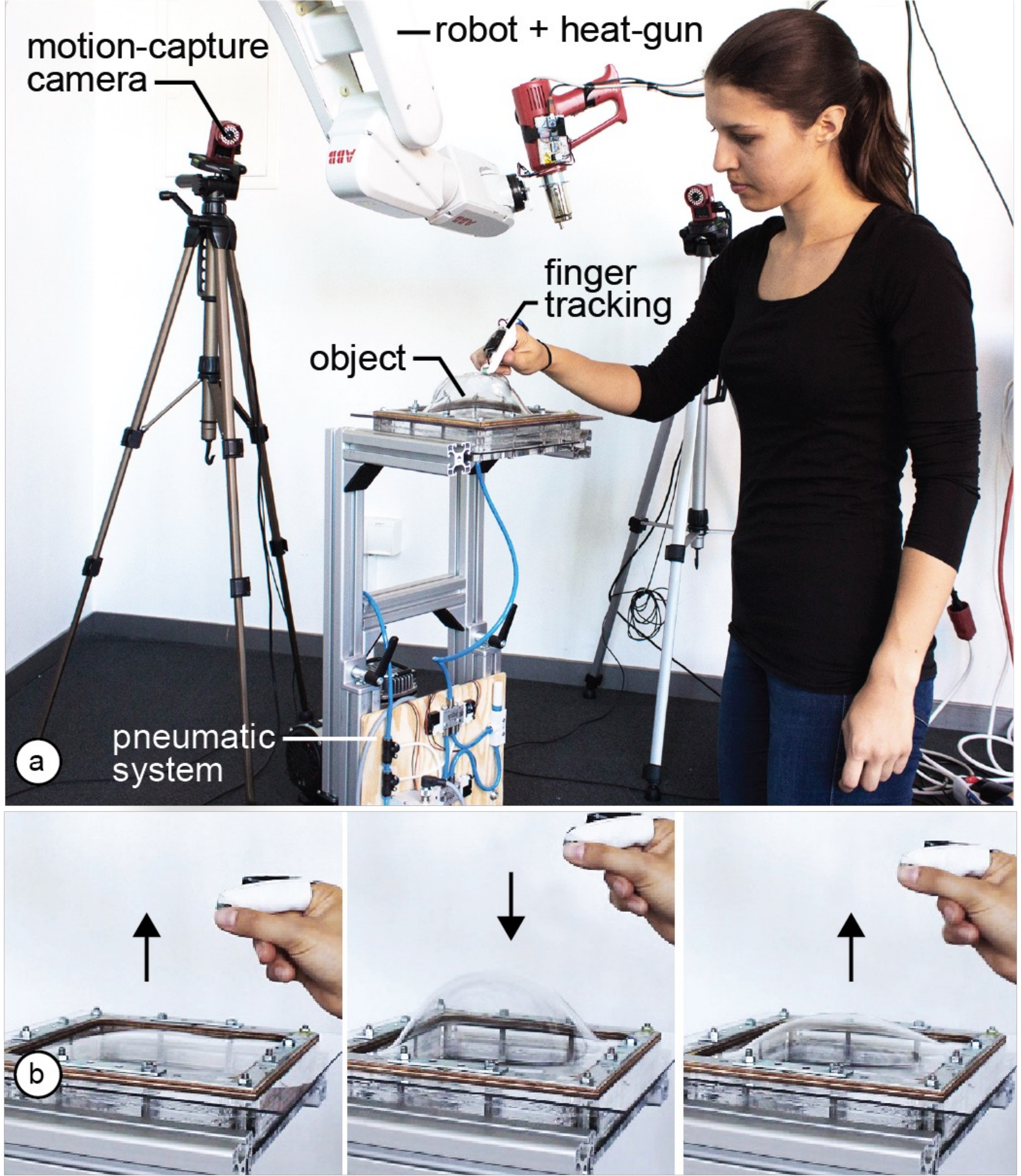
Formative manufacturing

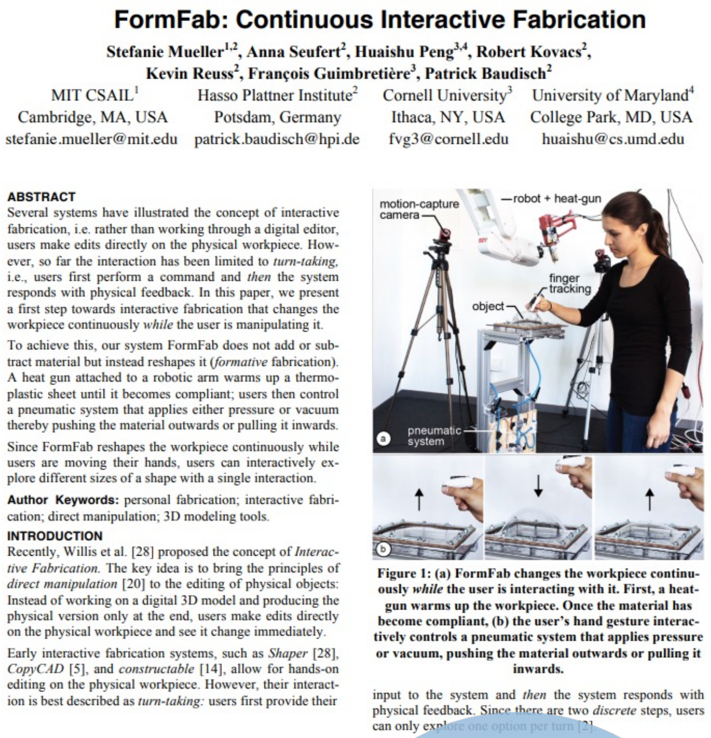


Subtractive manufacturing



Additive manufacturing





FormFab: Continuous Interactive Fabrication

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ABSTRACT

Several systems have illustrated the concept of interactive fabrication, i.e. rather than working through a digital editor, users make edits directly on the physical workpiece. However, so far the interaction has been limited to *turn-taking*, i.e., users first perform a command and *then* the system responds with physical feedback. In this paper, we present a first step towards interactive fabrication that changes the workpiece continuously *while* the user is manipulating it.

To achieve this, our system FormFab does not add or subtract material but instead reshapes it (*formative* fabrication). A heat gun attached to a robotic arm warms up a thermoplastic sheet until it becomes compliant; users then control a pneumatic system that applies either pressure or vacuum thereby pushing the material outwards or pulling it inwards.

Since FormFab reshapes the workpiece continuously while users are moving their hands, users can interactively explore different sizes of a shape with a single interaction.

Author Keywords: personal fabrication; interactive fabrication; direct manipulation; 3D modeling tools.

INTRODUCTION

Recently, Willis et al. [28] proposed the concept of *Interactive Fabrication*. The key idea is to bring the principles of *direct manipulation* [20] to the editing of physical objects: Instead of working on a digital 3D model and producing the physical version only at the end, users make edits directly on the physical workpiece and see it change immediately.

Early interactive fabrication systems, such as *Shaper* [28], *CopyCAD* [5], and *constructable* [14], allow for hands-on editing on the physical workpiece. However, their interaction is best described as *turn-taking:* users first provide their input to the system and *then* the system responds with physical feedback. Since there are two *discrete* steps, users can only explore one option per turn [2].

Figure 1: (a) FormFab changes the workpiece continuously *while* the user is interacting with it. First, a heat-gun warms up the workpiece. Once the material has become compliant, (b) the user's hand gesture interactively controls a pneumatic system that applies pressure or vacuum, pushing the material outwards or pulling it inwards.

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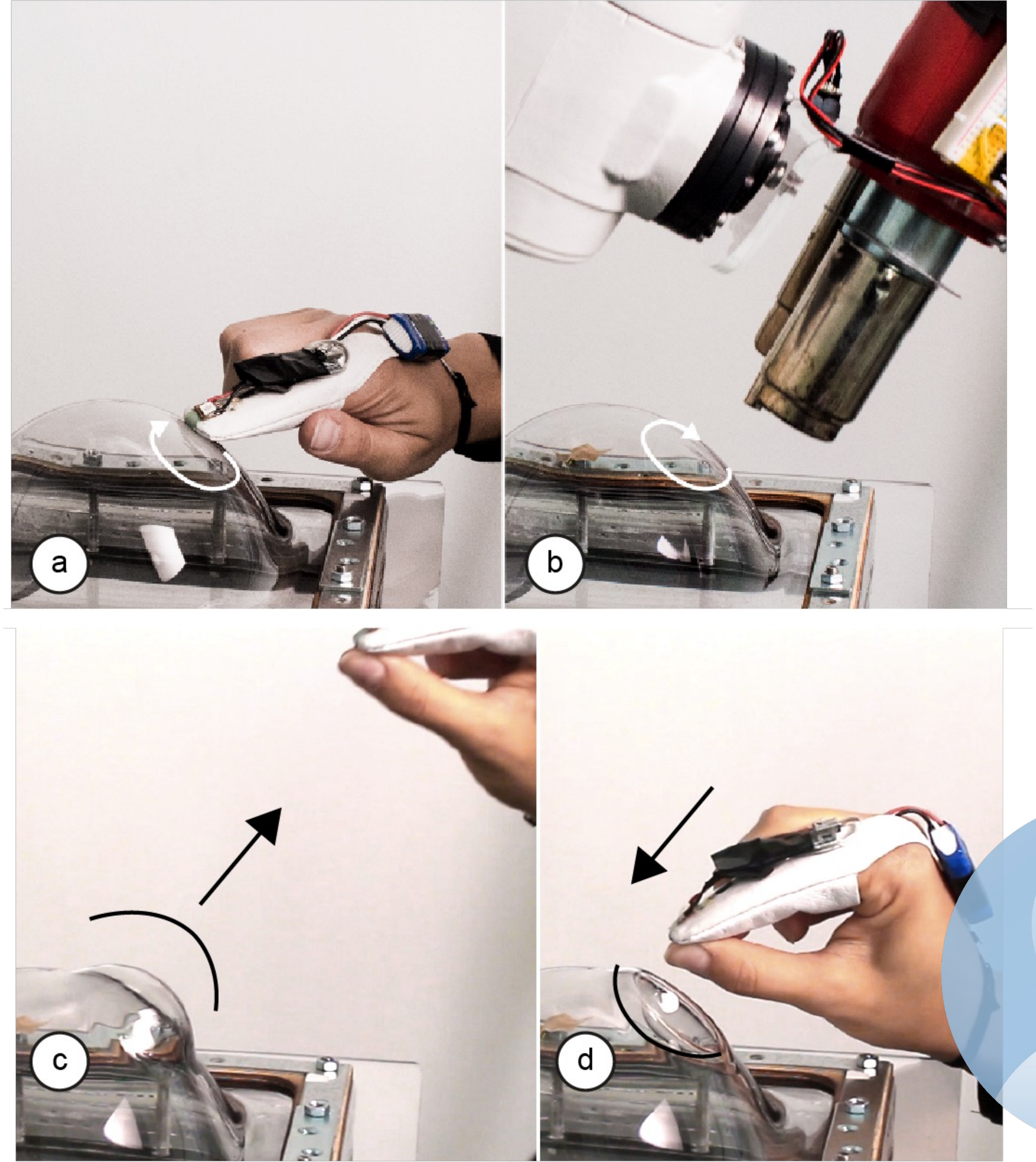
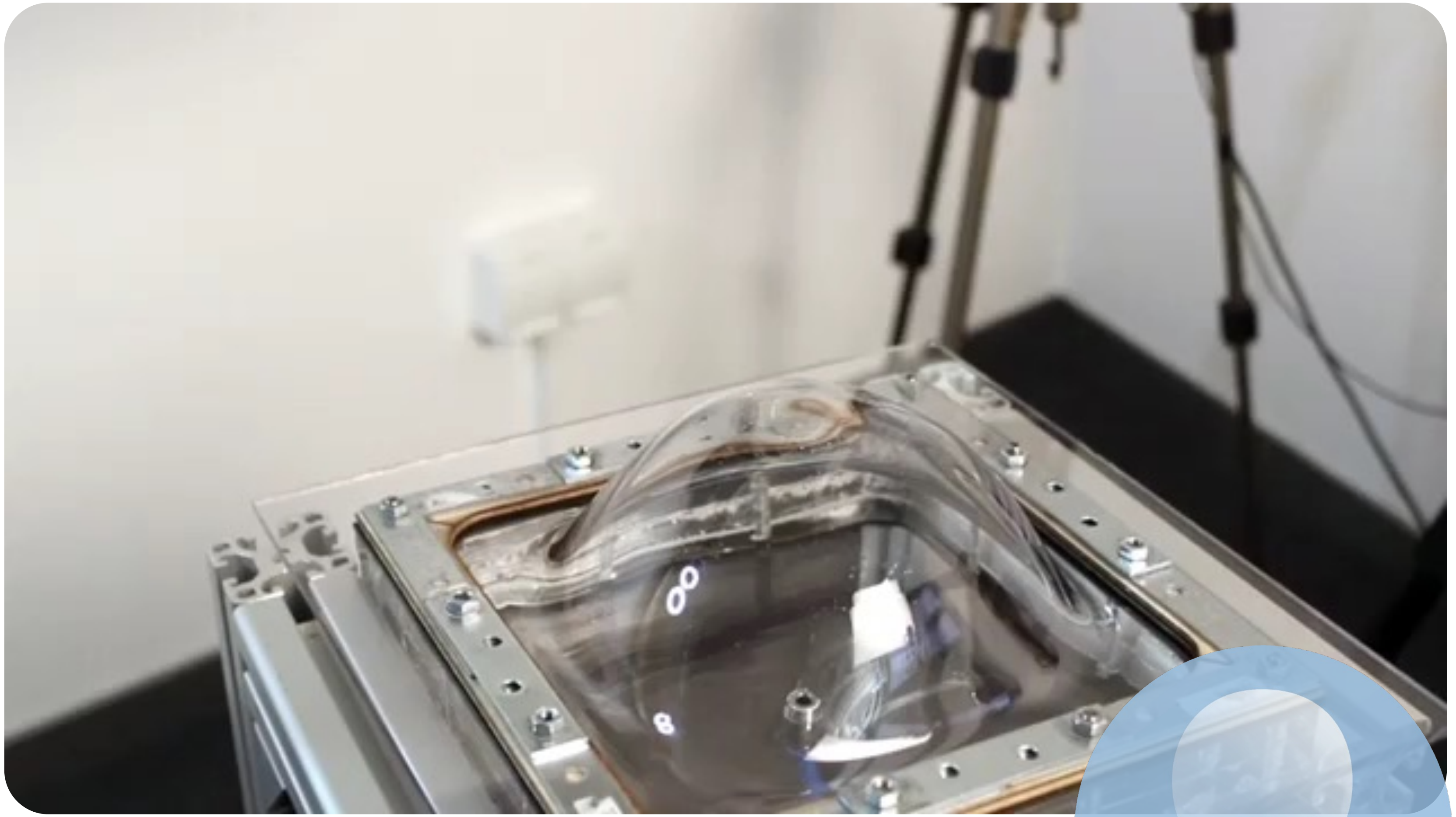
Selectively heat the material

Directly manipulating the area with gestures



Limitations

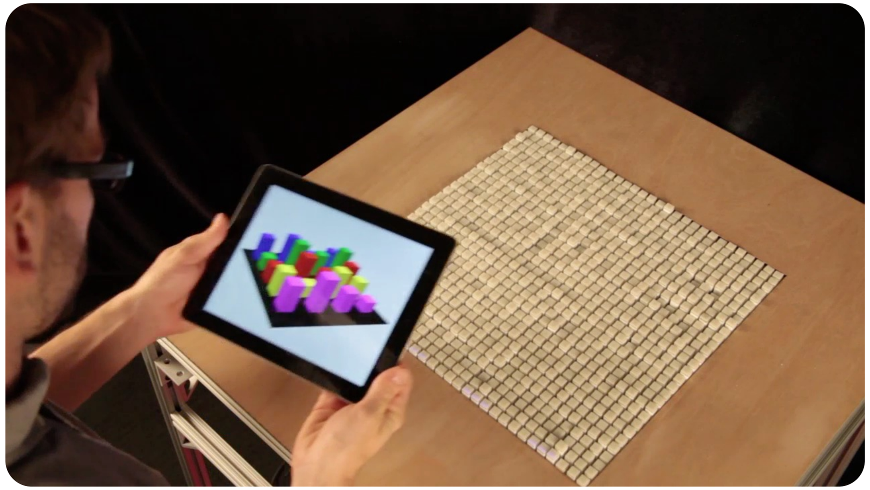
Slow heating process
Limited expressiveness



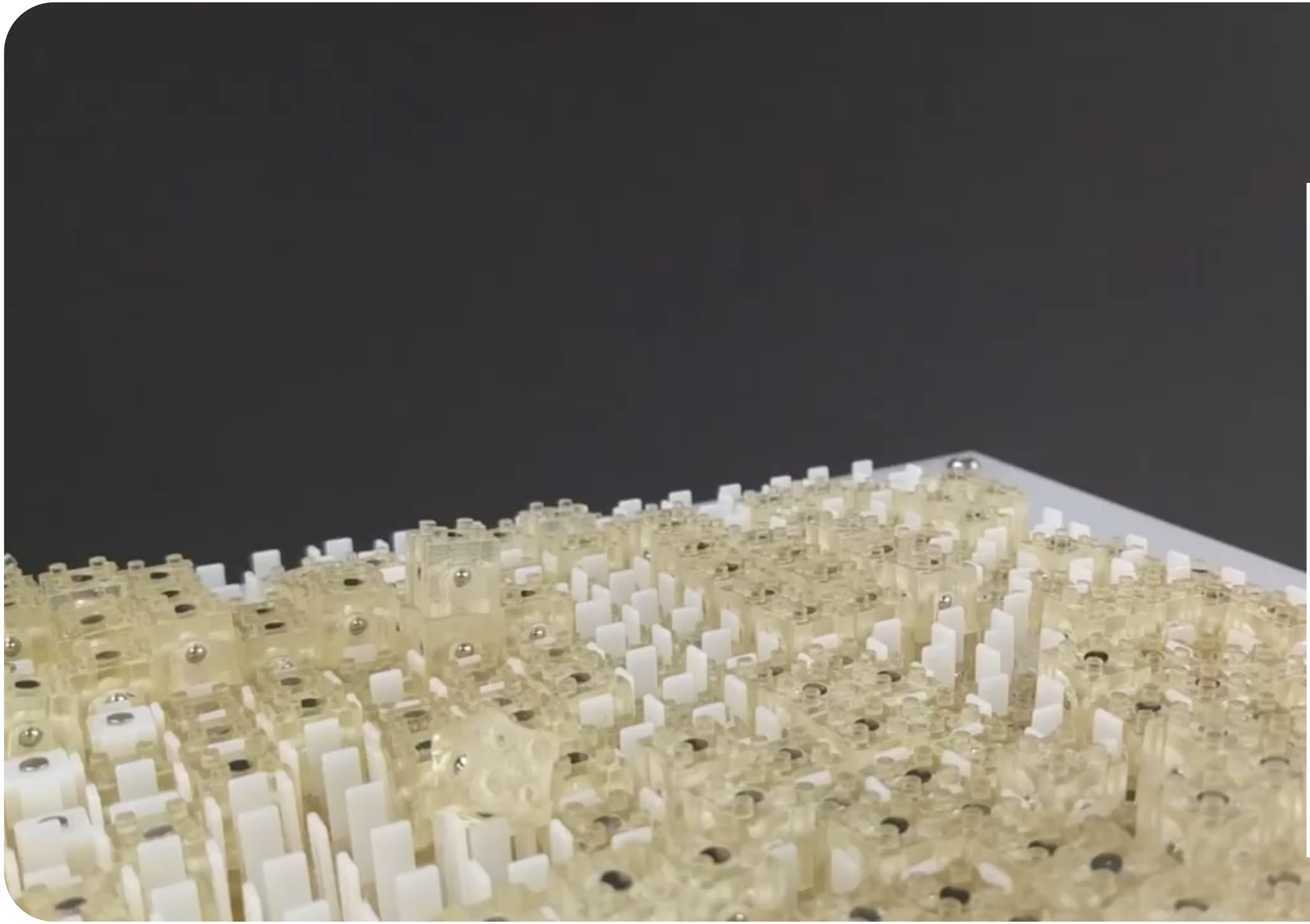
How to further improve the system?

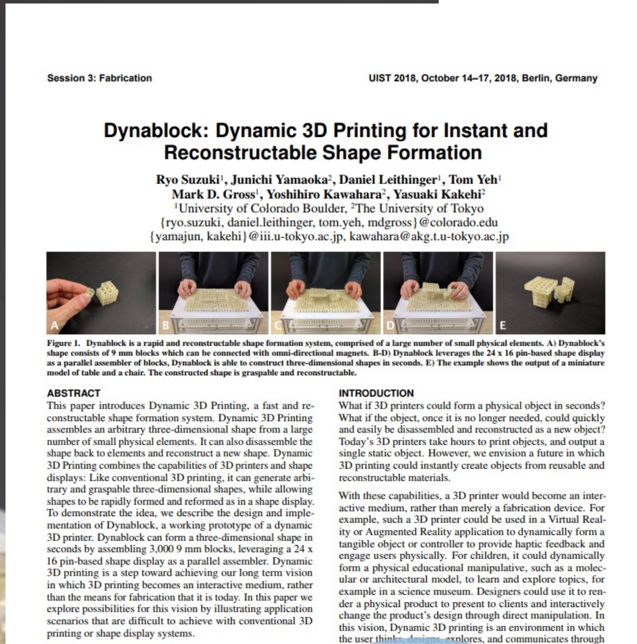
What if we can generate physical models **in seconds**?

What if we can generate physical models **in seconds**?



Fast shape changing speed
But only 2.5D
And it's not detachable





Session 3: Fabrication UIST 2018, October 14–17, 2018, Berlin, Germany

Dynablock: Dynamic 3D Printing for Instant and Reconstructable Shape Formation

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Figure 1. Dynablock is a rapid and reconstructable shape formation system, comprised of a large number of small physical elements. A) Dynablock's shape consists of 9 mm blocks which can be connected with omni-directional magnets. B-D) Dynablock leverages the 24 x 16 pin-based shape display as a parallel assembler of blocks, Dynablock is able to construct three-dimensional shapes in seconds. E) The example shows the output of a miniature model of table and a chair. The constructed shape is graspable and reconstructable.

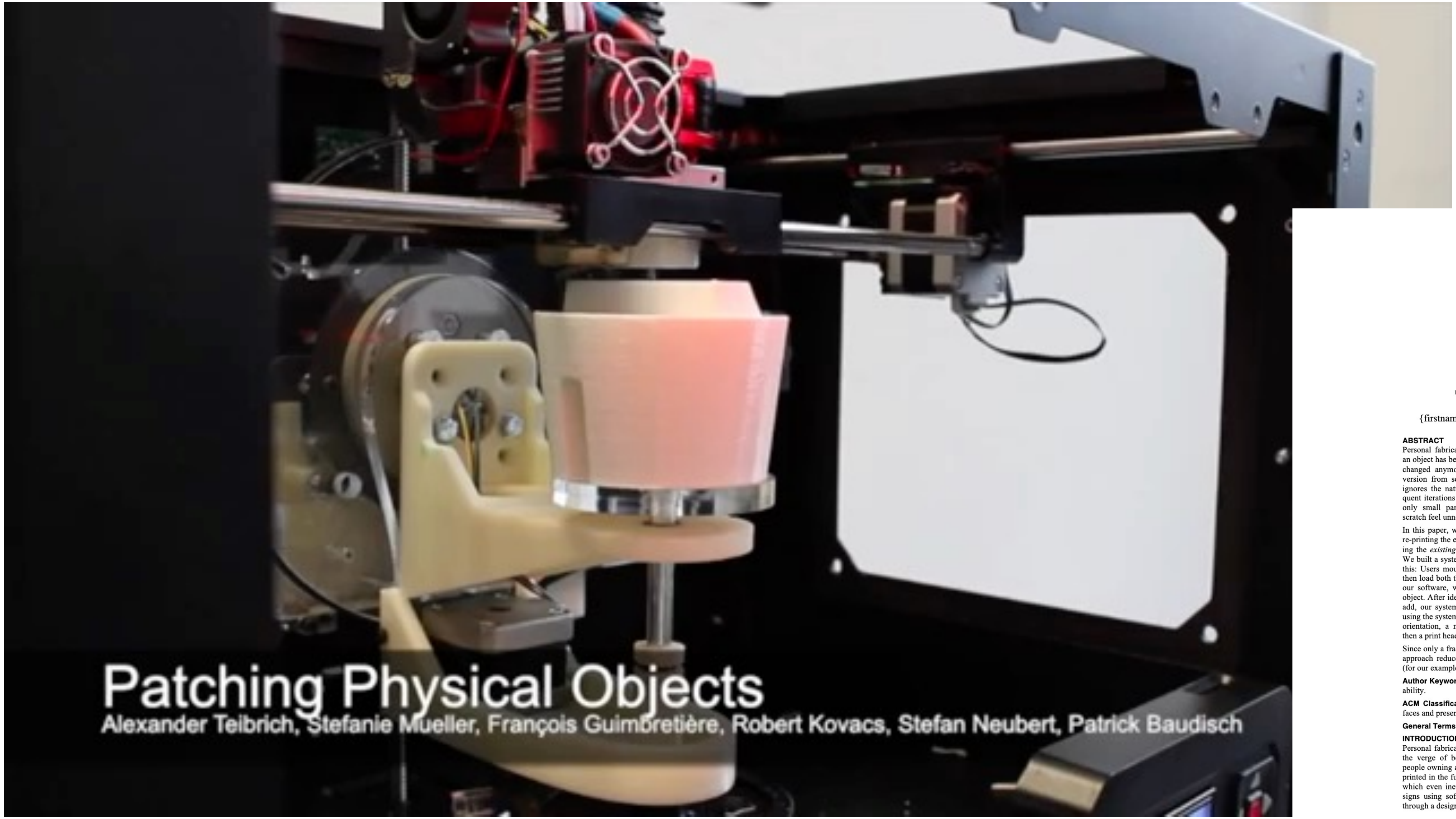
ABSTRACT
This paper introduces Dynamic 3D Printing, a fast and reconstructable shape formation system. Dynamic 3D Printing assembles an arbitrary three-dimensional shape from a large number of small physical elements. It can also disassemble the shape back to elements and reconstruct a new shape. Dynamic 3D Printing combines the capabilities of 3D printers and shape displays: Like conventional 3D printing, it can generate arbitrary and graspable three-dimensional shapes, while allowing shapes to be rapidly formed and reformed as in a shape display. To demonstrate the idea, we describe the design and implementation of Dynablock, a working prototype of a dynamic 3D printer. Dynablock can form a three-dimensional shape in seconds by assembling 3,000 9 mm blocks, leveraging a 24 x 16 pin-based shape display as a parallel assembler. Dynamic 3D printing is a step toward achieving our long term vision in which 3D printing becomes an interactive medium, rather than the means for fabrication that it is today. In this paper we explore possibilities for this vision by illustrating application scenarios that are difficult to achieve with conventional 3D printing or shape display systems.

CCS Concepts

INTRODUCTION
What if 3D printers could form a physical object in seconds? What if the object, once it is no longer needed, could quickly and easily be disassembled and reconstructed as a new object? Today's 3D printers take hours to print objects, and output a single static object. However, we envision a future in which 3D printing could instantly create objects from reusable and reconstructable materials.

With these capabilities, a 3D printer would become an interactive medium, rather than merely a fabrication device. For example, such a 3D printer could be used in a Virtual Reality or Augmented Reality application to dynamically form a tangible object or controller to provide haptic feedback and engage users physically. For children, it could dynamically form a physical educational manipulative, such as a molecular or architectural model, to learn and explore topics, for example in a science museum. Designers could use it to render a physical product to present to clients and interactively change the product's design through direct manipulation. In this vision, Dynamic 3D printing is an environment in which the user thinks, designs, explores, and communicates through dynamic and interactive physical representation.

For an already printed 3D artifact, can we still “edit” it?



Patching Physical Objects

Alexander Teibrich[1], Stefanie Mueller[1], François Guimbretière[1,2], Robert Kovacs[1], Stefan Neubert[1], Patrick Baudisch[1]

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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 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].

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 ISBN 978-1-4503-3779-3/15/11…$15.00
DOI: http://dx.doi.org/10.1145/2807442.2807467

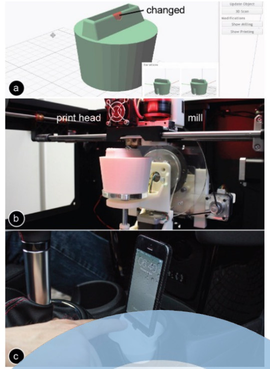

Figure 1: To minimize material consumption and to reduce waste during design iteration, we propose *patching* the existing object rather than reprinting it from scratch. (a) First, our software calculates which part changed, then (b) a mill removes outdated geometry, followed by a print head that prints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

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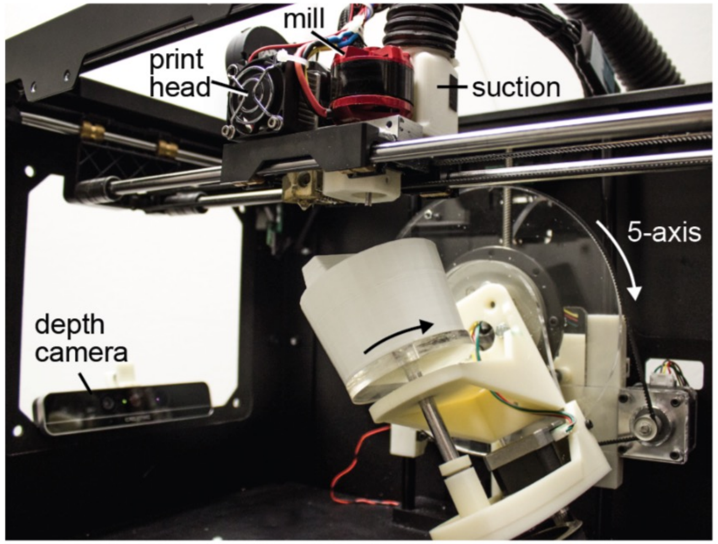
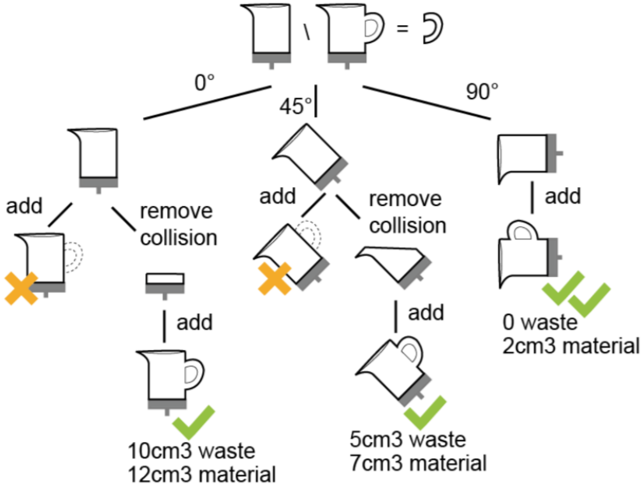
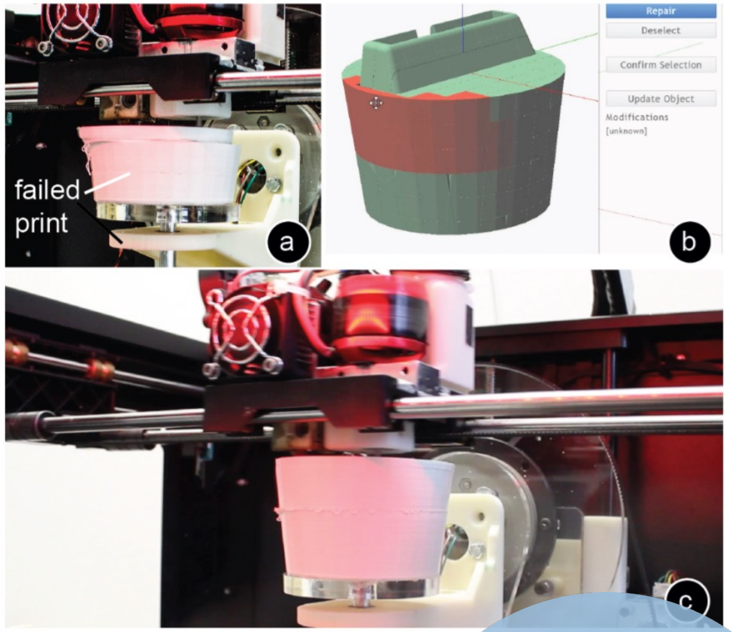
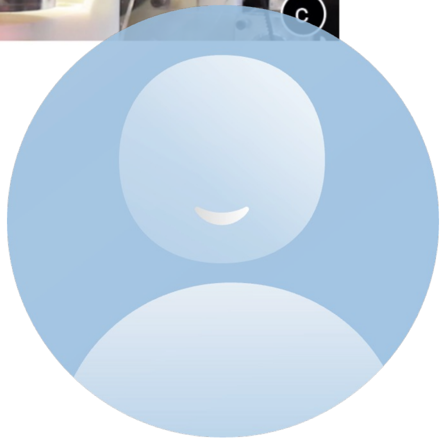
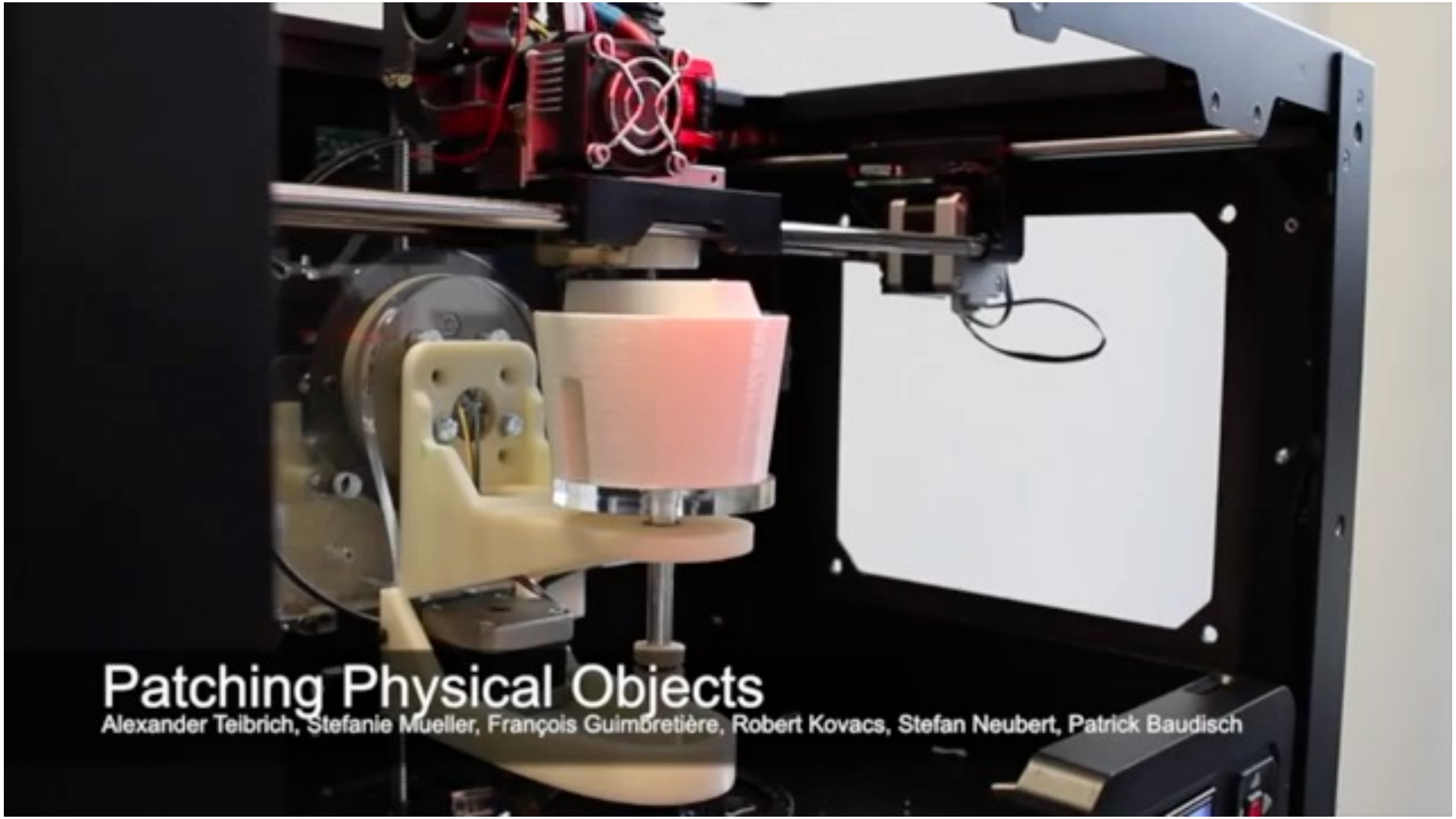

mill
print head
suction
5-axis
depth camera


0°
45°
90°
add
remove collision
add
remove collision
add
add
add
10cm3 waste
12cm3 material
5cm3 waste
7cm3 material
0 waste
2cm3 material


failed print
a
Repair
Deselect
Confirm Selection
Update Object
Modifications
[unknown]
b
c





Besides physical "editing," what are its other potential uses?

Reducing material (plastic) waste;)

Sustainable making has rapidly emerged as a significant research interest among technical HCI researchers, particularly with the growing democratization and accessibility of digital fabrication tools.

But what’s the flip side? As we democratize making, we are also inadvertently **democratizing the creation of waste.**

Some of the current explorations to mitigate this issue

Scrappy: Using Scrap Material as Infill to Make Fabrication More Sustainable

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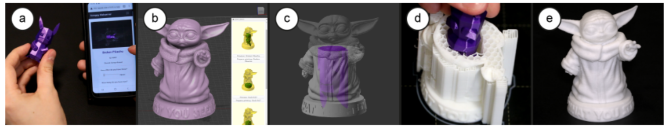

Figure 1: Scrappy is a system that lets users use scrap objects as infill to reduce time, cost, and material: (a) a library tracks scrap objects, like an old print, as well as other common objects; (b) an add-in for Fusion 360 suggests scraps from the library that can fit into a model, sorted by saved printing time; (c) an algorithm finds the best scrap placement and generates a modified model; (d) a custom slicer optimizes infill and adds machine commands to pause the printer with instructions how to insert the scrap into the object; (e) the final printed object has the scrap inside, reducing the material, time, and energy needed to print.

ABSTRACT

We present a software system for fused deposition modelling 3D printing that replaces infill material with scrap to reduce material and energy consumption. Example scrap objects include unused 3D prints from prototyping and calibration, household waste like coffee cups, and off-cuts from other fabrication projects. To achieve this, our system integrates into an existing CAD workflow and manages a database of common items, previous prints, and manually entered objects. While modelling in a standard CAD application, the system suggests objects to insert, ranked by how much infill material they could replace. This computation extends an existing nesting algorithm to determine which objects fit, optimize their alignment, and adjust the enclosing mesh geometry. While printing, the system uses custom tool-paths and animated instructions to enable anyone nearby to manually insert the scrap material.

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CCS CONCEPTS

• **Human-centered computing → Interaction tech.**

KEYWORDS

fabrication, geometry processing, sustainability

ACM Reference Format:
Ludwig Wilhelm Wall, Alec Jacobson, Daniel Vogel, and Oliver Schneider. 2021. Scrappy: Using Scrap Material as Infill to Make Fabrication More Sustainable. In *CHI Conference on Human Factors in Computing Systems (CHI'21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3411764.3445187

1 INTRODUCTION

Personal fabrication methods naturally generate scrap. Our formative study showed that failed prints, tests, and offcuts occur naturally in the iterative, creative practice of designing and testing physical objects. While experts might strive to use material efficiently, there will still be waste; with novices, there will be even more. These scrap objects are often thrown out, but some end up cluttering work spaces with the hope they can be used in the future. In some fabrication environments, bags of waste objects are stored for years with the hope of finding an eventual use. The process of re-melting waste filament to create new spools is commonly known, but almost never implemented, since it requires specialized machines and reduces filament quality.

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The main idea of this work is to reduce the infill by using scrap materials lying around us

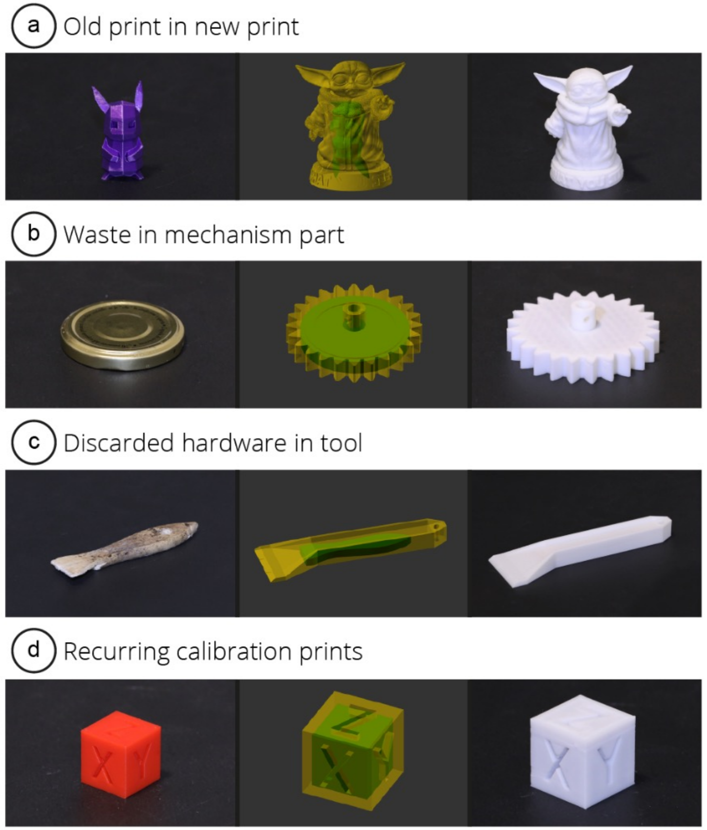
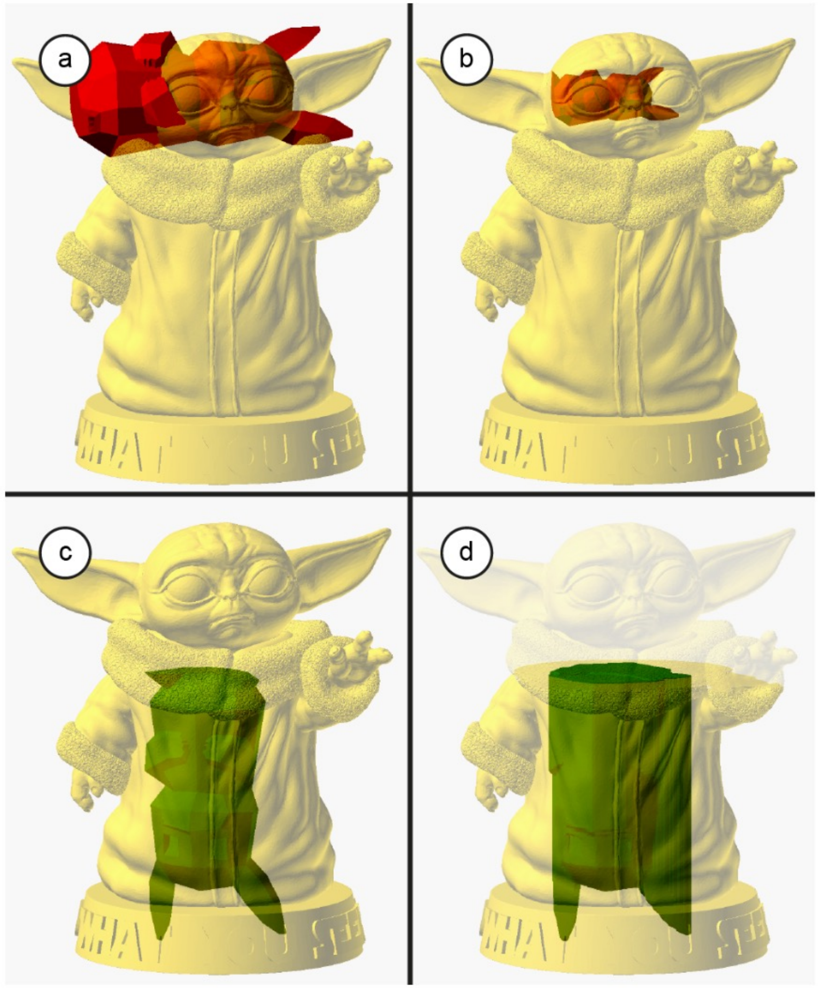


Figure 4: Examples showing scrap, computed mesh, and printed model: (a) an outdated print inside a new one; (b) household waste inside a mechanical part; (c) the broken handle of a hand tool inside another tool, (d) and a recurring print used to calibrate printers inside a bigger version of the same model.



The main idea of this work is to reduce the infill by using scrap materials lying around us

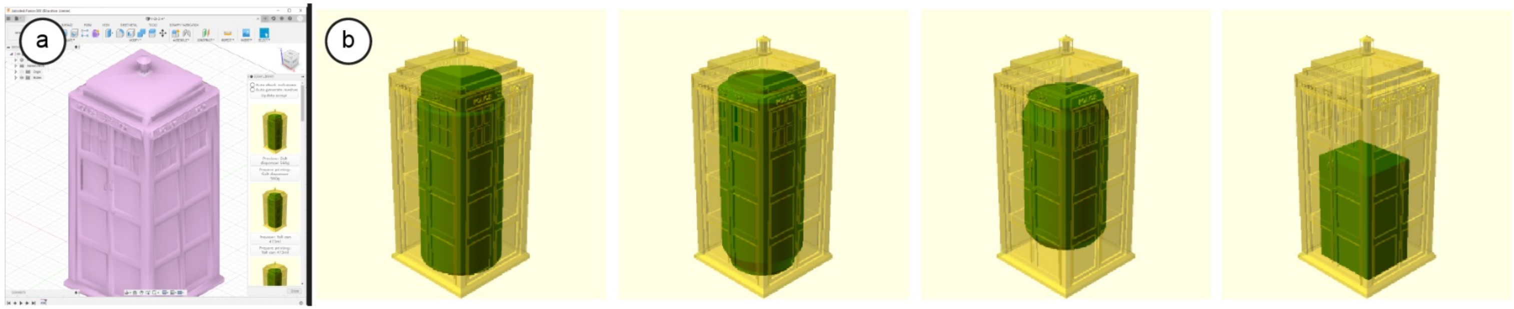


Figure 2: Fusion 360 integration: (a) our add-in panel displays a list of compatible scrap with previews; (b) detail of previews showing compatible scraps that would fit into a large model, such as a plastic salt shaker, a beer can, a soda can, or a cardboard packaging box.

Model	Scrap	Print time without scrap	Scrappy print time savings	Material weight without scrap	Scrappy material weight savings
Tardis	Salt dispenser	1730 min		285 g	
Gear	Jar lid	150 min		25 g	
Fossil token	Rock	55 min		10 g	
Large XYZ-cube	XYZ-cube	33 min		7 g	
Baby Yoda	Pikachu	472 min		52 g	
Phone stand	I-Pod	272 min		58 g	
Scraping tool	Broken handle	160 min		33 g	

Substiports: User-Inserted Ad Hoc Objects as Reusable Structural Support for Unmodified FDM 3D Printers

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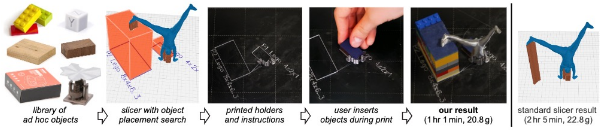

Figure 1: Our approach uses a modified slicer to select reusable objects to use as ad hoc structural support. Object "holders" and instructions are printed, then the user inserts objects during one or more pauses during the print. In this example, our approach reduced print time by 1 hour and saved 87% of support (2.0g out of 2.3g): even a small savings in support material can result in pronounced time savings due to reduced printer movements.

ABSTRACT

We contribute a technical solution to reduce print time and material with unmodified fused deposition modelling printers. The approach uses ad hoc objects inserted by a user during printing as a replacement for printed support of overhanging structures. Examples of objects include household items like books, toy bricks, and custom mechanisms like a screw jack. A software-only system is integrated into existing slicing software to analyze generated support print paths, search a library of objects to find suitable replacements, optimize combinations of replacement objects, and make necessary adjustments to impacted printing layers and paths. During printing, the user is prompted to insert objects with the help of lightweight printed holders to guide placement and prevent movement. Instructions printed on the build-plate help identify and position objects. A technical evaluation measures performance and benefits with different sets of ad hoc objects and different levels of user involvement.

CCS CONCEPTS

• **Human-centered computing → Interaction tech.**

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https://doi.org/10.1145/3586183.3606718

KEYWORDS

fabrication, interactive 3D printing, sustainability

ACM Reference Format:
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1 INTRODUCTION

3D printers that employ fused deposition modelling (FDM) use printable support structures to reliably manufacture models with overhangs, bridges, and other geometry extending more than 45° from the Z-axis (we collectively refer to all of these as "overhangs"). Disposable support structures are pure waste, costing additional material and time, so it is desirable to minimize them.

One strategy is to optimize the support structure itself, for example, using lightweight structures that branch out from lower parts of the model to support overhangs [10]. However, this introduces additional connections between support material and the model, marring the surface finish. In general, optimizing support geometry increases the chance of failure: thin tall structures are more severely affected by thermal deformation and their low stiffness can result in accidental displacement. For these and similar reasons, support structures typically generated by slicers are sturdy with a substantial connection to the build plate and filling much of the volume beneath overhangs [1] .

Another approach is to replace support structures with something else. For example, Hongyao et al. [13], Xu et al. [39] replaced a printer build plate with a mechanically actuated grid of supporting surfaces and Yiğit et al. [40] propose using a robot arm to place a set

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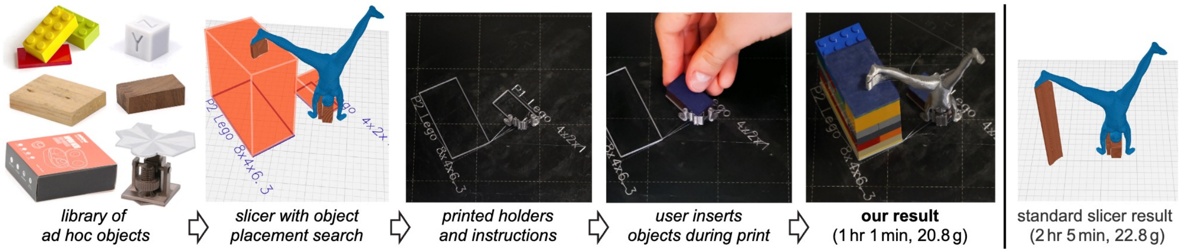
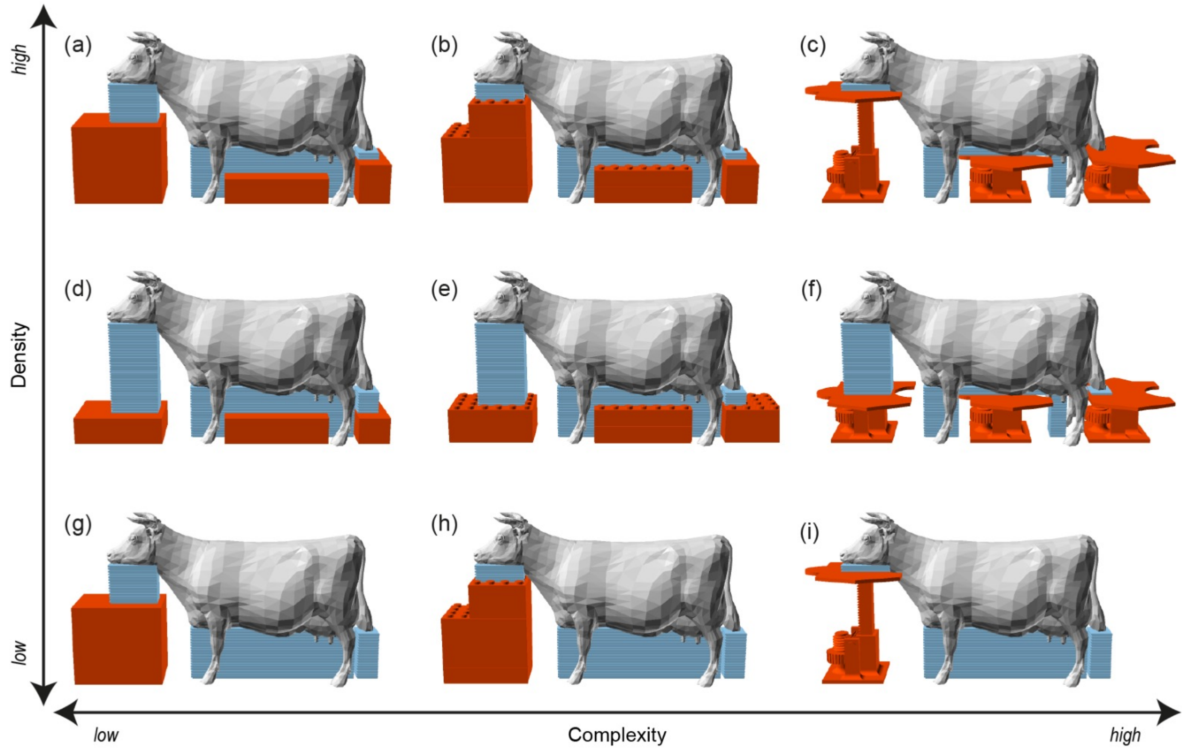
The main idea of this work is to reduce the supporting structure by using existing objs around us





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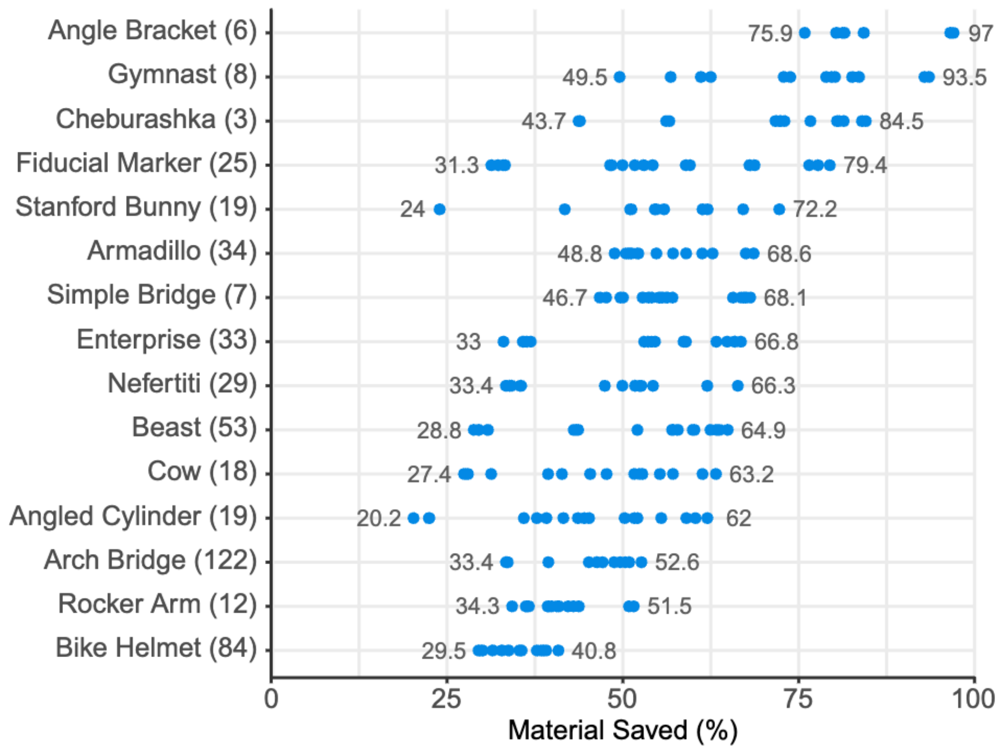

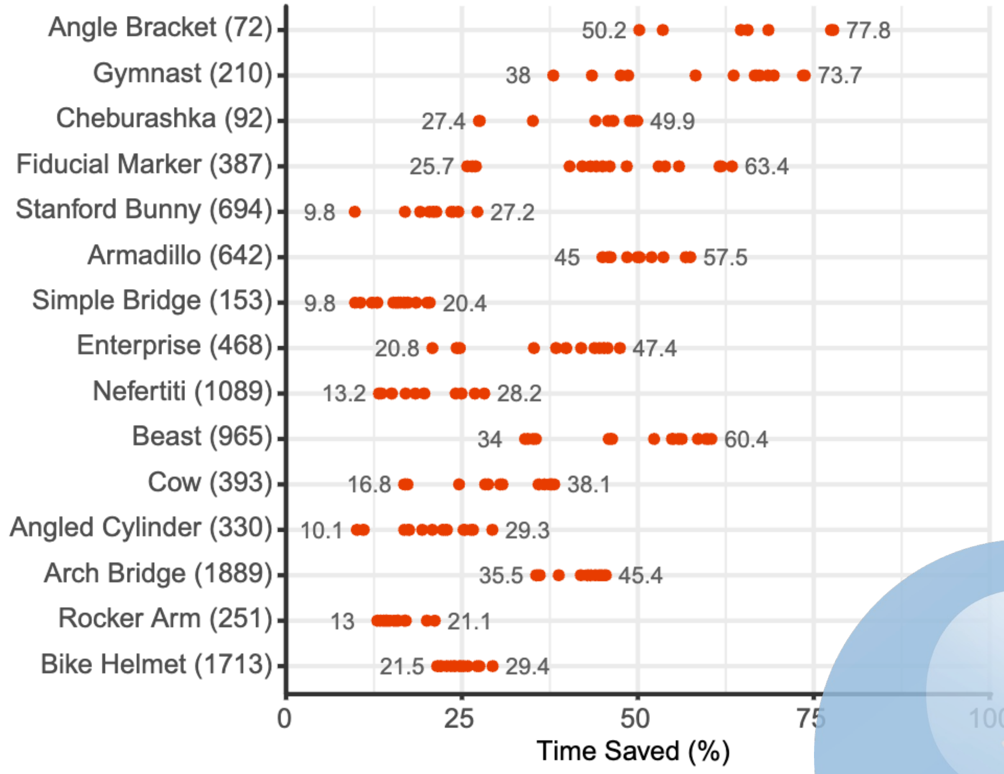

Some of the current explorations to mitigate this issue

- Reduce the material usage
- New material

Designing a Sustainable Material for 3D Printing with Spent Coffee Grounds

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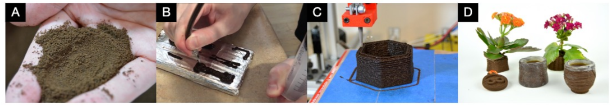

Figure 1: Design Process Overview. We investigated spent coffee grounds—a commonly wasted natural material—as a sustainable material for 3D printing (A). We experimented with different food-based binders and adjusted material composition to make the material self-supporting with hand-extrusion (B). We tuned 3D printing parameters for quality and reliability (C). We then explored how our material could enable sustainable prototyping workflows and creating objects like biodegradable espresso cups and planter pots (D).

ABSTRACT

The widespread adoption of 3D printers exacerbates existing environmental challenges as these machines increase energy consumption, waste output, and the use of plastics. Material choice for 3D printing is tightly connected to these challenges, and as such researchers and designers are exploring sustainable alternatives. Building on these efforts, this work explores using spent coffee grounds as a sustainable material for prototyping with 3D printing. This material, in addition to being compostable and recyclable, can be easily made and printed at home. We describe the material in detail, including the process of making it from readily available ingredients, its material characteristics and its printing parameters. We then explore how it can support sustainable prototyping practices as well as HCI applications. In reflecting on our design process, we discuss challenges and opportunities for the HCI community to support sustainable prototyping and personal fabrication. We conclude with a set of design considerations for others to weigh when exploring sustainable materials for 3D printing and prototyping.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI).**

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KEYWORDS

3D printing, personal fabrication, environmental sustainability, zero-waste prototyping, bio-based materials

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1 INTRODUCTION

Environmental challenges including climate change, pollution, and waste production have reached global concern. Within the Human-Computer Interaction (HCI) community, there is a growing interest in addressing these sustainability issues that are associated with the materials and the energy we use for digital technologies [17, 28, 67, 74, 77, 98]. Researchers are examining the effects of digital technology use on energy consumption [36, 130] as well as introducing strategies to mitigate energy over-use [87, 131]. Others have investigated reducing waste output by reusing objects—such as electronics [47, 55] and textiles [135]—and designing them for decomposition [65, 66, 68, 113].

The sustainability of personal fabrication technologies, particularly 3D printing, is a pressing issue [10, 31, 57, 124]. As of 2019, over 2 million 3D printers have been integrated into the homes of consumers and small businesses [103]. This widespread adoption has been enabled by open-source movements (e.g., Fab@Home [73] and RepRap [52]) and cheap kits, costing less than $160 USD[1]. Consequently, the adoption of these machines exacerbates three

[1]Best Cheap/Budget 3D Printers: https://all3dp.com/1/best-cheap-budget-3d-printer-affordable-under-500-1000/

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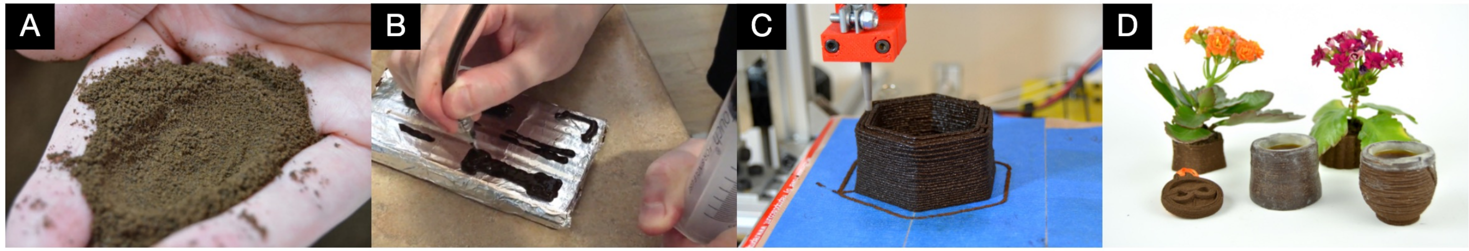
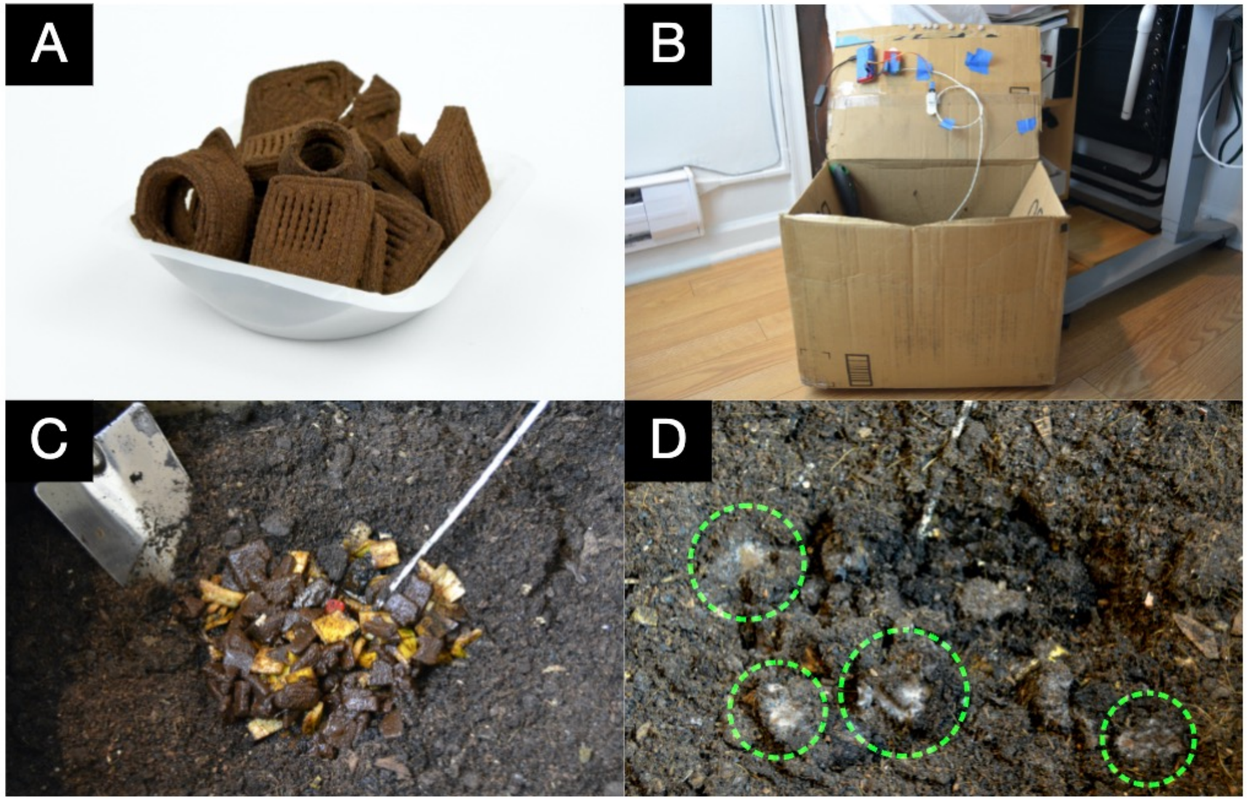
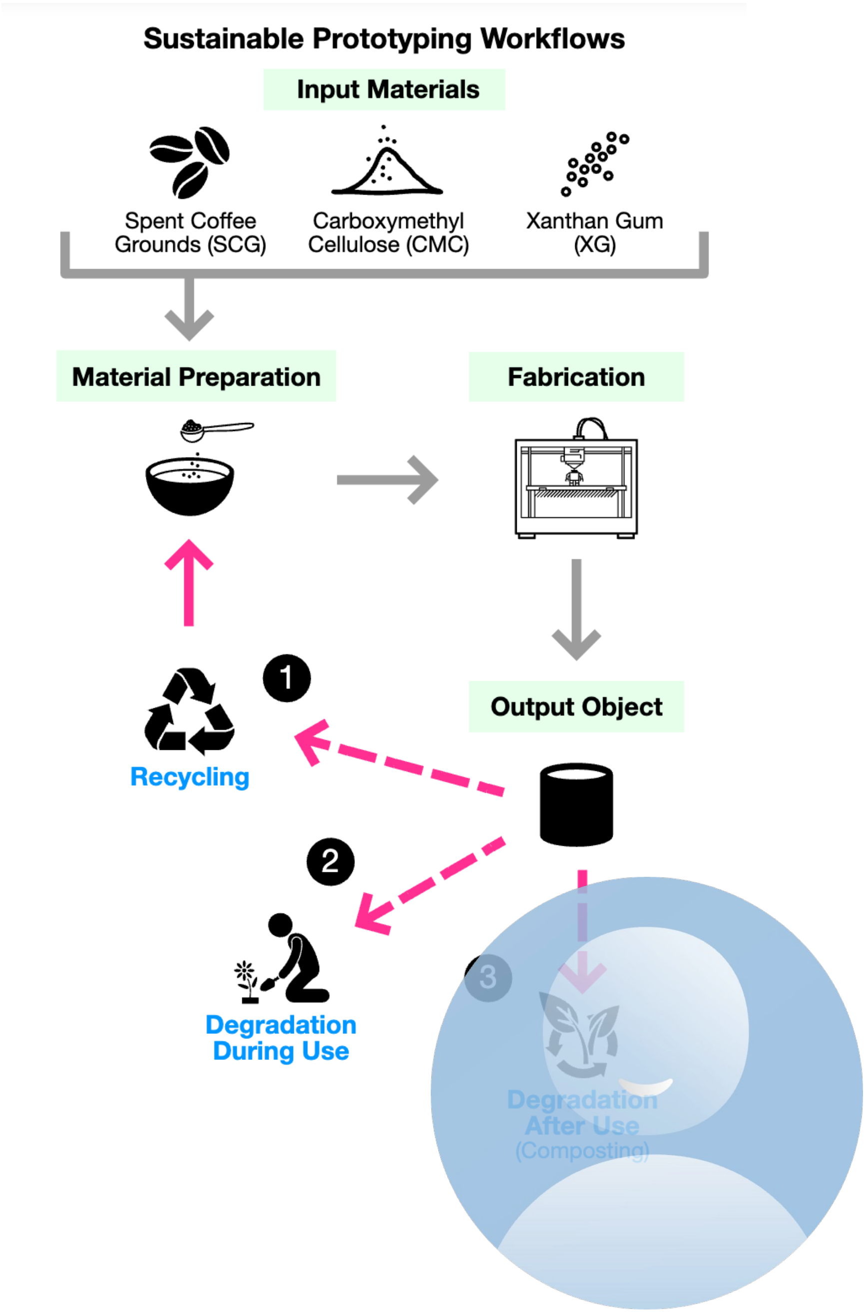


Figure 1: Design Process Overview. We investigated spent coffee grounds—a commonly wasted natural material—as a sustainable material for 3D printing (A). We experimented with different food-based binders and adjusted material composition to make the material self-supporting with hand-extrusion (B). We tuned 3D printing parameters for quality and reliability (C). We then explored how our material could enable sustainable prototyping workflows and creating objects like biodegradable espresso cups and planter pots (D).





Biohybrid Devices: Prototyping Interactive Devices with Growable Materials

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Figure 1: We combine Bacterial Cellulose with traditional electronics to create *Biohybrid Devices*. We identify three phases to embed electronics, based on the material's life cycle: Growth, Stabilization, and Inanimate. The embedding techniques allow to grow functional input and output devices.

ABSTRACT

Living bio-materials are increasingly used in HCI for fabricating objects by growing. However, how to integrate electronics to make these objects interactive still needs to be clarified. This paper presents an exploration of the fabrication design space of Biohybrid Interactive Devices, a class of interactive devices fabricated by merging electronic components and living organisms. From the exploration of this space using bacterial cellulose, we outline a fabrication framework centered on the biomaterials' life cycle phases. We introduce a set of novel fabrication techniques for embedding conductive elements, sensors, and output components through biological (e.g. bio-fabrication and bio-assembling) and digital processes. We demonstrate the combinatory aspect of the framework by realizing three tangible, wearable, and shape-changing interfaces. Finally, we discuss the sustainability of our approach, its limitations, and the implications for bio-hybrid systems in HCI.

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1 INTRODUCTION

The HCI community has pivoted towards making use of the natural growth or reproduction processes of living organisms for fabrication. As an emergent and promising material practice, Growing Design [15] employs fermentation, biomineralization or cellular division as a form of bio-fabrication. Growing materials is a compelling, novel addition to the fabrication of DIY Materials [7], allowing designers to engage with the material at different steps

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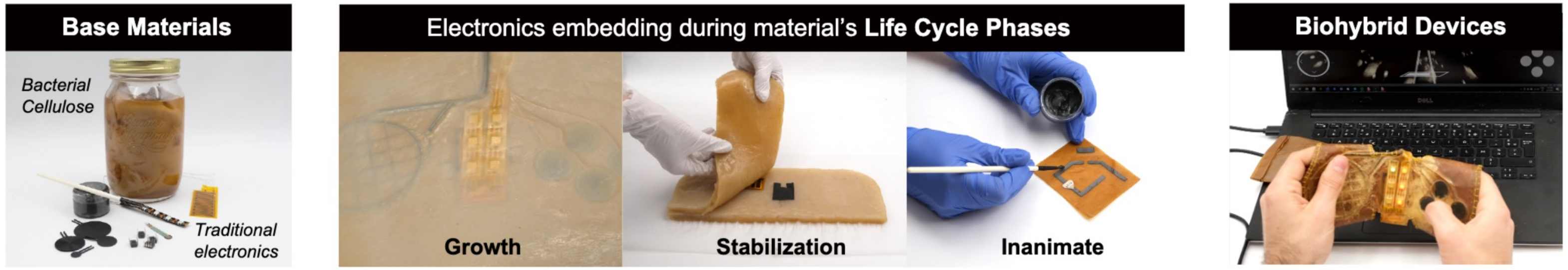

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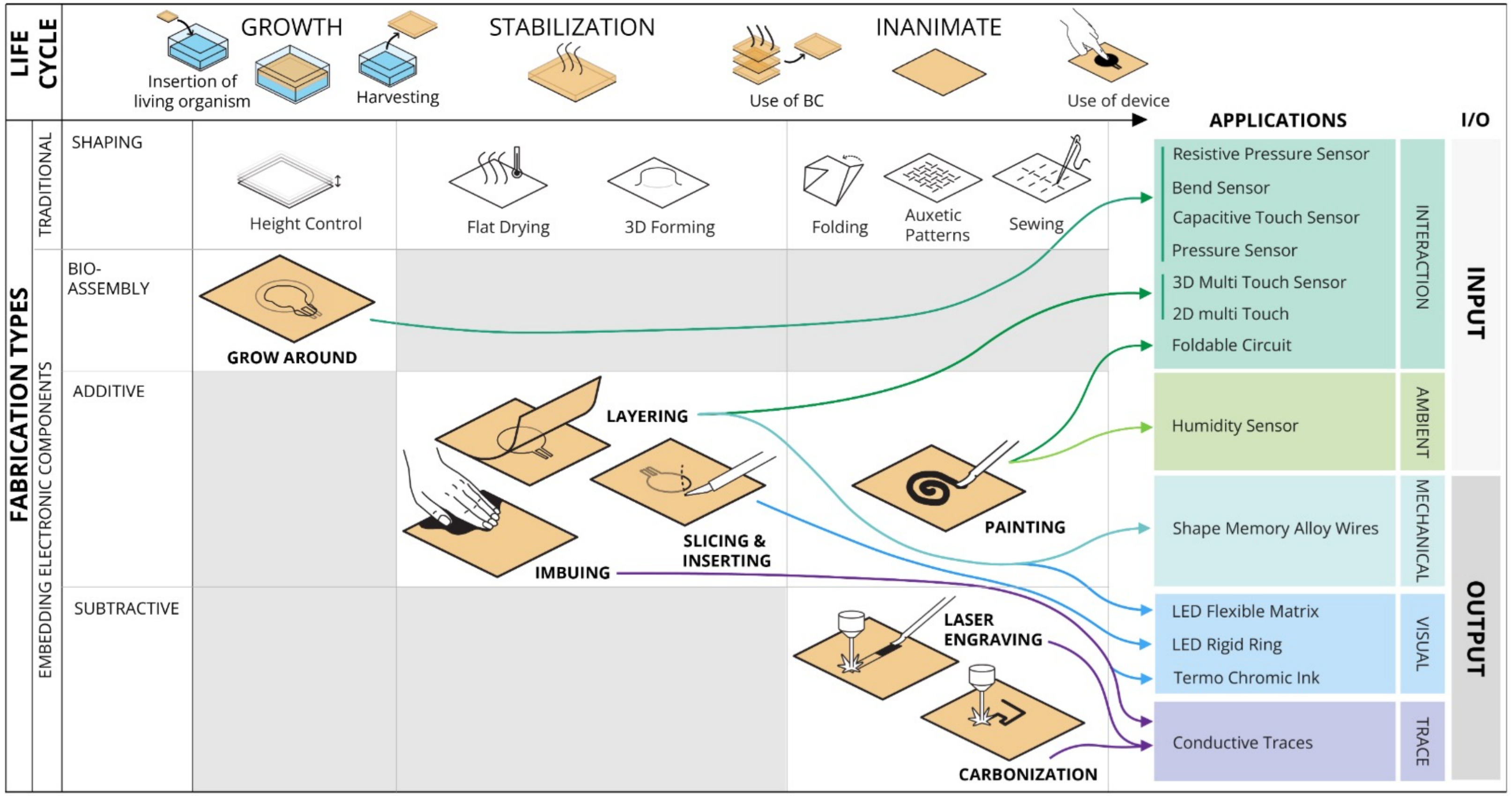

PCB Renewal process

Some of the current explorations to mitigate this issue

- Reduce the material usage
- New material

Zoom out:

Throughout your own making and prototyping practices in this semester,
>Where do you see waste happens?
>What are things we can do?
>At what cost?

Have a good break;) I will see you next Monday.