Announcement

Final Exam –

- Date: Fri, Dec. 15, 1:30pm - 3:30pm
- Location: Online
- Open book: laptop and digital material – Yes; Chat/ChatGPT – No

Final Milestone Presentation –

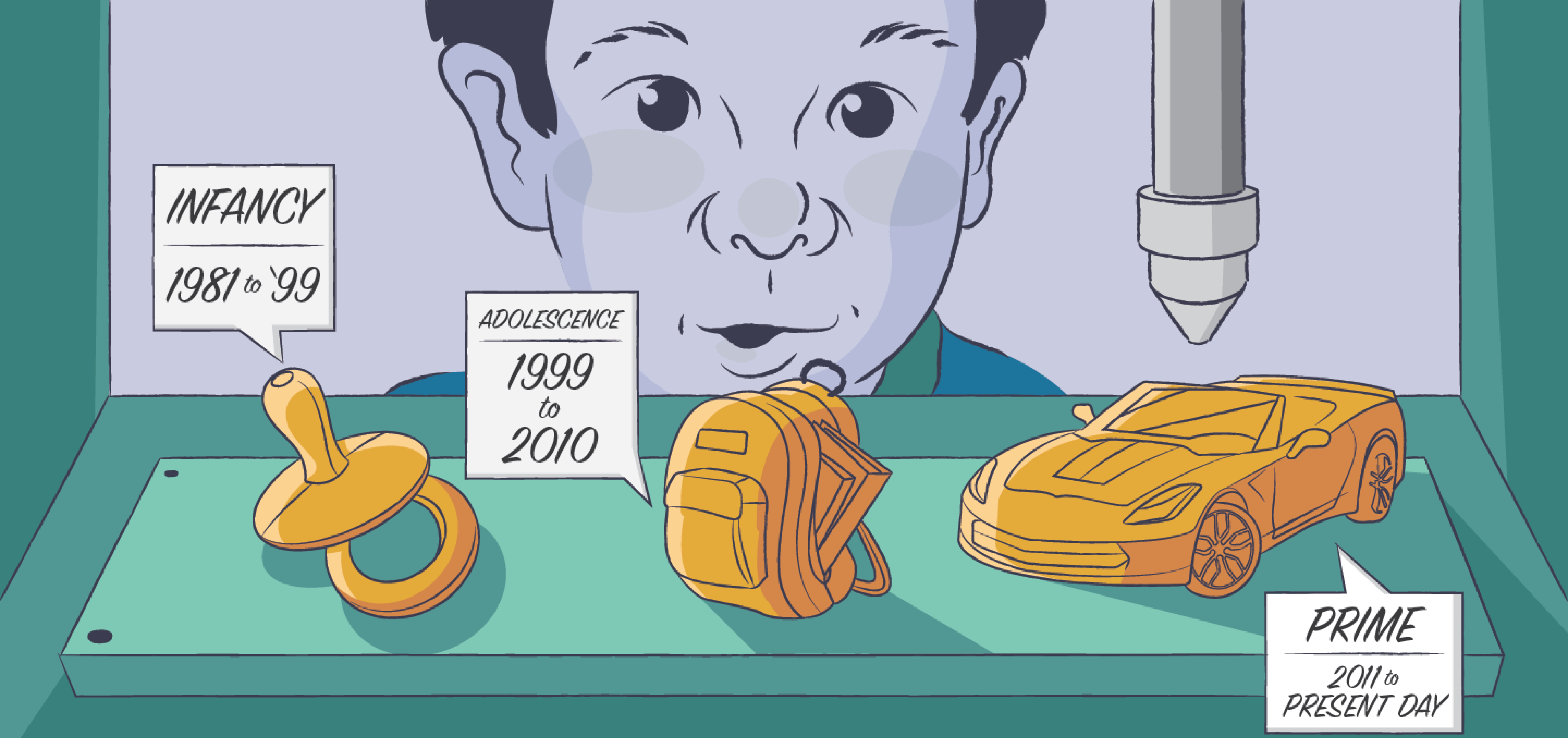
- Date: Dec 11th 3:30pm - 5:00pm (Be there at least 15 min ahead of time to setup your ‘booth’)
- Location: Sandbox
- Live Demo! Bring your setup to Sandbox early, and prepare to give a live demonstration.

Final Milestone Summary –

- Date: Dec 15 EOD
- Format: Online https://www.hackster.io/smartlab/projects
- Documentation + simple video.
- More details on ELMS.

Team Eval Survey –

- Date: Dec 15 EOD
- https://forms.gle/sBFZEsk75o74t2bS9

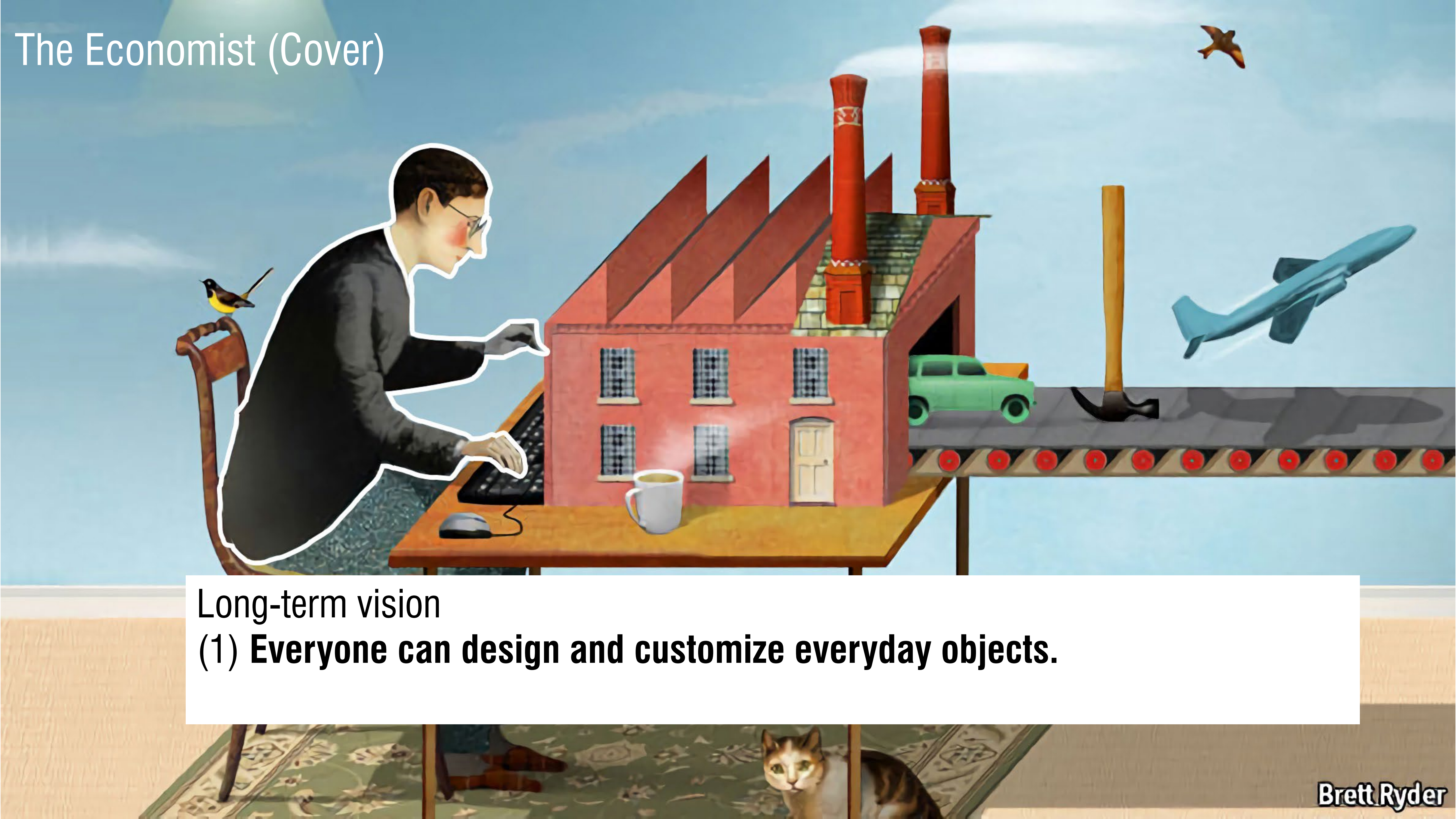


Fabrication + Interactivity | Creative Process

CMSC730 | Huaishu Peng | UMD CS

Industrial 3D Printer

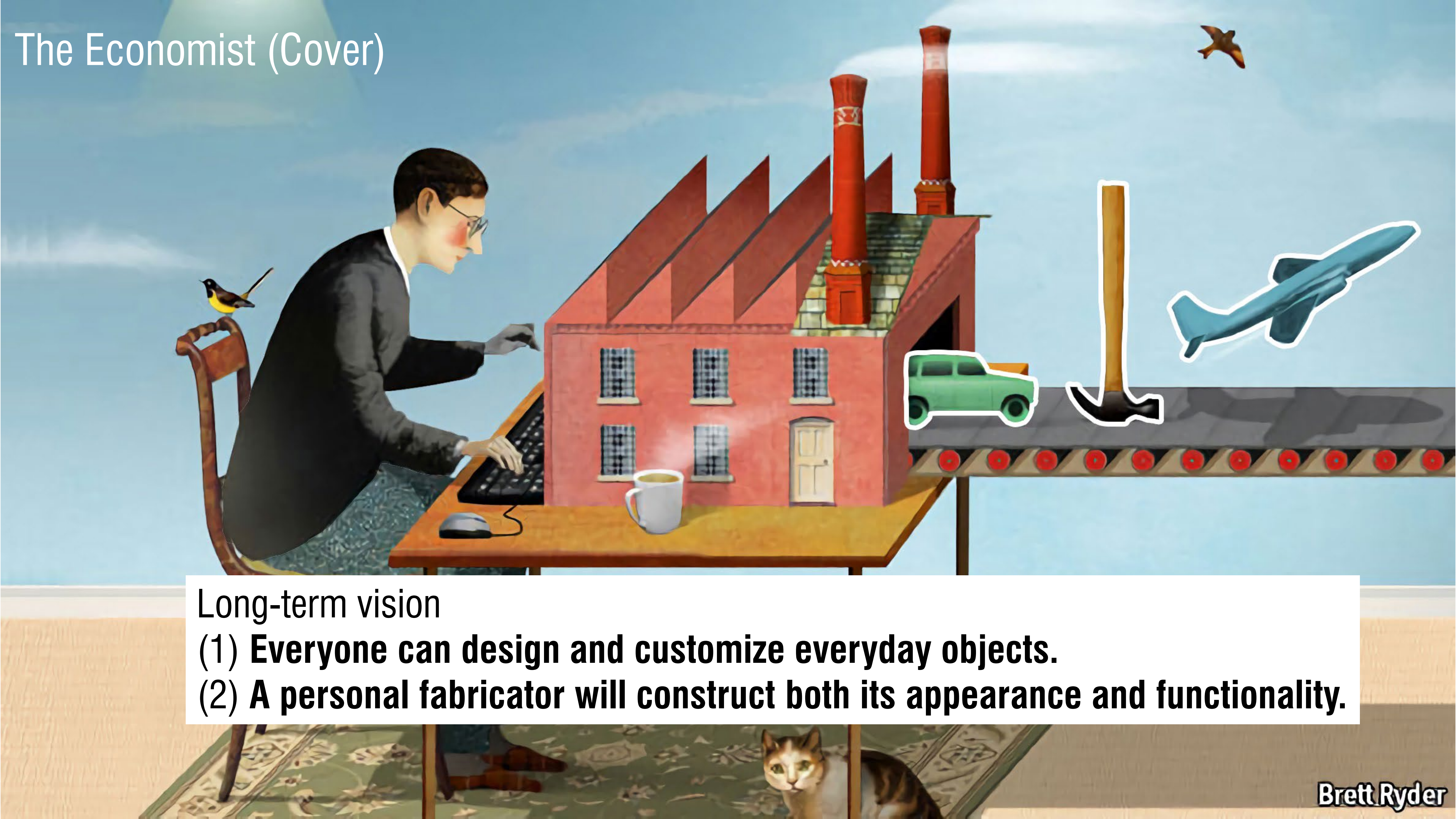
The Economist (Cover)



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.**

1 surface added to selection.

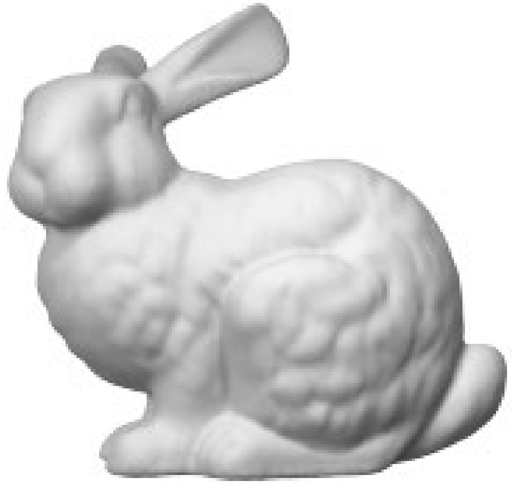
Command:

Design 3D digital models is difficult

Brett Ryder

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)



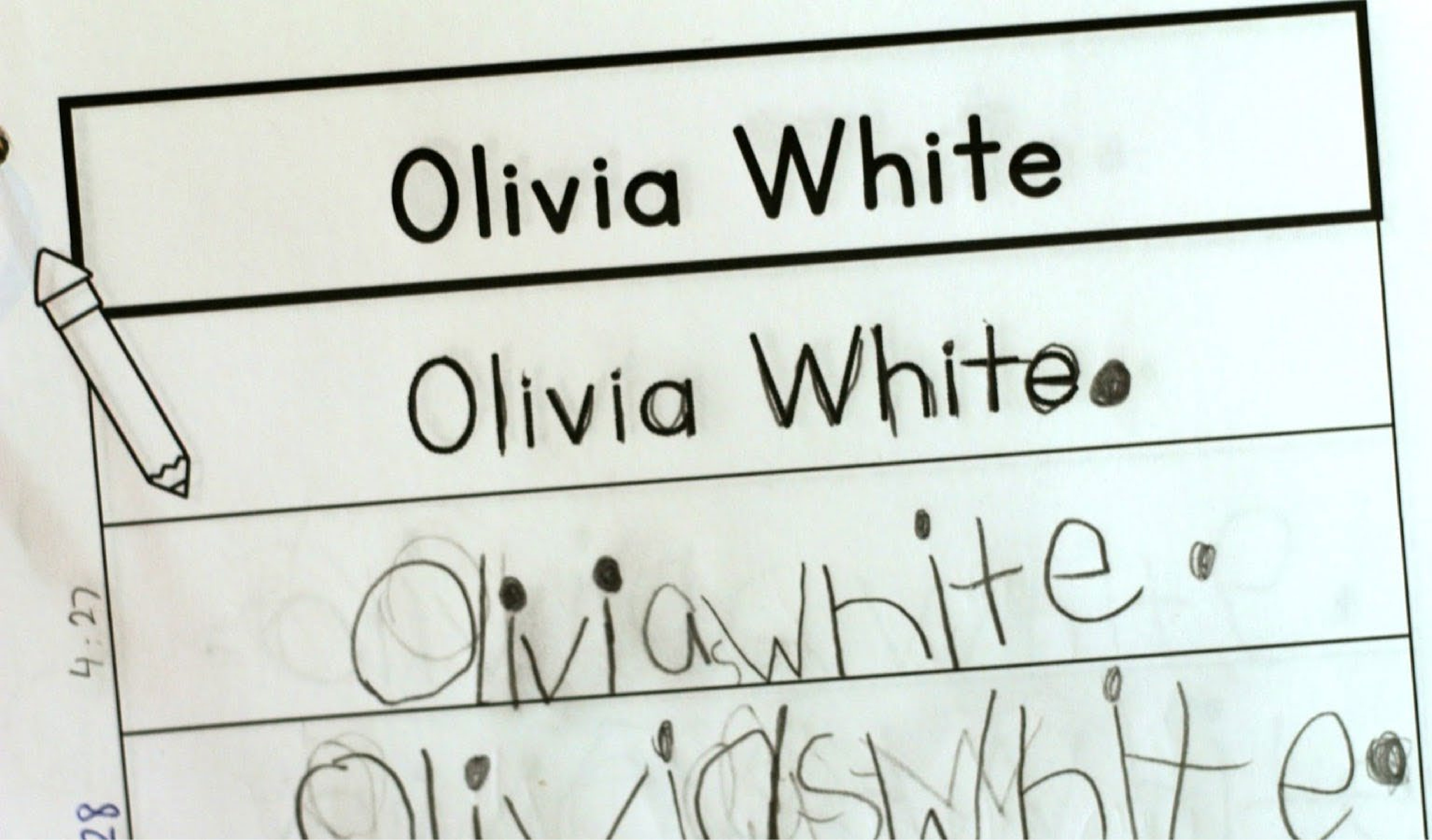
(a) Target 3D model

Input: 3D digital model

?

(c) Sculpted physical replica

Output: 3D clay model



Olivia White

Olivia White

4:27 oliviaswhite

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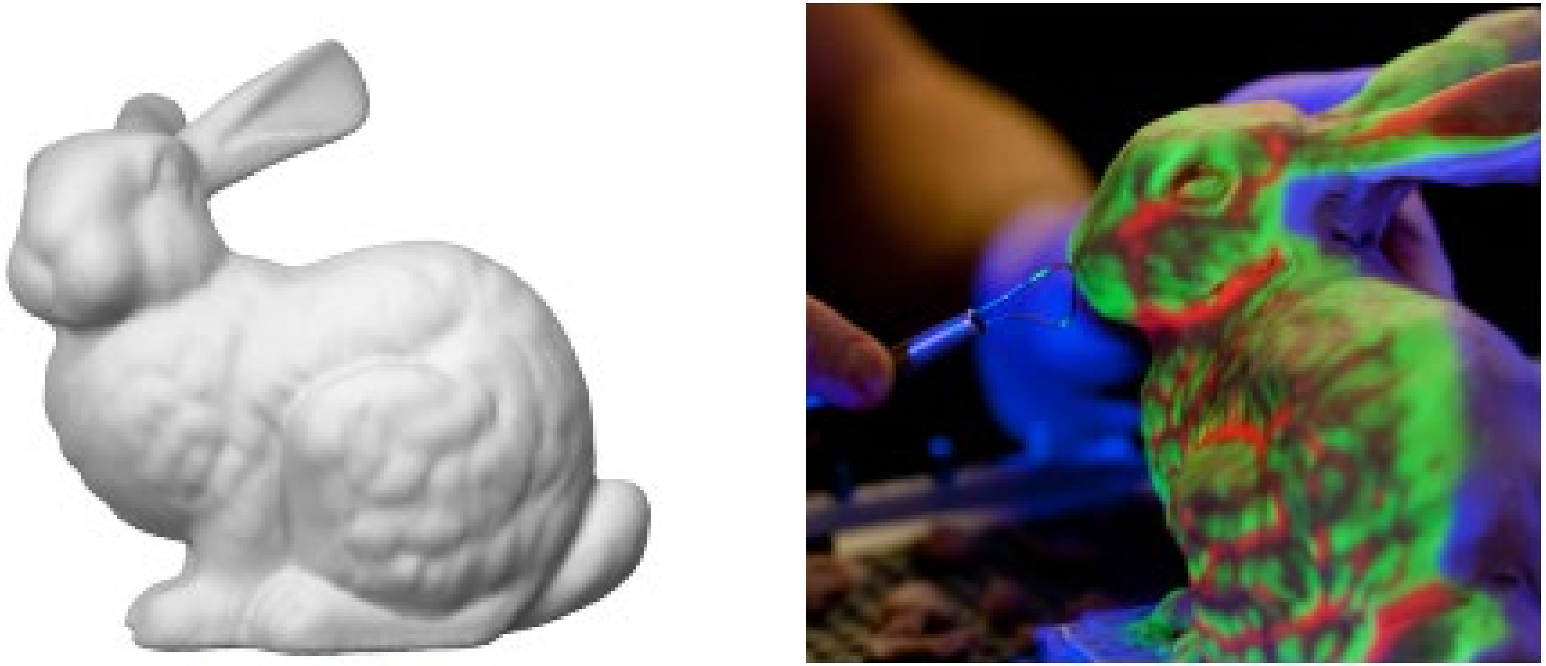
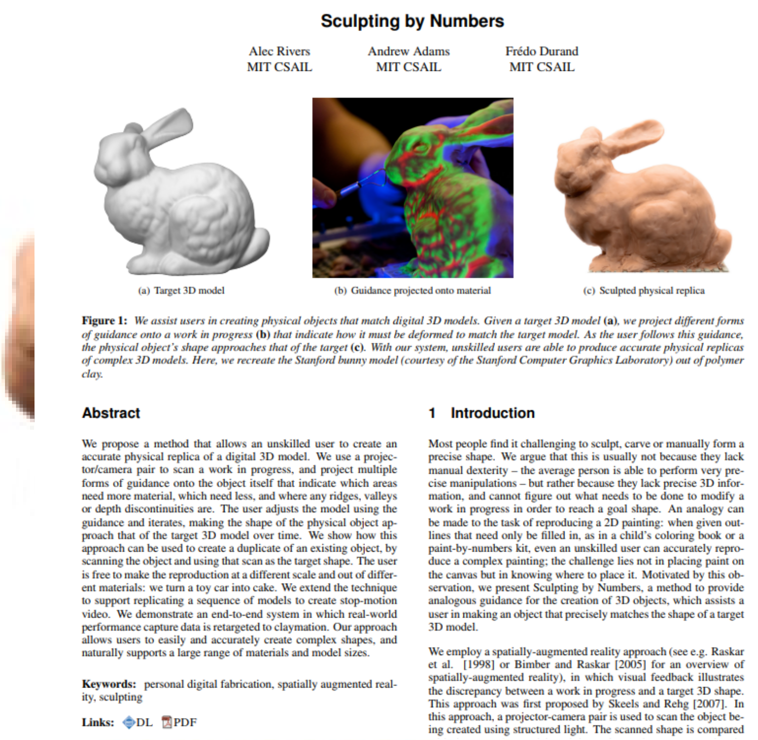


(a) Target 3D model

(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

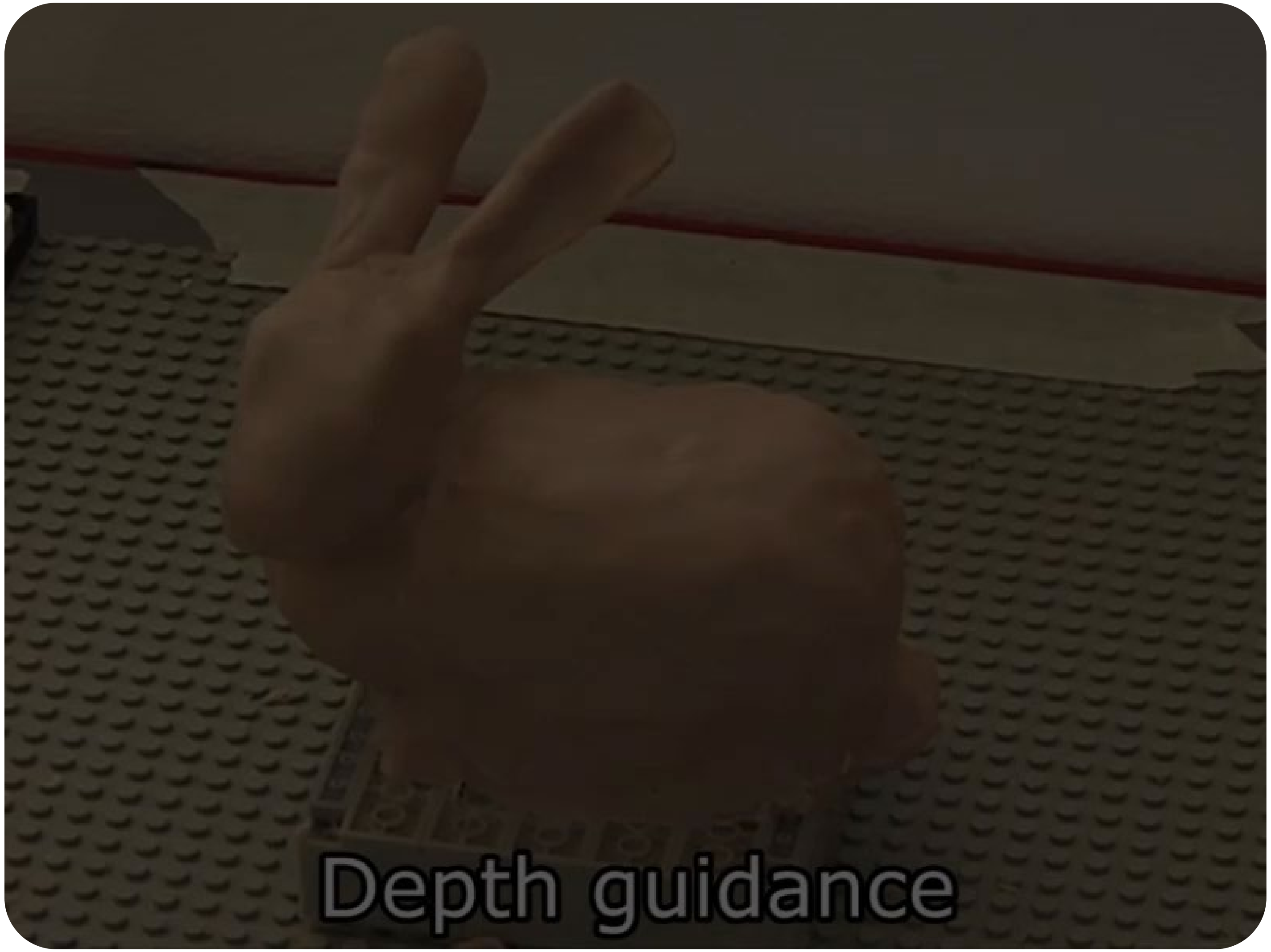
(c) Sculpted physical replica

Rivers et.al. from MIT
2012

Structured light 3D scanning

Compare the scanning result with the 3D digital model

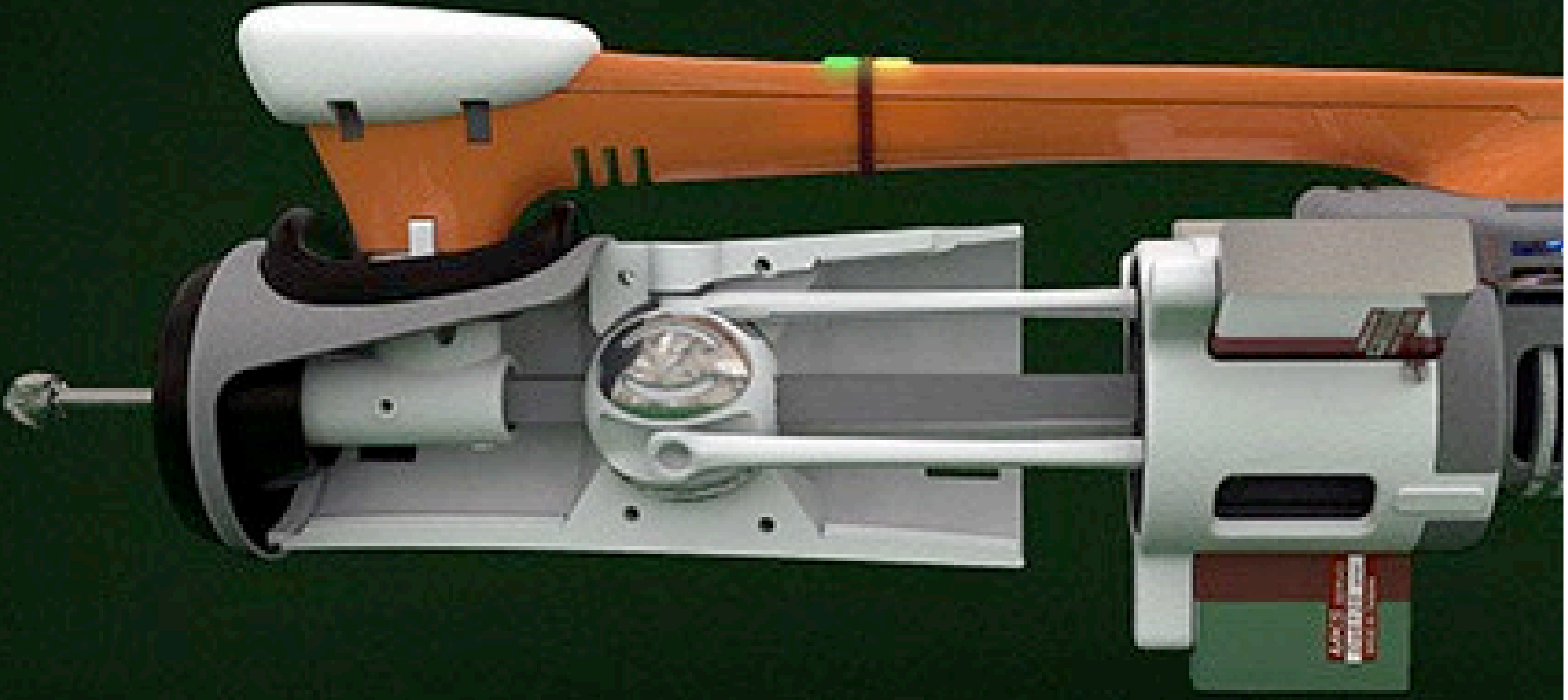
Differences are projected at each step with green/red colors



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.

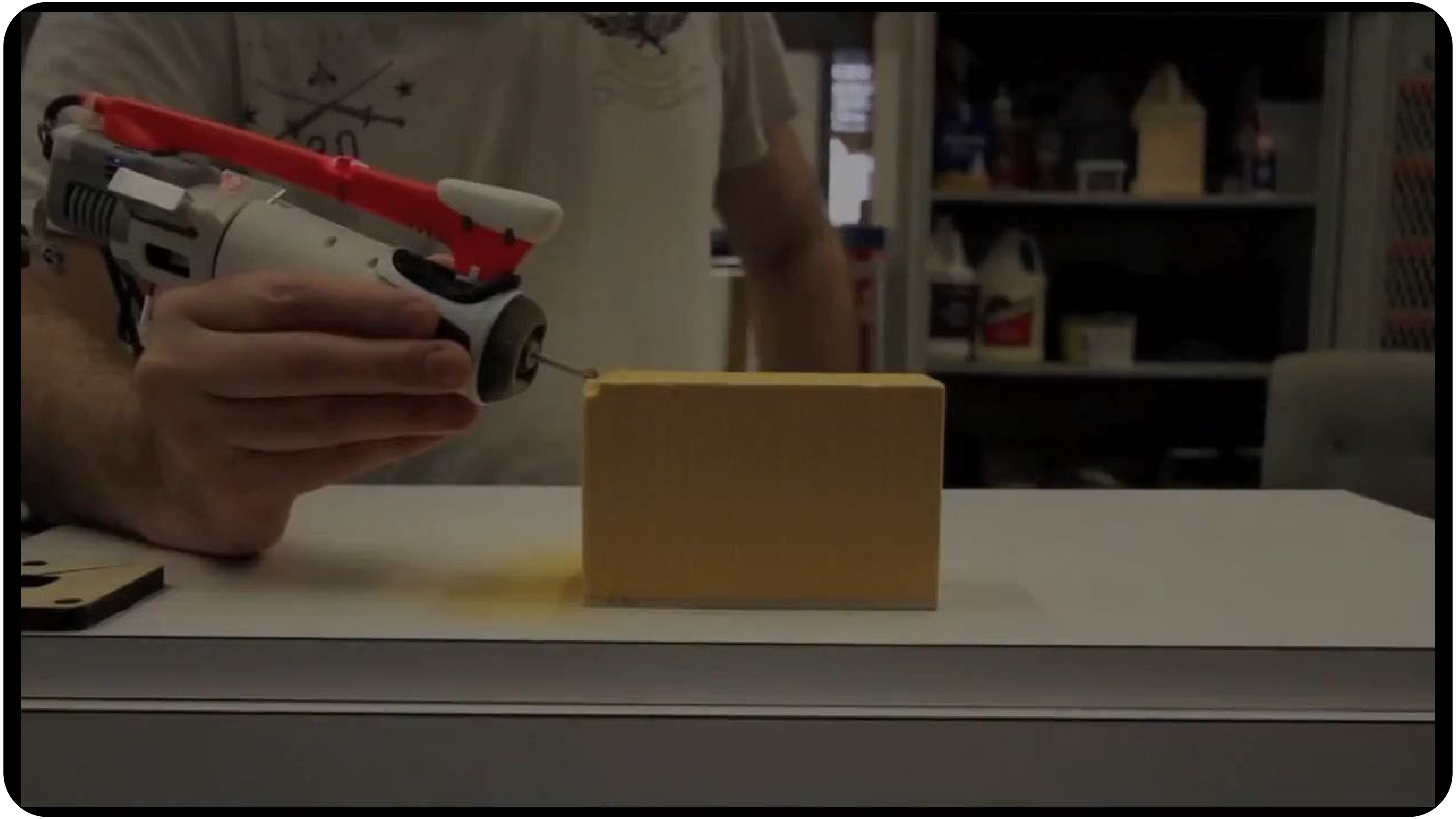
While the process of engineering minimizes risks, seeks efficiency, and enables automation and repetition, craft is about involvment and engagement, uniqueness of the final products, and authenticity of the experience [7]. Engaging in an intimate fabrication process and enjoying the experience of shaping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

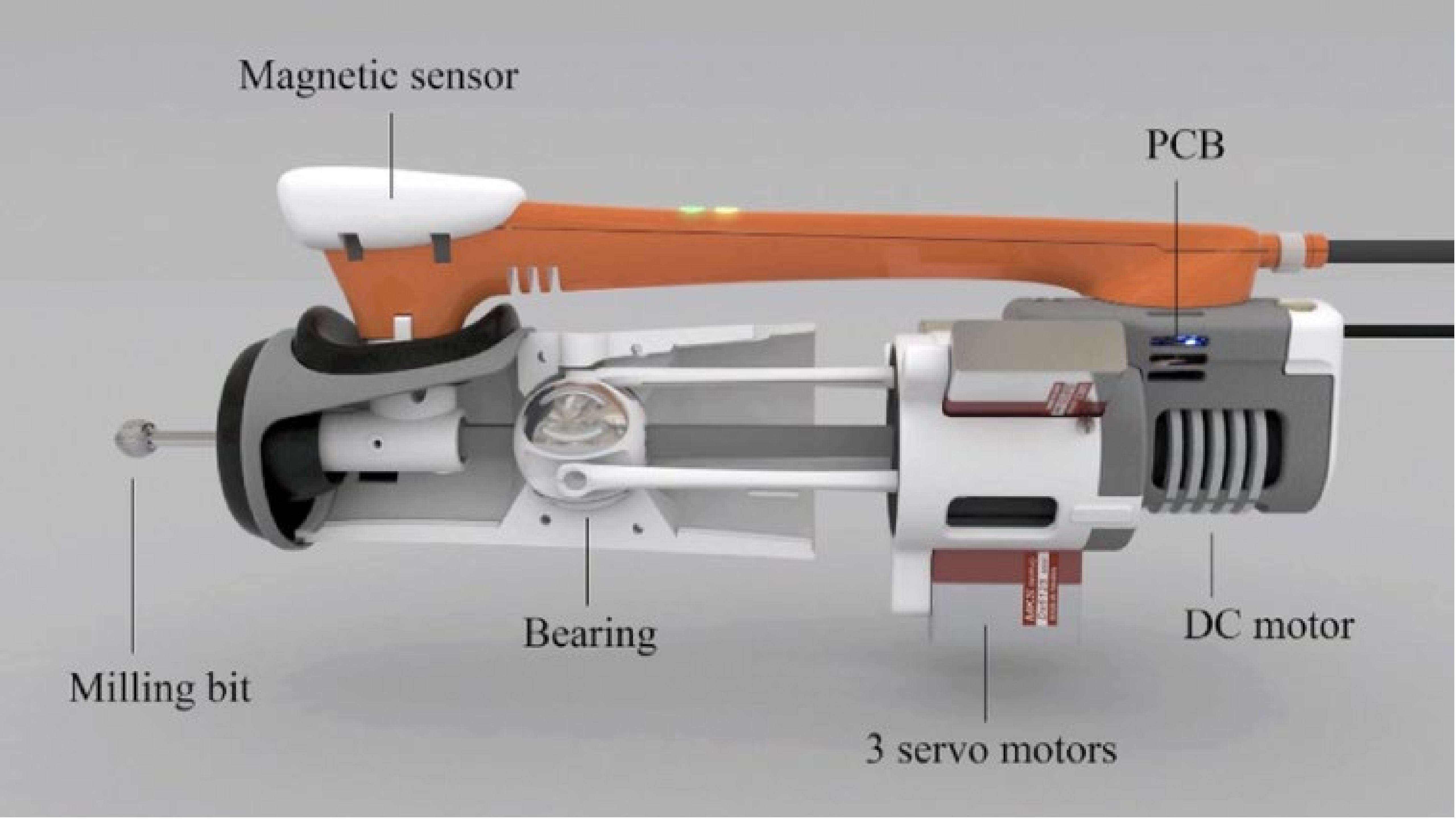
Our research interest lies in the cross-section between digital fabrication and the study of the craft experience. We wish to allow designers to engage with the physical material, not only the CAD environment. We hope to encourage the exploration of an intimate digital fabrication approach, introducing 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

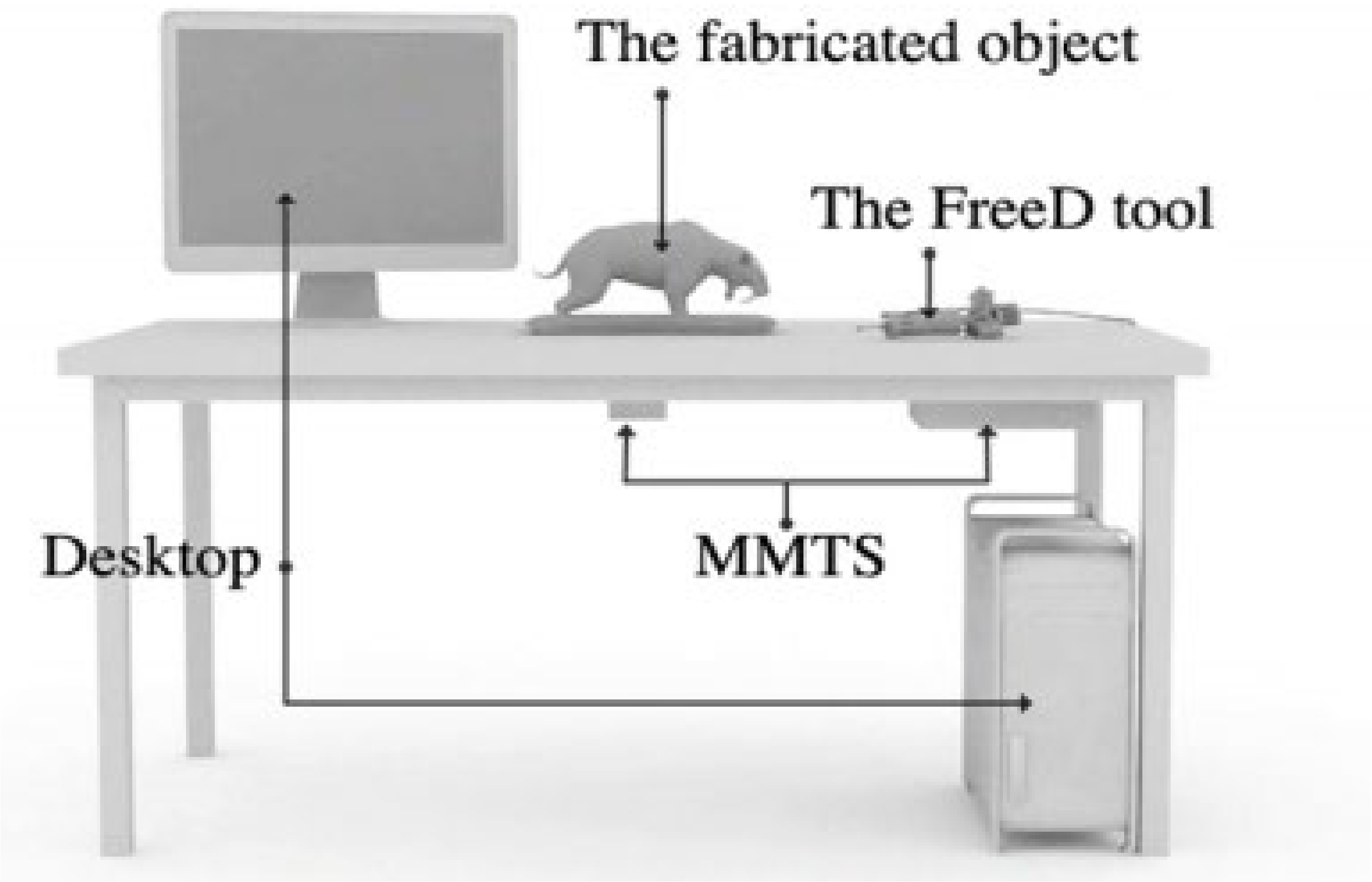



Magnetic sensor
PCB
Milling bit
Bearing
3 servo motors
DC motor

Tracking: 6DOF Magnetic tracking

Control: stop milling at the edge of the digital model

Control can be overridden with manual control

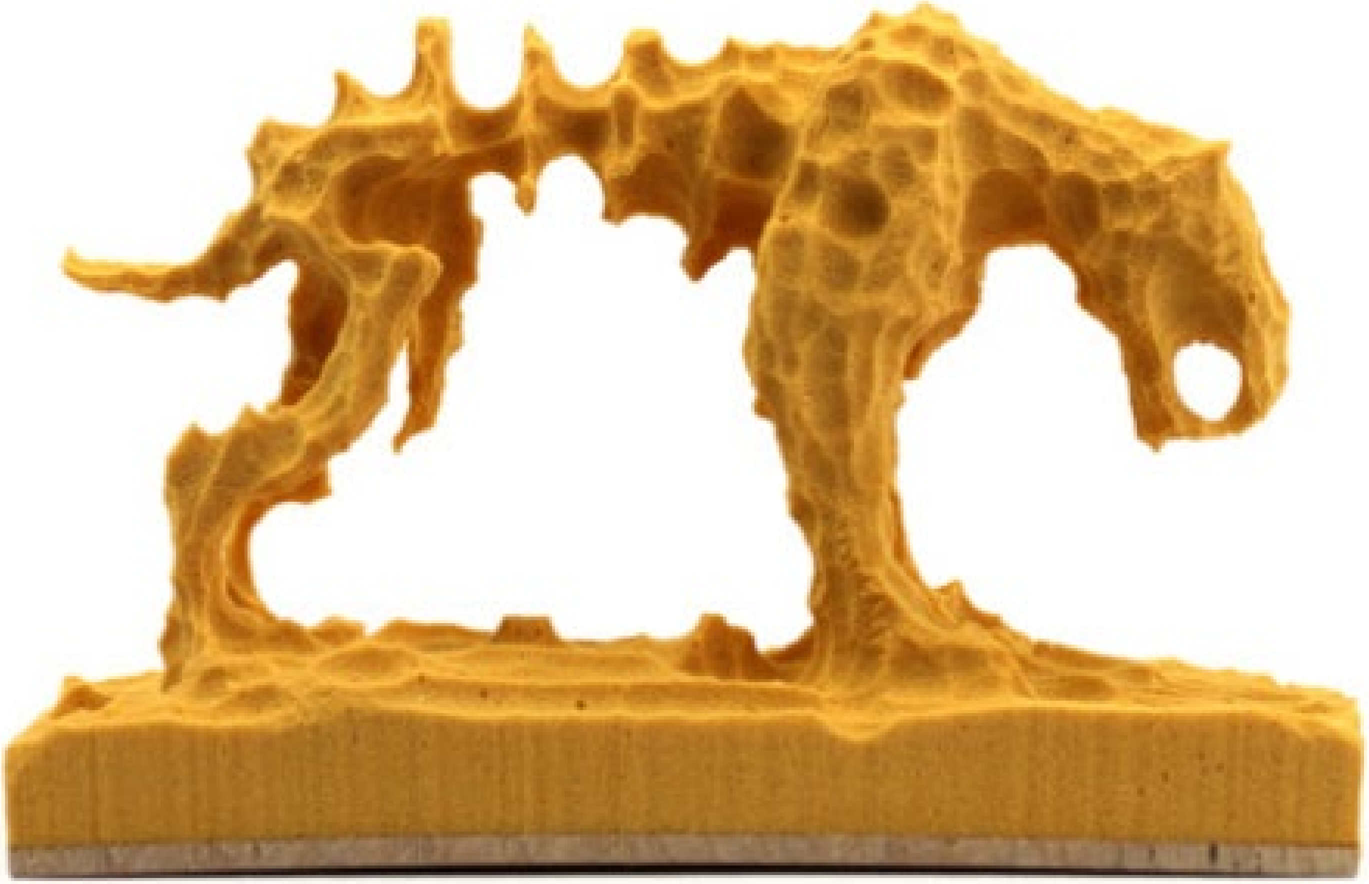


What can this do that the previous project cannot?


(a)

(b)

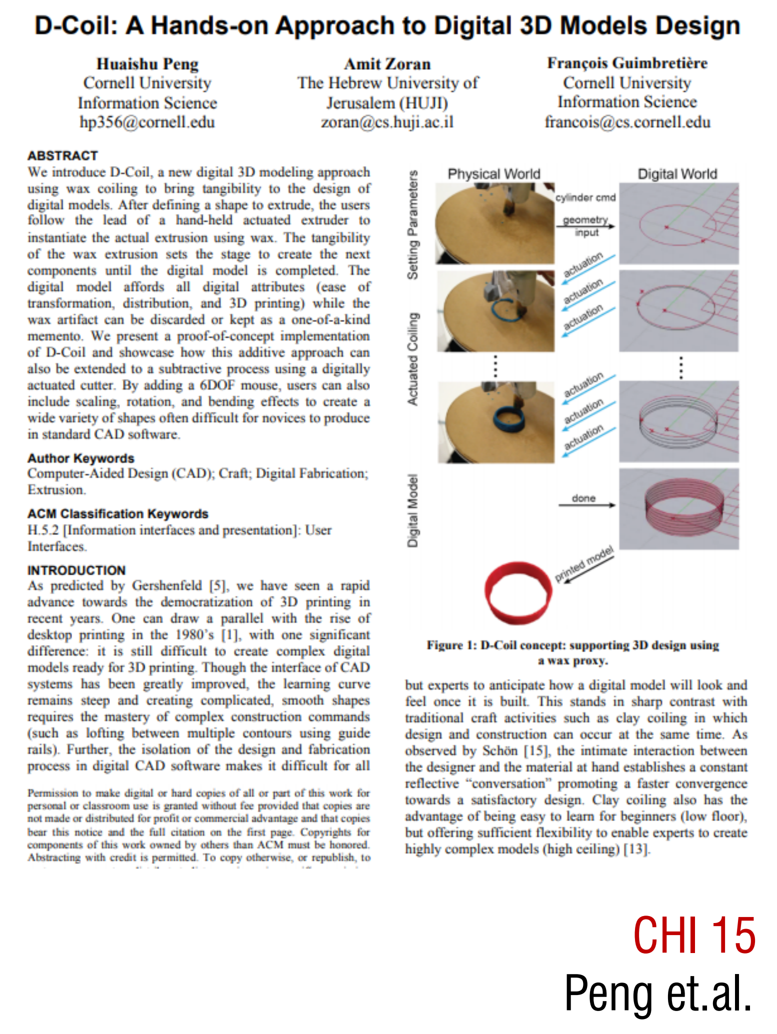
Manual override



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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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

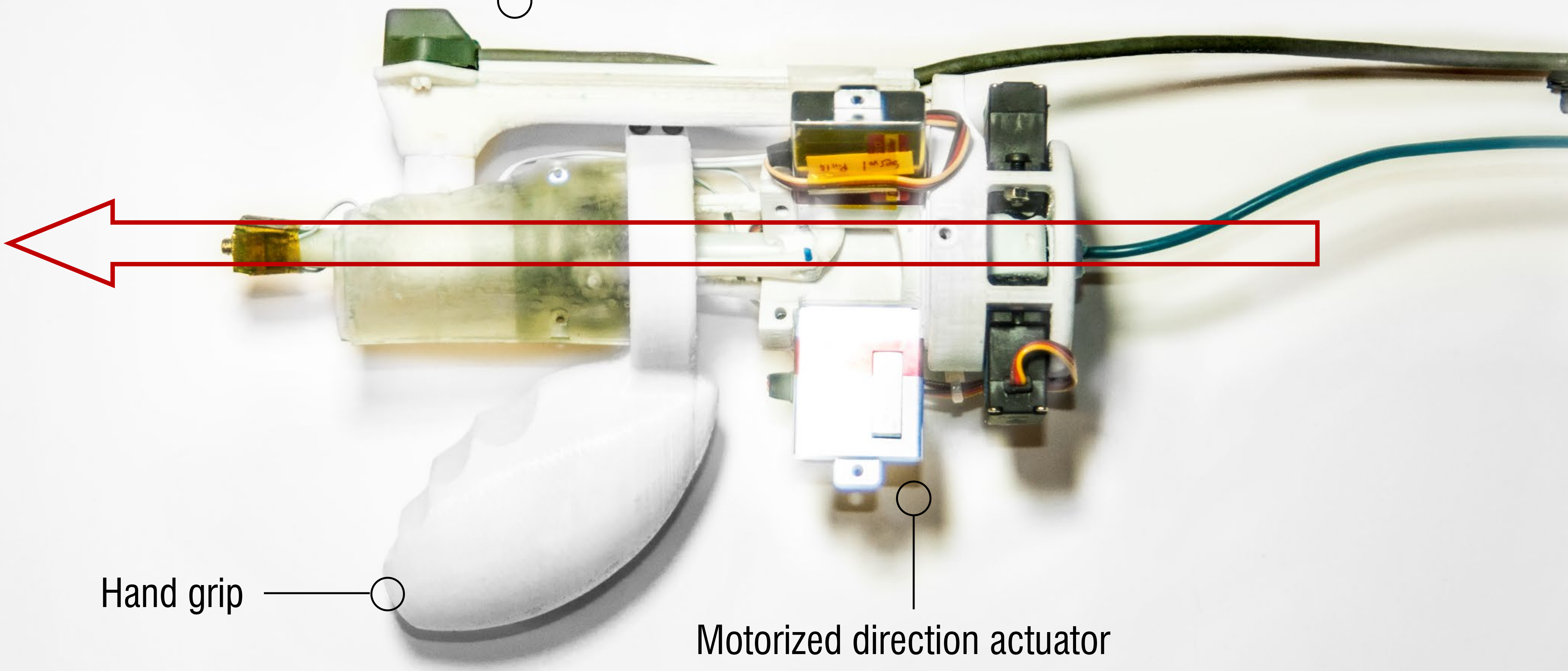
H.5.2 [Information interfaces and presentation]: User Interfaces.

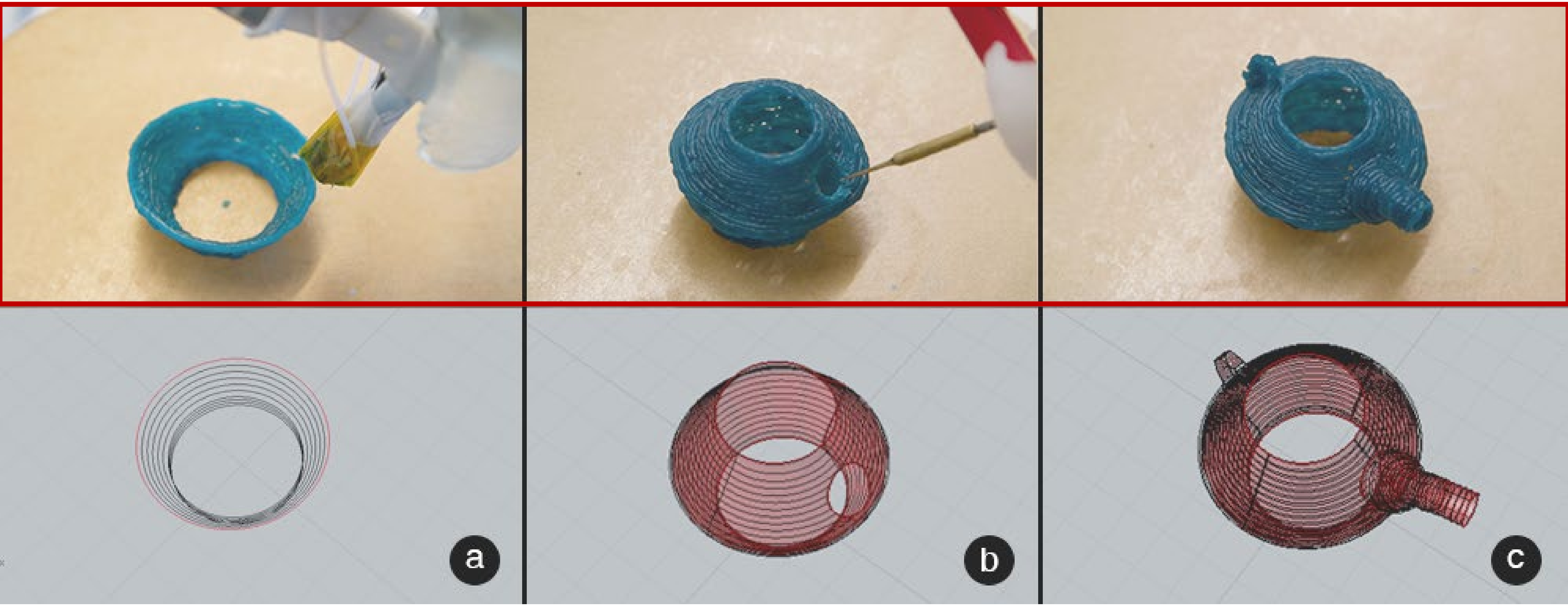
INTRODUCTION

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 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].

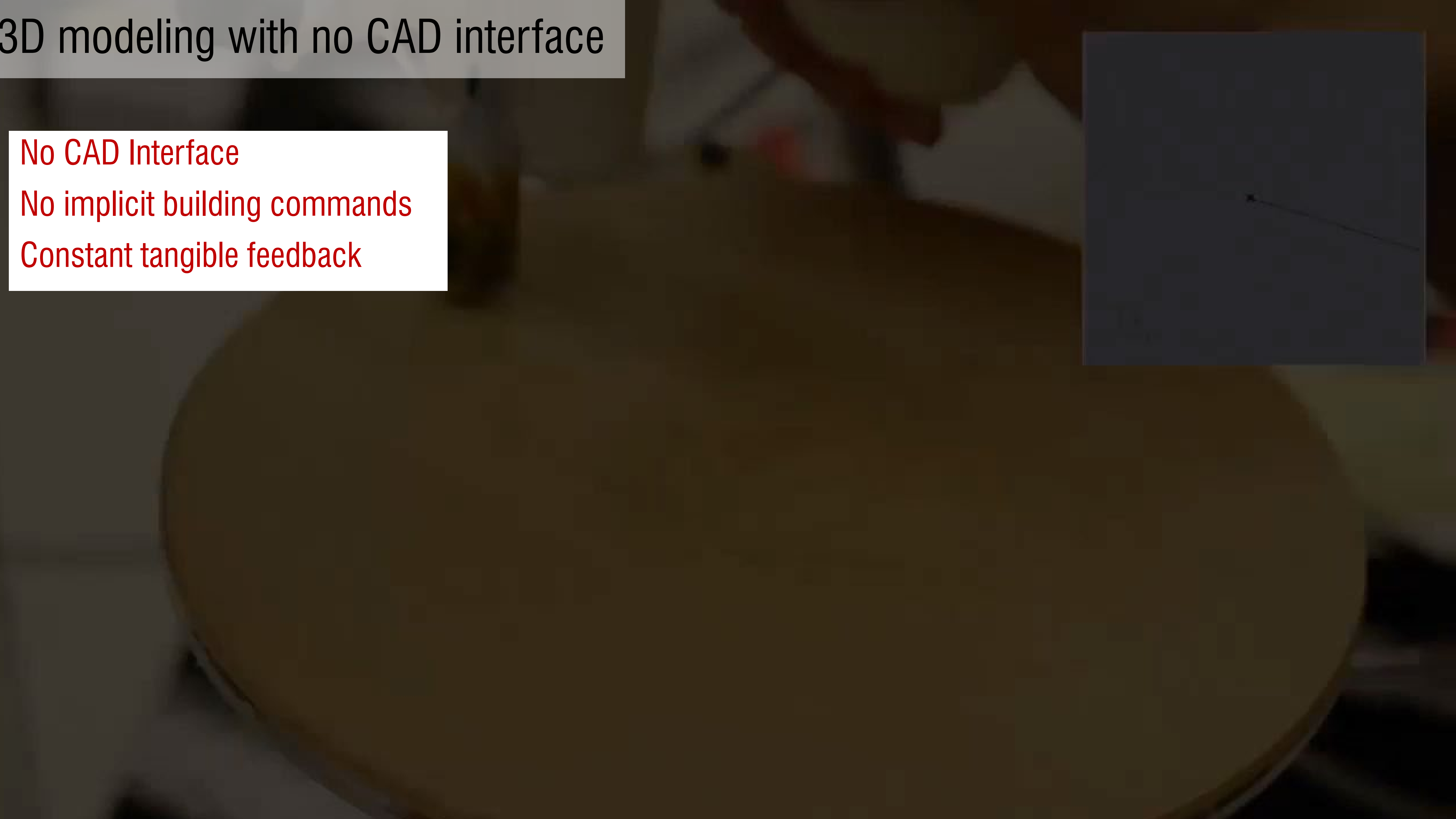
Figure 1: D-Coil concept: supporting 3D design using a wax proxy.

CHI 15
Peng et.al.


Magnetic tracker
Hand grip
Motorized direction actuator


a
b
c

3D modeling with no CAD interface

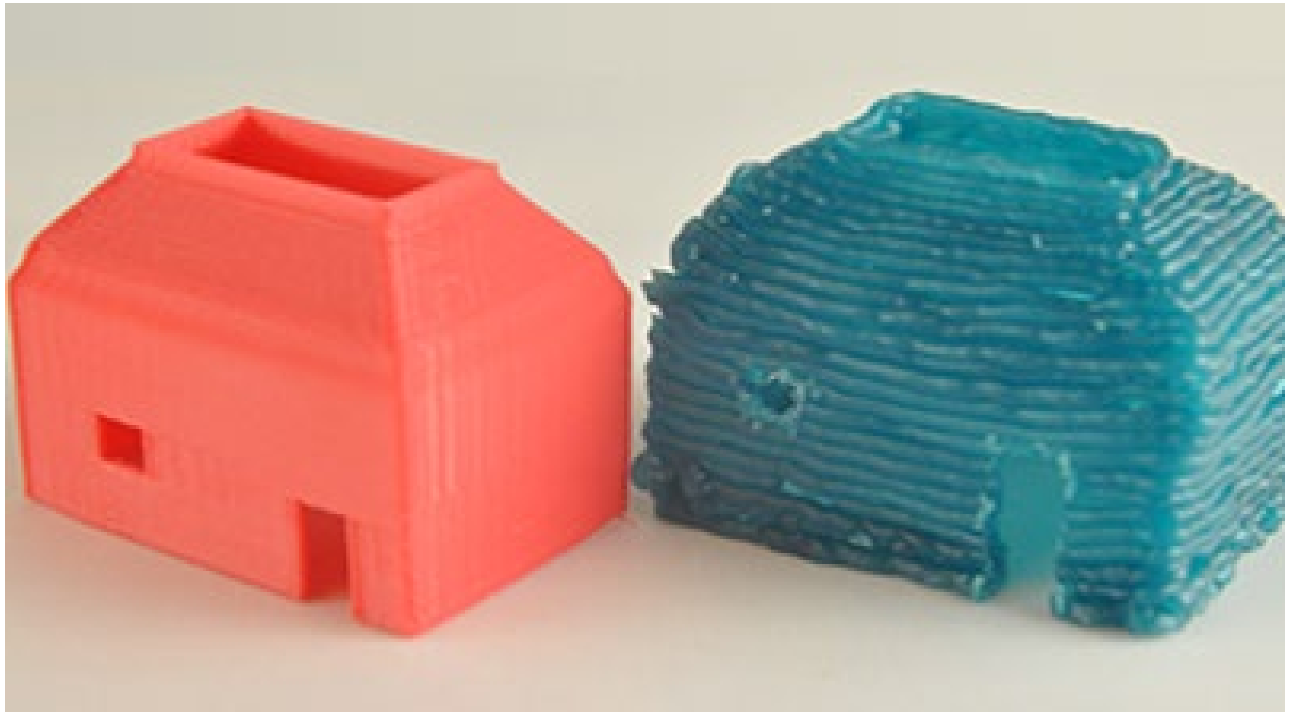


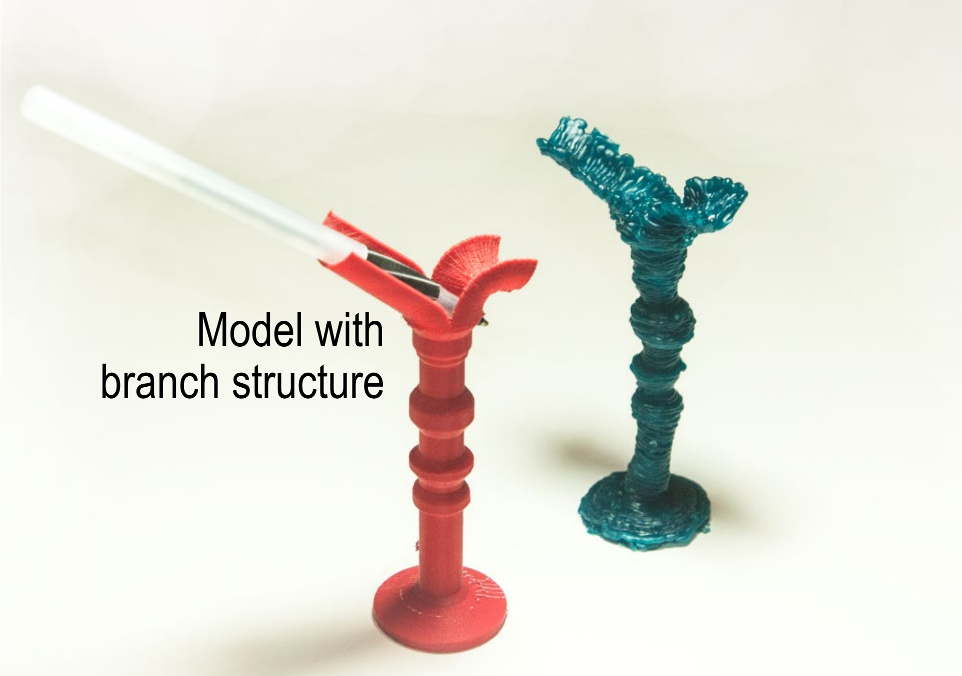
No CAD Interface

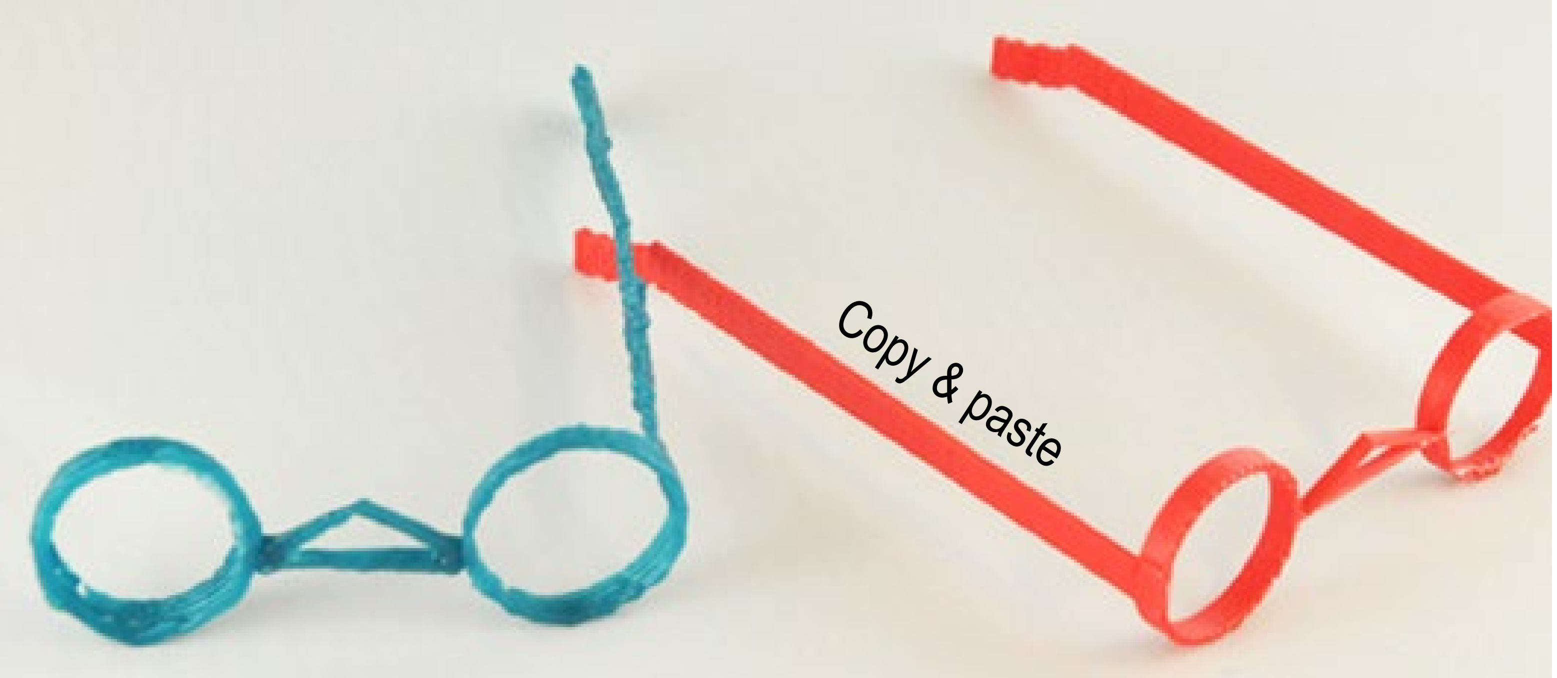
No implicit building commands

Constant tangible feedback


Compound model




Model with
branch structure

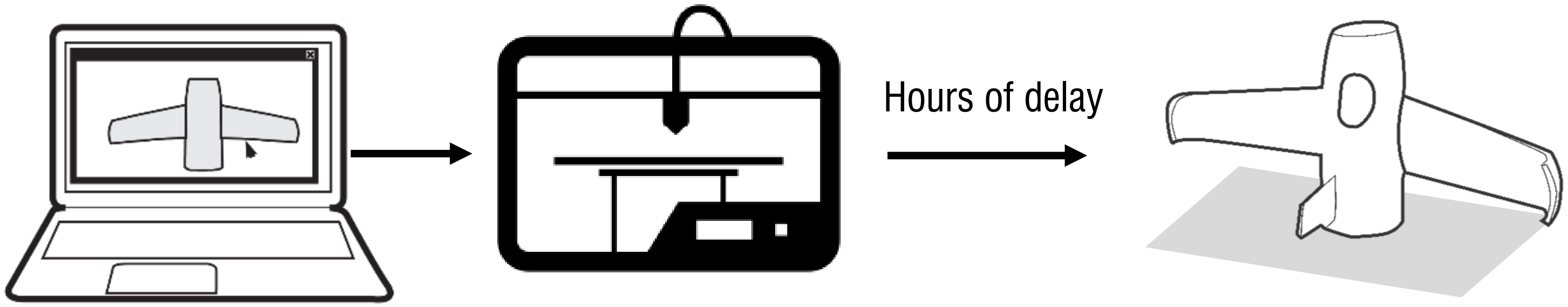

Copy & paste

D-Coil

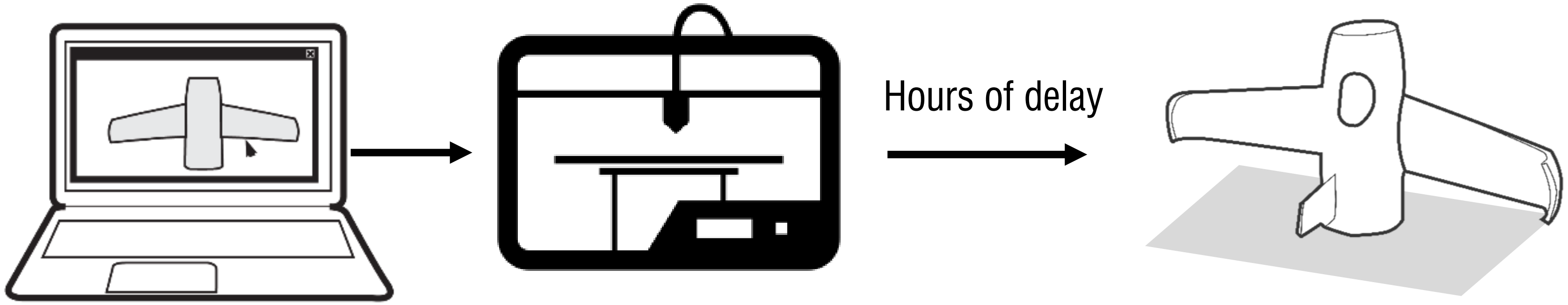
No CAD interface
Digitalization

Slow in building speed
Not for CAD users

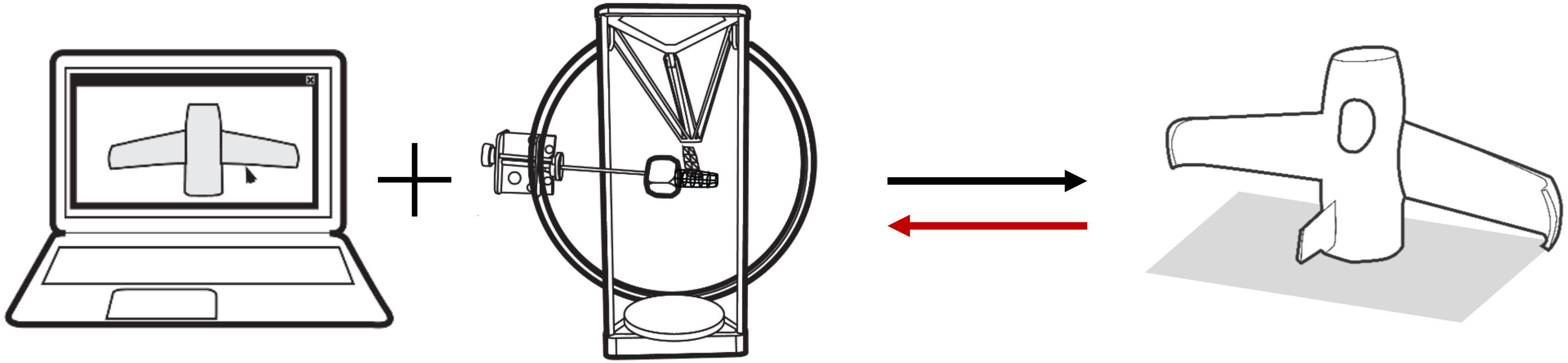
What if we can have a system **for CAD users**
but with timely **physical feedback**?

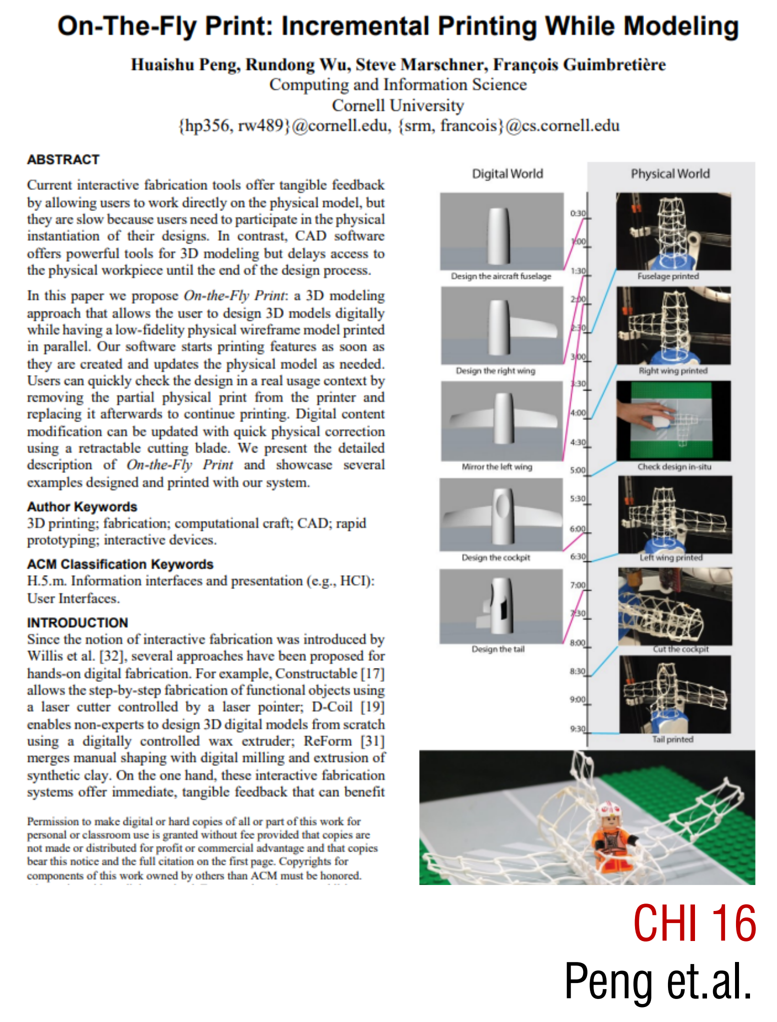


Hours of delay



Hours of delay





On-The-Fly Print: Incremental Printing While Modeling

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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

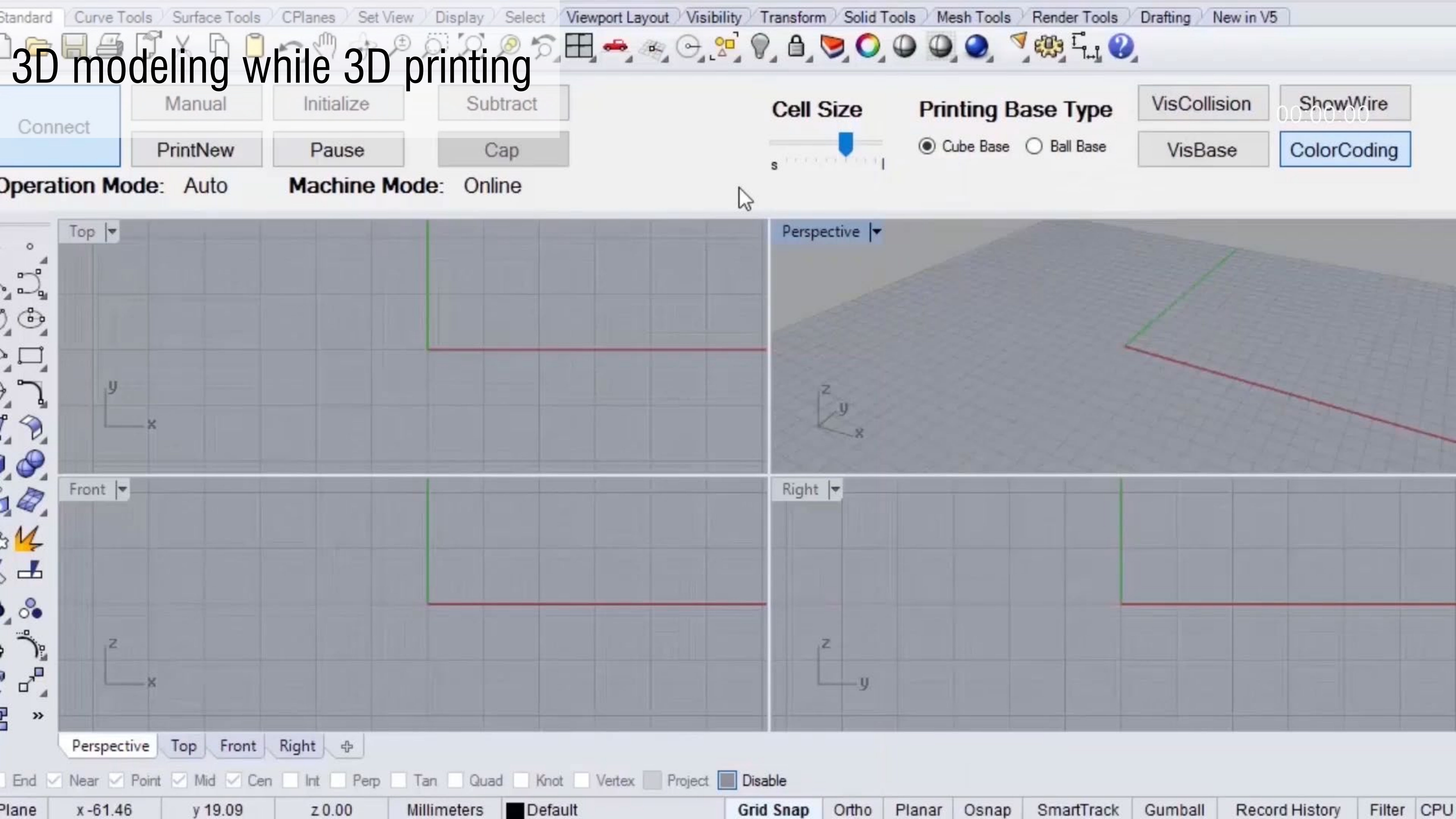
H.5.m. Information interfaces and presentation (e.g., HCI): User Interfaces.

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



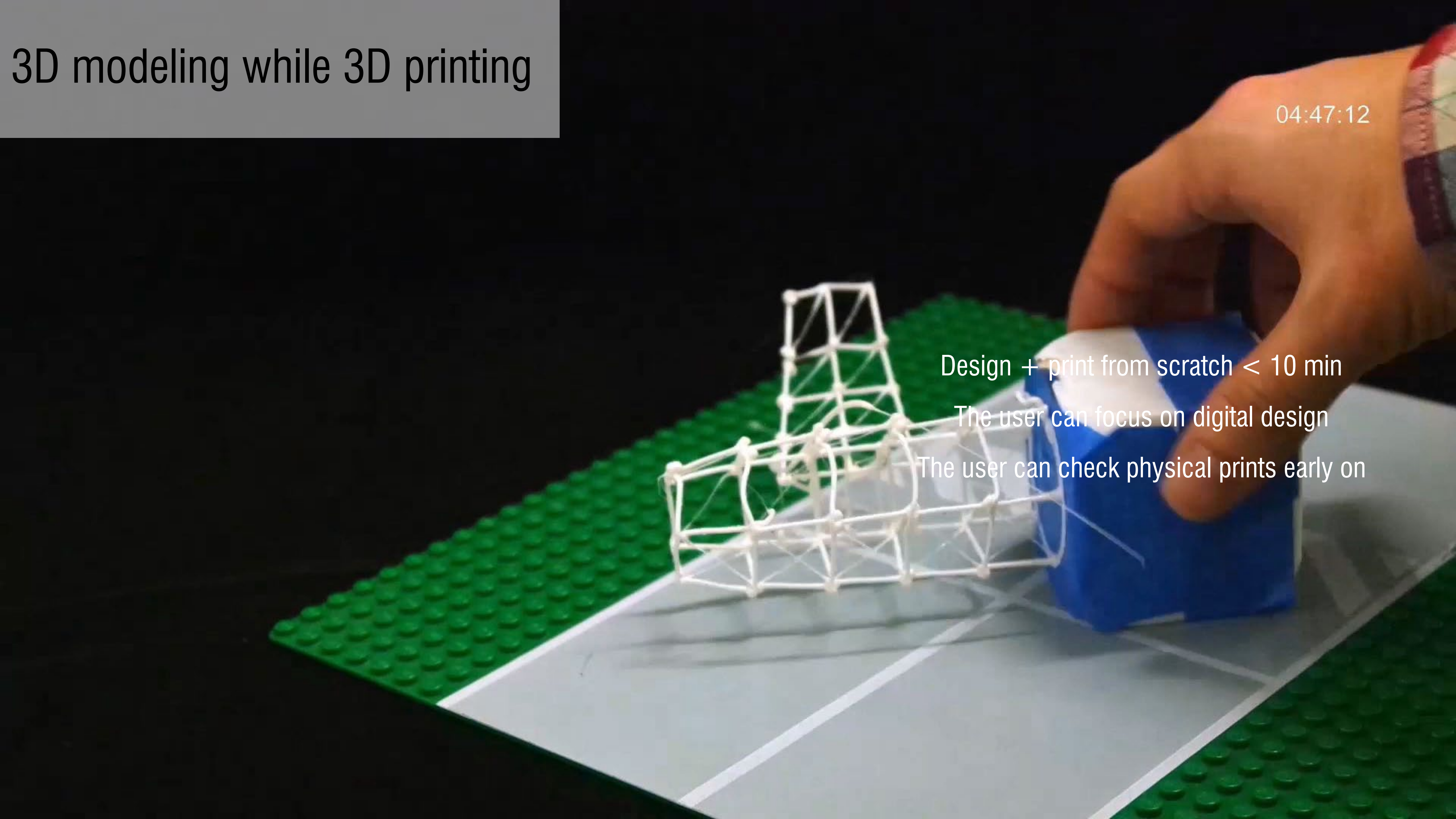
Operation Mode: Auto

Machine Mode: Online

Printing Base Type
● Cube Base ○ Ball Base

x -61.46 y 19.09 z 0.00 Millimeters

3D modeling while 3D printing



Design + print from scratch < 10 min

The user can focus on digital design

The user can check physical prints early on

To support design and fab **in parallel**

our machine should be able to

print fast
print incrementally
make subtractive changes

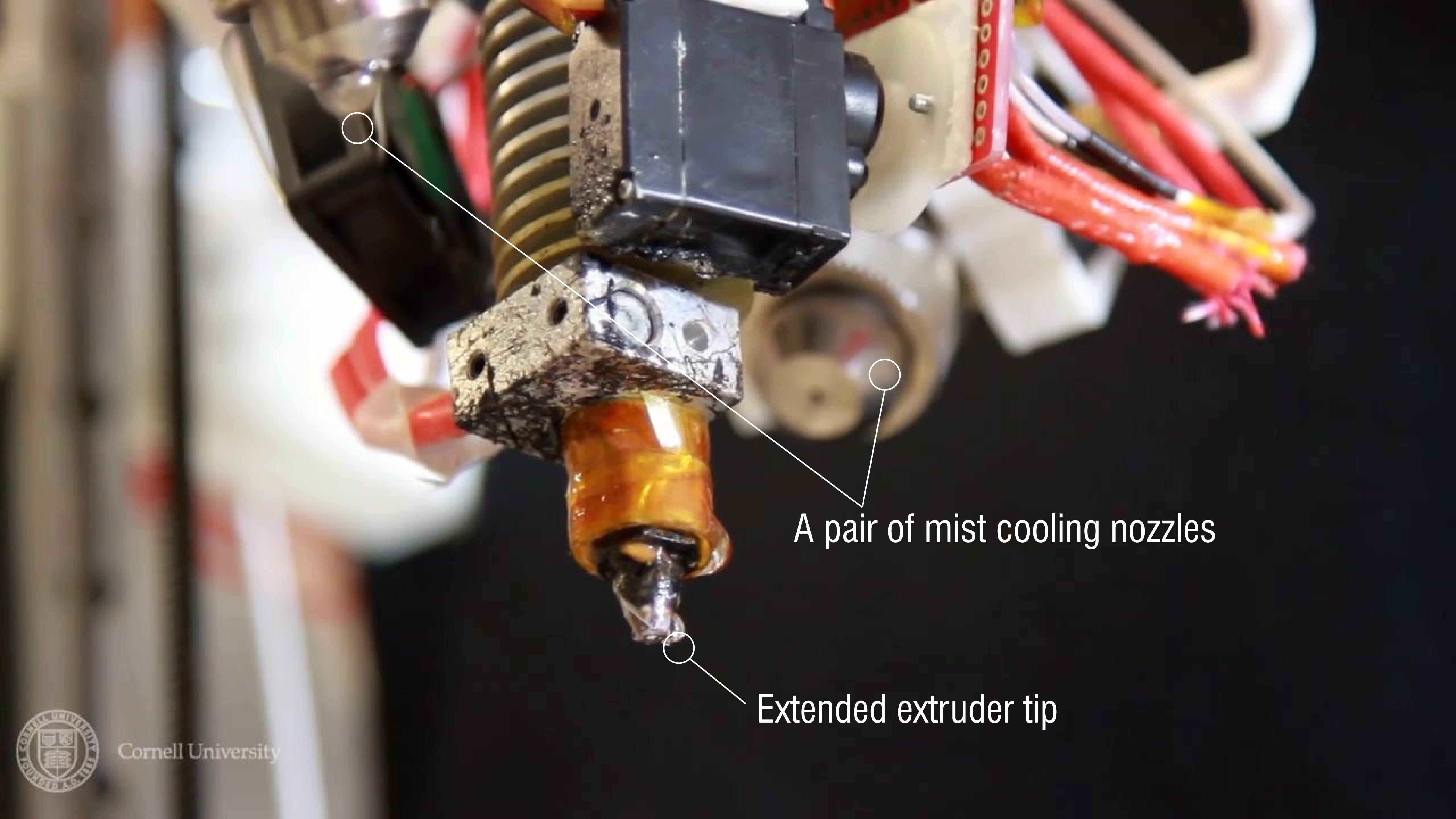
To support design and fab **in parallel**

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

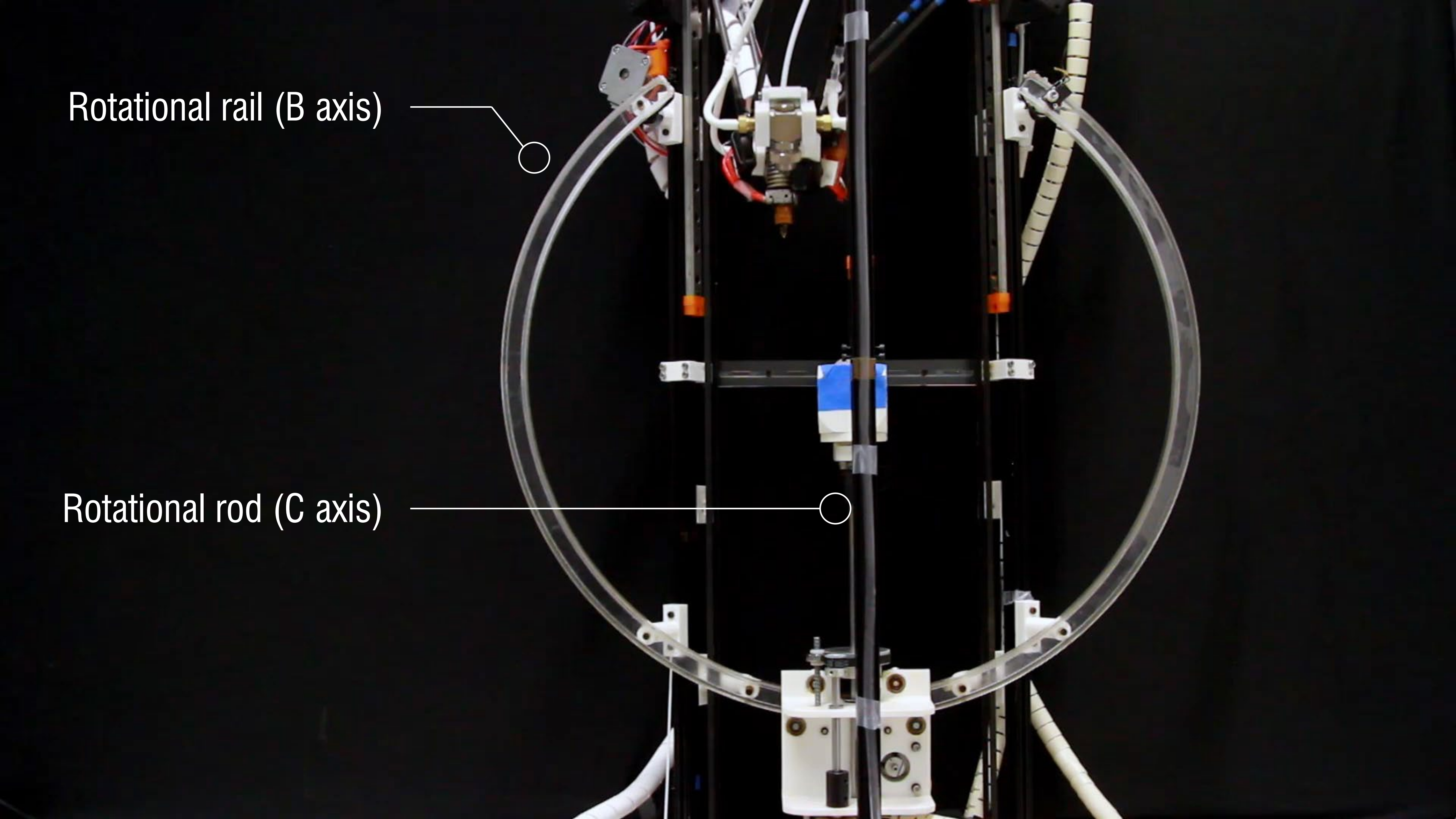
To support design and fab **in parallel**

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)

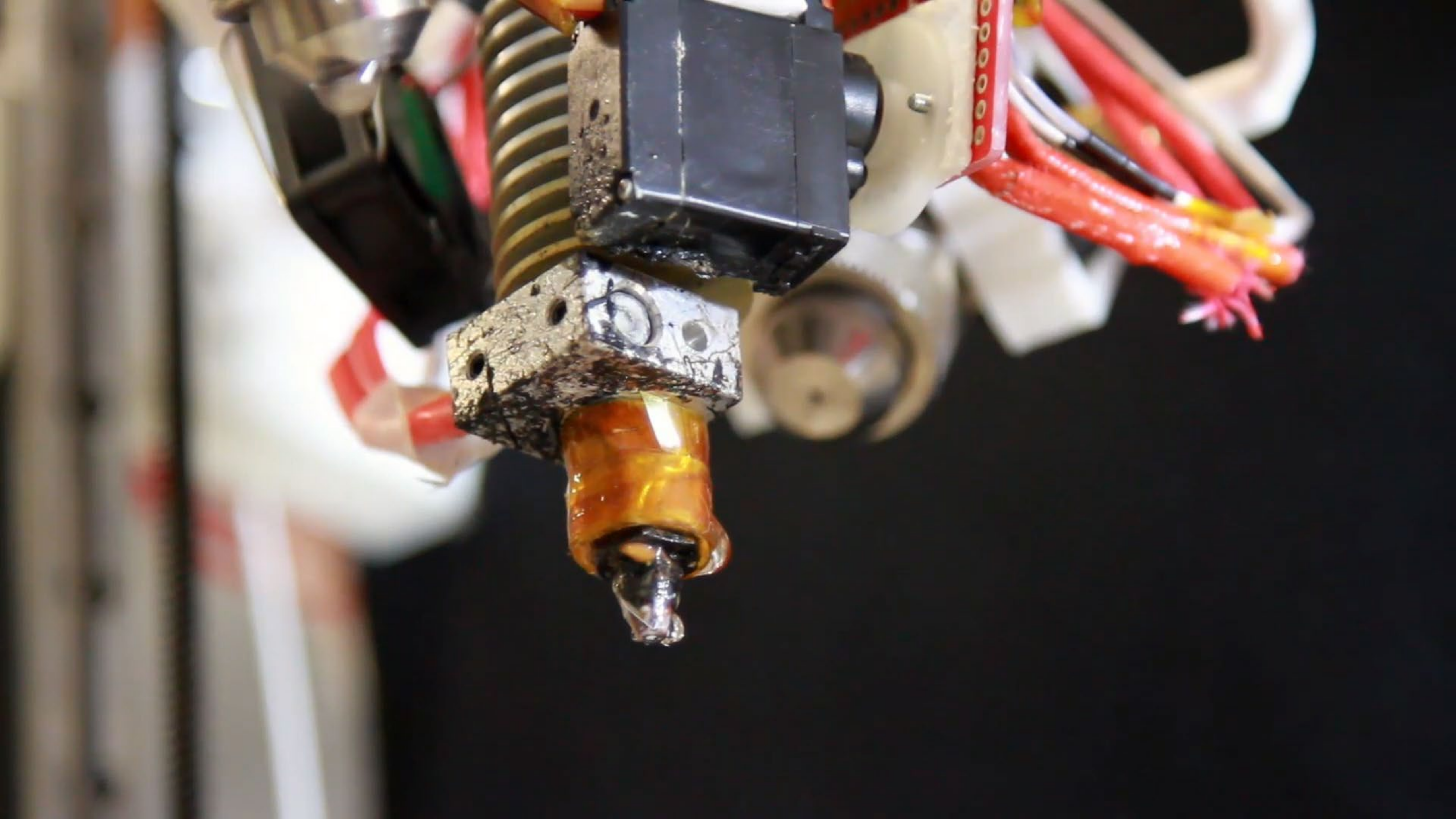
To support design and fab **in parallel**

our machine should be able to

print fast

print incrementally

make subtractive changes (to reflect digital editing)

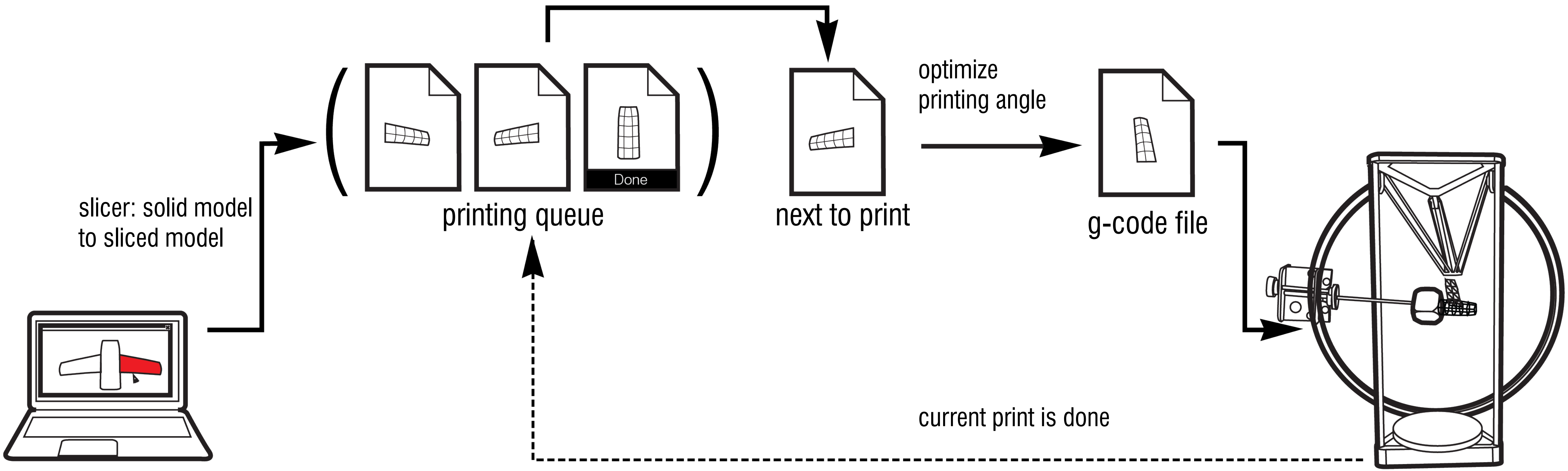


To allow the designer to focus on the design

our software should be able to

print new primitives automatically
solve potential collisions

Software Workflow



optimize printing order
Relaxing printing orientation | Out of order printing | Omitting geometries

slicer: solid model
to sliced model

printing queue

next to print

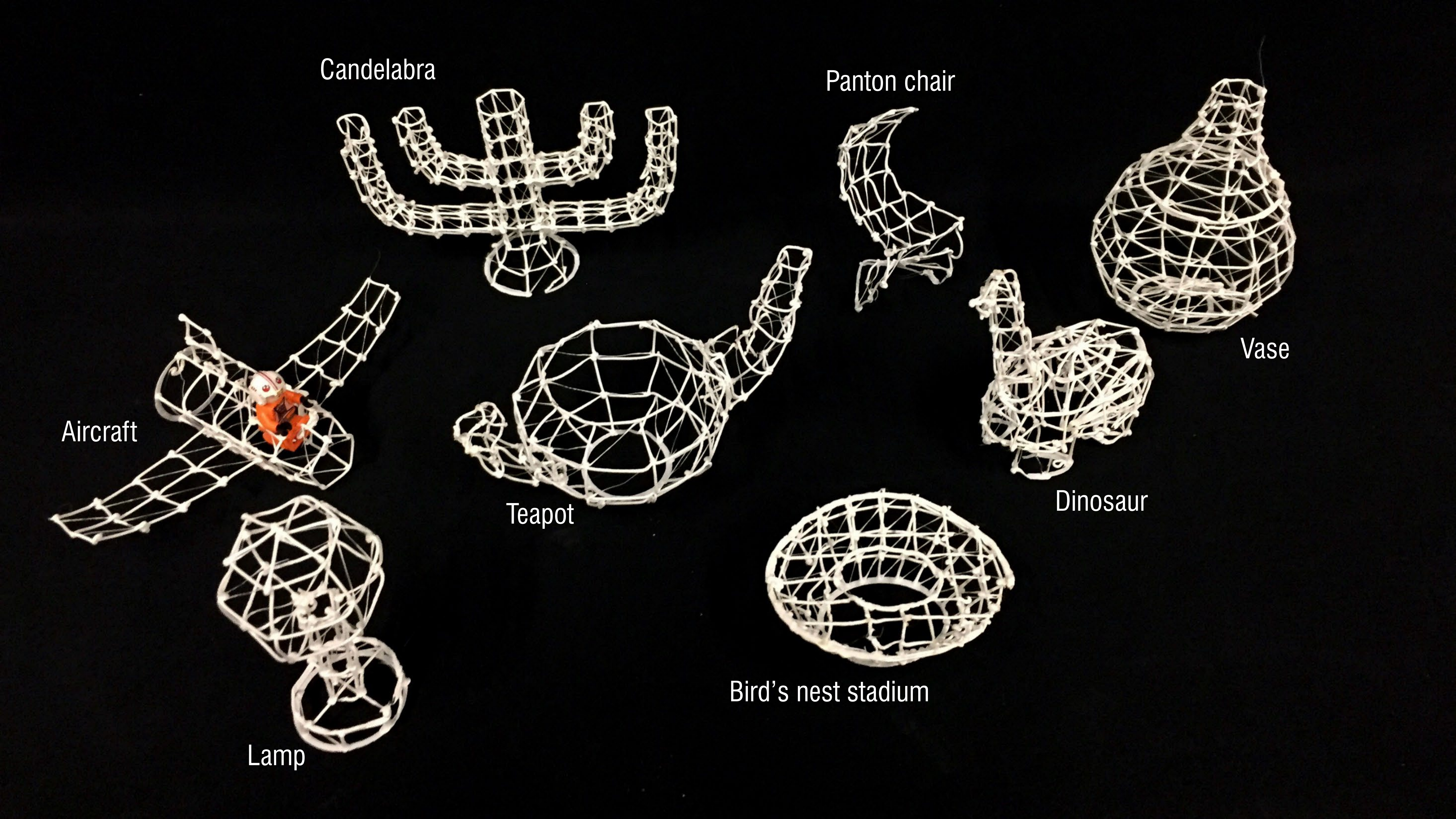
optimize
printing angle

g-code file

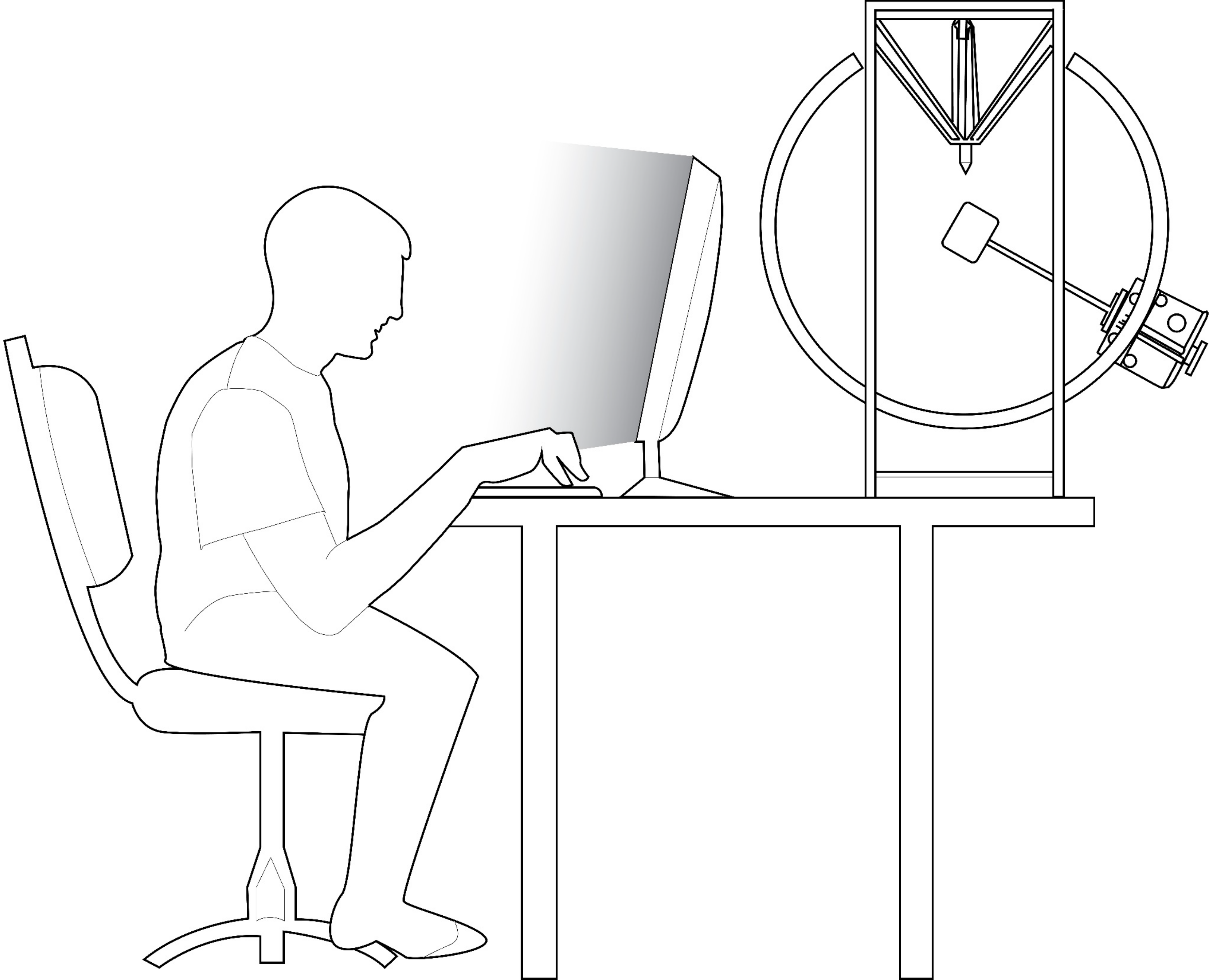
current print is done

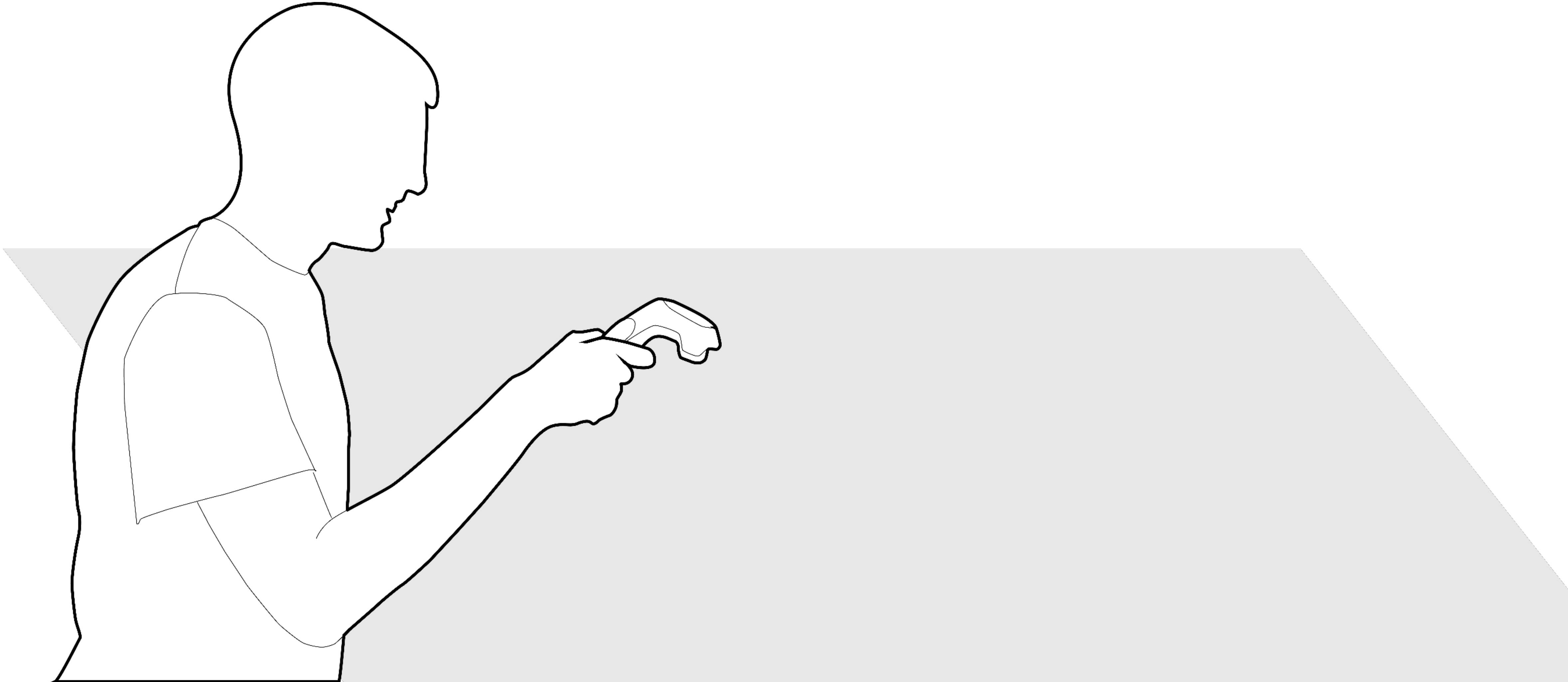
design new
primitives in CAD

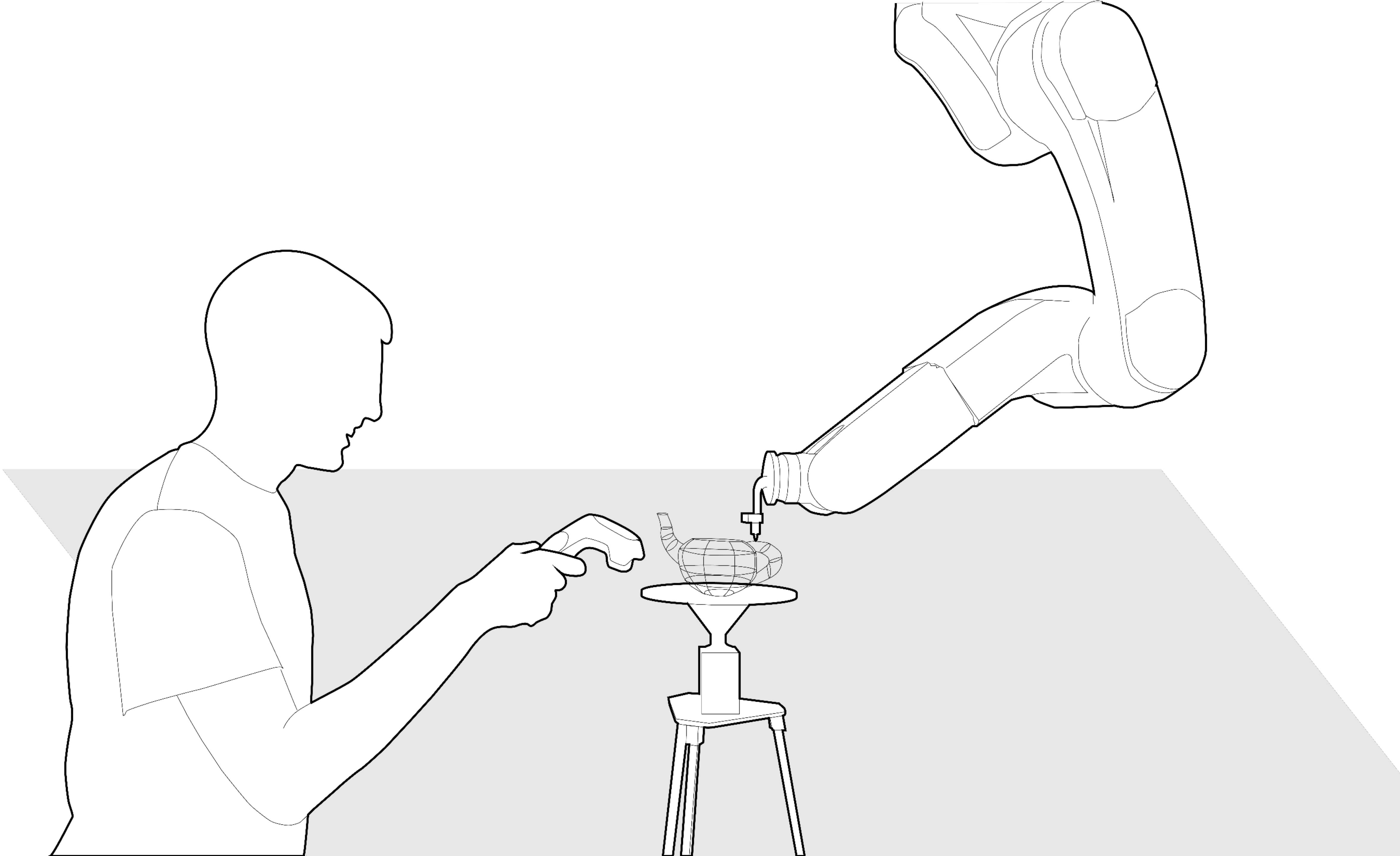
print physical
preview

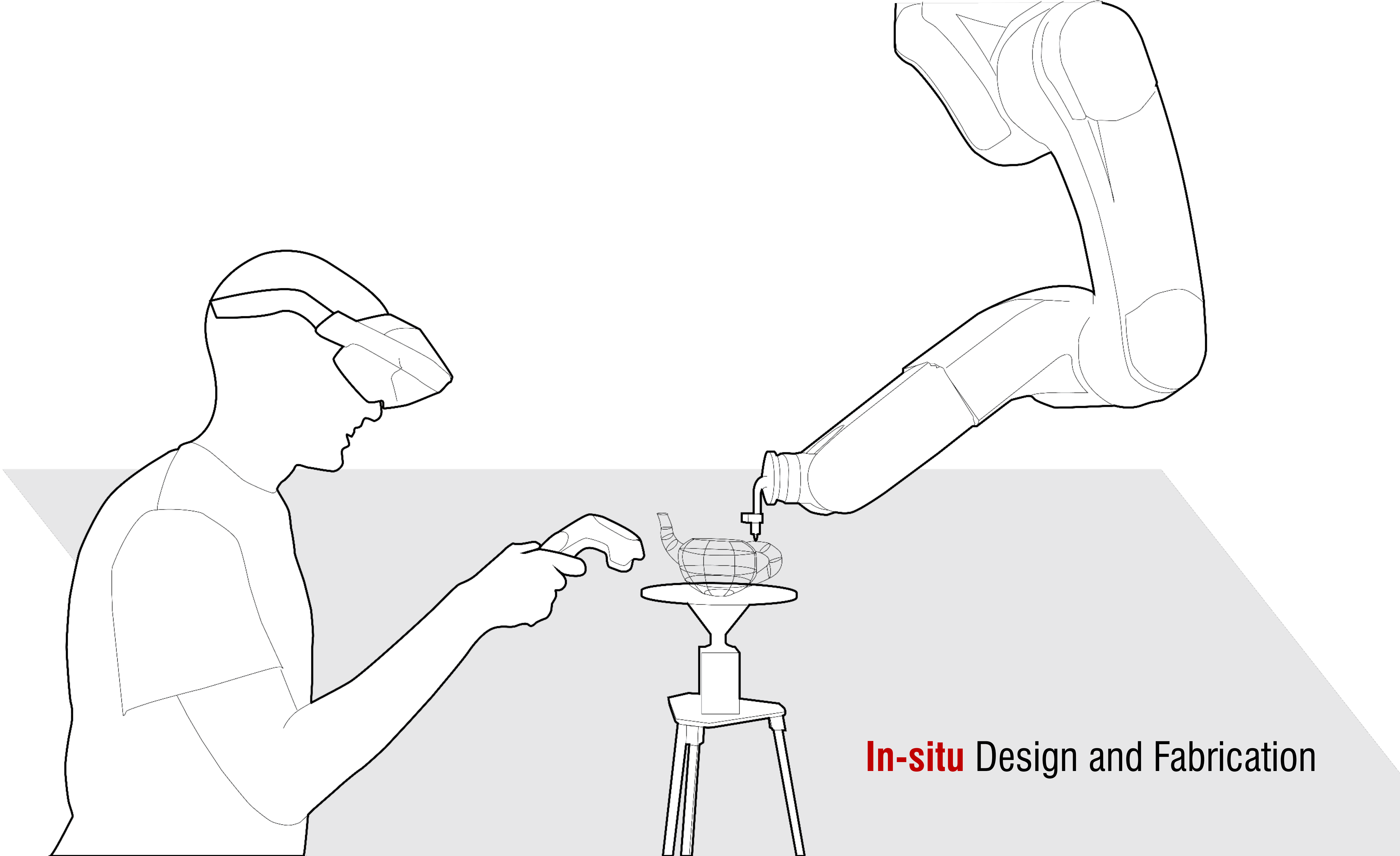


Candelabra
Panton chair
Vase
Aircraft
Teapot
Dinosaur
Bird’s nest stadium
Lamp

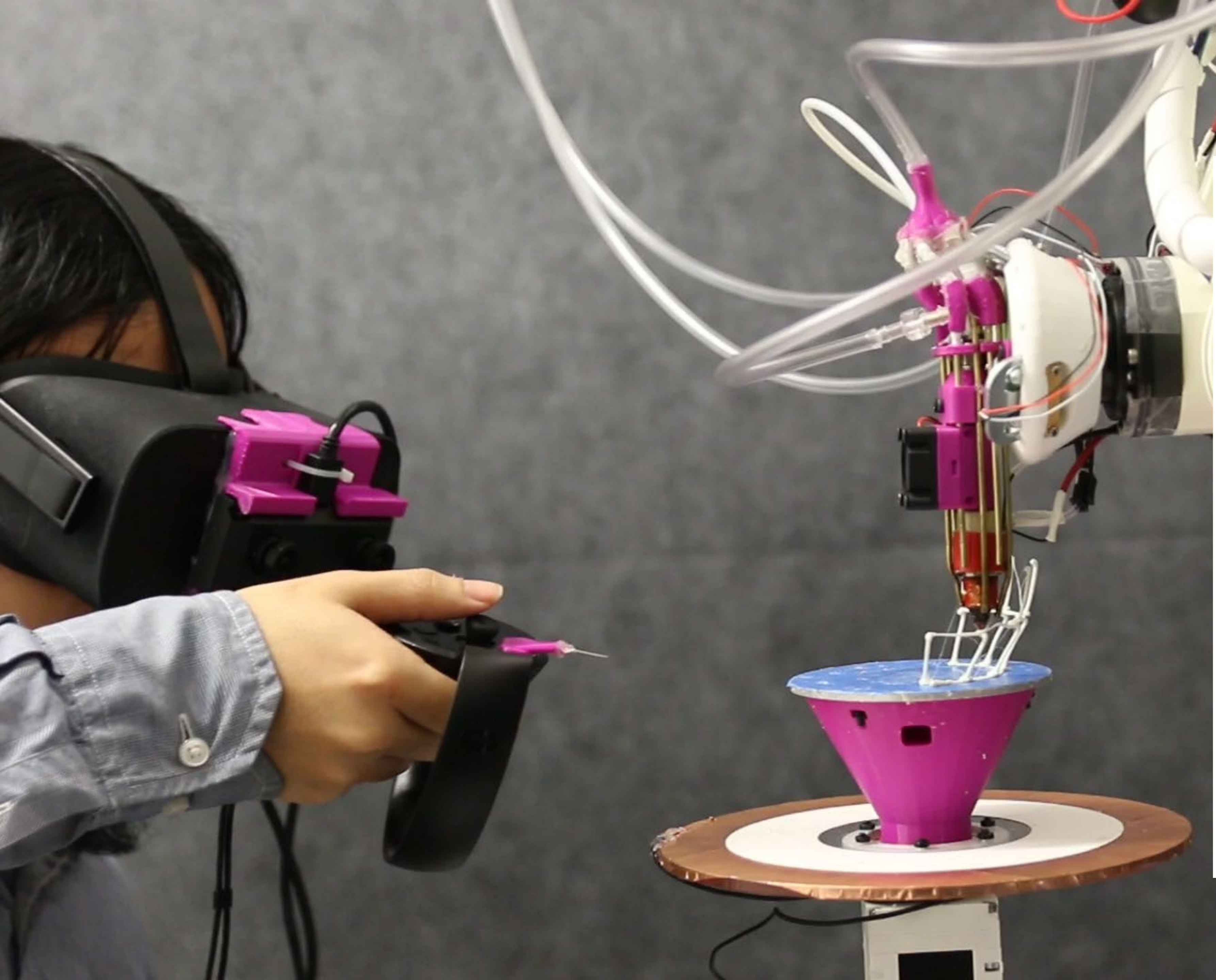








In-situ Design and Fabrication



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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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

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.

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 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

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*The two authors contributed equally to this work.

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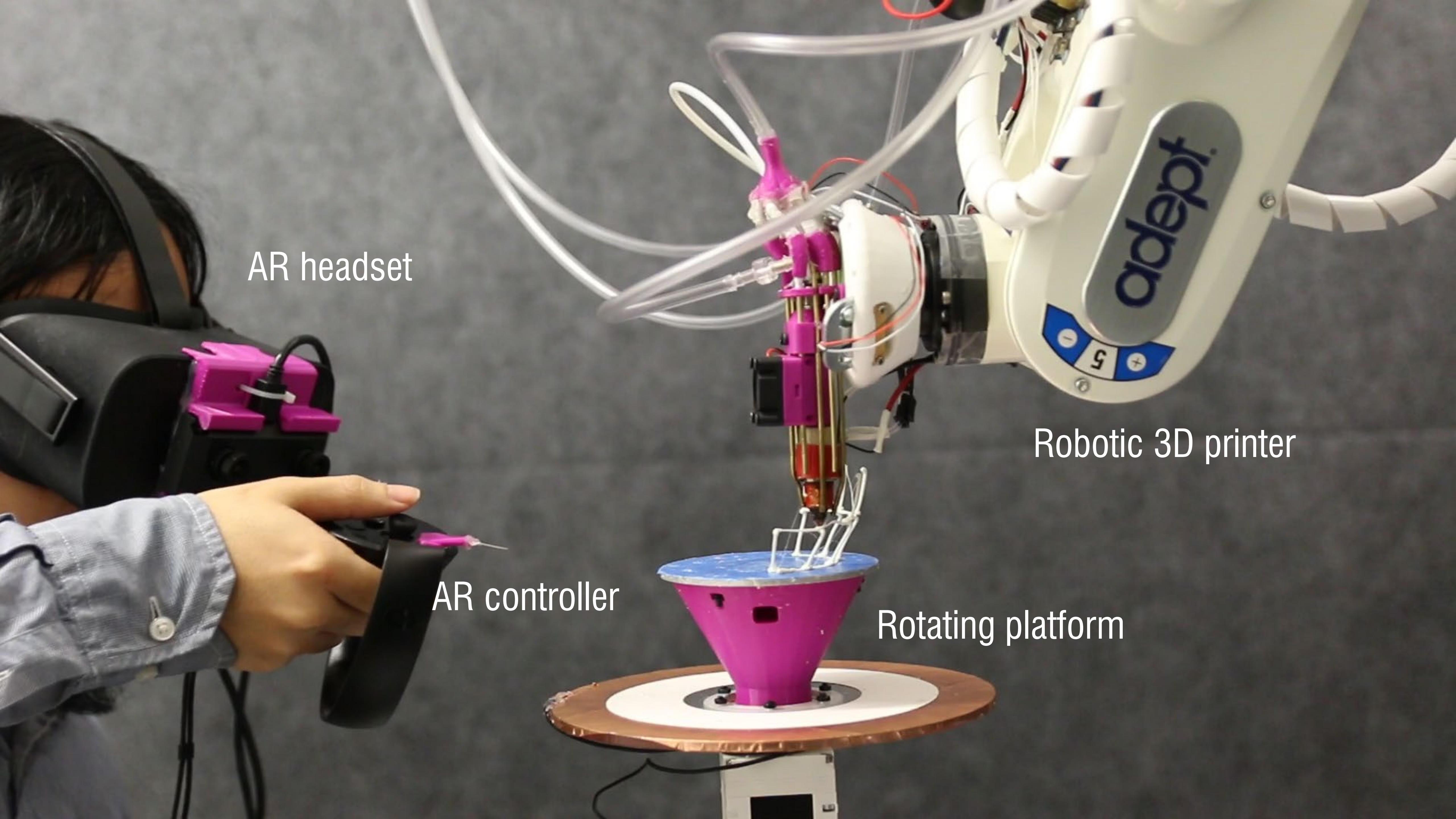
AR headset
Robotic 3D printer
AR controller
Rotating platform
adept
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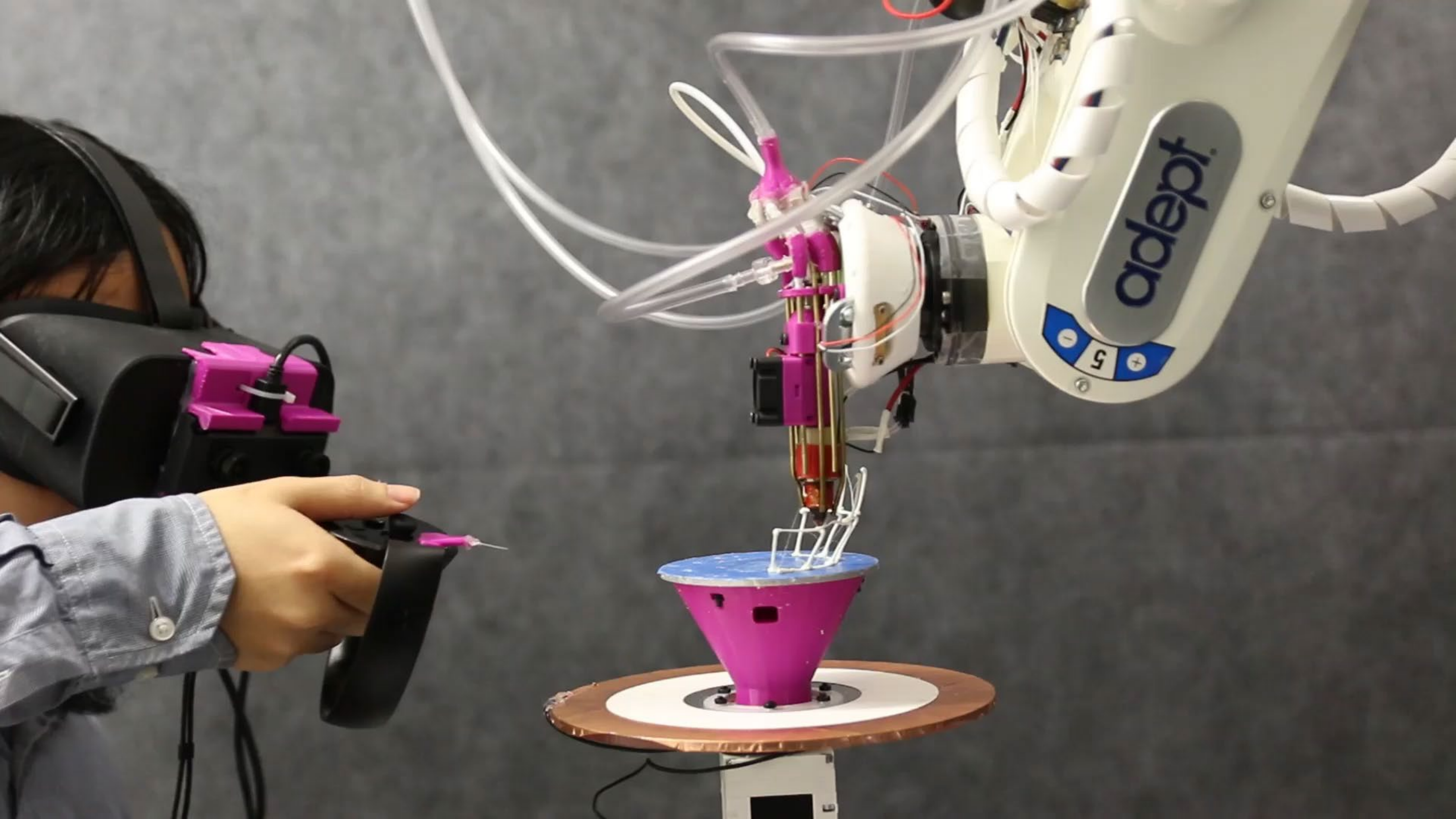
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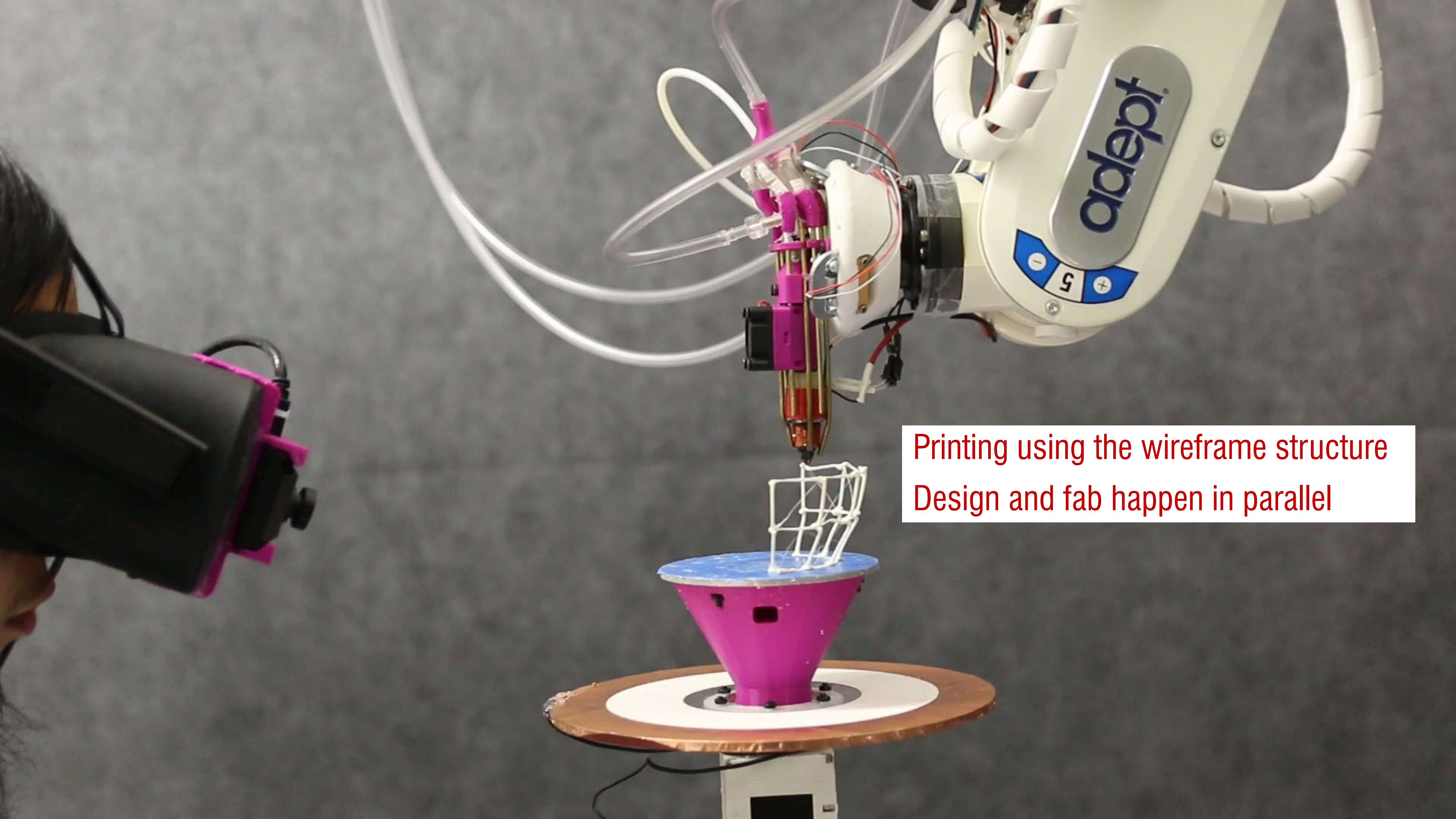
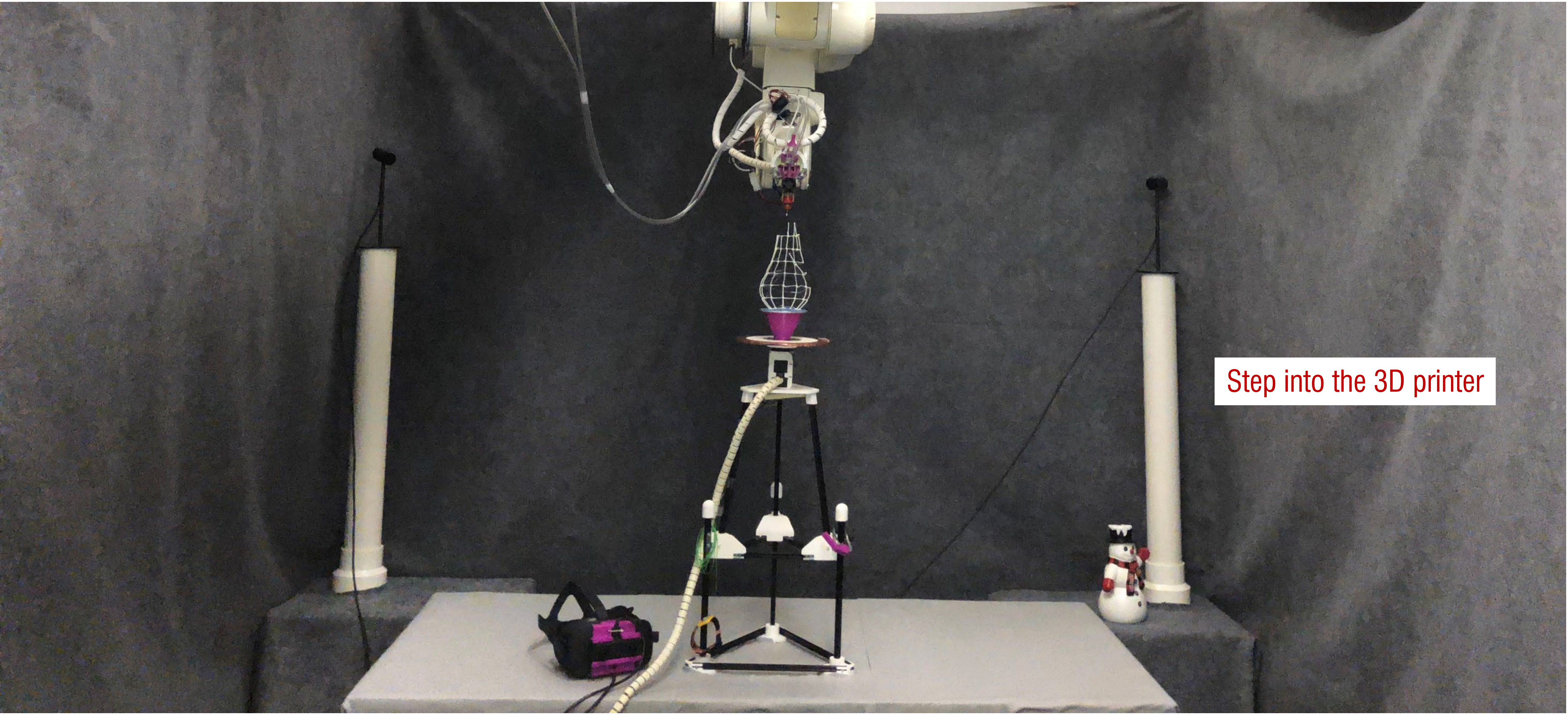


Printing using the wireframe structure

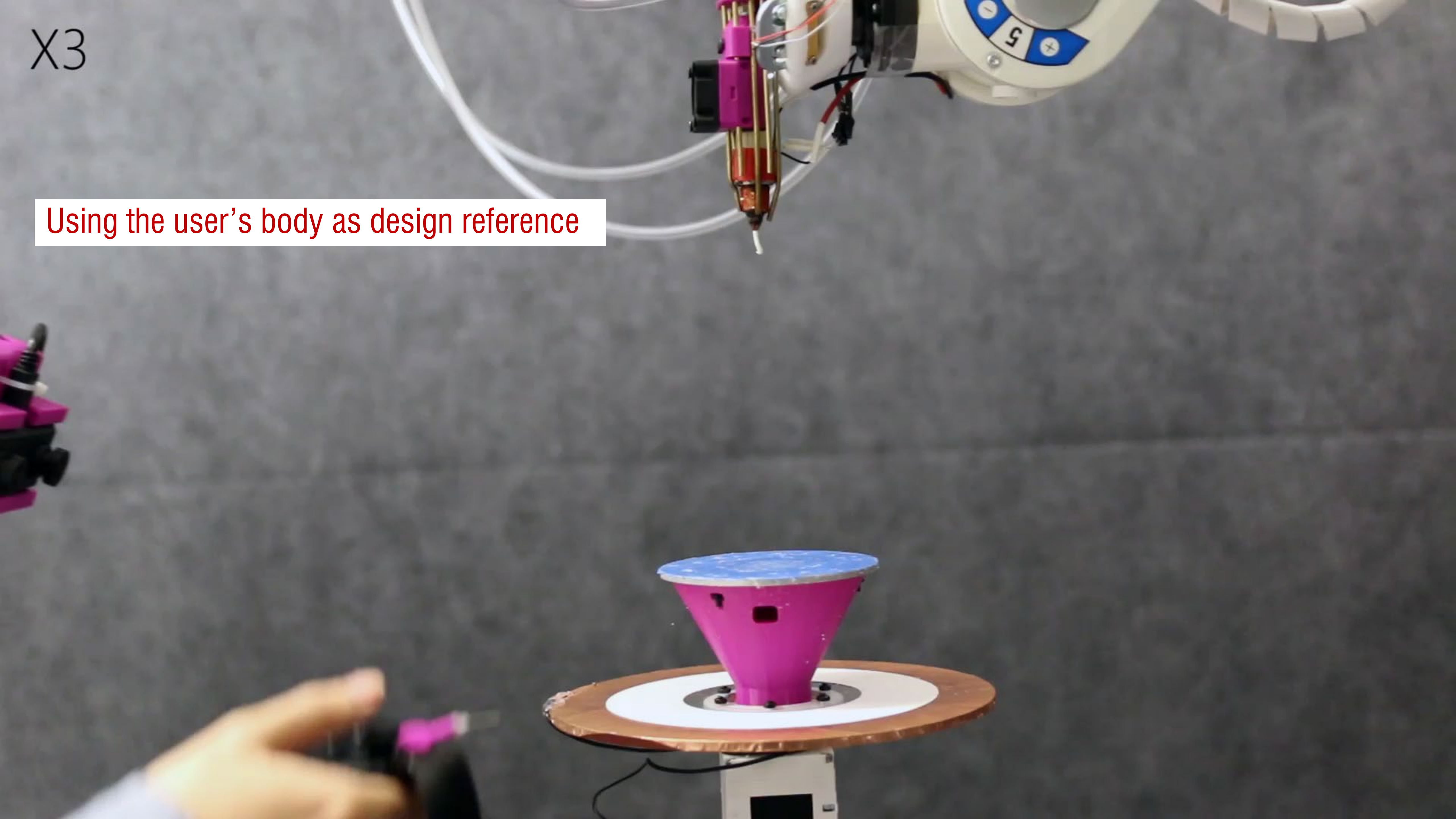
Design and fab happen in parallel

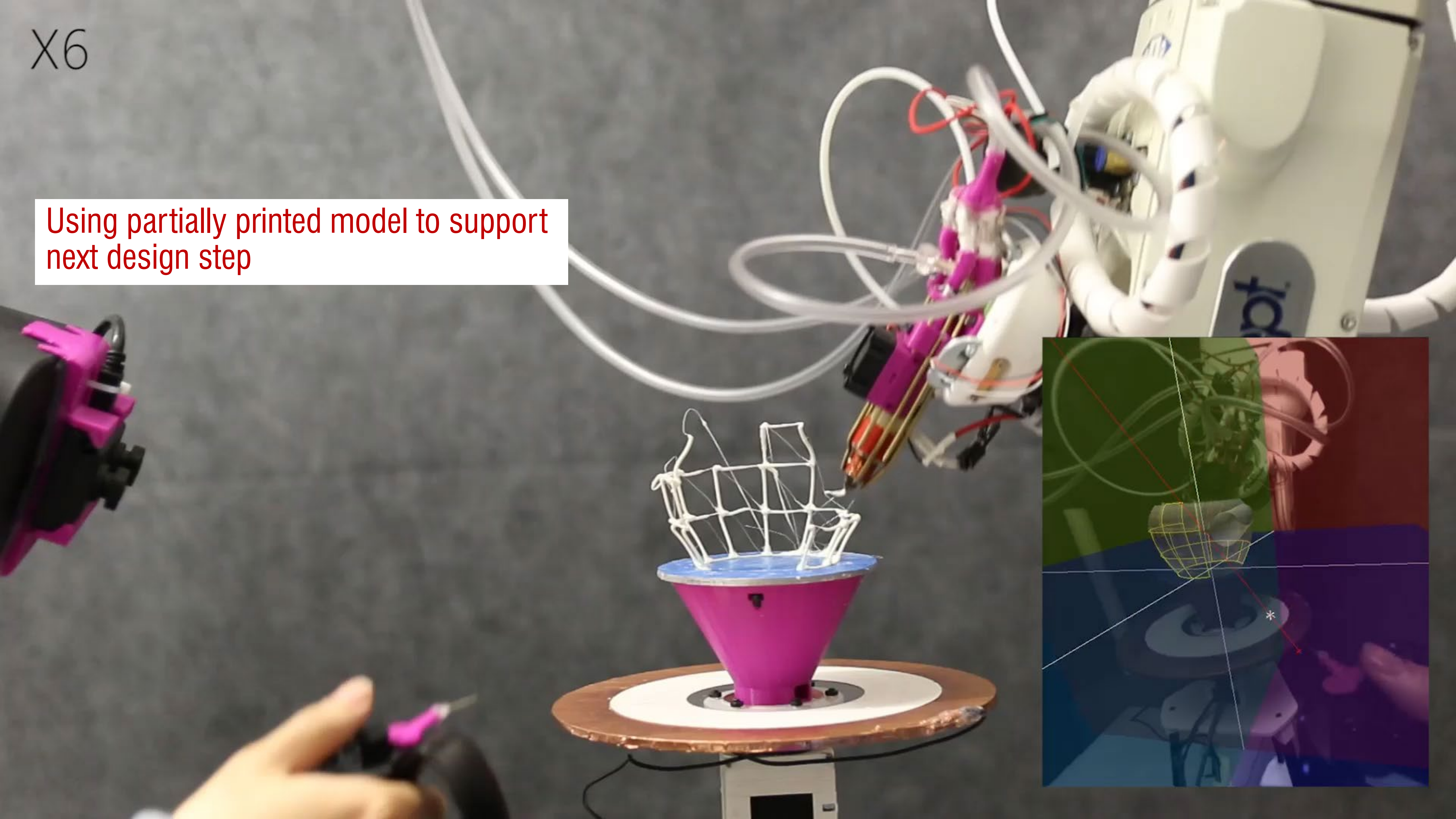


Step into the 3D printer

X3

Using the user's body as design reference

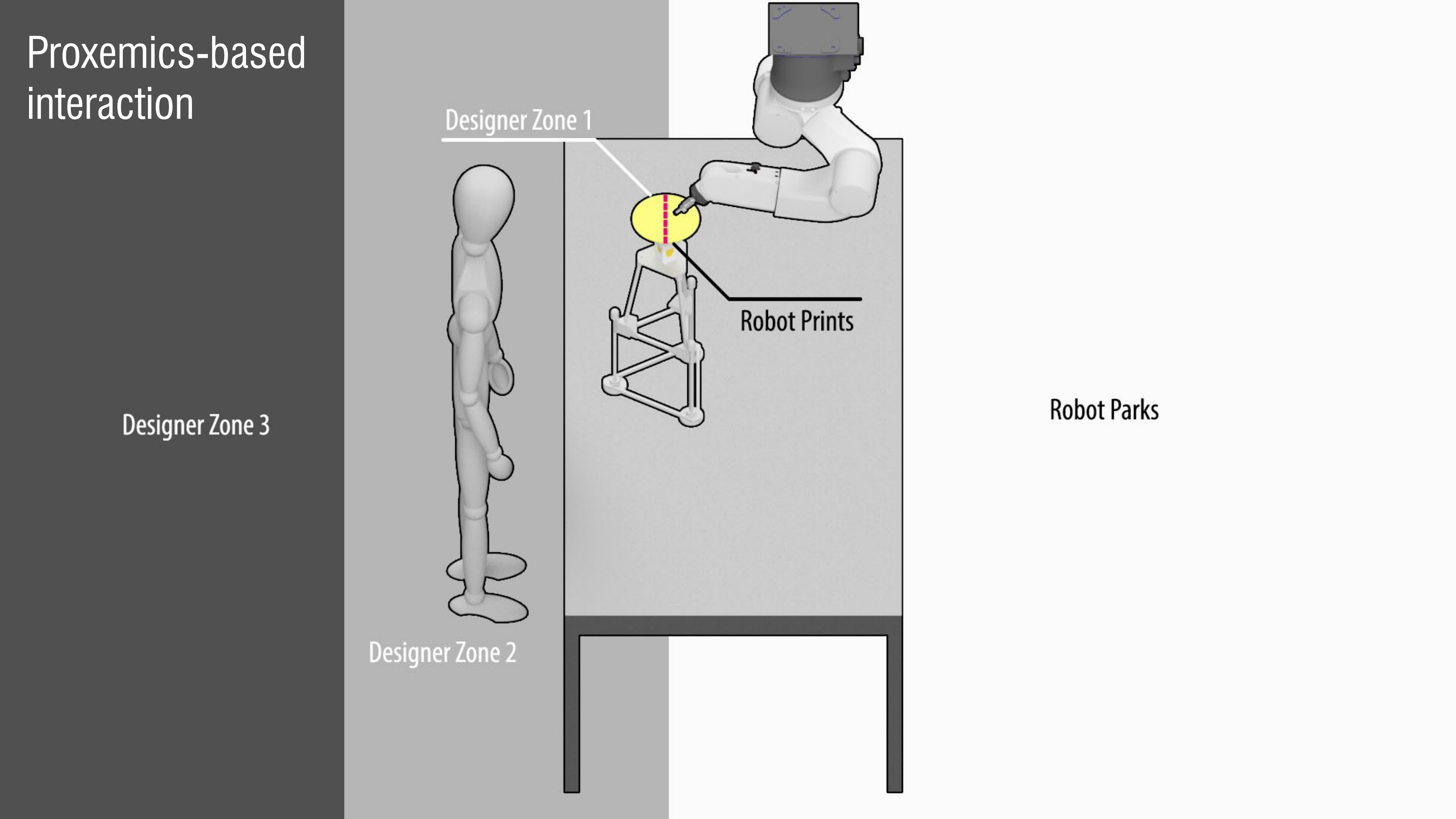




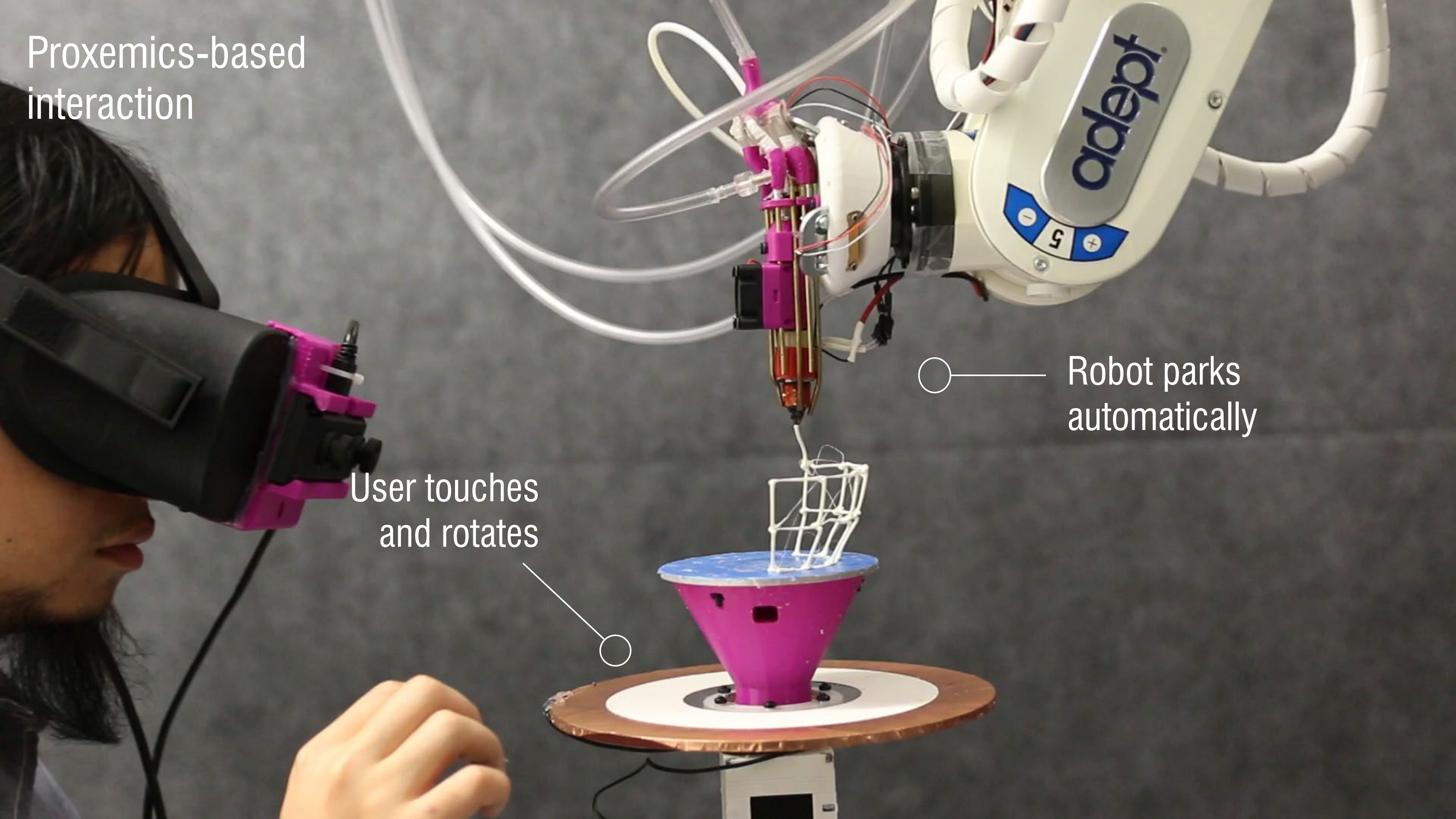
Using partially printed model to support next design step

Design and fabrication directly ON a physical object

Proxemics-based interaction



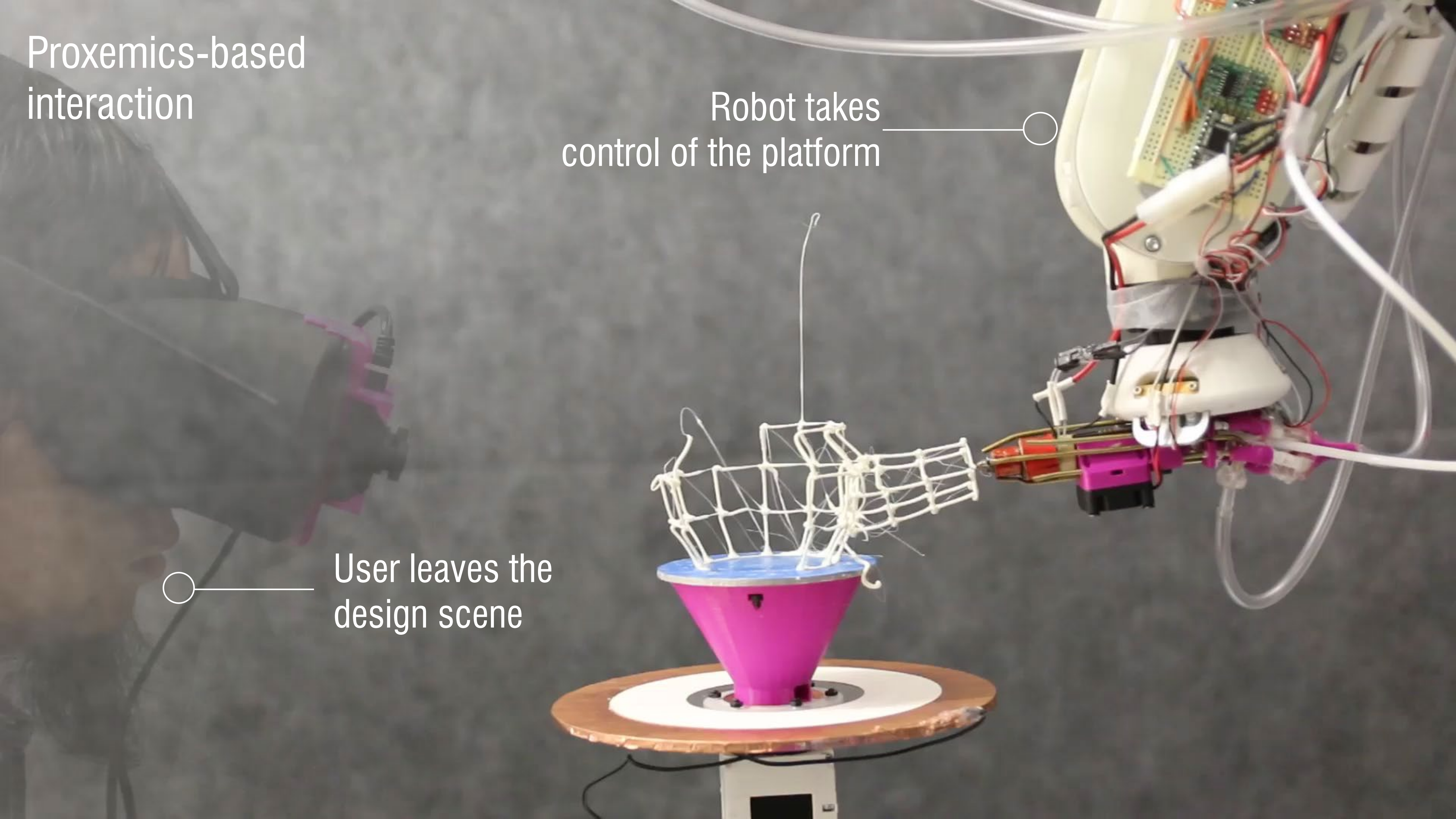
Proxemics-based interaction



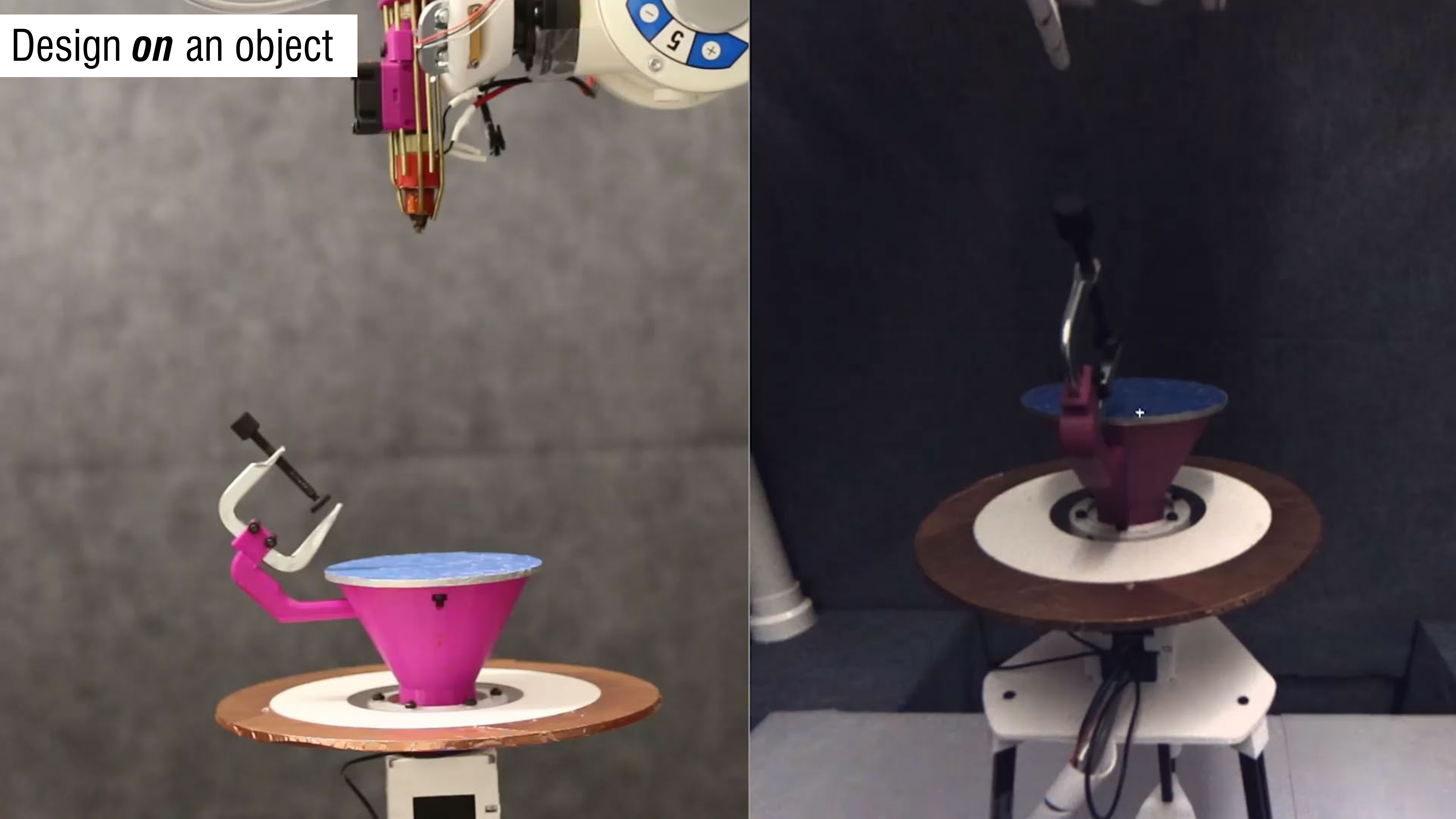
Robot parks automatically

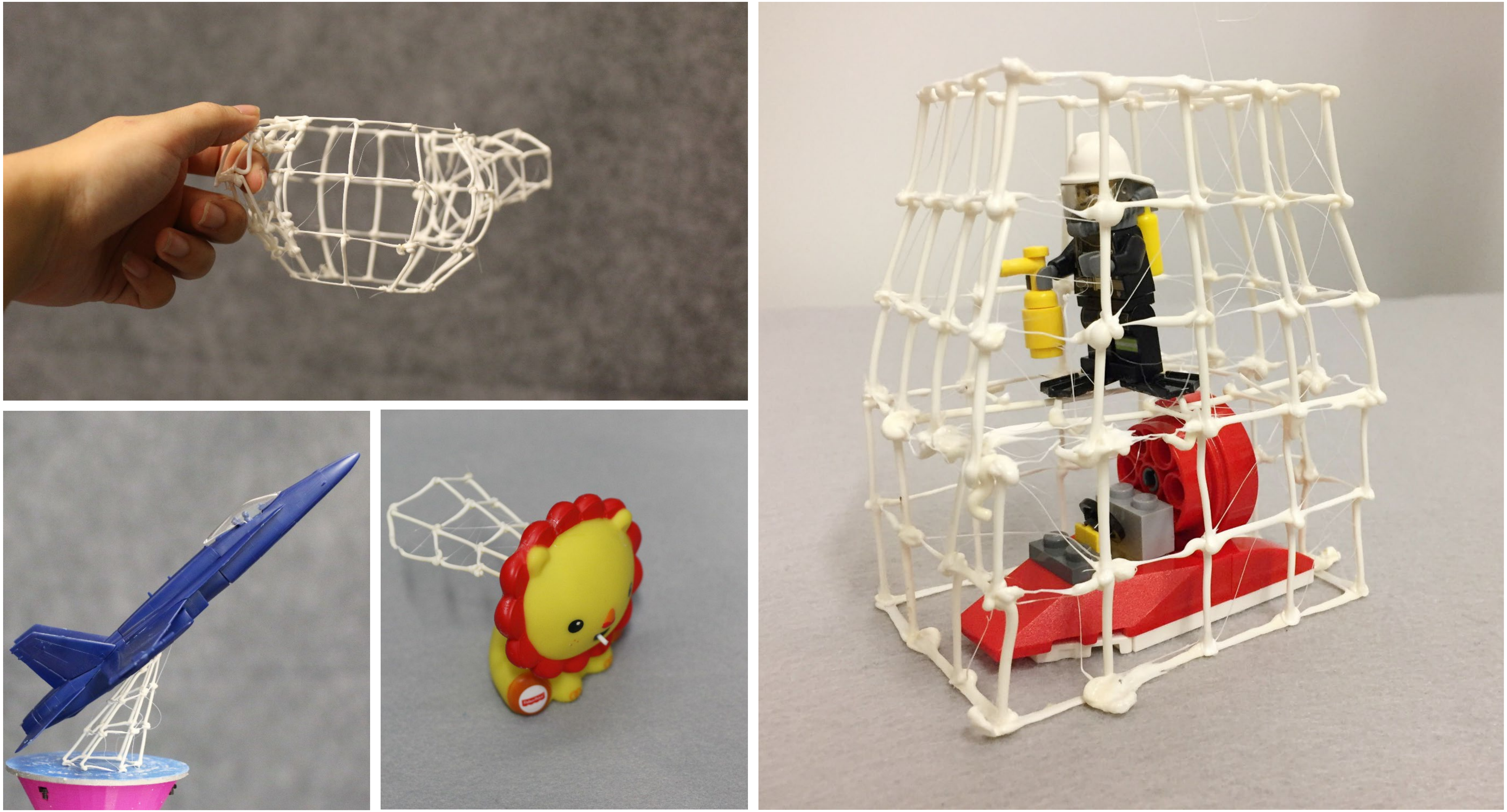
User touches and rotates

Proxemics-based interaction



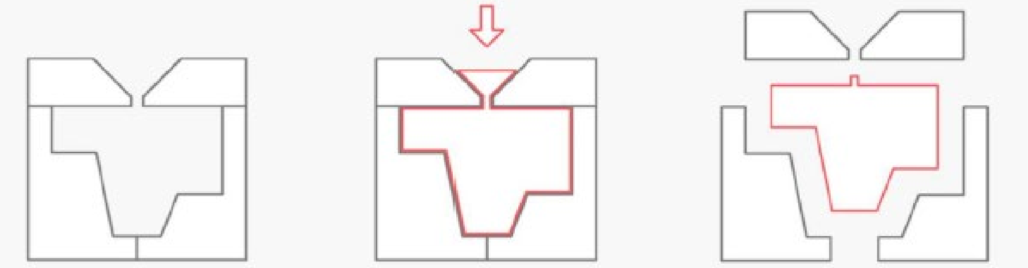
Design *on* an object



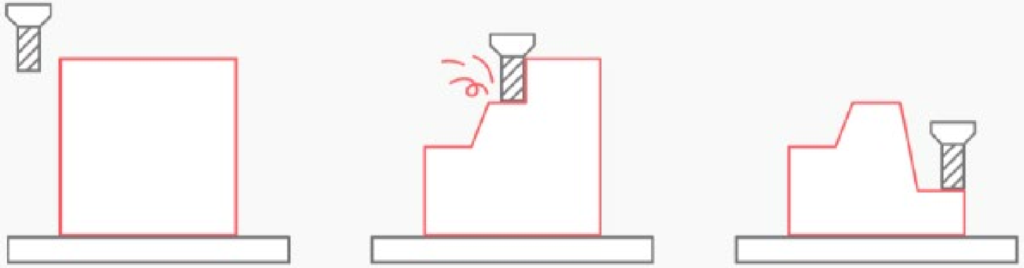


Adding and removing material is still very slow

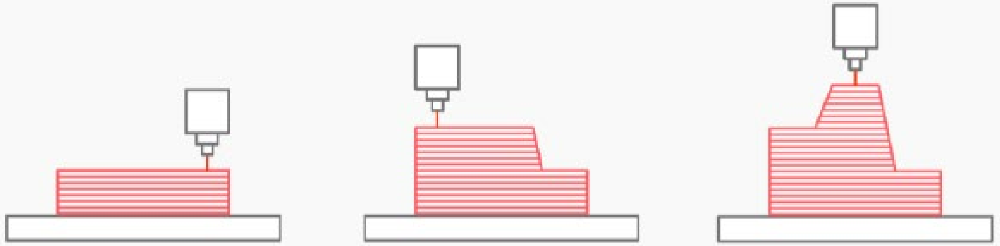
Can we **directly reshape** the material?



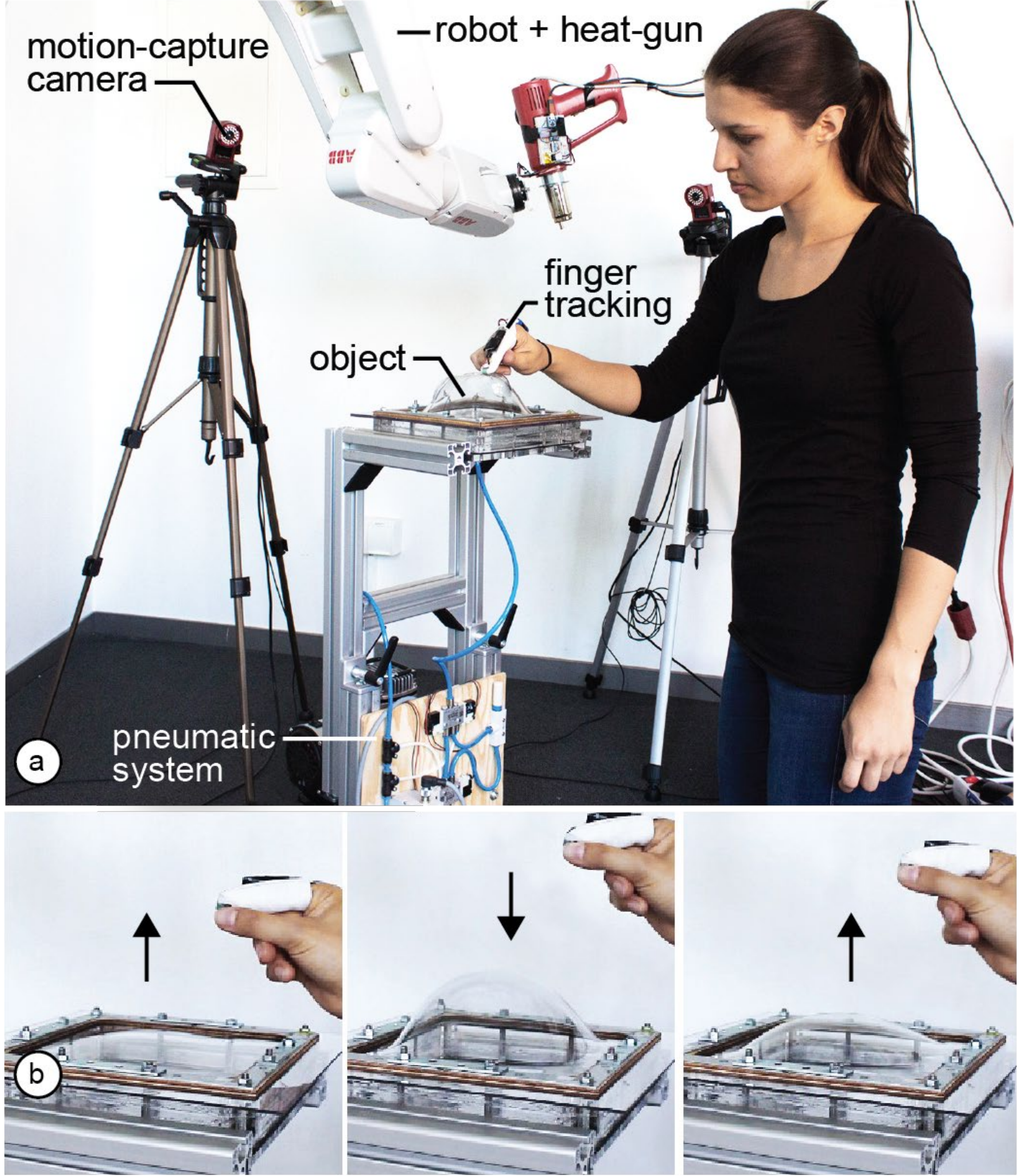
Formative manufacturing

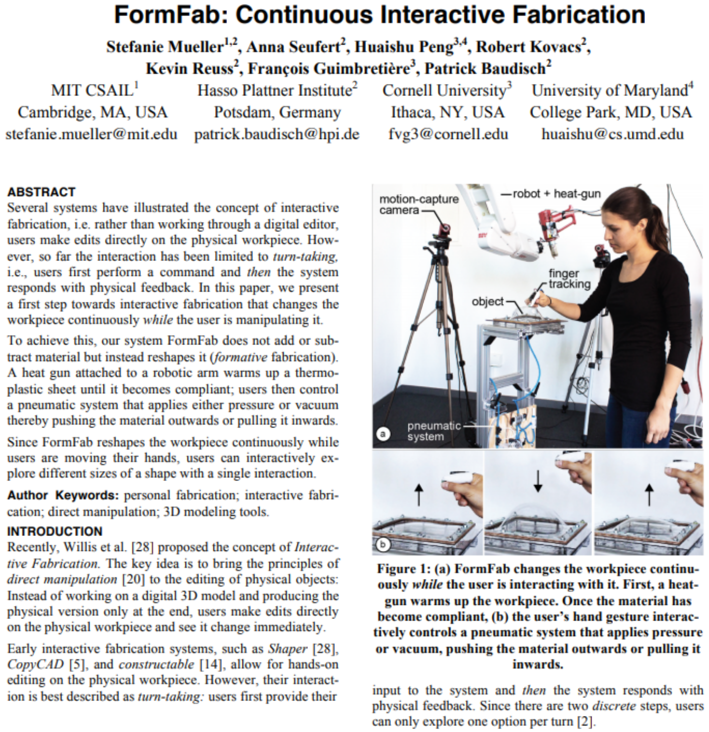


Subtractive manufacturing



Additive manufacturing





FormFab: Continuous Interactive Fabrication

**Stefanie Mueller[1,2], Anna Seufert[2], Huaishu Peng[3,4], Robert Kovacs[2],
Kevin Reuss[2], François Guimbretière[3], Patrick Baudisch[2]**

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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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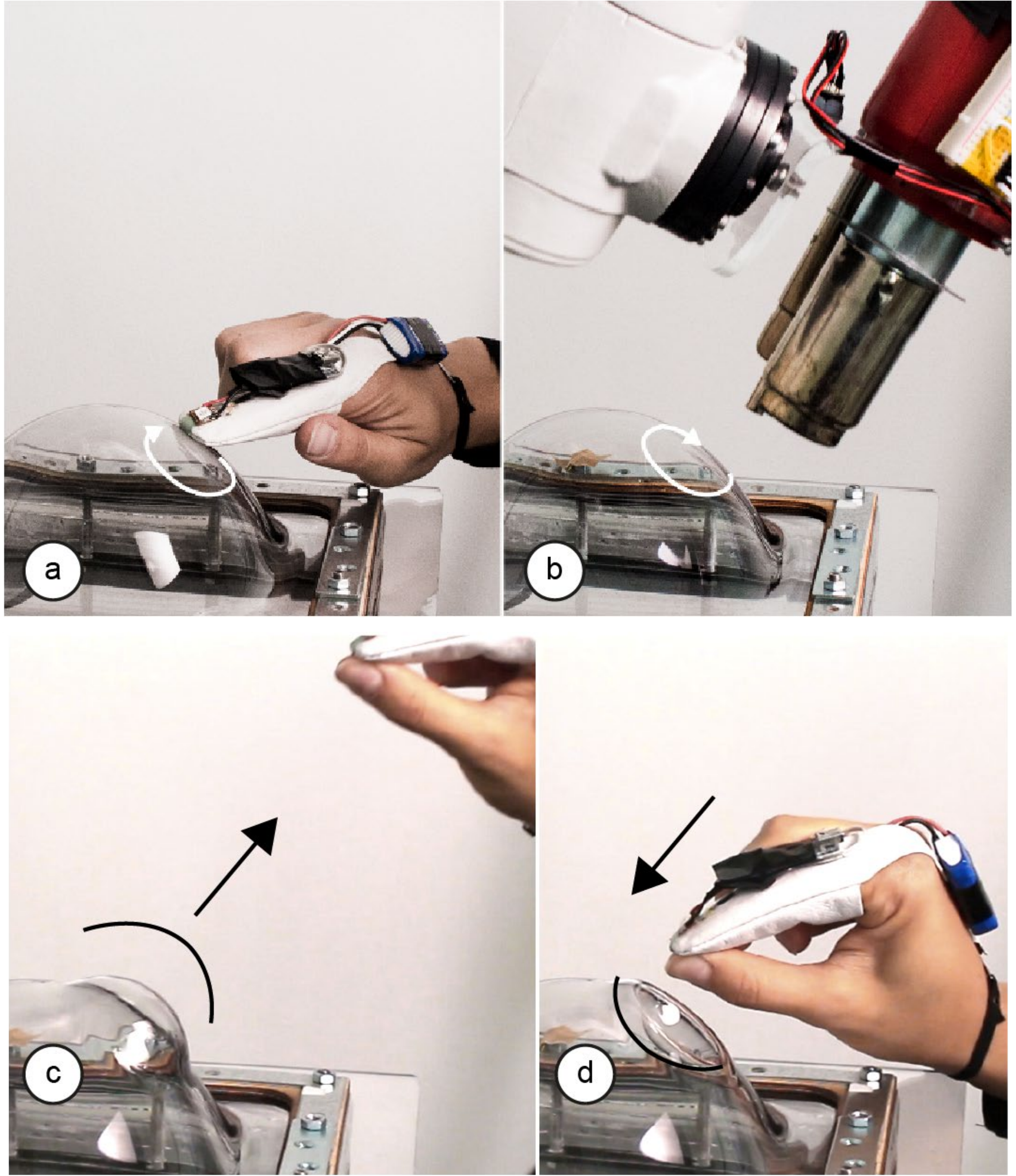
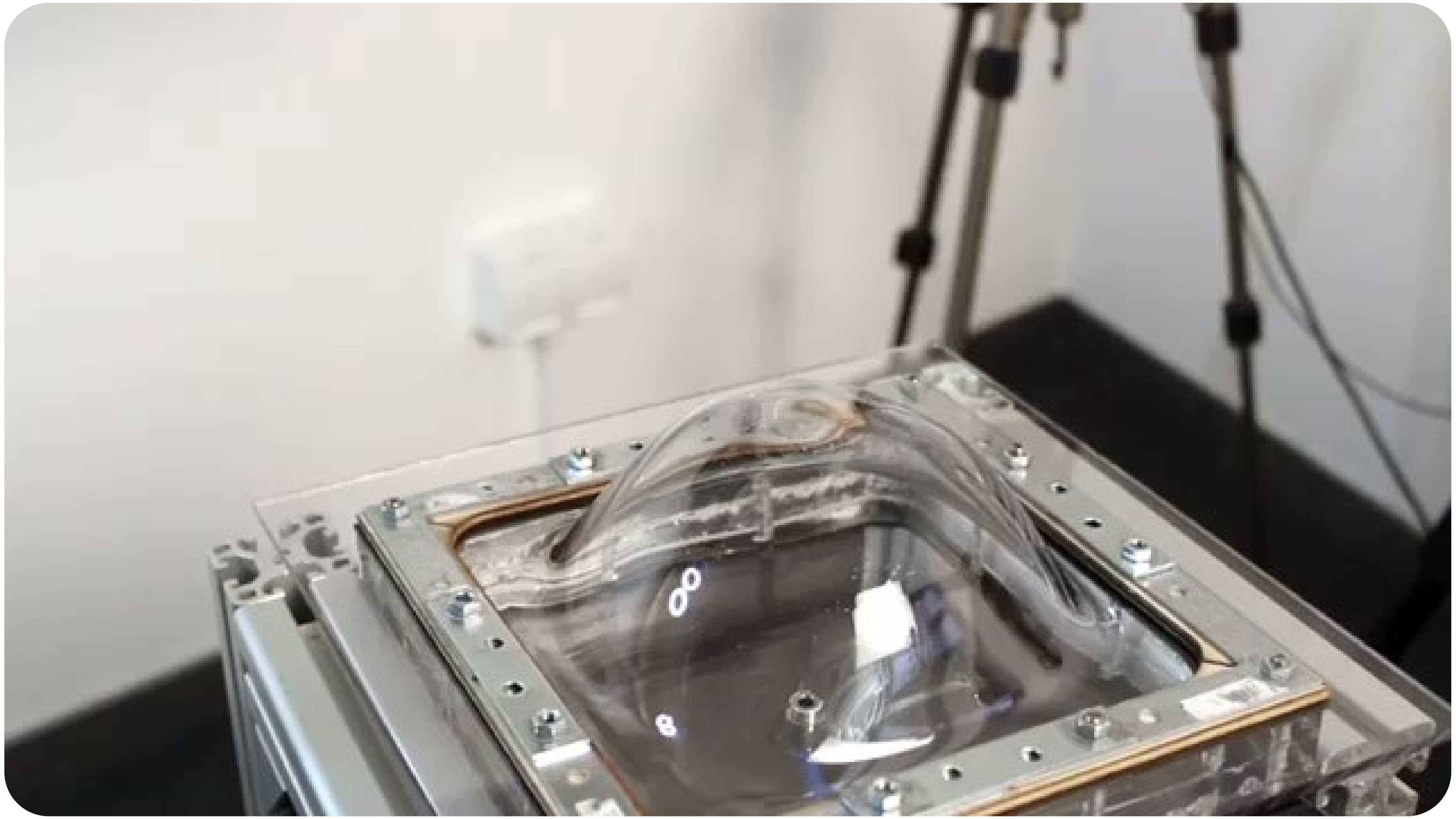
Selectively heat the material

Directly manipulating the area with gestures



Limitations

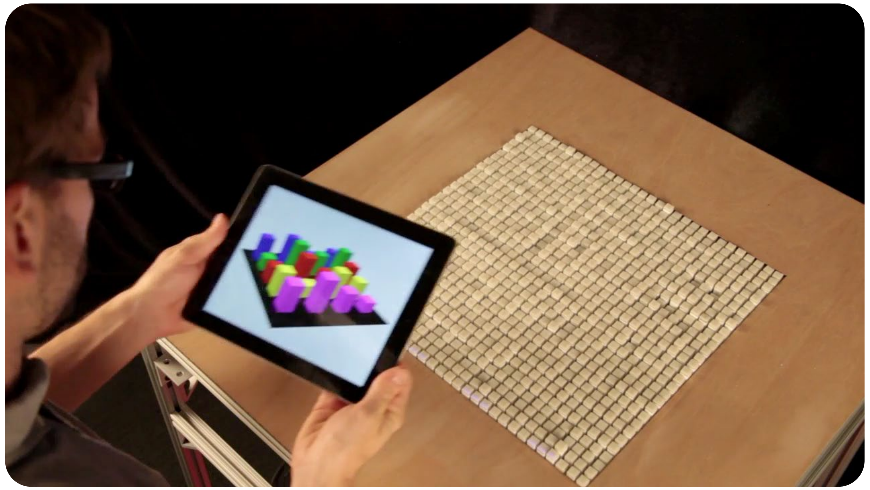
Slow heating process
Limited expressiveness



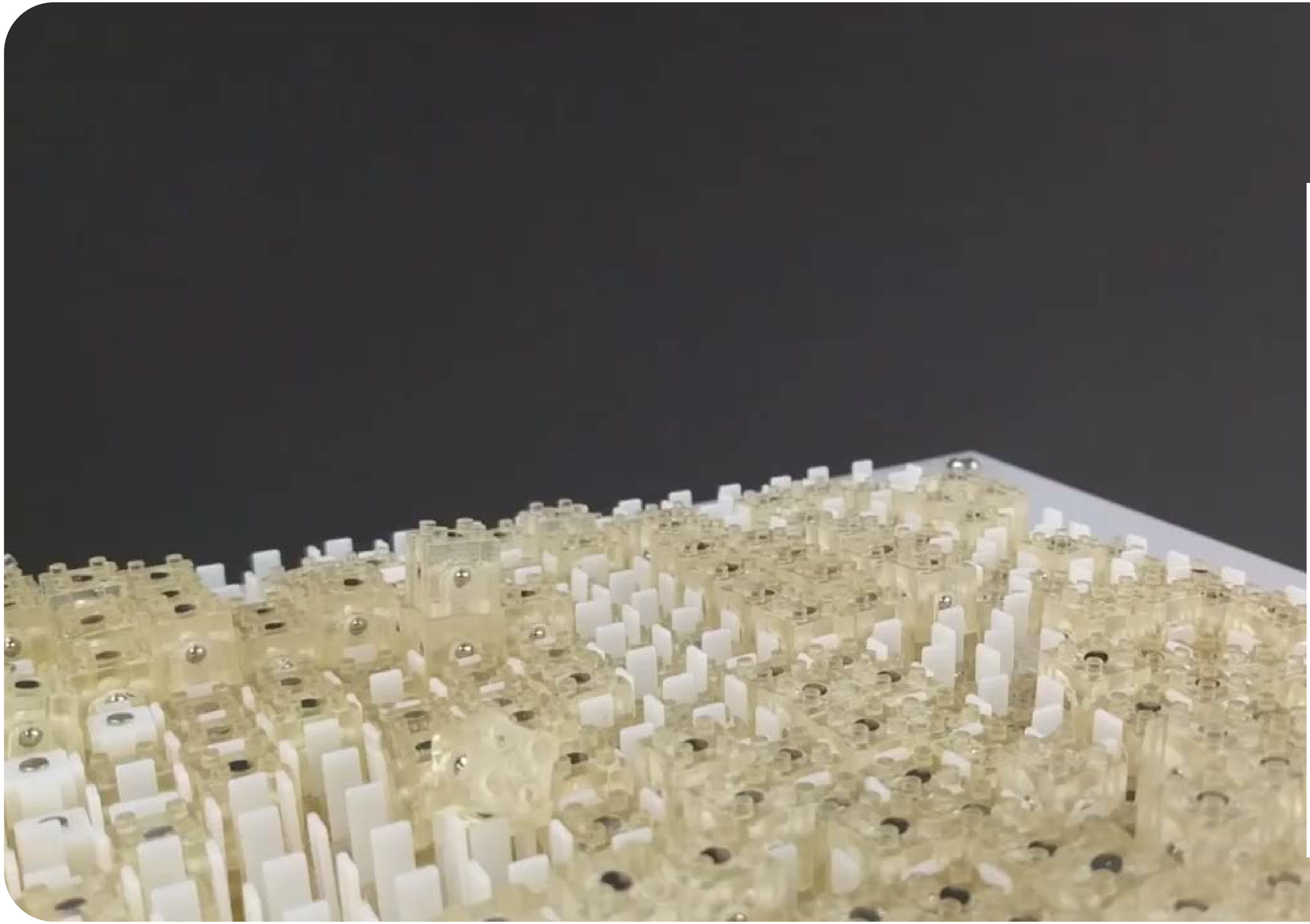
How to further improve the system?

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.

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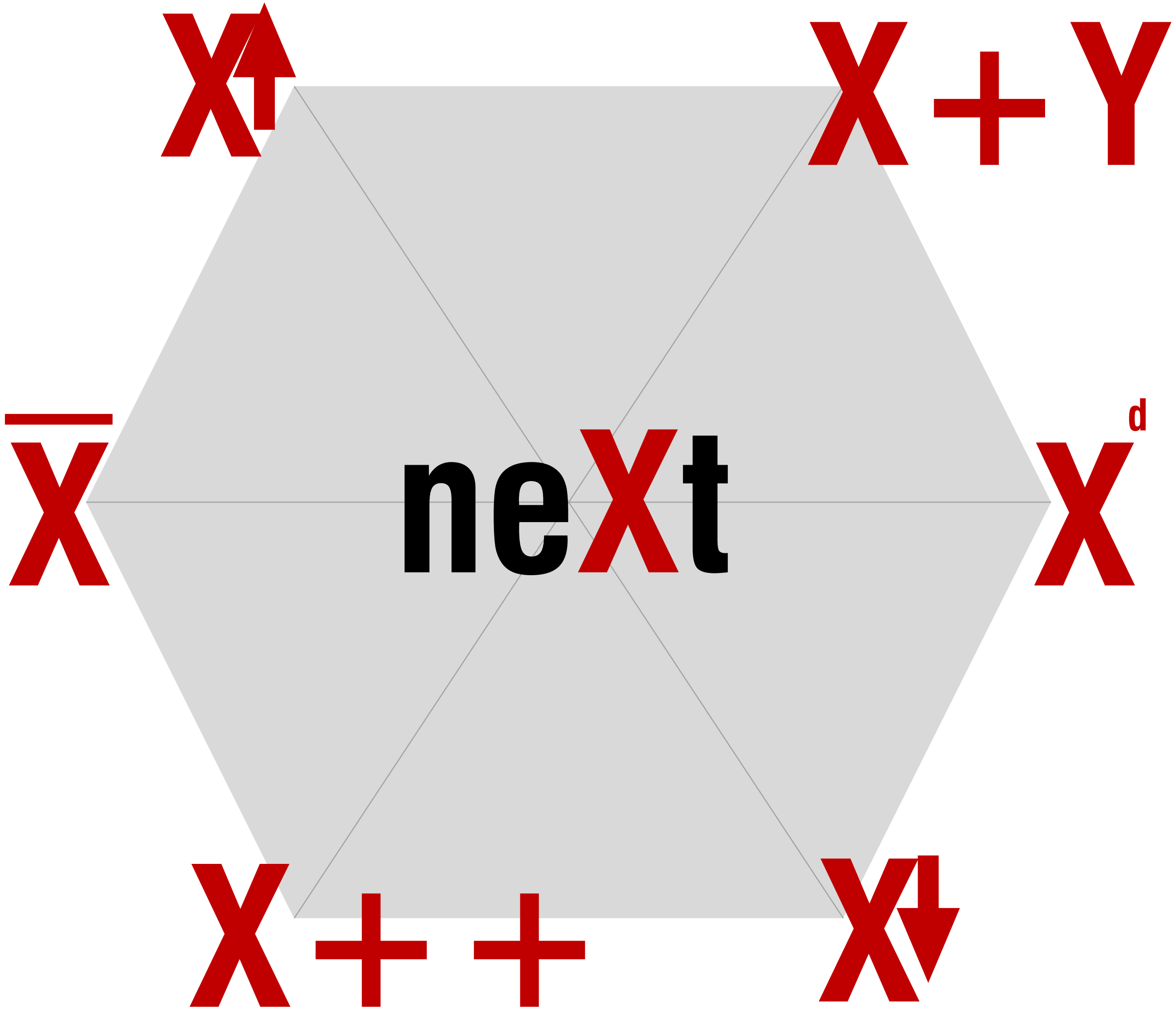


Future Interactive Tech

A quick recap

Learn

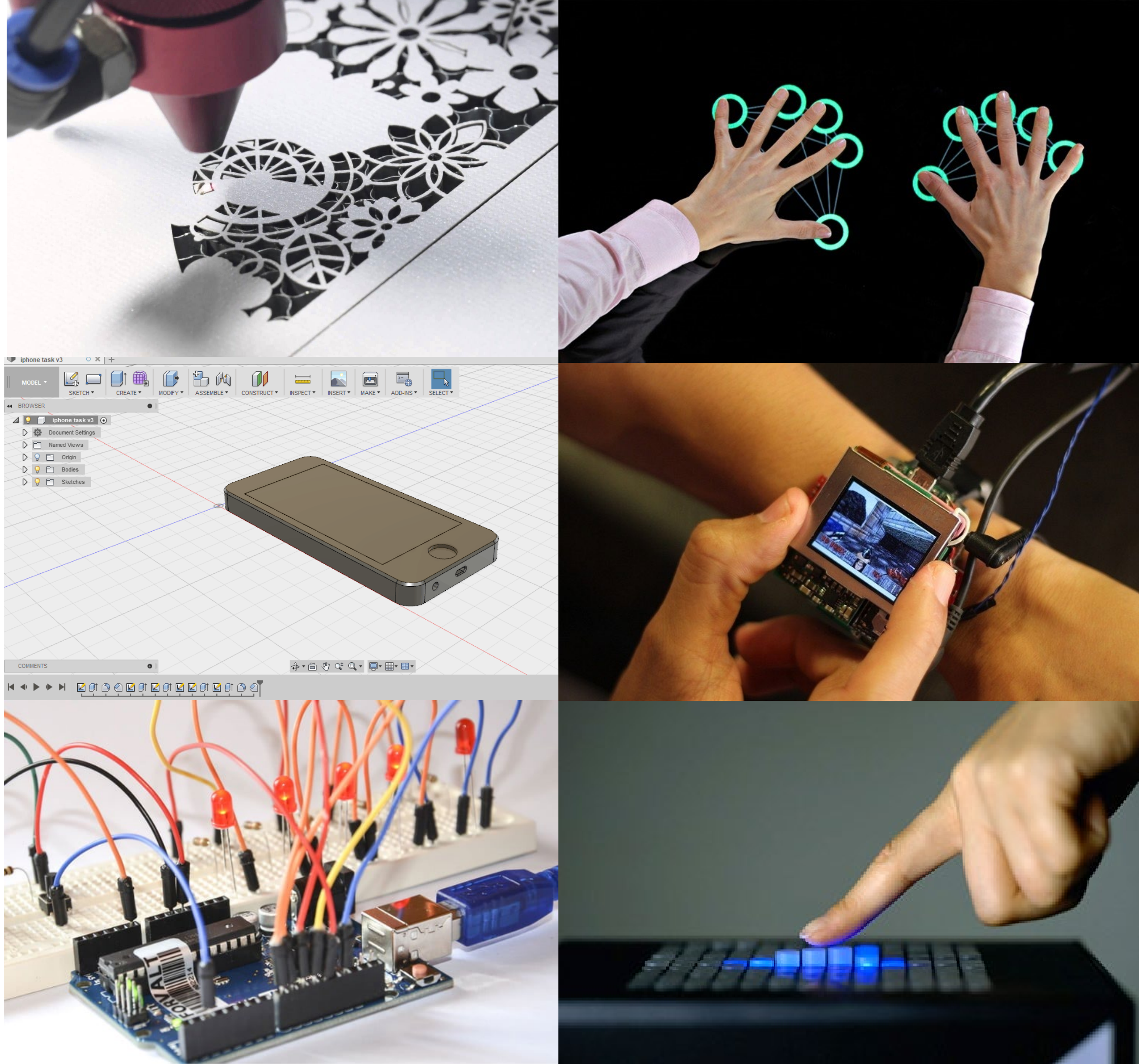
Varies interactive technologies

Technologies behind the scene

Do

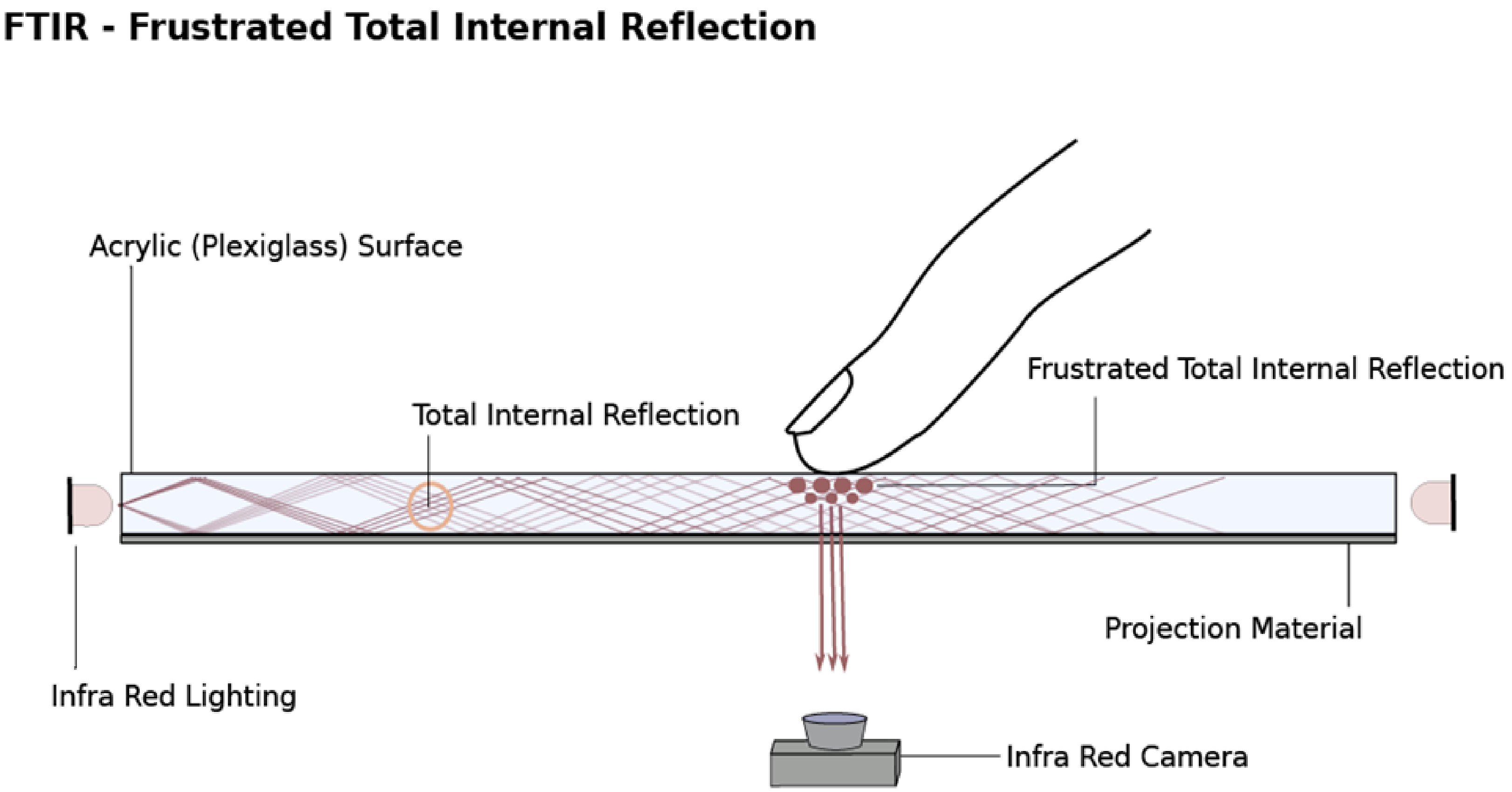
Hands-on building skills

Build interactive gadgets



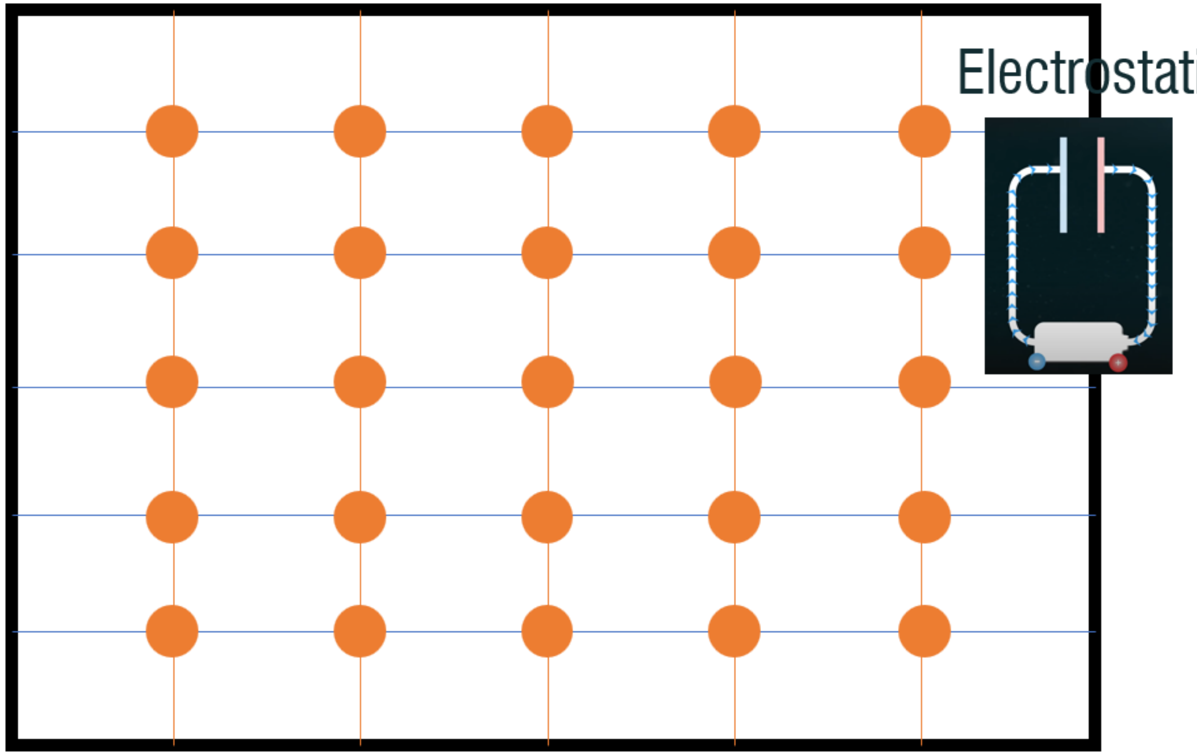
Varies interactive technologies

Multi-touch



Varies interactive technologies

Multi-touch



Sensing lines
to detect
electric current

Electrostatic Field

Driving lines
with constant
electric current

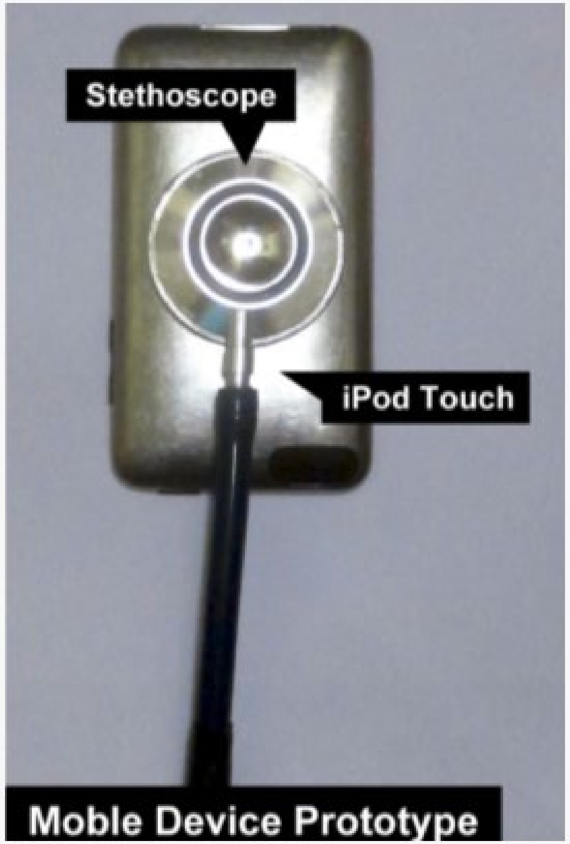
Varies interactive technologies

Mobile interaction

TapSense: Enhancing Finger Interaction on Touch Surfaces

Acoustic sensing: Sensing vibration –> Microphone; IMU, etc

For prototyping?



Benefit?
fast and less noise

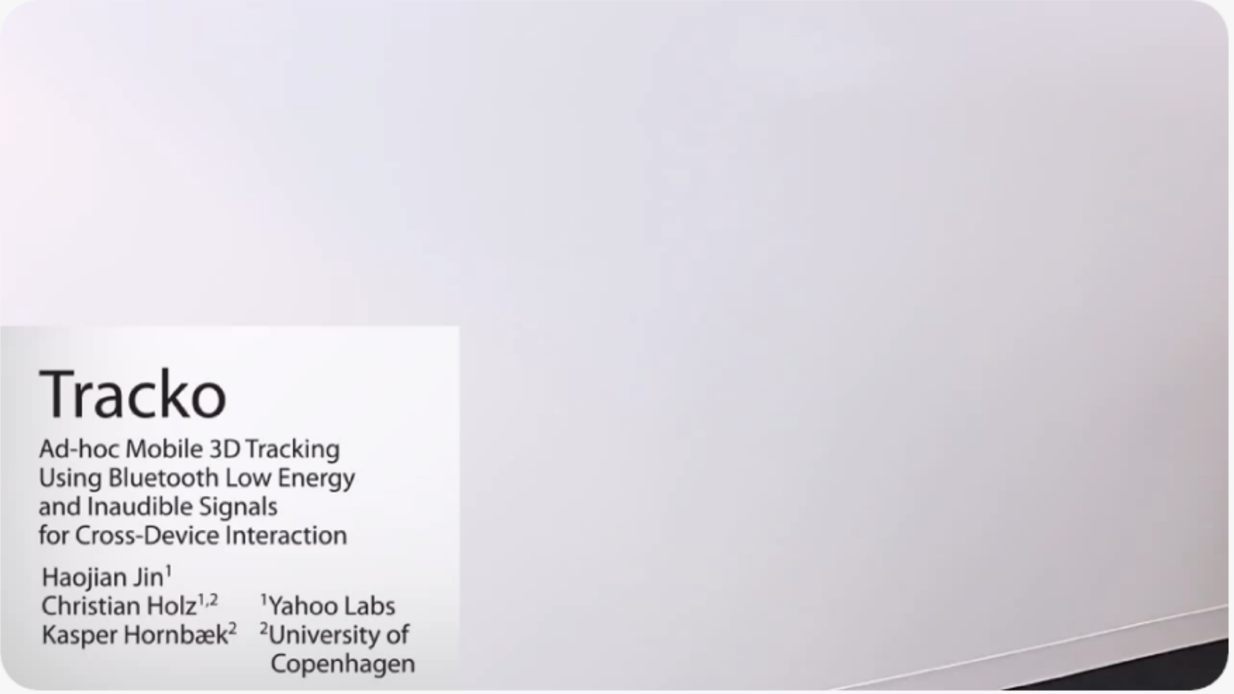
Varies interactive technologies

Mobile interaction

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

BLE (only) knows the **presence** of a neighbor device

Tracko knows the **actual locations**



Tracko

Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

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Christian Holz[1,2]
Kasper Hornbæk[2]

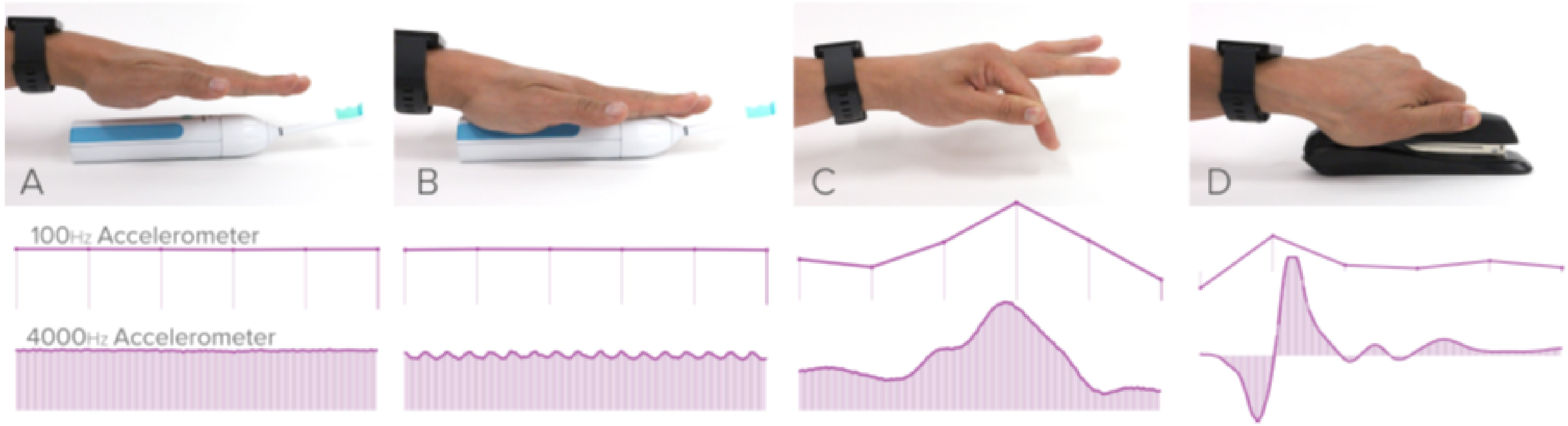
[1]Yahoo Labs
[2]University of Copenhagen

Varies interactive technologies

Smart watch interactions

ViBand: High-Fidelity Bio-Acoustic Sensing Using Commodity Smartwatch Accelerometers

Sensing principle

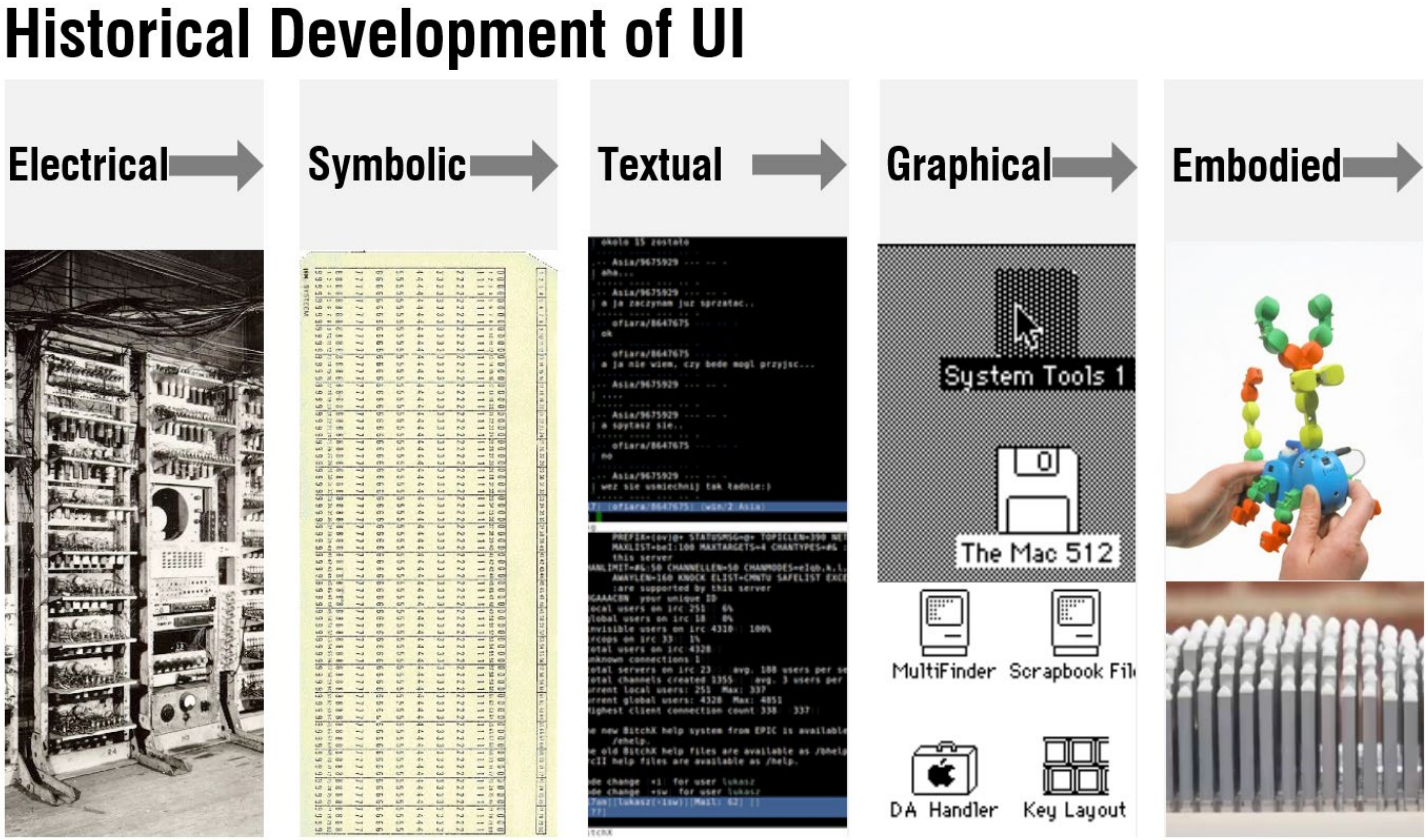


Use the high-speed mode of existing accelerometer

Only need to modify it's kernel – pure software solution!

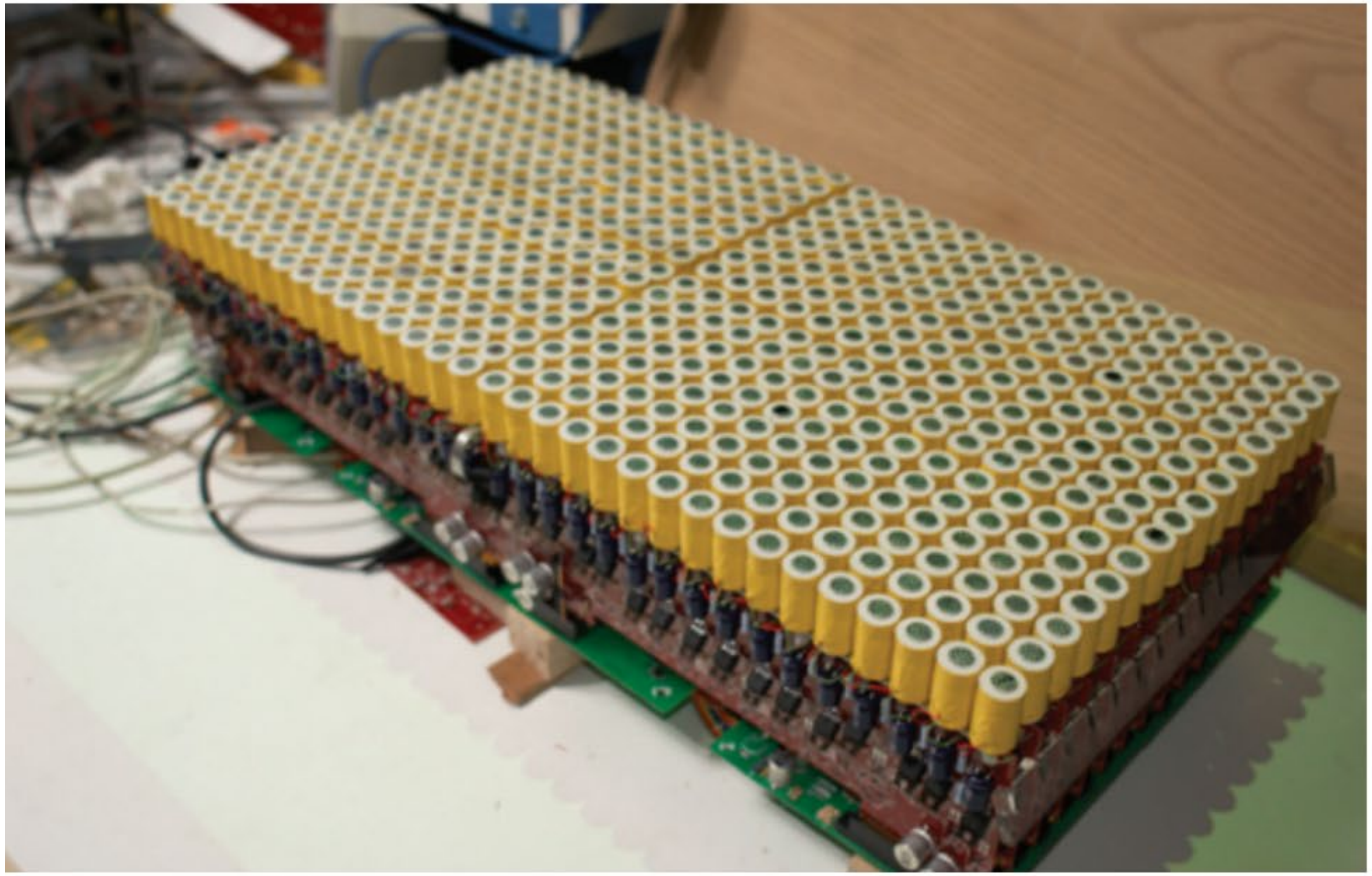
Varies interactive technologies

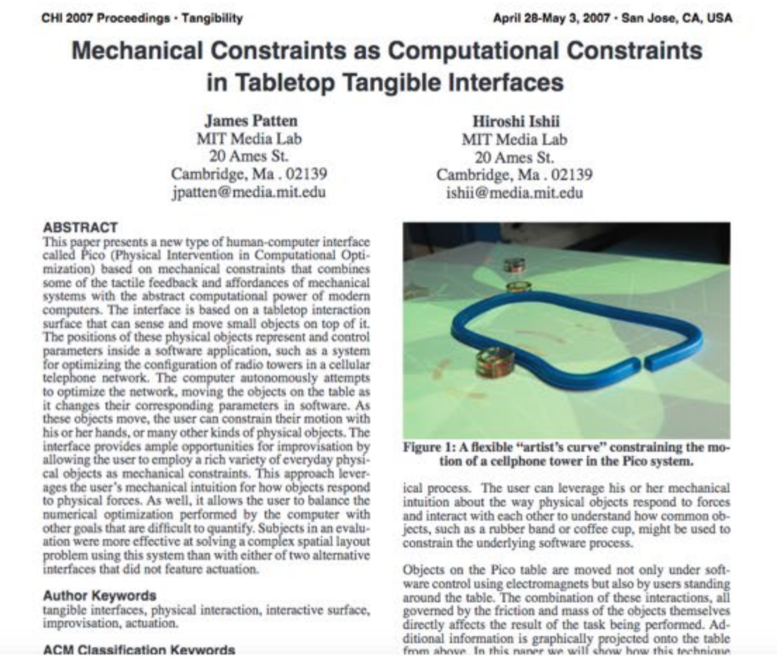
Tangible interaction



Varies interactive technologies

Tangible interaction





CHI 2007 Proceedings · Tangibility April 28-May 3, 2007 · San Jose, CA, USA

Mechanical Constraints as Computational Constraints in Tabletop Tangible Interfaces

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ABSTRACT

This paper presents a new type of human-computer interface called Pico (Physical Intervention in Computational Optimization) based on mechanical constraints that combines some of the tactile feedback and affordances of mechanical systems with the abstract computational power of modern computers. The interface is based on a tabletop interaction surface that can sense and move small objects on top of it. The positions of these physical objects represent and control parameters inside a software application, such as a system for optimizing the configuration of radio towers in a cellular telephone network. The computer autonomously attempts to optimize the network, moving the objects on the table as it changes their corresponding parameters in software. As these objects move, the user can constrain their motion with his or her hands, or many other kinds of physical objects. The interface provides ample opportunities for improvisation by allowing the user to employ a rich variety of everyday physical objects as mechanical constraints. This approach leverages the user's mechanical intuition for how objects respond to physical forces. As well, it allows the user to balance the numerical optimization performed by the computer with other goals that are difficult to quantify. Subjects in an evaluation were more effective at solving a complex spatial layout problem using this system than with either of two alternative interfaces that did not feature actuation.

Author Keywords

tangible interfaces, physical interaction, interactive surface, improvisation, actuation.

ACM Classification Keywords

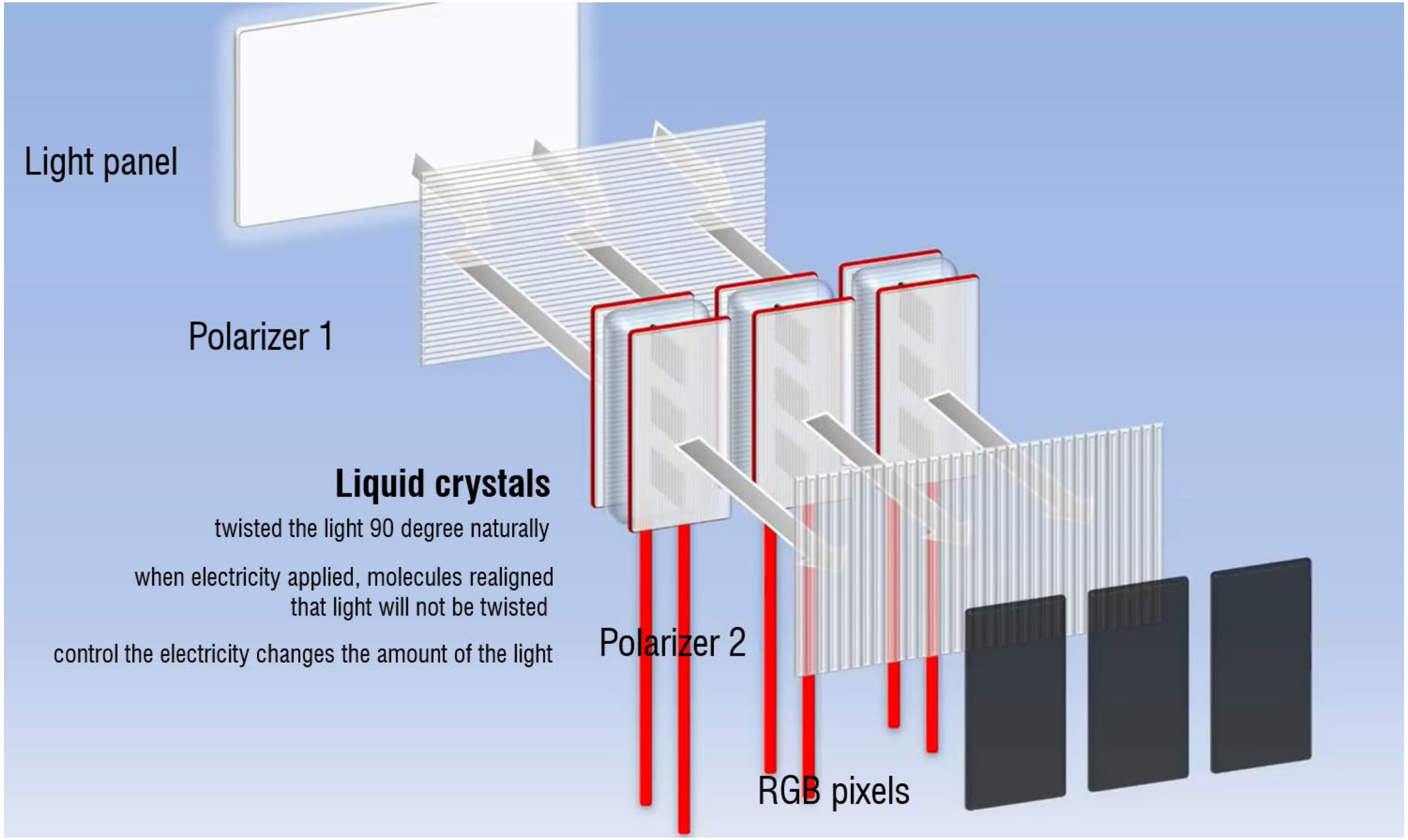
Figure 1: A flexible "artist's curve" constraining the motion of a cellphone tower in the Pico system.

ical process. The user can leverage his or her mechanical intuition about the way physical objects respond to forces and interact with each other to understand how common objects, such as a rubber band or coffee cup, might be used to constrain the underlying software process.

Objects on the Pico table are moved not only under software control using electromagnets but also by users standing around the table. The combination of these interactions, all governed by the friction and mass of the objects themselves directly affects the result of the task being performed. Additional information is graphically projected onto the table from above. In this paper we will show how this technique

Varies interactive technologies

Display



Liquid crystals

twisted the light 90 degree naturally

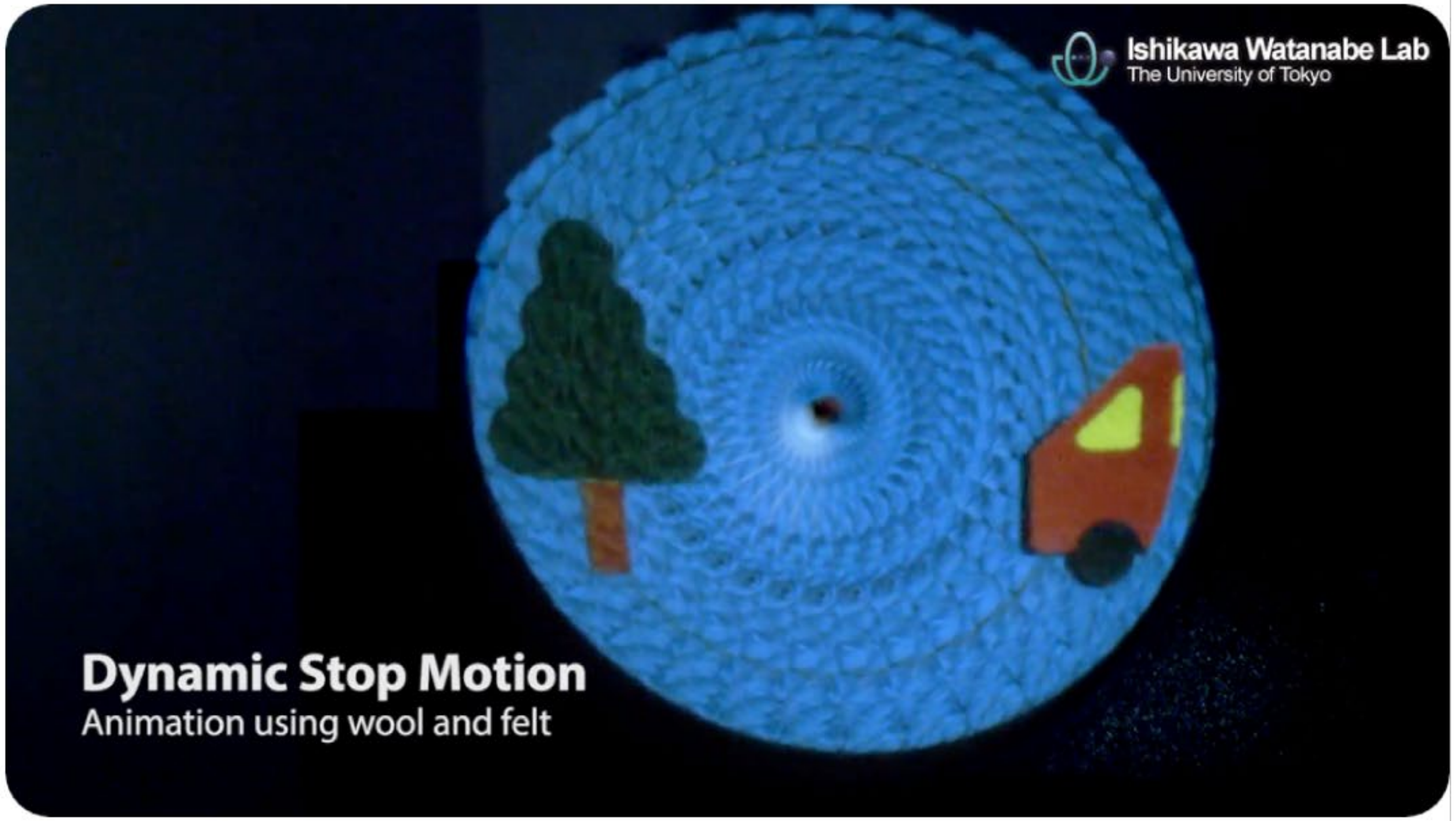
when electricity applied, molecules realigned
that light will not be twisted

control the electricity changes the amount of the light

Varies interactive technologies

Display

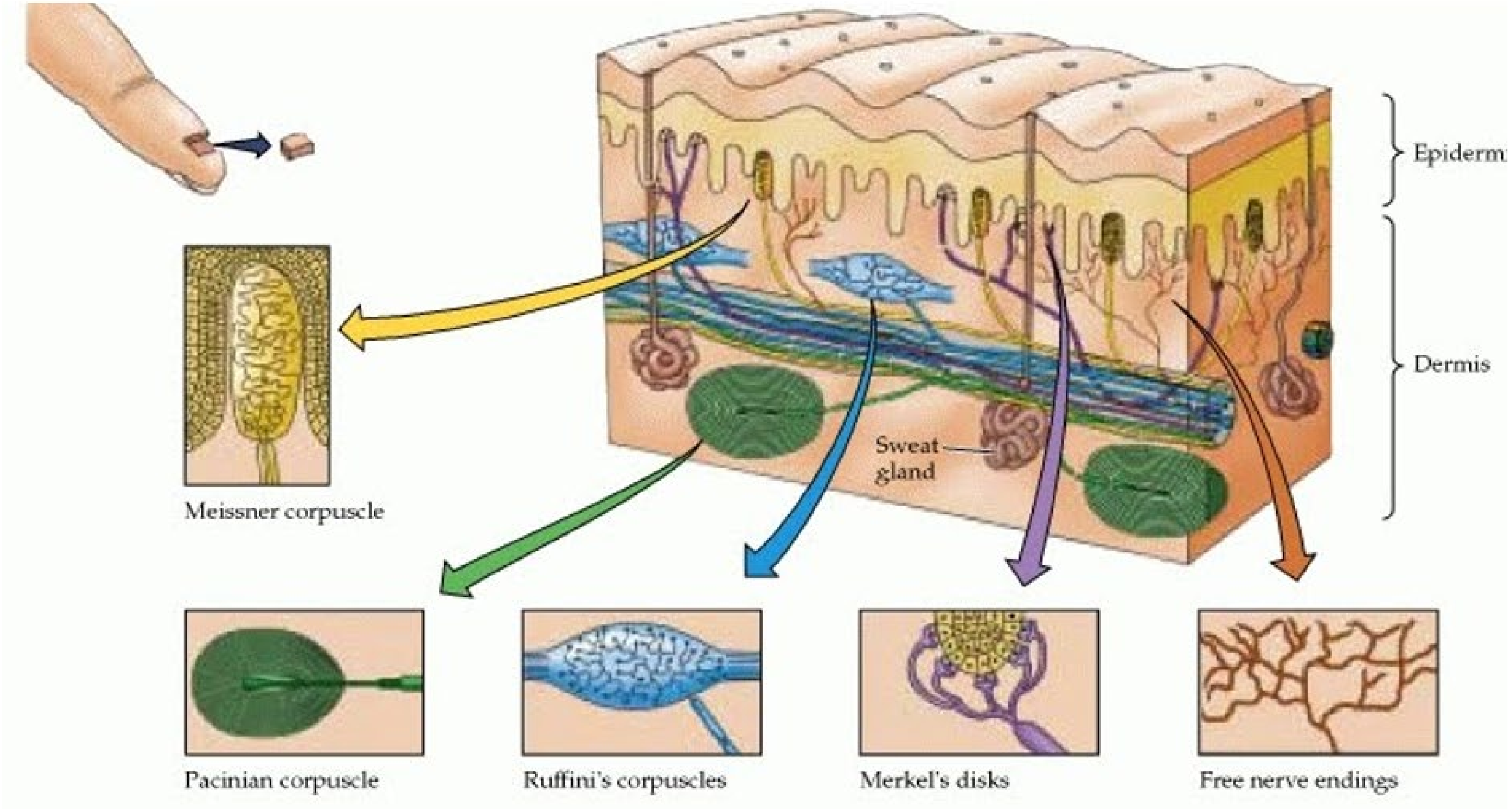
yes this is real wool and real felt.
any idea how this works?



Varies interactive technologies

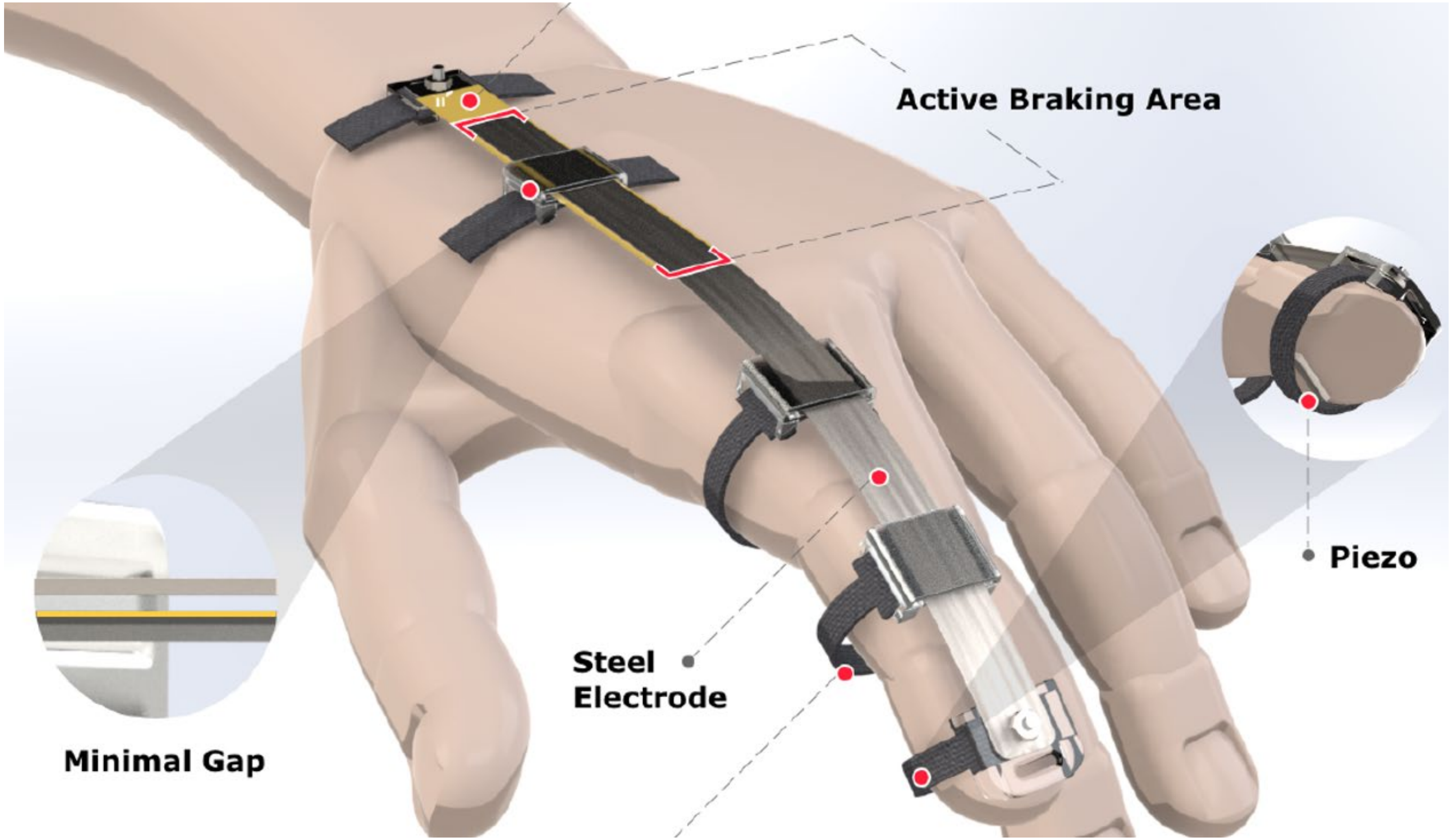
Haptic

Mechanoreception



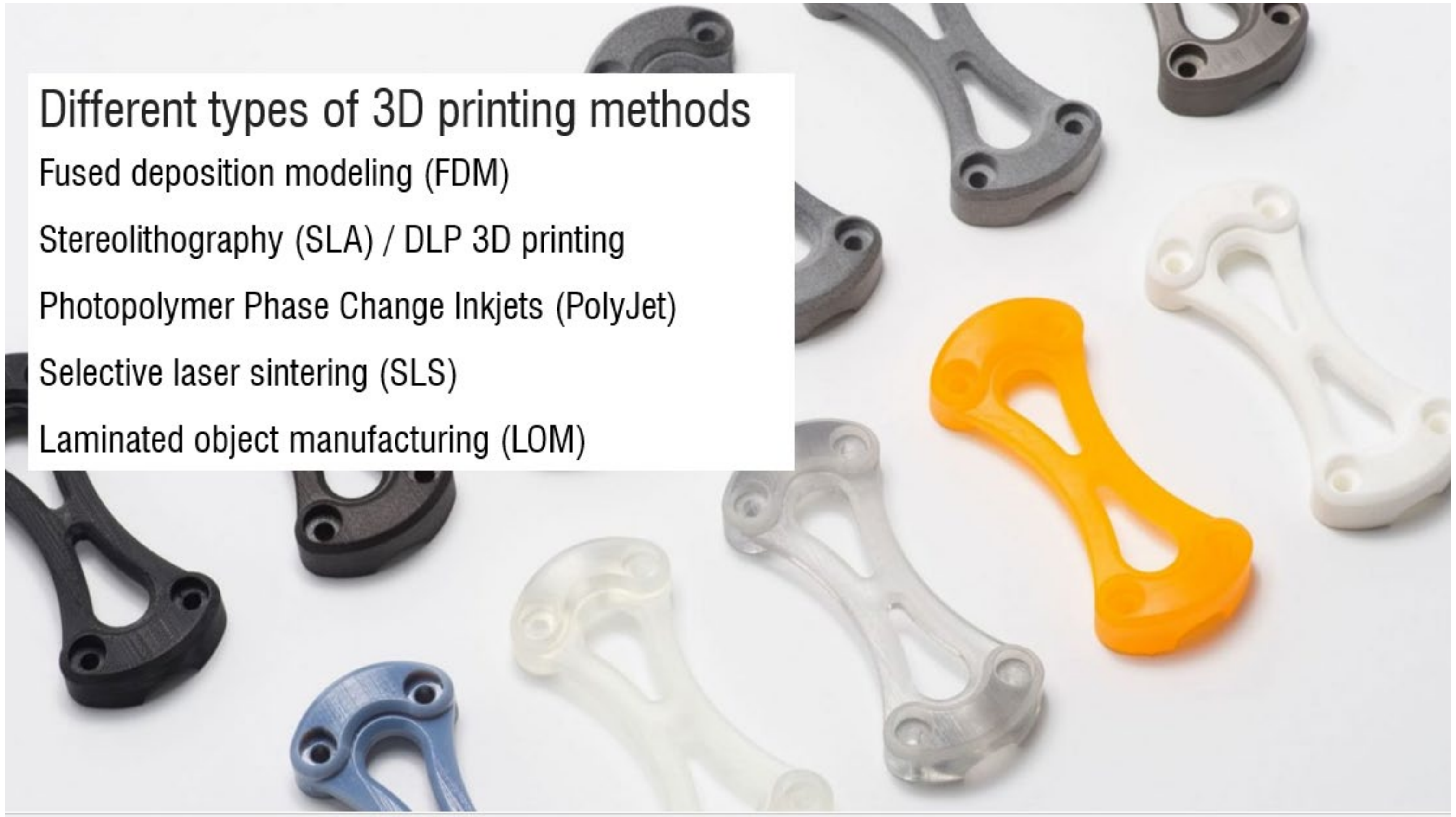
Varies interactive technologies

Haptic + VR



Varies interactive technologies

Fabrication



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)

Varies interactive technologies

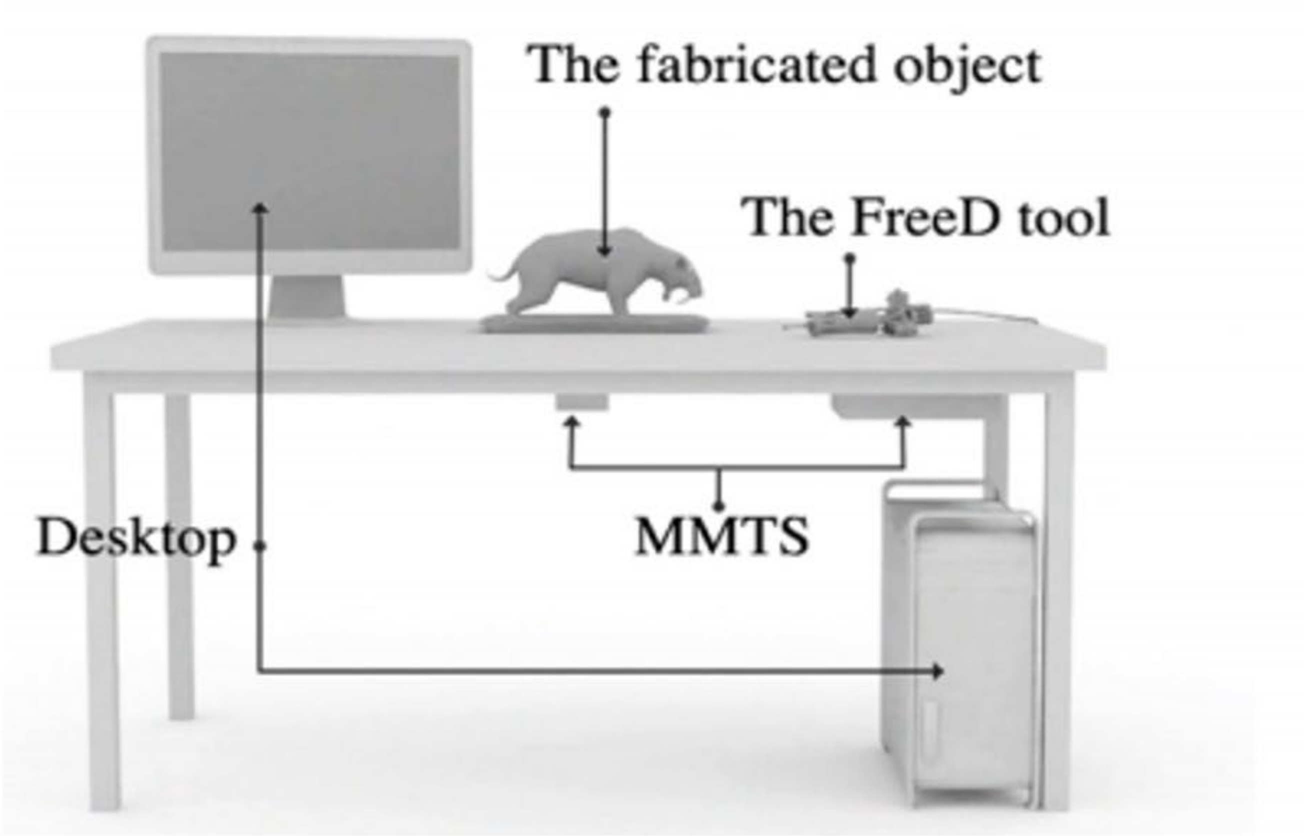
Fabrication

Tracking: 6DOF Magnetic tracking

Control: stop milling at the edge of the digital model

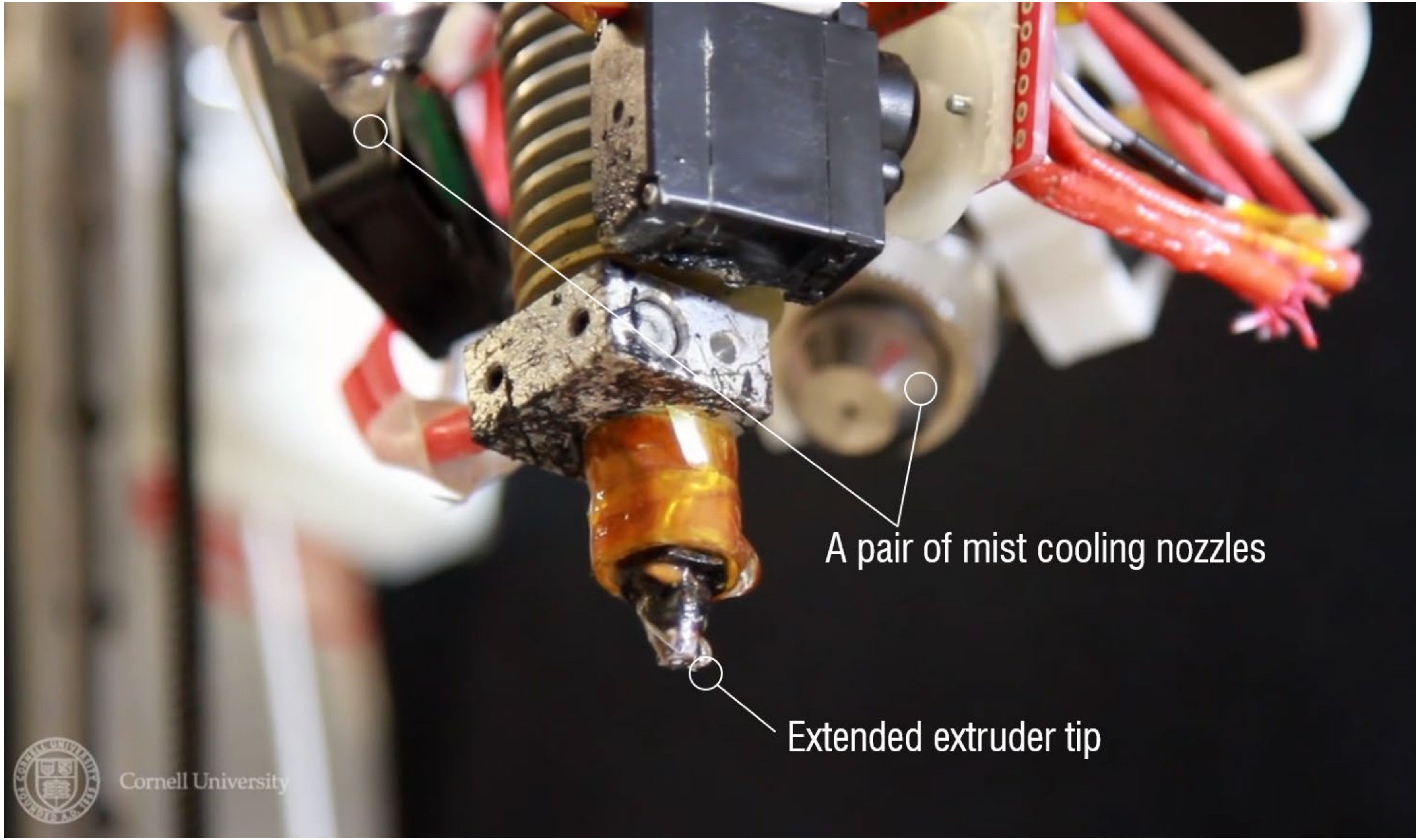
Control can be overridden with manual control

What can this do that the previous project cannot?



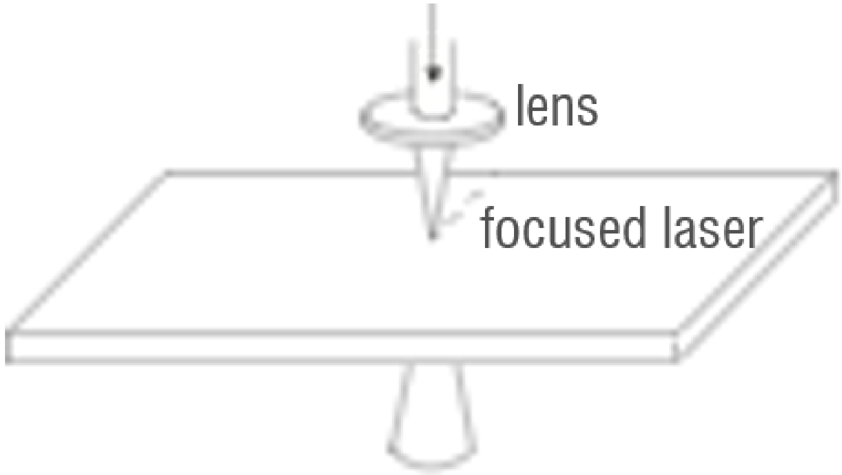
Varies interactive technologies

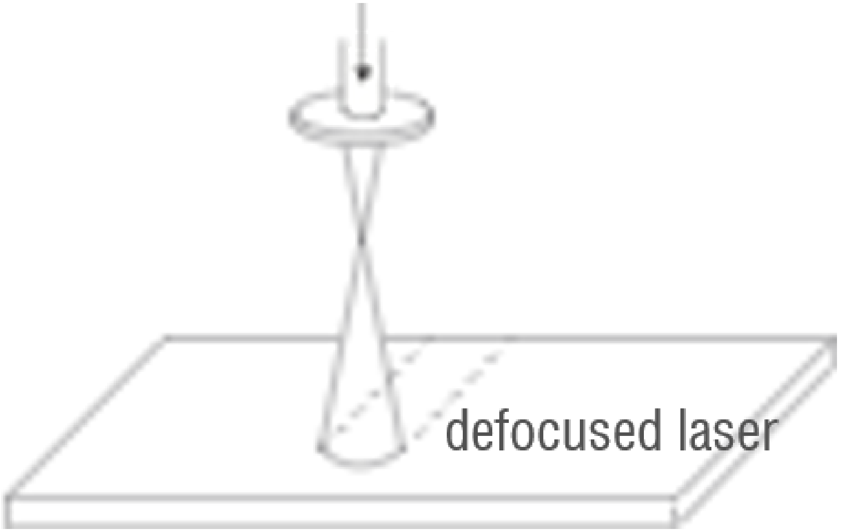
Fabrication



Varies interactive technologies

Fabrication





To cut-through we need to have the laser focused to the top surface of the material

Any benefit of defocusing a laser?

A quick recap

Learn

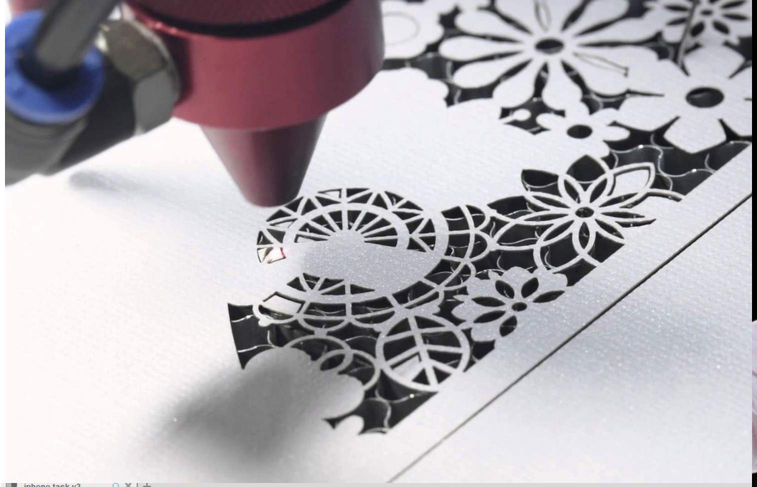
Varies interactive technologies

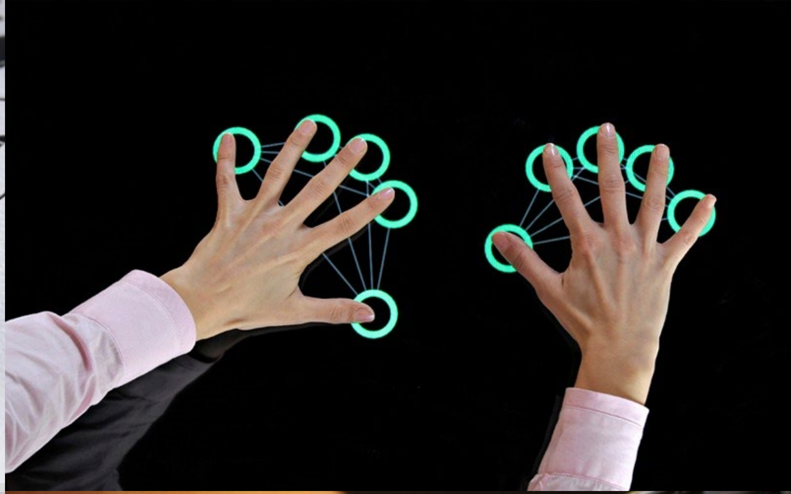
Technologies behind the scene

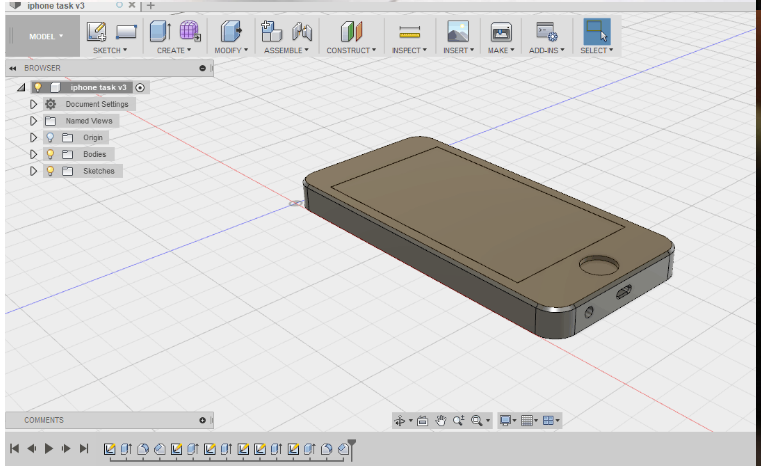
Do

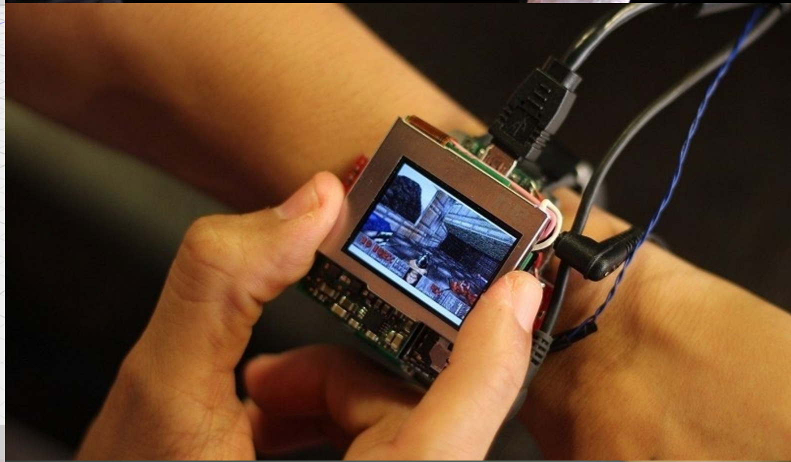
Hands-on building skills

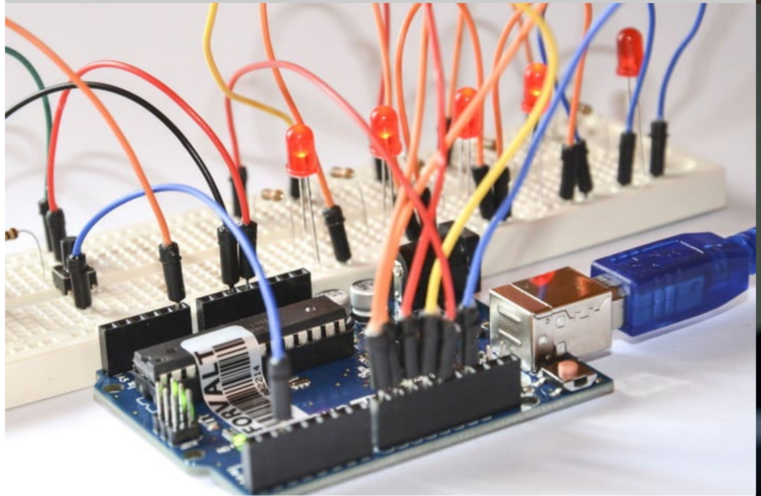
Build interactive gadgets







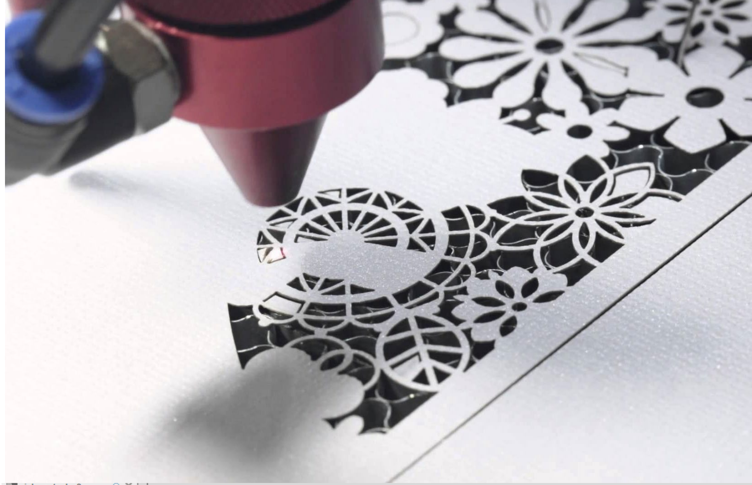


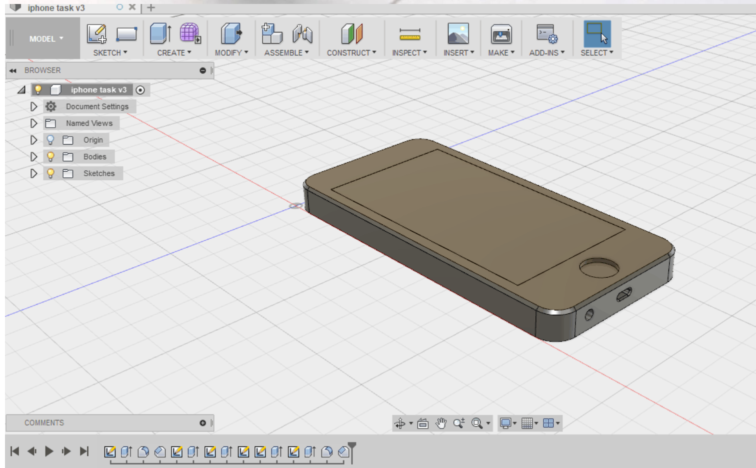


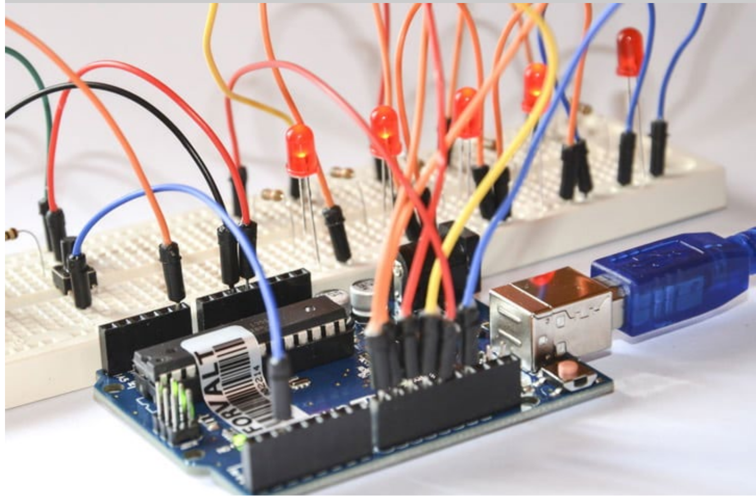
Varies interactive technologies

Hands-on building skills

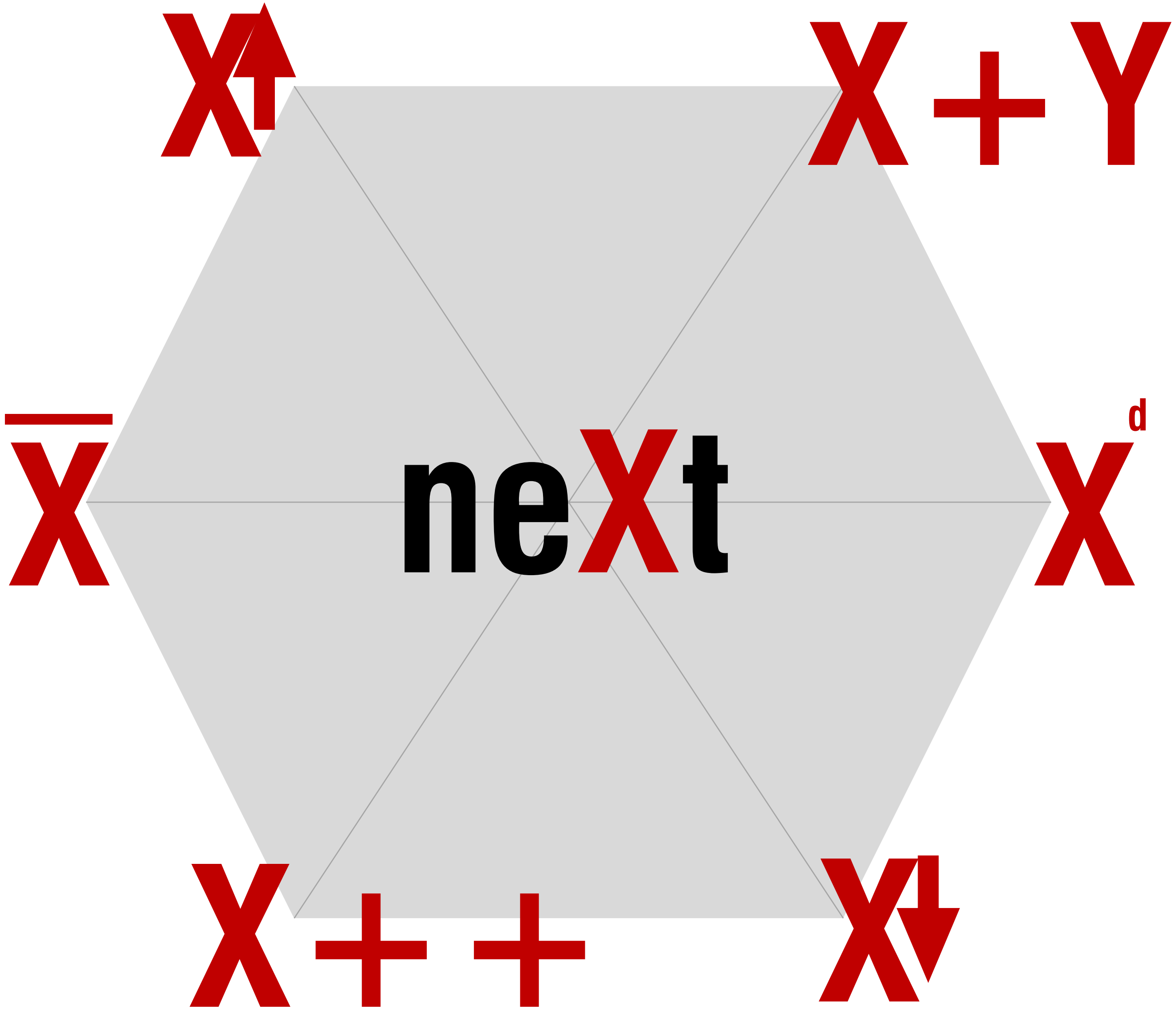
3D modeling
Digital IO -> ESP32
Analog sensing
Servo motor
Ultrasonic sensor
I2C protocol
IMU
Shift register
3D printing
Laser cutting







Robot Competition



how to invent
Future Interactive Tech

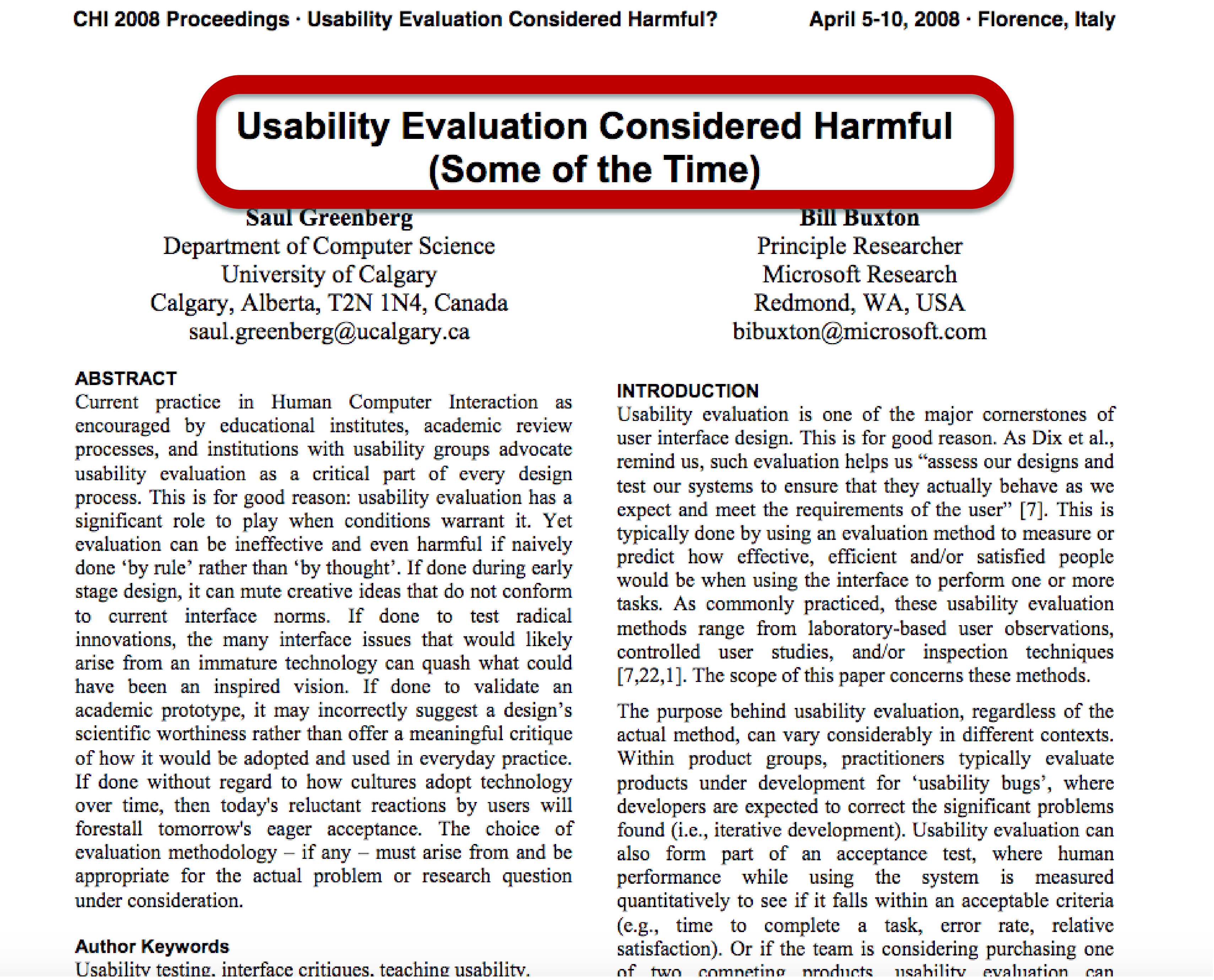
how about user centered design?

- interview potential users
- find something that is hard to do or hard to use…
- e.g. via evaluation (5 experts list usability issues)

We talk about user-centered design in
CMSC434 Introduction to Human-Computer Interaction

do you think any of the cool stuff
I showed in the past few weeks came out of this?

nope.



Usability Evaluation Considered Harmful (Some of the Time)

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ABSTRACT

Current practice in Human Computer Interaction as encouraged by educational institutes, academic review processes, and institutions with usability groups advocate usability evaluation as a critical part of every design process. This is for good reason: usability evaluation has a significant role to play when conditions warrant it. Yet evaluation can be ineffective and even harmful if naively done 'by rule' rather than 'by thought'. If done during early stage design, it can mute creative ideas that do not conform to current interface norms. If done to test radical innovations, the many interface issues that would likely arise from an immature technology can quash what could have been an inspired vision. If done to validate an academic prototype, it may incorrectly suggest a design's scientific worthiness rather than offer a meaningful critique of how it would be adopted and used in everyday practice. If done without regard to how cultures adopt technology over time, then today's reluctant reactions by users will forestall tomorrow's eager acceptance. The choice of evaluation methodology – if any – must arise from and be appropriate for the actual problem or research question under consideration.

Author Keywords
Usability testing, interface critiques, teaching usability,

INTRODUCTION

Usability evaluation is one of the major cornerstones of user interface design. This is for good reason. As Dix et al., remind us, such evaluation helps us "assess our designs and test our systems to ensure that they actually behave as we expect and meet the requirements of the user" [7]. This is typically done by using an evaluation method to measure or predict how effective, efficient and/or satisfied people would be when using the interface to perform one or more tasks. As commonly practiced, these usability evaluation methods range from laboratory-based user observations, controlled user studies, and/or inspection techniques [7,22,1]. The scope of this paper concerns these methods.

The purpose behind usability evaluation, regardless of the actual method, can vary considerably in different contexts. Within product groups, practitioners typically evaluate products under development for 'usability bugs', where developers are expected to correct the significant problems found (i.e., iterative development). Usability evaluation can also form part of an acceptance test, where human performance while using the system is measured quantitatively to see if it falls within an acceptable criteria (e.g., time to complete a task, error rate, relative satisfaction). Or if the team is considering purchasing one of two competing products, usability evaluation can

Challenge:

we have it pretty good already.
the current world offers most
of what the current world needs

going with **immediate needs -> small steps**

but if user-centered design won’t work here
how do you do it, how to make **big steps into the future?**

but if user-centered design won’t work here
how do you do it, how to make **big steps into the future?**

anticipate the future using **what-if questions**

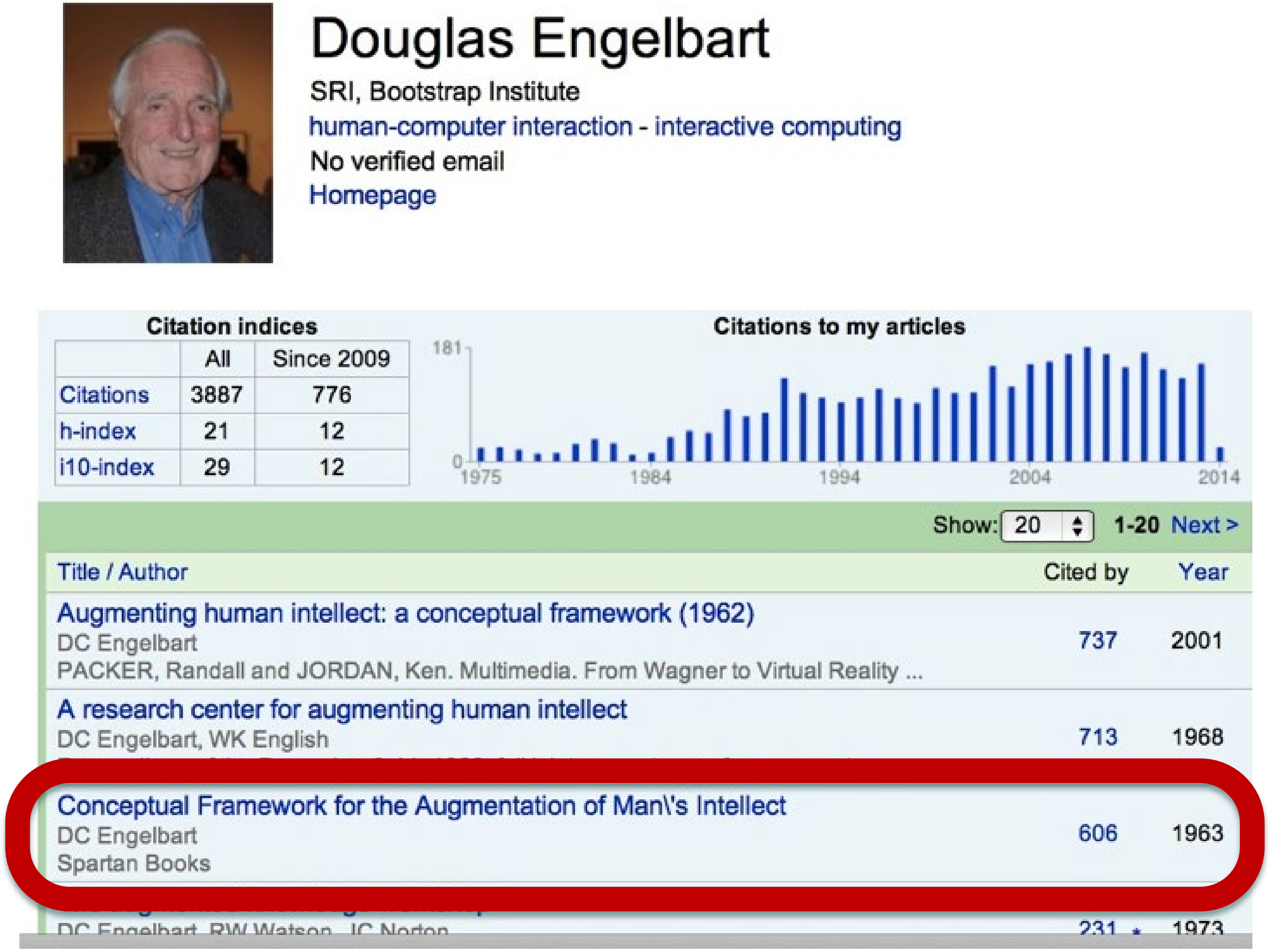
what-if questions

The Mother of All Demos, presented by Douglas Engelbart (1968)

565,601 views

first time the world saw:
the mouse, interactive editing, hyperlinks…

-> his **main contribution was not these technologies,** but…



Douglas Engelbart

SRI, Bootstrap Institute
human-computer interaction - interactive computing
No verified email
Homepage

Citation indices

	All	Since 2009
Citations	3887	776
h-index	21	12
i10-index	29	12

Citations to my articles

Title / Author	Cited by	Year
Augmenting human intellect: a conceptual framework (1962) DC Engelbart PACKER, Randall and JORDAN, Ken. Multimedia. From Wagner to Virtual Reality ...	737	2001
A research center for augmenting human intellect DC Engelbart, WK English	713	1968
Conceptual Framework for the Augmentation of Man\'s Intellect DC Engelbart Spartan Books	606	1963
DC Engelbart, RW Watson, JC Norton	231 *	1973

‘How can we augment human intellect using computing?’

keep in mind
that he asked this at a time when it **sounded absurd:**

this was the time of mainframes & time sharing systems
no one had personal access to a computer;
there were no tools for intellectual workers

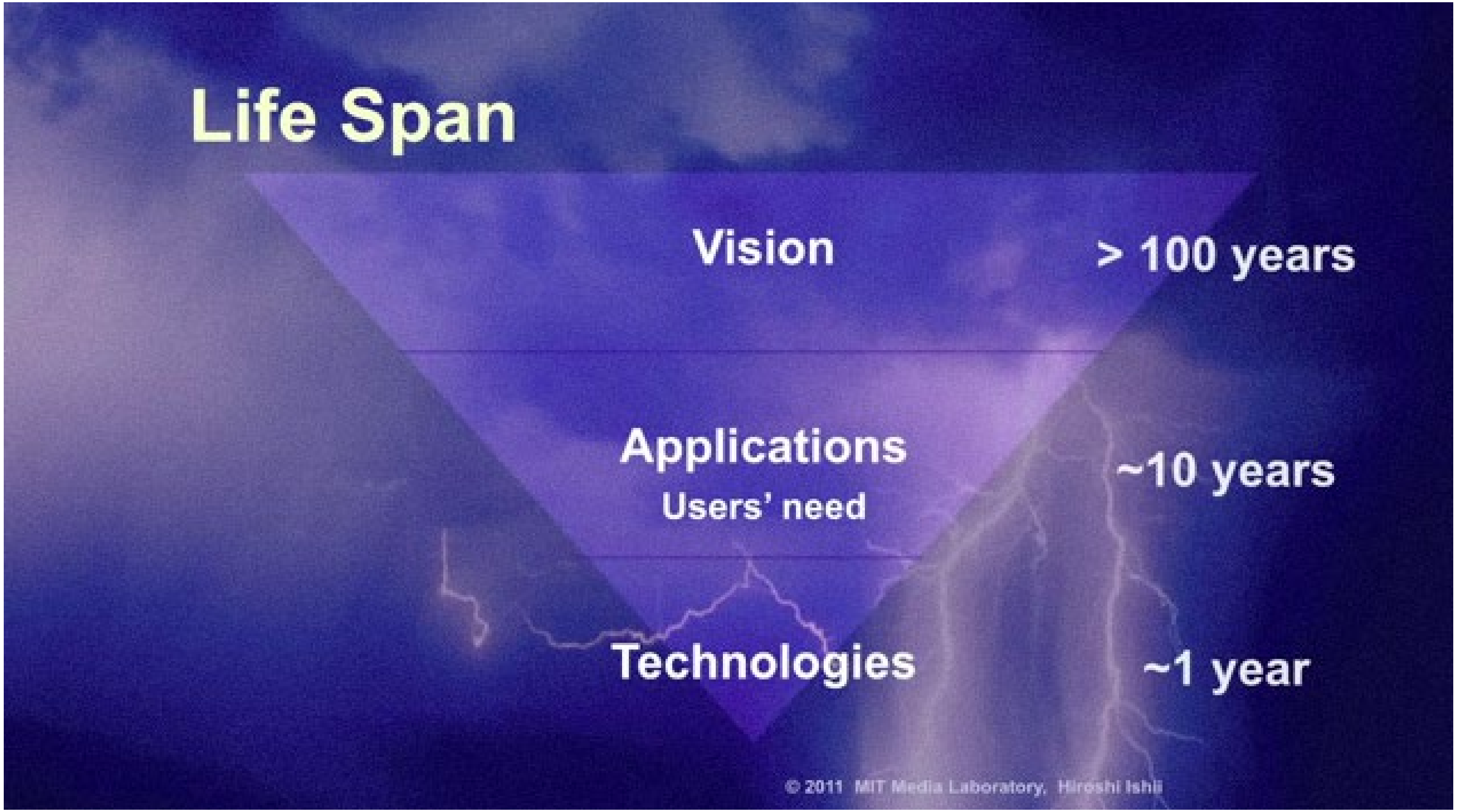
(also, he could have been wrong. computer prices could have stayed high; his work would never have become relevant)

Turing Award

From Wikipedia, the free encyclopedia

		contributions to program and systems verification.
1997	Douglas Engelbart	For an inspiring vision of the future of interactive computing and the invention of key technologies to help realize this vision.
1998	Jim Gray	For seminal contributions to database and transaction processing research and technical leadership in

what-if vision questions are more important



Life Span

Vision > 100 years

Applications
Users' need ~10 years

Technologies ~1 year

© 2011 MIT Media Laboratory, Hiroshi Ishii

How would you like to be remembered by the people who will live in 2200?

What would you leave for them?

Hiroshi Ishii, Keynote at TEI 2008, Bonn Germany, 18.02.2008

Making Digital Tangible

The Battle Against the “Pixel Empire”

SIGCHI Lifetime Research Award Lecture

CHI 2019 in Glasgow, UK, May 6th, 2019

Hiroshi Ishii
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mit
media
lab

Photo courtesy of Nobukazu Kuriki

ACM SIG CHI Lifetime Research Award

how to **choose** a what-if question?

what-if question

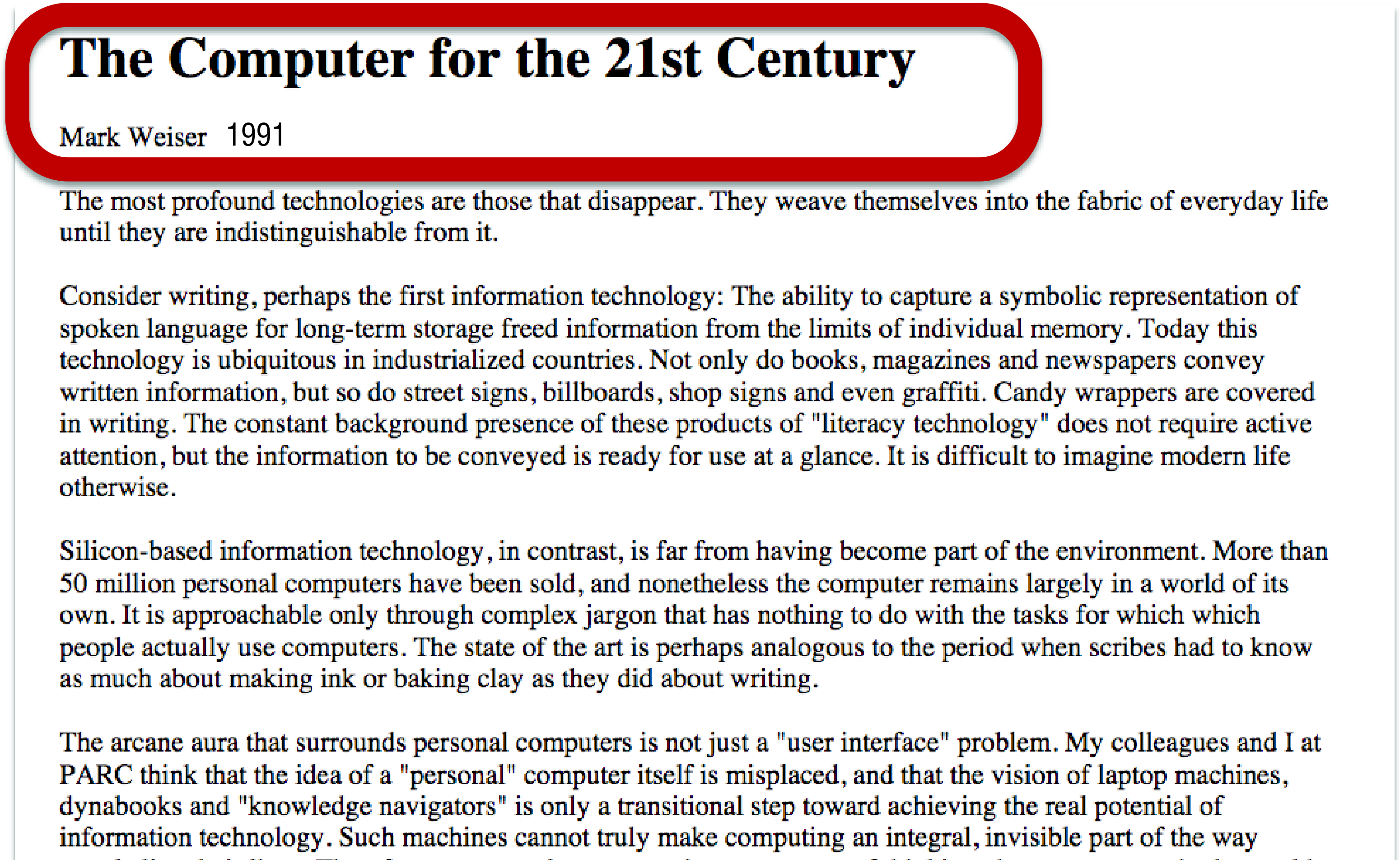
= a wild extrapolation of what we see today

(and maybe there’s nothing, but at least you tried to be the first!)

some more selected **what-if questions**…

ubiquitous computing (1991):

what if a user had multiple computers/CPUs available?



The Computer for the 21st Century

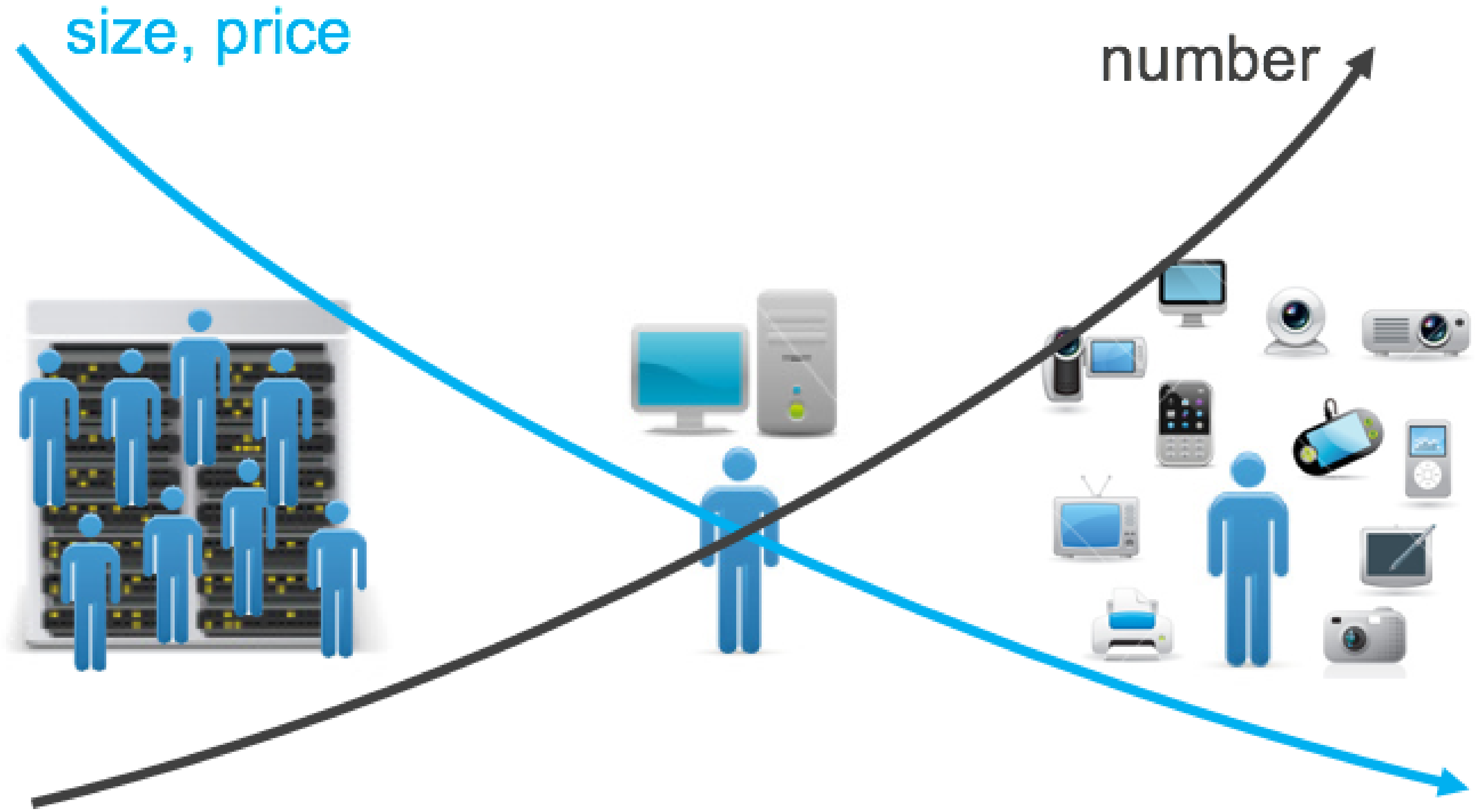
Mark Weiser 1991

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

Consider writing, perhaps the first information technology: The ability to capture a symbolic representation of spoken language for long-term storage freed information from the limits of individual memory. Today this technology is ubiquitous in industrialized countries. Not only do books, magazines and newspapers convey written information, but so do street signs, billboards, shop signs and even graffiti. Candy wrappers are covered in writing. The constant background presence of these products of "literacy technology" does not require active attention, but the information to be conveyed is ready for use at a glance. It is difficult to imagine modern life otherwise.

Silicon-based information technology, in contrast, is far from having become part of the environment. More than 50 million personal computers have been sold, and nonetheless the computer remains largely in a world of its own. It is approachable only through complex jargon that has nothing to do with the tasks for which which people actually use computers. The state of the art is perhaps analogous to the period when scribes had to know as much about making ink or baking clay as they did about writing.

The arcane aura that surrounds personal computers is not just a "user interface" problem. My colleagues and I at PARC think that the idea of a "personal" computer itself is misplaced, and that the vision of laptop machines, dynabooks and "knowledge navigators" is only a transitional step toward achieving the real potential of information technology. Such machines cannot truly make computing an integral, invisible part of the way



1960's

1 computer : n users

1980's

1 computer :: 1 user

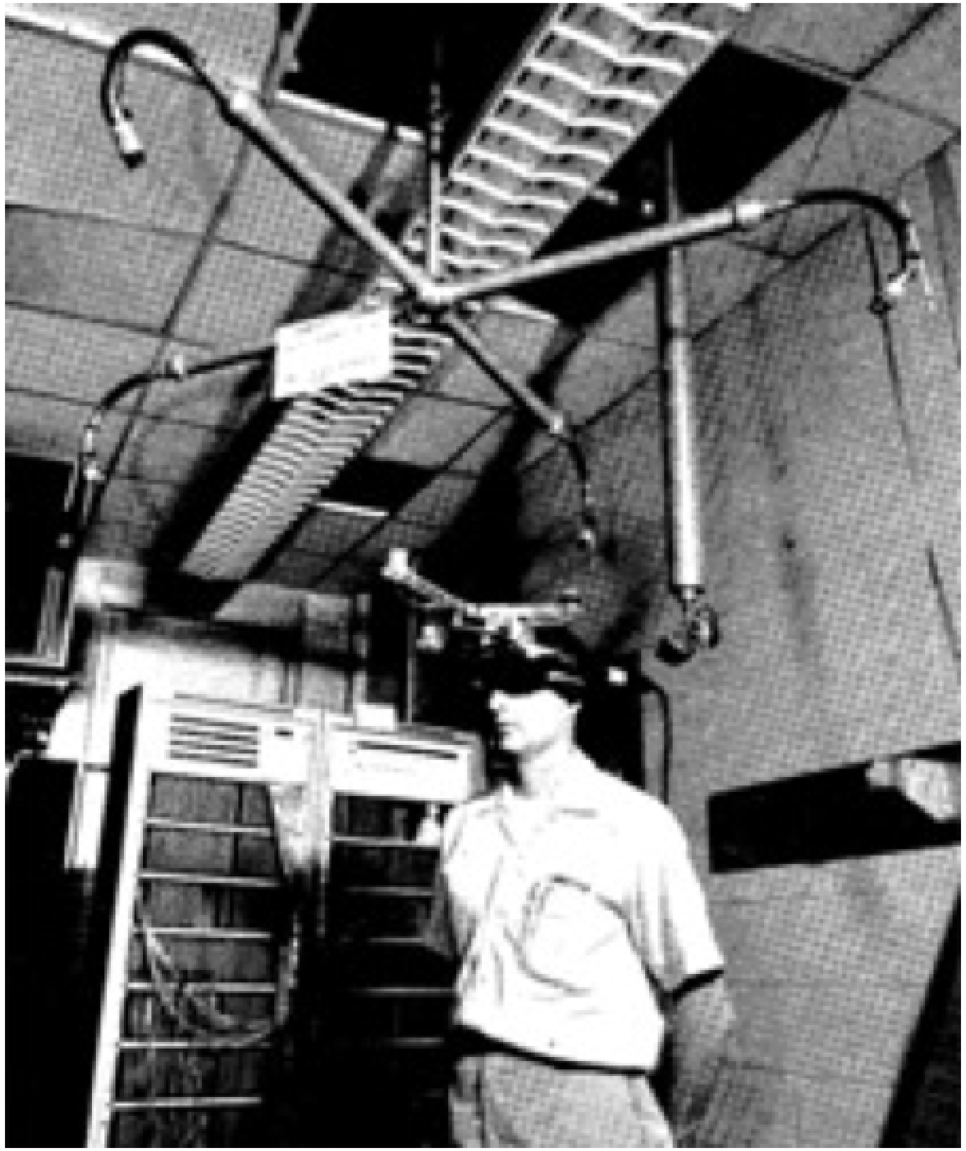
2000's

n computers :: 1 user


huc:99

augmented reality (1968):

what if there was the perfect display
everywhere I look



tangible computing (1997):

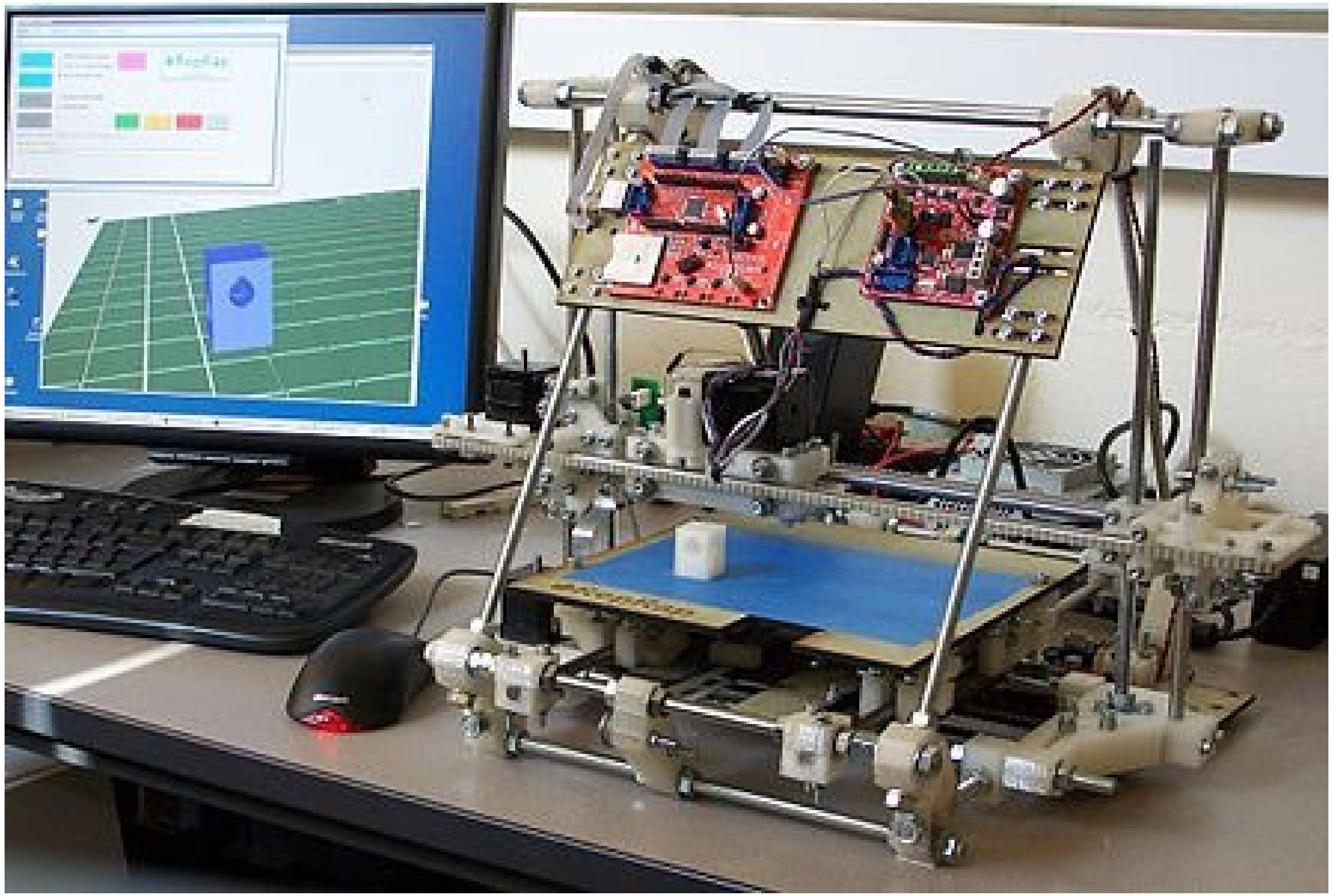
what if I operated stuff in the world not via a computer,
but by actually **manipulating it?**

wearable (1961) + implanted:

what if **technology shrink past mobile?**

personal fabrication (2005):

what if **fabrication machinery is available** in every office and/or every household?



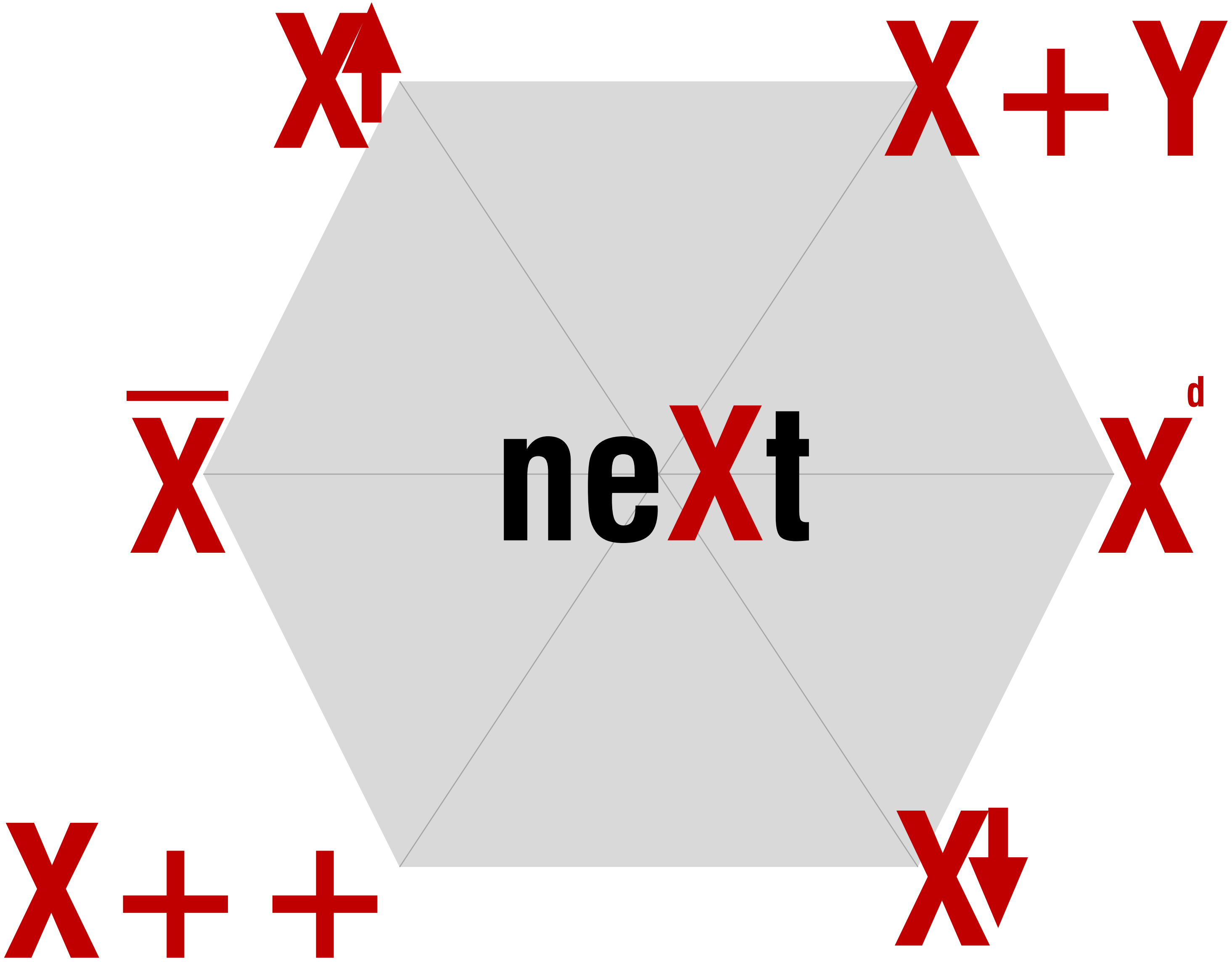
looking back through the history of HCI,
we see that **quantum leaps have rarely resulted from studies on user needs or market research;**

they have come from people
asking **visionary what-if questions!**

what if questions are hard…

another way to extrapolate into the future
is to use **invention iterators…**

after X, what is neXt?



$X\uparrow$ $X+Y$

$\bar{X}$ **neXt** X^d

$X++$ $X\downarrow$

[Ramesh Raskar]

X =

idea you just heard
concept
patent
new product
product feature
design
art
algorithm

X++

increment

(make it faster, better, cheaper)

the first iPhone was a huge leap forward…
everything else is mainly **incremental**

	iPhone	iPhone 3G	iPhone 3GS	iPhone 4	iPhone 4S	iPhone 5	iPhone 5c	iPhone 5s
Code Name	M68	N82	N88	N90	N94	N41	N48	N51
Model Name	iPhone 1,1	iPhone 1,2	iPhone 2,1	iPhone 3,1	iPhone 4,1	iPhone 5,1	iPhone 5,3	iPhone 6,1
OS	iPhone OS 1.0	iPhone OS 2.0	iPhone OS 3.0	iOS 4	iOS 5	iOS 6	iOS 7	iOS 7
Screen Size	3.5-inch 480x320 at 163ppi	3.5-inch 480x320 at 163ppi	3.5-inch 480x320 at 163ppi	3.5-inch IPS 960x640 at 326ppi	3.5-inch IPS 960x640 at 326ppi	4-inch 1136x640 in-cell IPS LCD at 326ppi	4-inch 1136x640 in-cell IPS LCD at 326ppi	4-inch 1136x640 in-cell IPS LCD at 326ppi
System-on-chip	Samsung S5L8900	Samsung S5L8900	Samsung APL0298C05	Apple A4	Apple A5	Apple A6	Apple A6	64-bit Apple A7, M7 motion c-processor
CPU	ARM 1176JZ(F)-S	ARM 1176JZ(F)-S	600MHz ARM Cortex A8	800MHz ARM Cortex A8	800MHz dual-core ARM Cortex A9	1.3GHz dual-core Swift (ARM v7s)	1.3GHz dual-core Swift (ARM v7s)	1.3GHz dual-core Cyclone (ARM v8)
GPU	Power VR MBX Lite 3D	Power VR MBX Lite 3D	PowerVR SGX535	PowerVR SGX535	PowerVR dual-core SGX543MP4	PowerVR triple-core SGX543MP3	PowerVR triple-core SGX543MP3	PowerVR G6430
RAM	128MB	128MB	256MB	512MB	512MB	1GB	1GB	1GB DDR3
Storage	4GB/8GB (16GB later)	8GB/16GB	16GB/32GB	16GB/32GB	16GB/32GB/64GB	16GB/32GB/64GB	16GB/32GB	16GB/32GB/64GB
Top Data Speed	EDGE	3G 3.6	HSPA 7.2	HSPA 7.2	HSPA 14.4	LTE/DC-HSPA	LTE/DC-HSPA	LTE/DC-HSPA
SIM	Mini	Mini	Mini	Micro	Micro	Nano	Nano	Nano
Rear Camera	2MP	2MP	3MP/480p	5MP/720p, f2.8, 1.75μ	8MP/1080p, f2.4, BSI, 1.4μ	8MP/1080p, f2.4, BSI, 1.4μ	8MP/1080p, f2.4, BSI, 1.4μ	8MP/1080p, f2.2, BSI, 1.5μ
Front Camera	None	None	None	VGA	VGA	1.2MP/720p, BSI	1.2MP/720p, BSI	1.2MP/720p, BSI
Bluetooth	Bluetooth 2.0 + EDR	Bluetooth 2.0 + EDR	Bluetooth 2.1 + EDR	Bluetooth 2.1 + EDR	Bluetooth 4.0	Bluetooth 4.0	Bluetooth 4.0	Bluetooth 4.0
WiFi	802.11 b/g	802.11 b/g	802.11 b/g	802.11 b/g/n (2.4GHz)	802.11 b/g/n (2.4GHz)	802.11 b/g/n (2.4 and 5GHz)	802.11 b/g/n (2.4 and 5GHz)	802.11 b/g/n (2.4 and 5GHz)
GPS	None	aGPS	aGPS	aGPS	aGPS, GLONASS	aGPS, GLONASS	aGPS, GLONASS	aGPS, GLONASS
Sensors	Light, accelerometer, proximity	Light, accelerometer, proximity	Light, accelerometer, proximity, compass	Light, accelerometer, proximity, compass, gyroscope	Light, accelerometer, proximity, compass, gyroscope, infrared	Light, accelerometer, proximity, compass, gyroscope, infrared	Light, accelerometer, proximity, compass, gyroscope, infrared	Light, accelerometer, proximity, compass, gyroscope, infrared, fingerprint identity

touch screen is better to use…
screen size becomes a bit bigger..
camera resolution becomes a bit higher…

better
= pick your favorite adjective:

- more context aware
- more adaptive
- more (temporally) coherent
- more progressive
- more efficient
- more parallelized
- more distributed
- more personalized/customized
- more democratized

least innovative

X++ is a sign that the **field or tech is “maturing”**

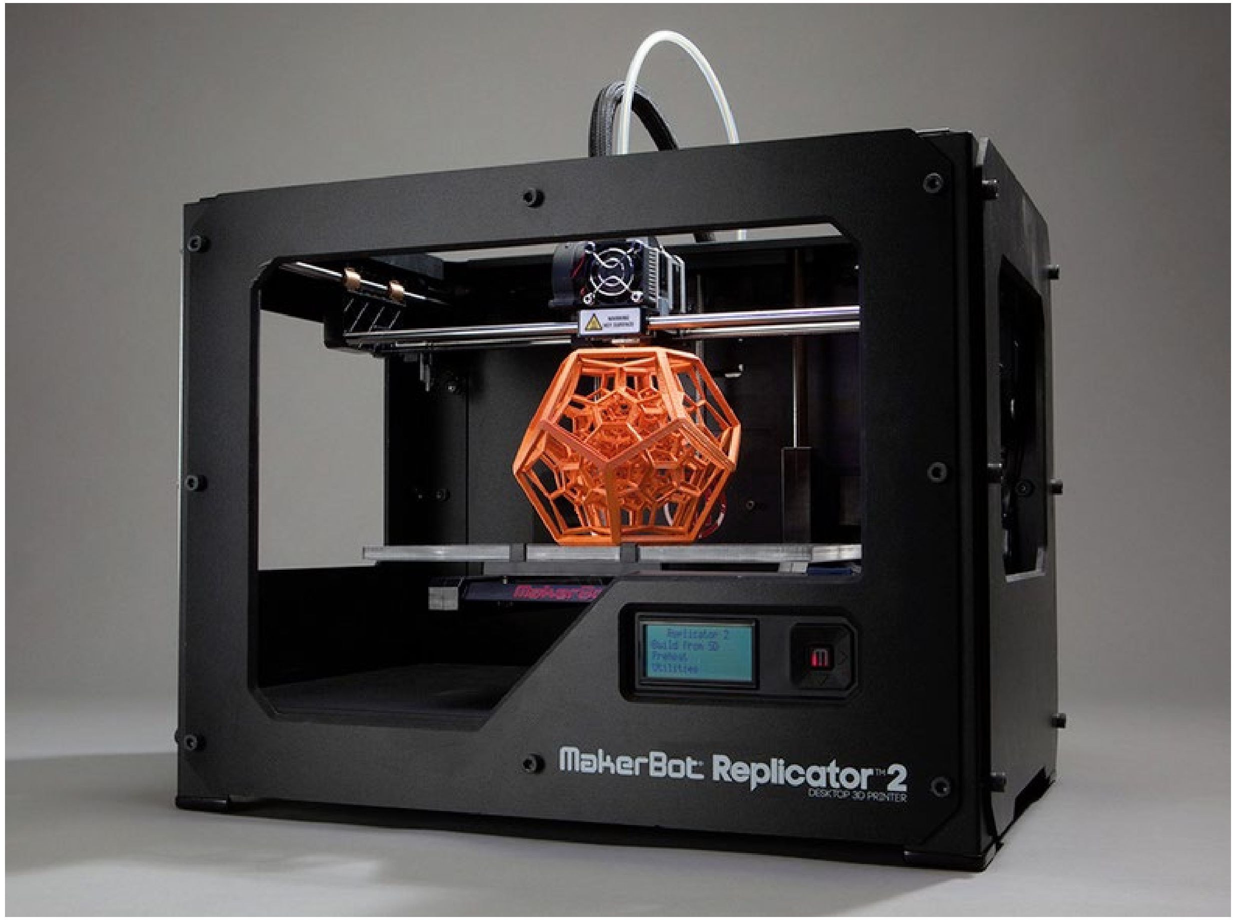
increments get smaller, less ground-breaking

given a nail

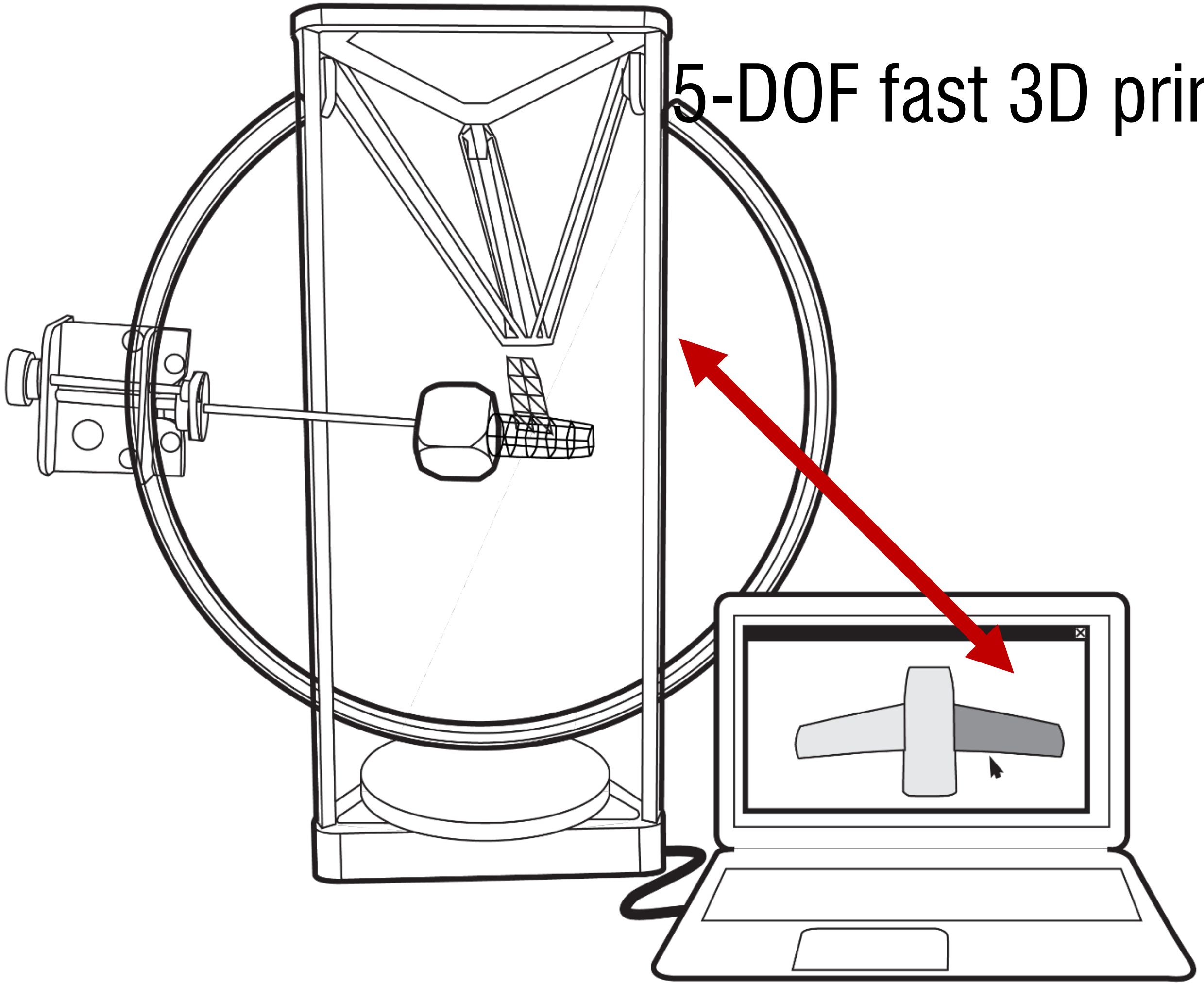
find all the hammers

given a problem,
find all solutions…

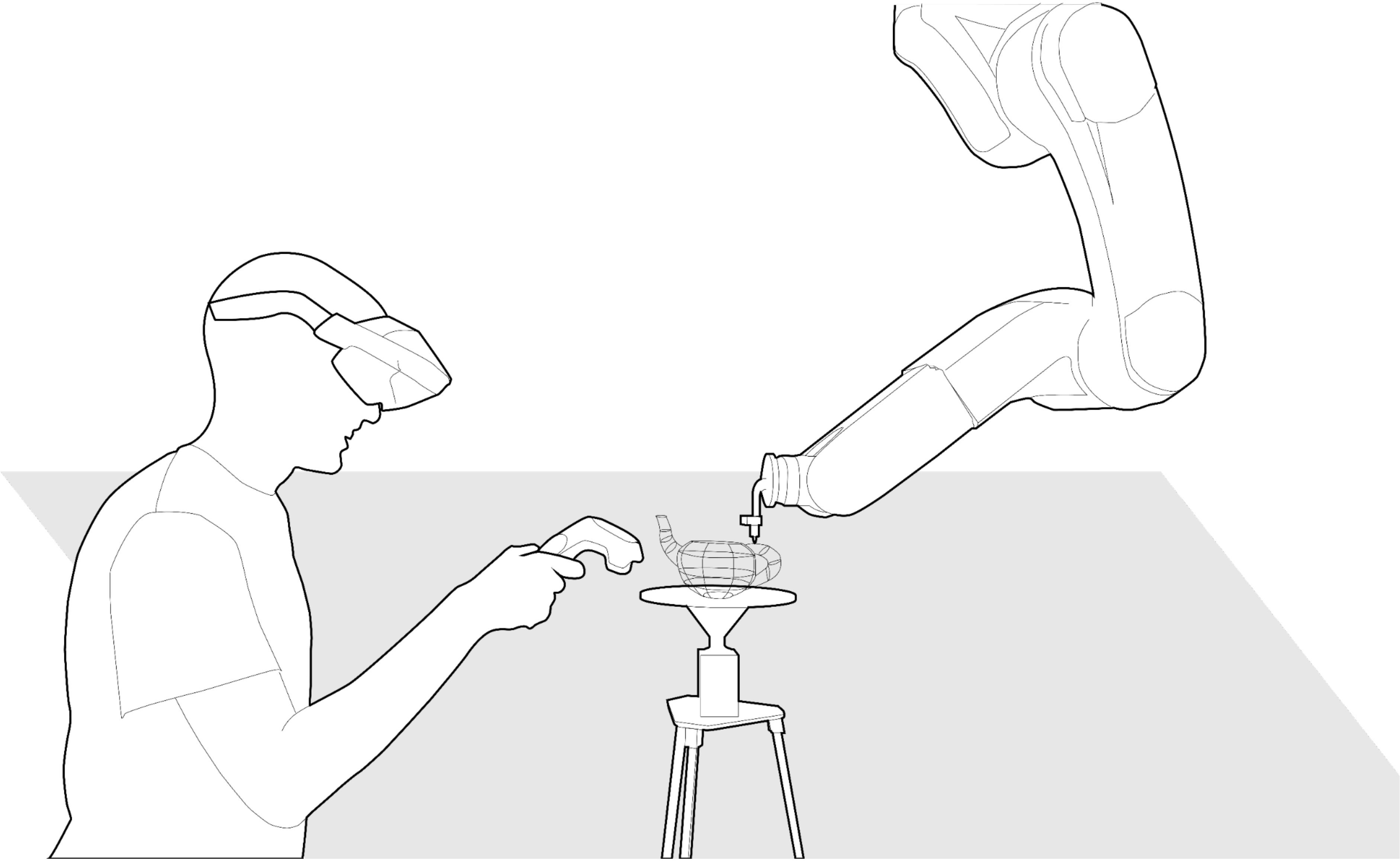
e.g. 3D Printing is **not interactive**



solution 1:



solution 2:



solution 3:

— dance **around the same problem**

given a hammer

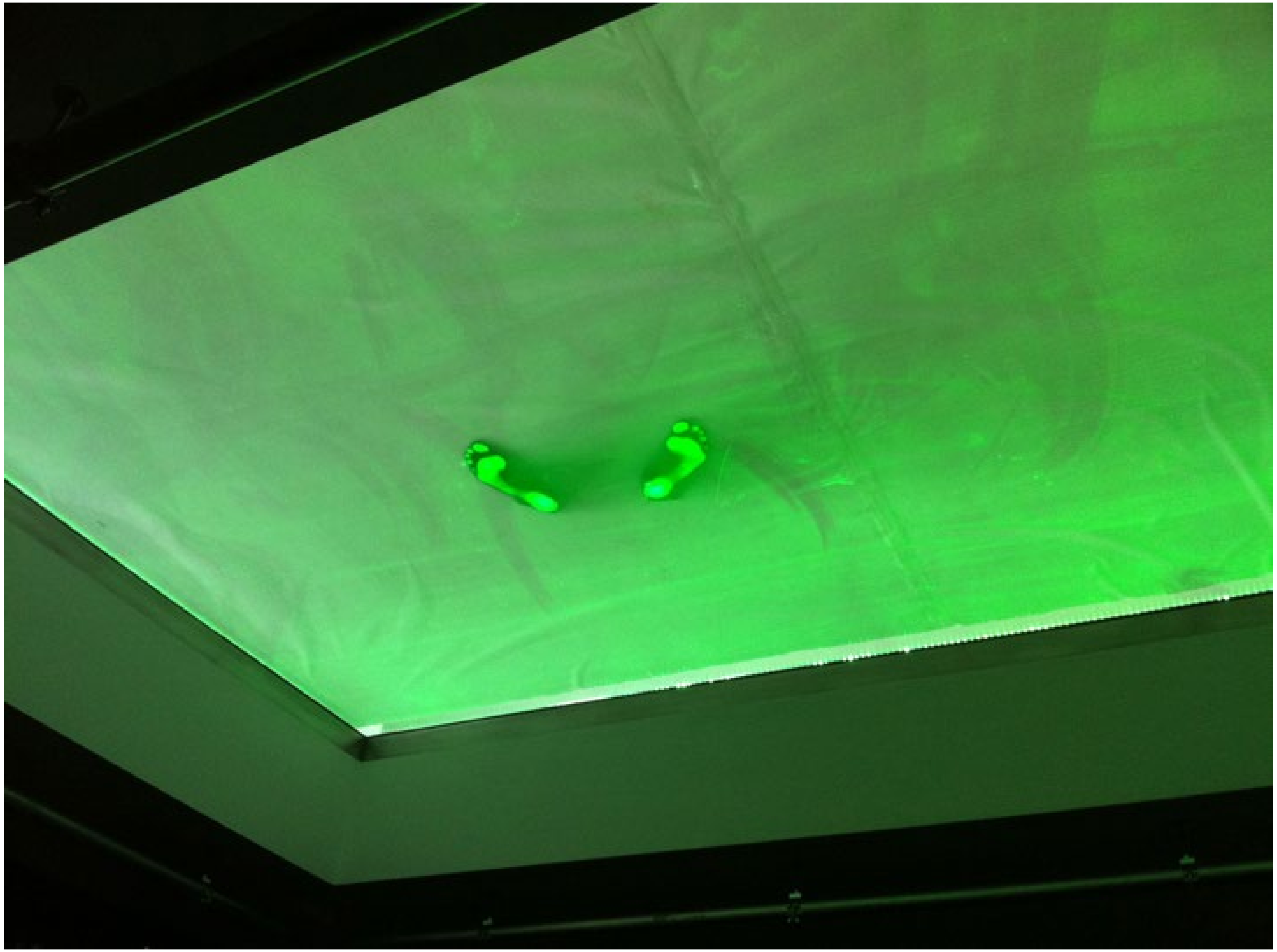
find all the nails

given a cool solution find other problems

-> high inventive power

multitouch:

for hands -> multitouch for feet



look back at your career
what could be **your hammer?**

<something you know a lot about but others know little>

extend it
to the **next dimension**

flickr -> youtube
text, audio (speech), image, video -> physical objects

visible images -> infrared
sound -> ultrasound -> electromagnetic spectrum

macro scale -> micro scale
airbag for car -> airbag for .. ?

= generalize the concept (common in patent applications)

variation for hammer re-use, but more **actionable**
(extend solution to next dimension)

X+Y fusion of the dissimilar

$X+Y$ is only good when

$$\text{value}(X+Y) > \text{value}(X)+\text{value}(Y)$$

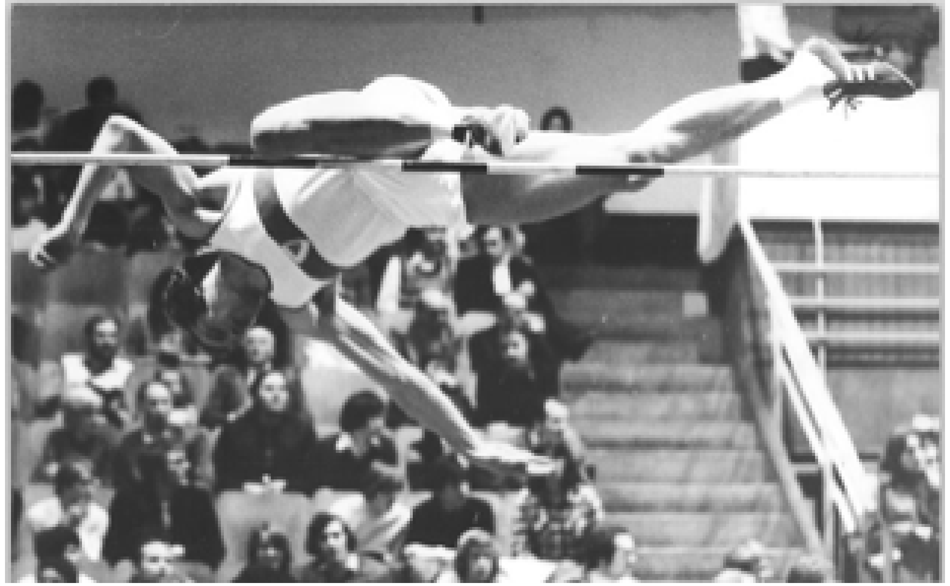
bad example:
mounting touchscreen on mouse offers
exactly the same value as mouse & touchscreen separate

good example: food printing + perception:

maybe automation can feed some new insight back into perception research

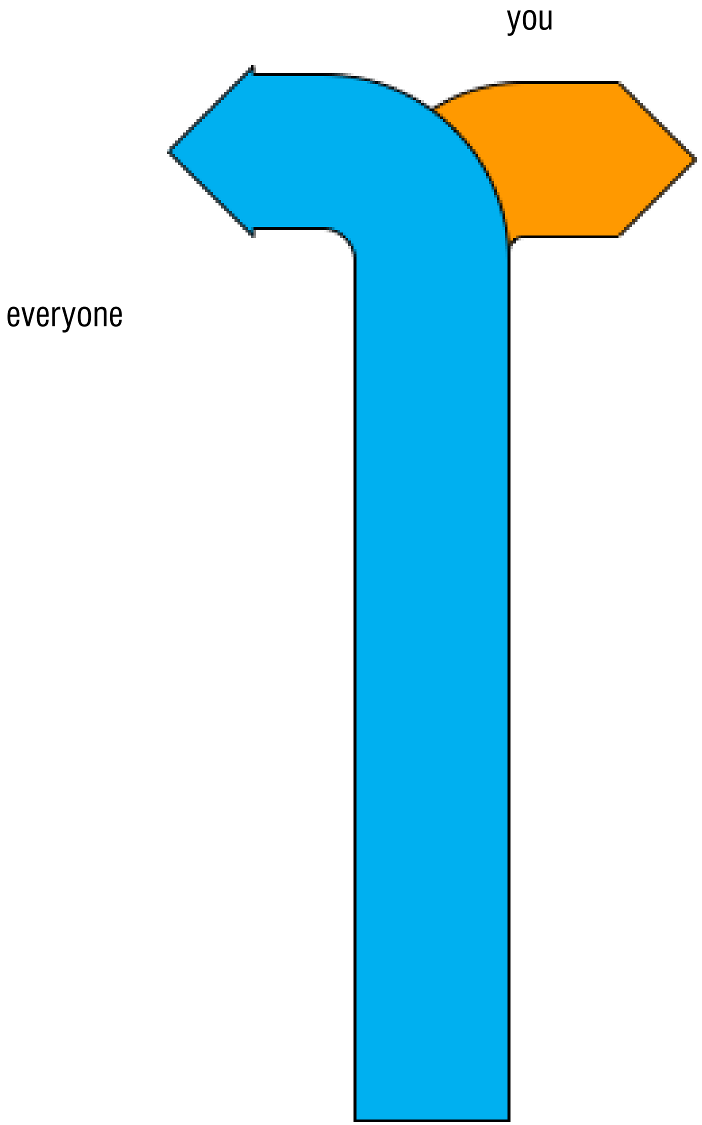
high innovative power, but not very actionable
because for a given X the search space of all Y is large and unstructured

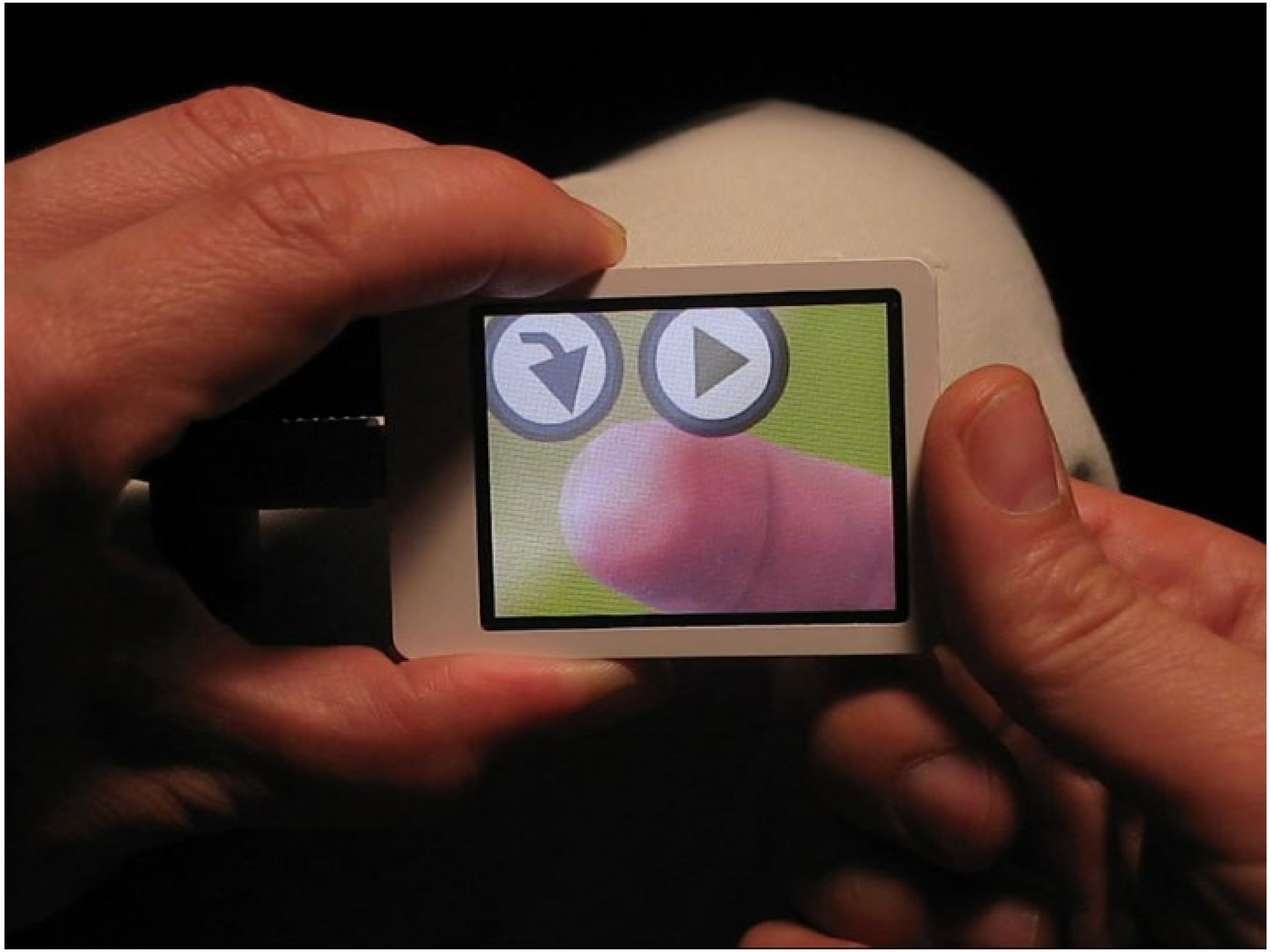
$\overline{\mathbf{X}}$ do the opposite



Straddle Method for High Jump

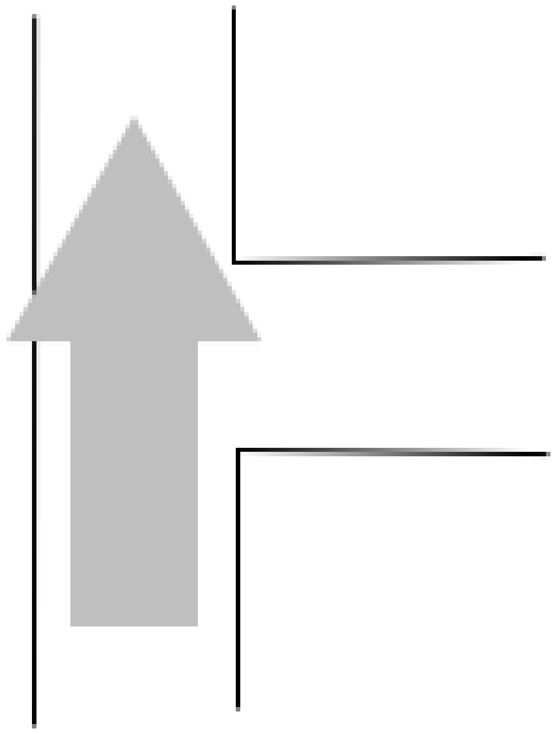
1968 Olympics: “Fosbury Flop”


you
everyone



everyone adds touch screens to the front,
instead add it on the back

process:
look at existing designs.
find point(s) where everyone
made the same decision



stand at the edge of the ‘known world’

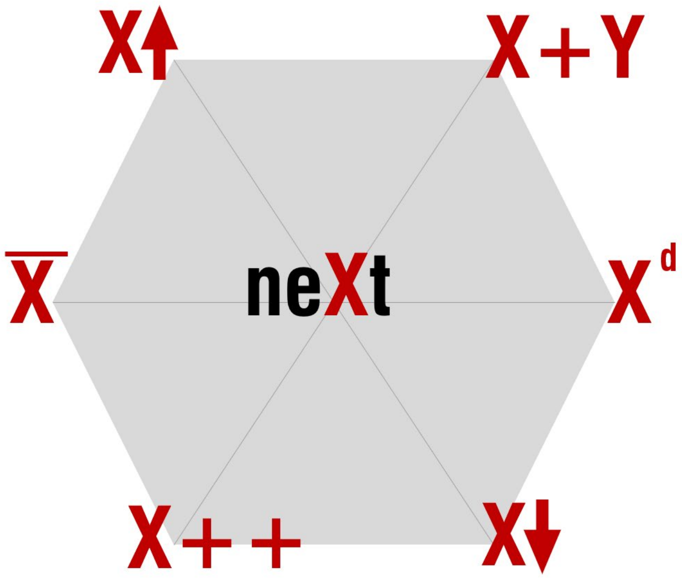
awards (best paper, best product, researchers)

network and talk to people:
avoid small-talk .. ask ‘what is the latest x’

patents (but searching them is time-consuming)

(do not always) follow the hype

too much competition



any template will produce the same ideas
as everyone else who uses the same templates

address this by
1. using a wilder set of iterators than others
2. make your very own iterators

conclusions

“so many people get **stuck in incremental research:**
‘my double click mouse is better
than your double click mouse’”

“do what I call **vision-driven research…**”

[Ishii at UIST’11]

great project:

1. **novel** = not done
2. **important** = future people will say “this matters to us”
3. **something you can do** = you have/can acquire the skills

Based on Prof. Stefanie Mueller’s slides.

https://courseexp.umd.edu/

Your feedback will help us improve the course in the future☺