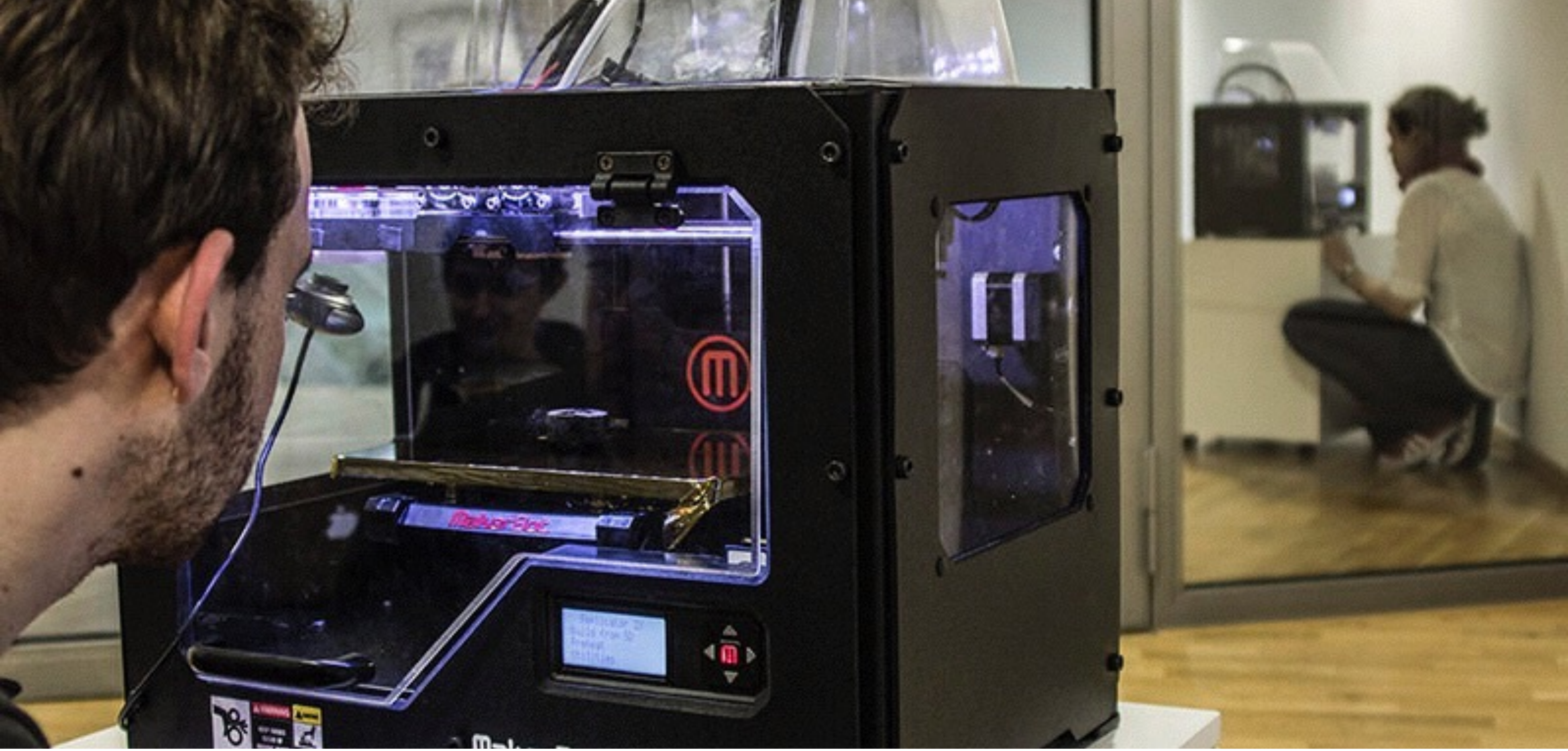


Personal Fabrication: Intellectual Property & Sustainability

6.S063 Engineering Interaction Technologies

Prof. Stefanie Mueller | HCI Engineering Group

intellectual property

anyone remembered recording music from the radio to compact cassette?

was this legal or illegal?

<30 sec brainstorming>

in Germany, it was **illegal** for large parts of the 1970s

at the same time,
more than 2.4 million recorders were already sold….

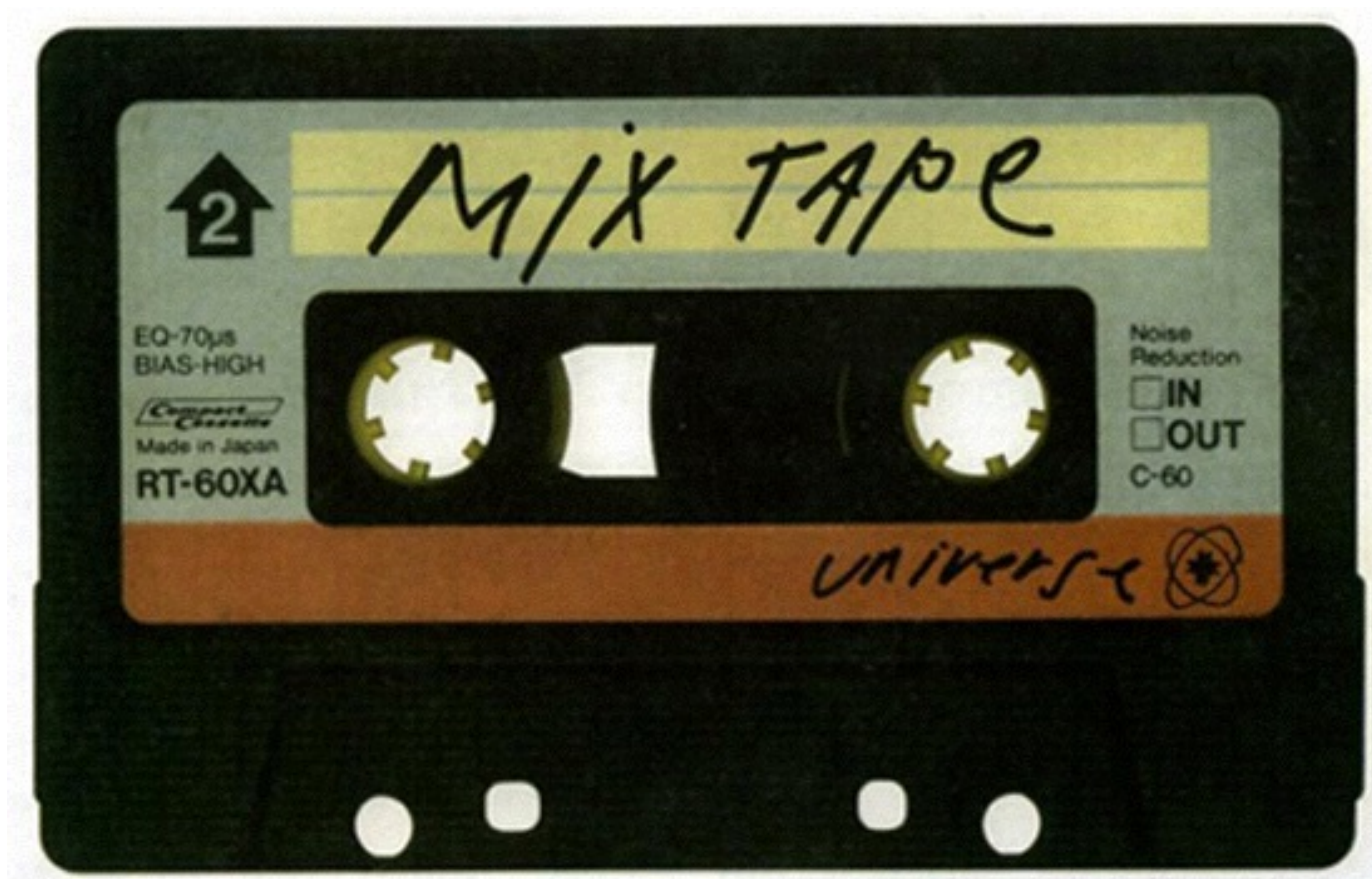
many people found themselves performing
copyright violations on a daily basis

before recorders,
people had to own the physical album in order to listen to the music
e.g. vinyl record

physical medium that contains music = license to own it

with cassette recorders:

physical medium that contains music != license to own it



1965: german copyright organization
charged 5 cents per empty cassette
(‘advance compensation for music to be recorded on cassette’)

this was later applied to CDs/DVDs to

GEMA (German organization)

From Wikipedia, the free encyclopedia

The **Gesellschaft für musikalische Aufführungs- und mechanische Vervielfältigungsrechte** (**GEMA**; English: Society for musical performing and mechanical reproduction rights) is a state-authorized collecting society and performance rights organization based in Germany, with administrative offices in Berlin and Munich. GEMA represents the usage rights stemming from authors' rights (e.g., mechanical licensing, broadcast licensing, synchronization licensing) for the musical works of those composers, lyricists, and publishers who are members in the organization. It is the only such institution in Germany and a member of BIEM and CISAC. Other collecting societies include the (AKM) *Society of authors, composers and music publishers* (de) in Austria and SUISA in Switzerland.

As an "accredited profit-making association with legal capacity" (de: *rechtsfähiger wirtschaftlicher Verein*), GEMA's capacity to be a subject of legal rights and duties is based upon state conferral (under Article 22 of the German civil code). The chairperson of the executive board (CEO) is Harald Heker (since 2007); the chairperson of the board of directors is Enjott Schneider.

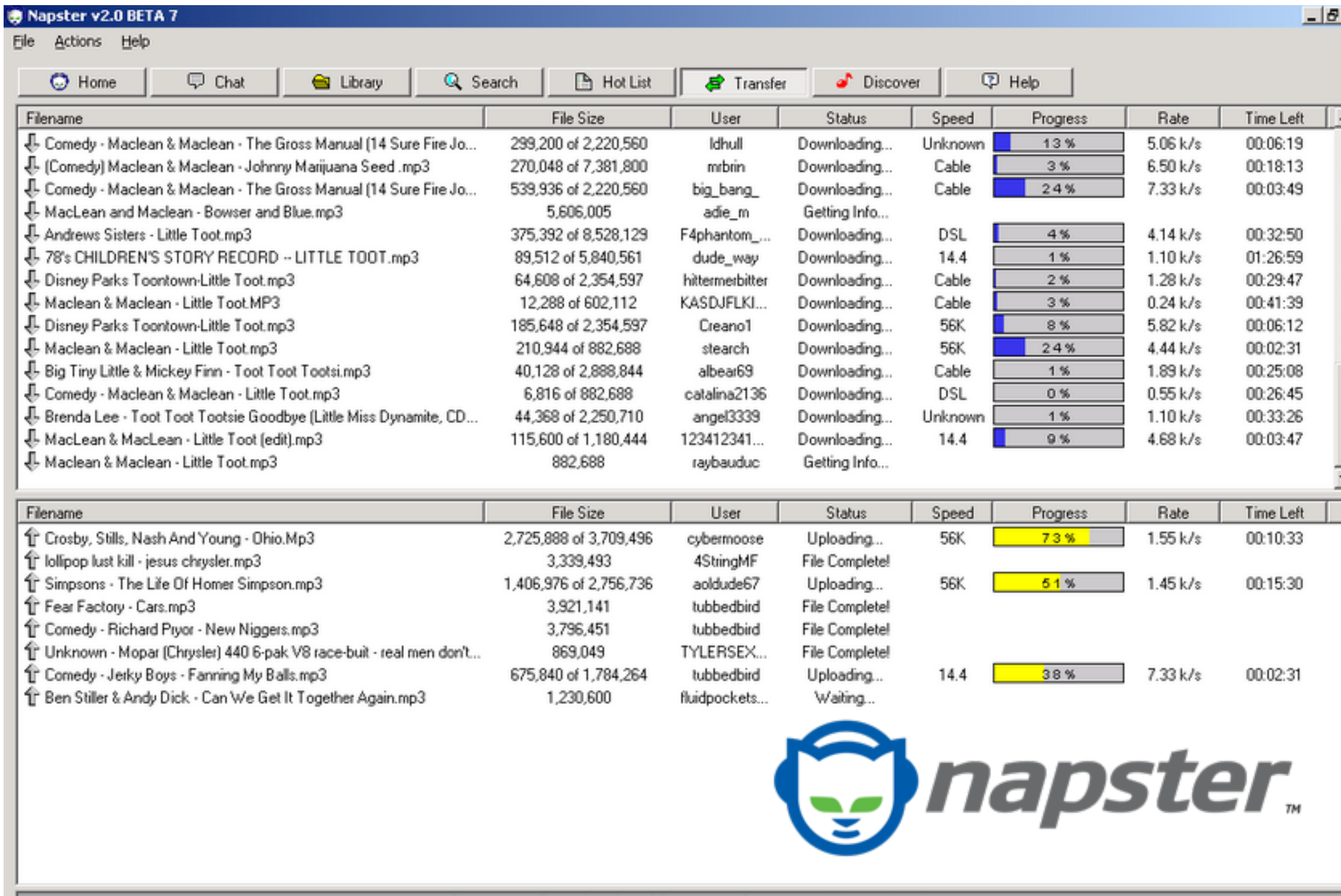
Contents [hide]

Gesellschaft für musikalische Aufführungs- und mechanische Vervielfältigungsrechte

GEMA

Abbreviation	GEMA
Formation	September 28, 1933; 84 years ago

but with the **internet** and sharing digital music online
the **physical medium could no longer be charged…**
(there were actually discussions on charging every hard drive you own)

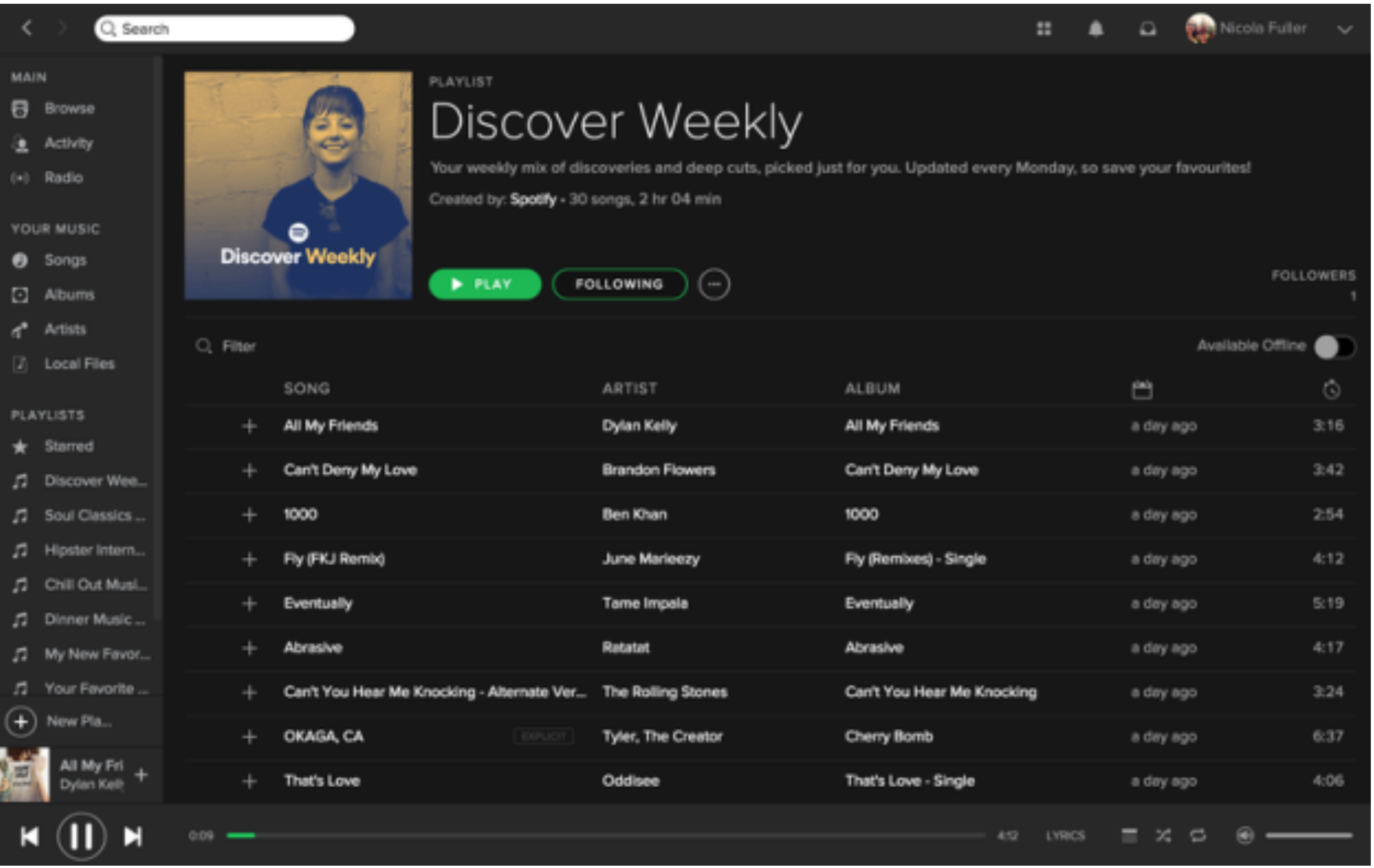


thousands and thousands of
cease and desist orders going out every month…

so where are we **today?**

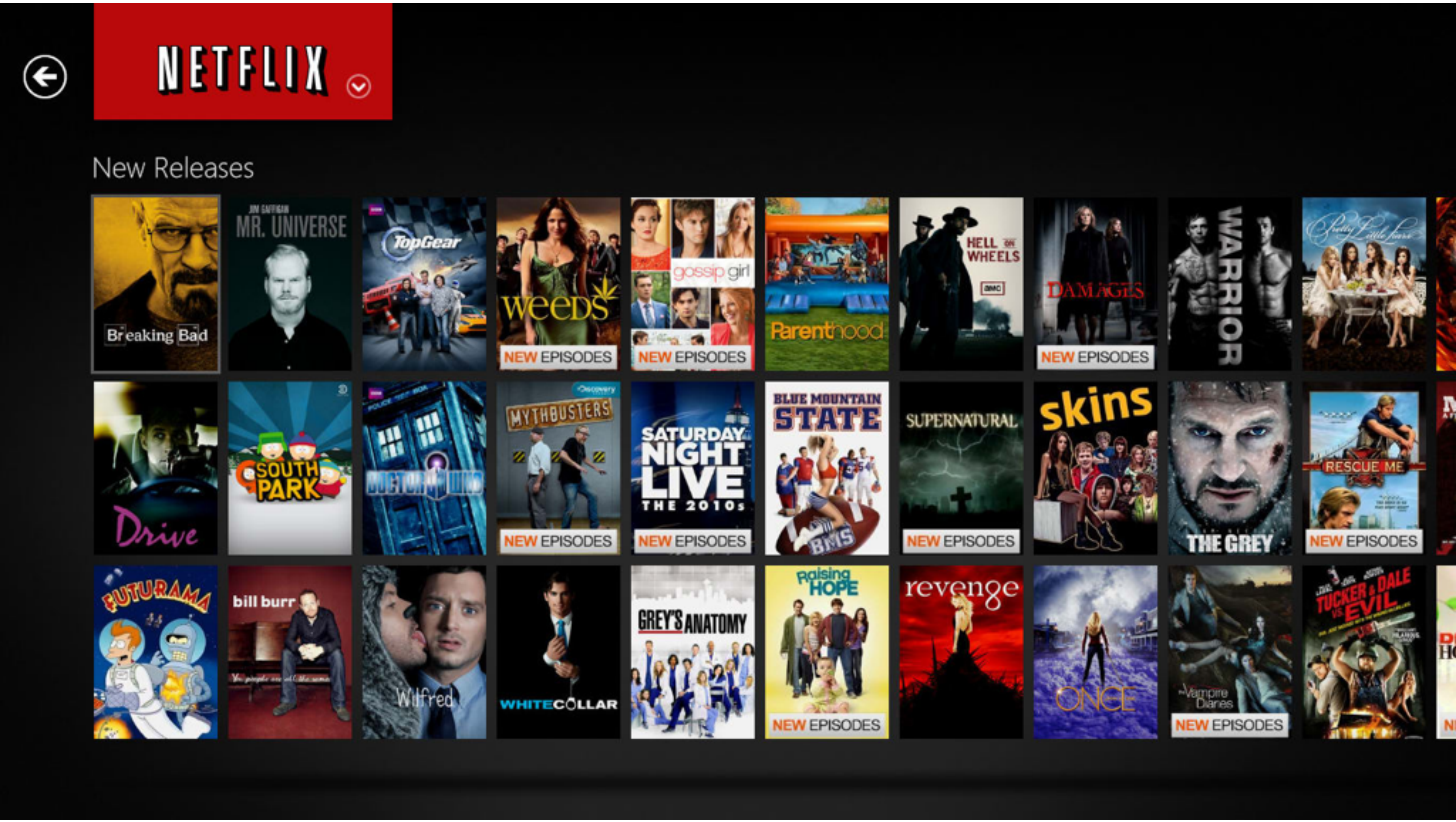
today:

monthly flat-rate fees like Spotify
seem to have fixed the problem broadly…

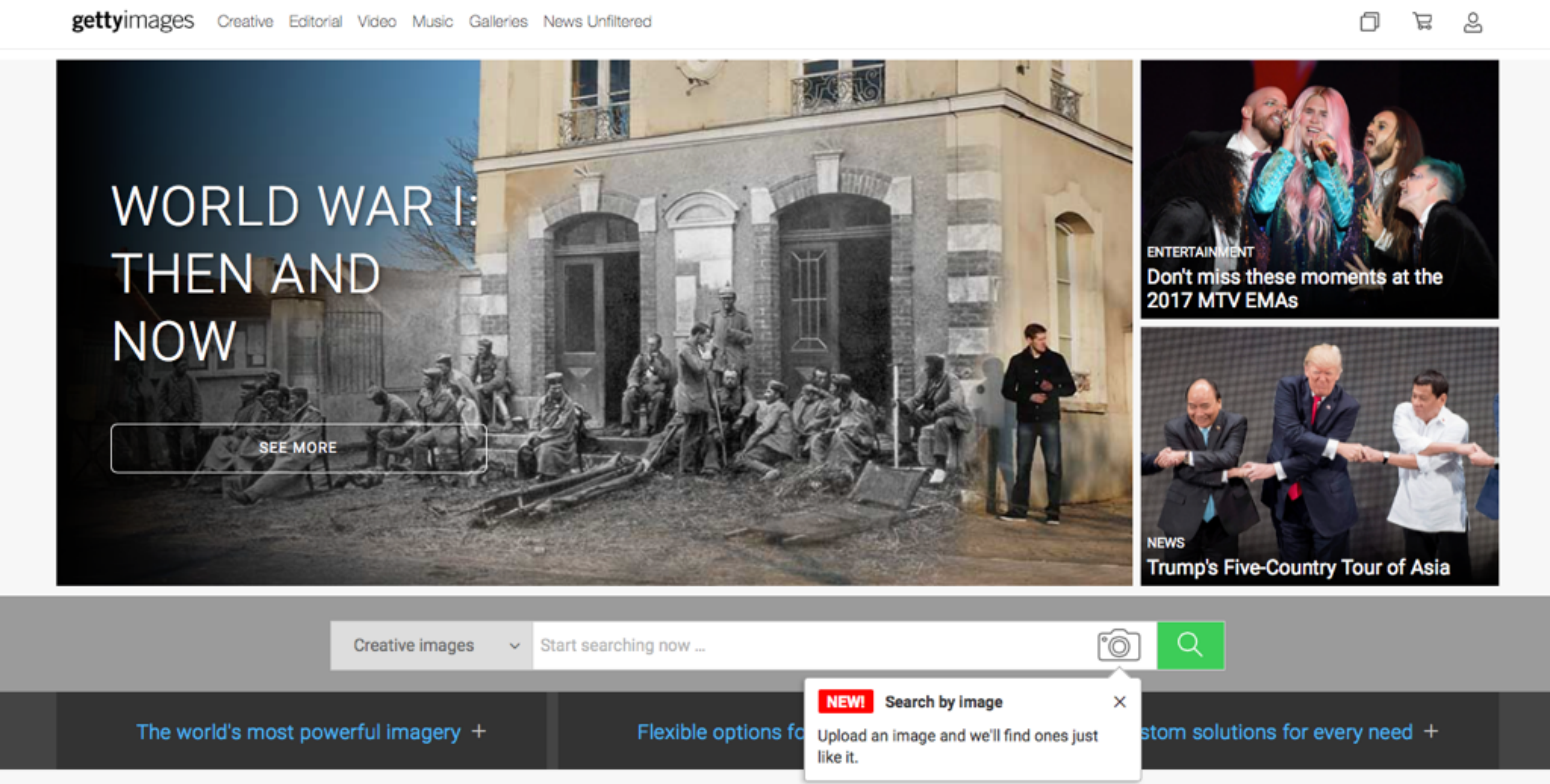


true for other **types of media** as well

Spotify: flatrate for music
Netflix: flatrate for video



Spotify: flatrate for music
Netflix: flatrate for video
GettyImages: flatrate for photos



so how about **physical objects?**

traditional product sales:

physical medium = license to own it

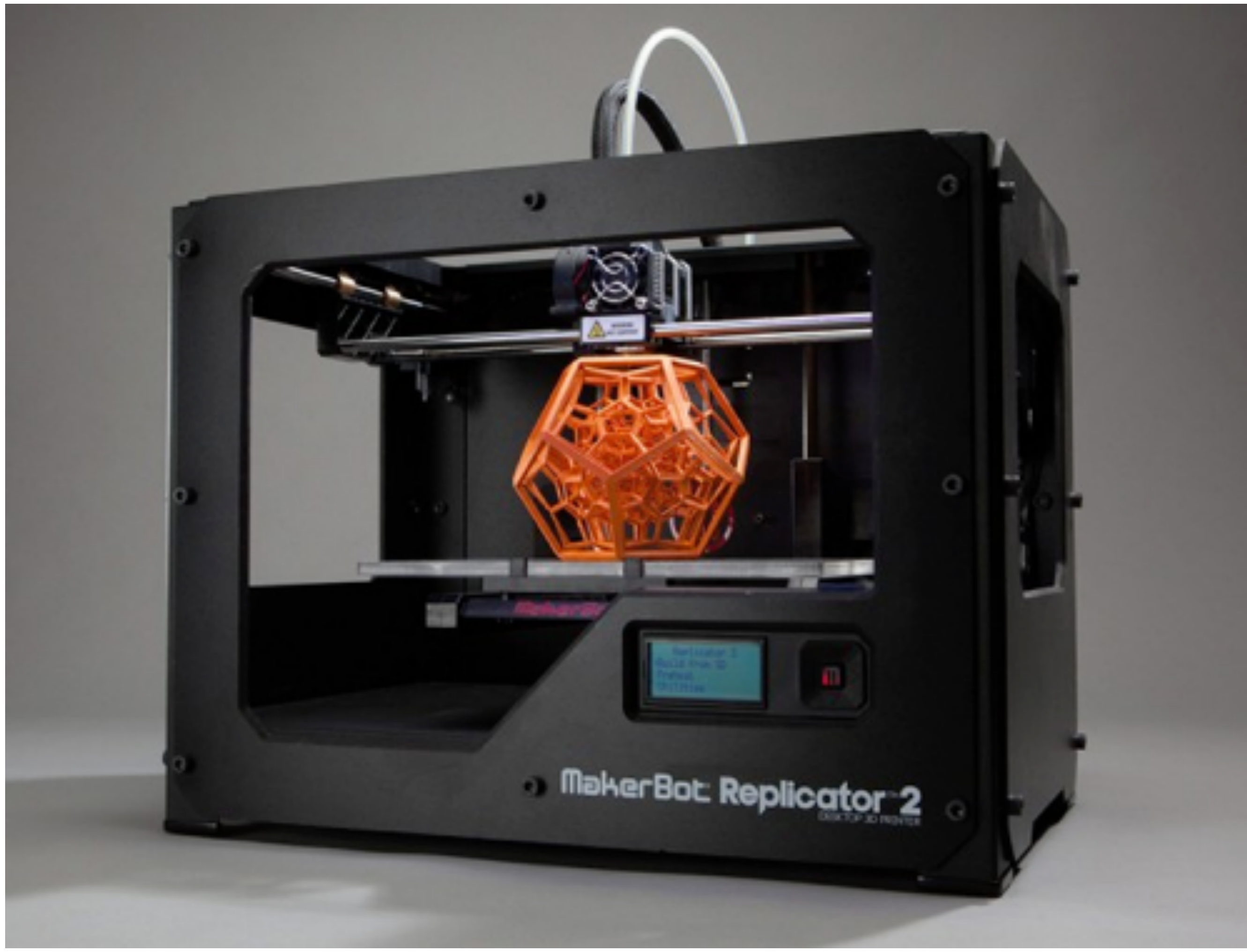
e.g. Gucci bag

physical medium != license to own it

3D model
share with others

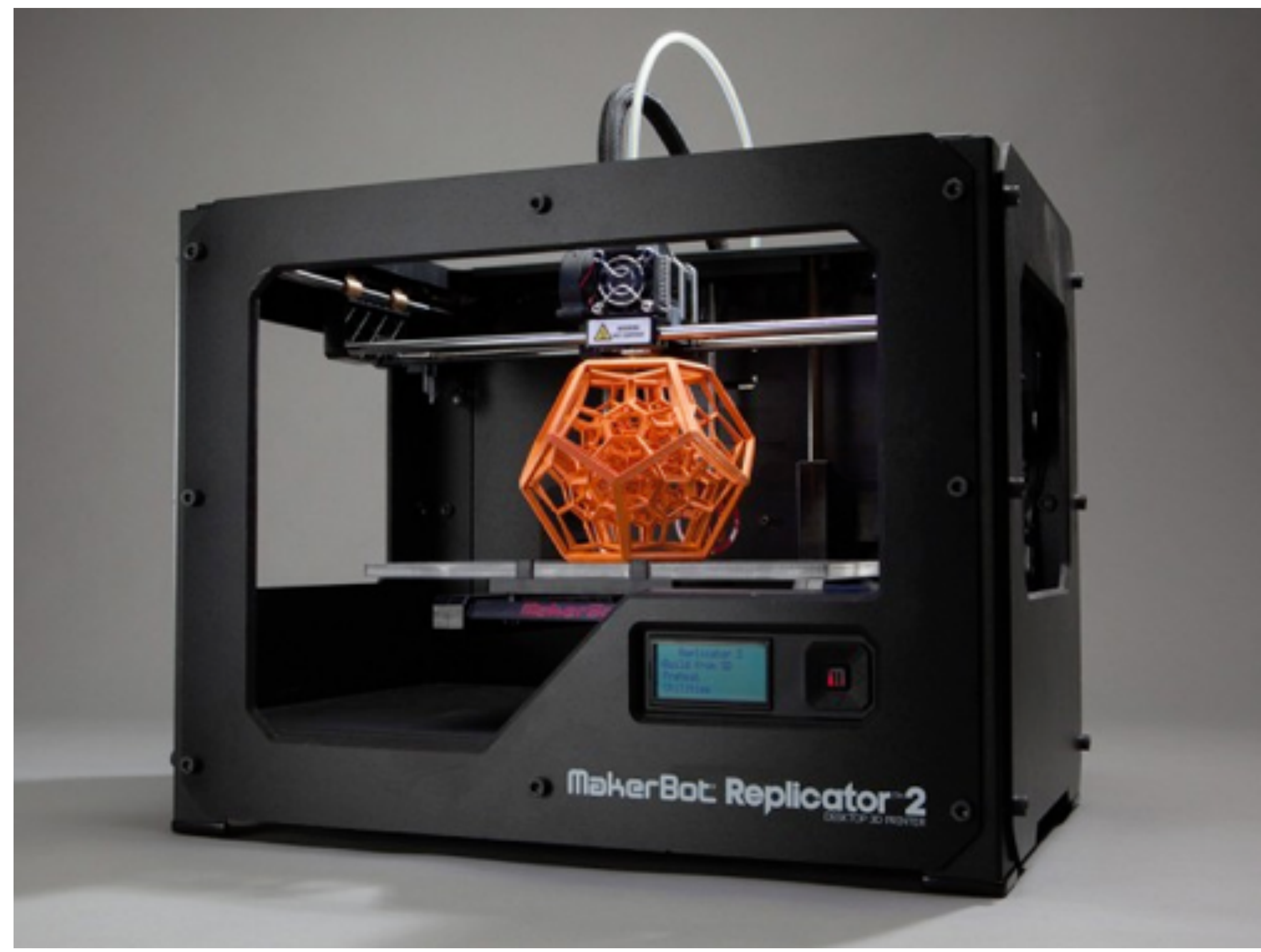
3D scan
once

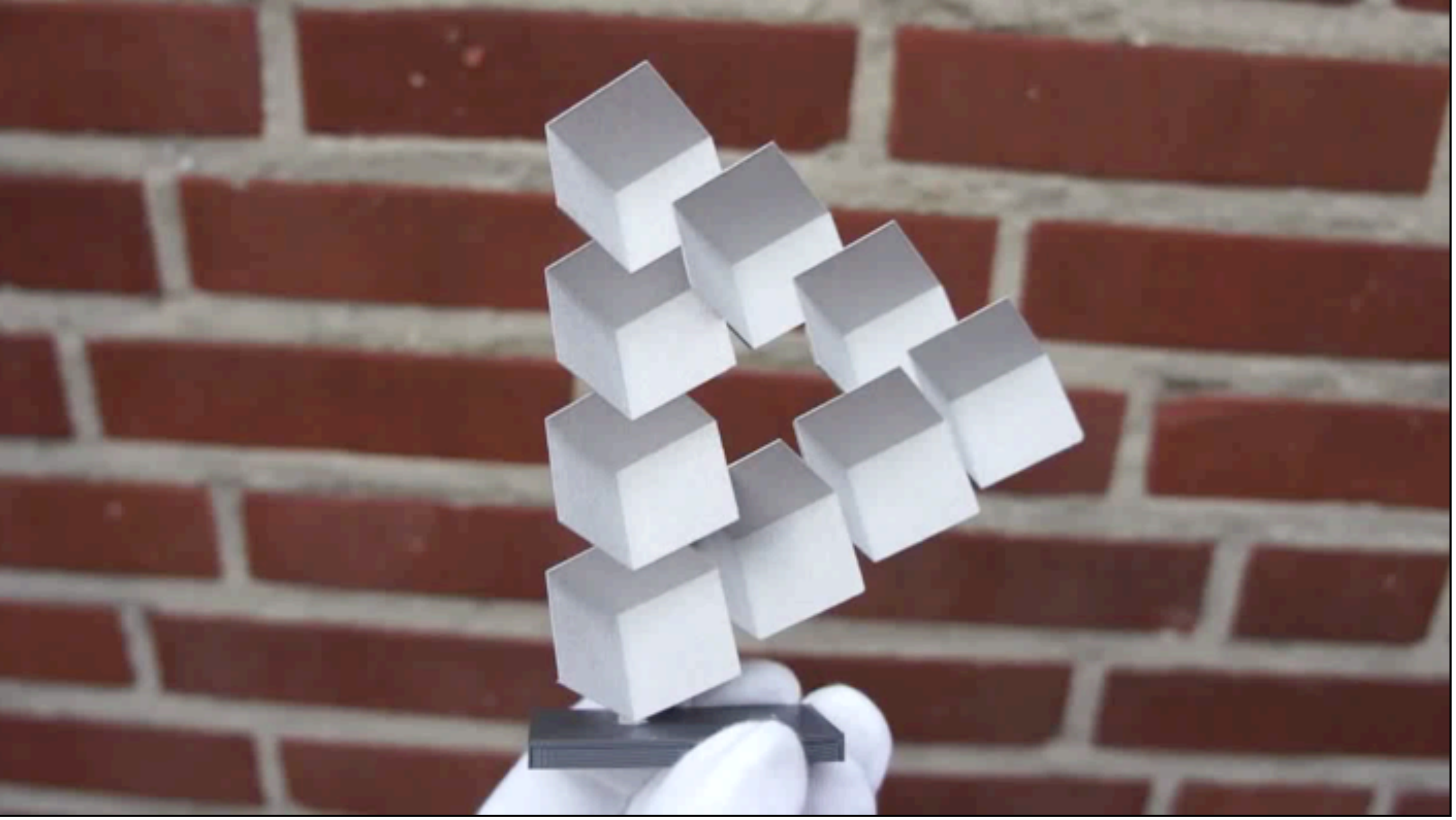
3D print
as many copies as you like



cost:
$50 material
$400 design / idea

cost:
$50 material
~~$400 design / idea~~





Ulrich Schwanitz - Penrose Triangle - 3D Design Takedown

The Penrose Triangle is an "impossible object" created by Oscar Reutersvärd of Sweden in the mid-1930s.Thingiverse, a site where users share 3D designs for printing, received a DMCA takedown notice for a 3D design of the triangle. Who sent this takedown notice? Not Reutersvärd. The sender and alleged copyright owner appears to be one Ulrich Schwanitz. Apparently, Mr. Schwanitz also created a 3D model of Reutersvärd's triangle and is claiming that the version on Thingiverse violated his copyright. You can see a photo of his version here.

Copyright in what, you might ask—the original image? If someone else created the earlier

PRINTING THE IMPOSSIBLE TRIANGLE: THE COPYRIGHT IMPLICATIONS OF THREE-DIMENSIONAL PRINTING

BRIAN RIDEOUT*

ABSTRACT

Three-dimensional printing (3D printing), which allows users to digitize and replicate objects, is emerging as the next potentially disruptive technology. It is now possible to "print" intricate objects from furniture to food to human organs. Because 3D printing relies on computer-based blueprints in order to create physical objects, digital copyright infringement can now impact the physical world. The first example occurred in February 2011, when the world's first Digital Millennium Copyright Act (DMCA) takedown notice for a 3D printed object was

Revenge of the (Cease and) Desist

Disney Pulls Star Wars Models From Thingiverse: An Inside Look at Copyright Issues in the 3D Space

by Tyler Koslow
1 day ago

‘80% of top 3D designers do not share
their design for **fear of theft'**

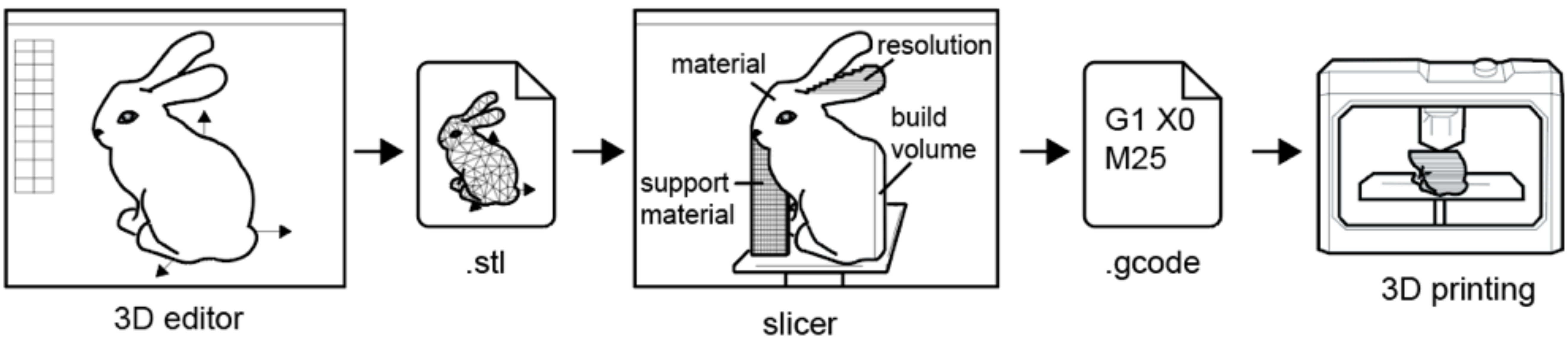
Gartner predicts that by 2018,
3D printing will result in the **loss of at least**
$100 billion per year
due to illegally shared content

this holds back the 3D printing market…

1) digital rights management:

how to prevent people from distributing a design for free?

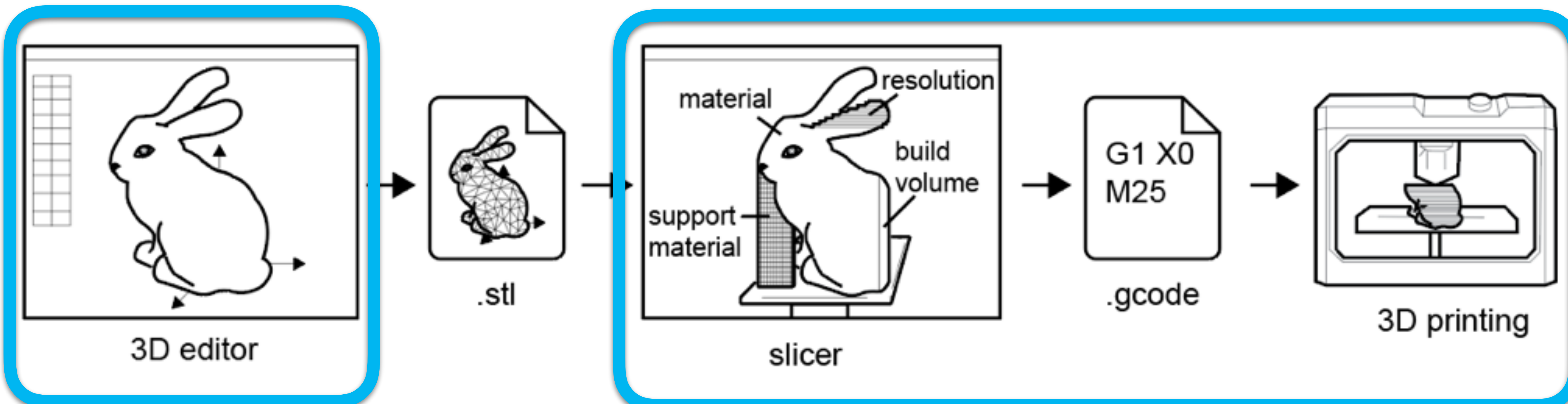
steps from 3D model to 3D print:



traditional workflow for getting a 3D design:

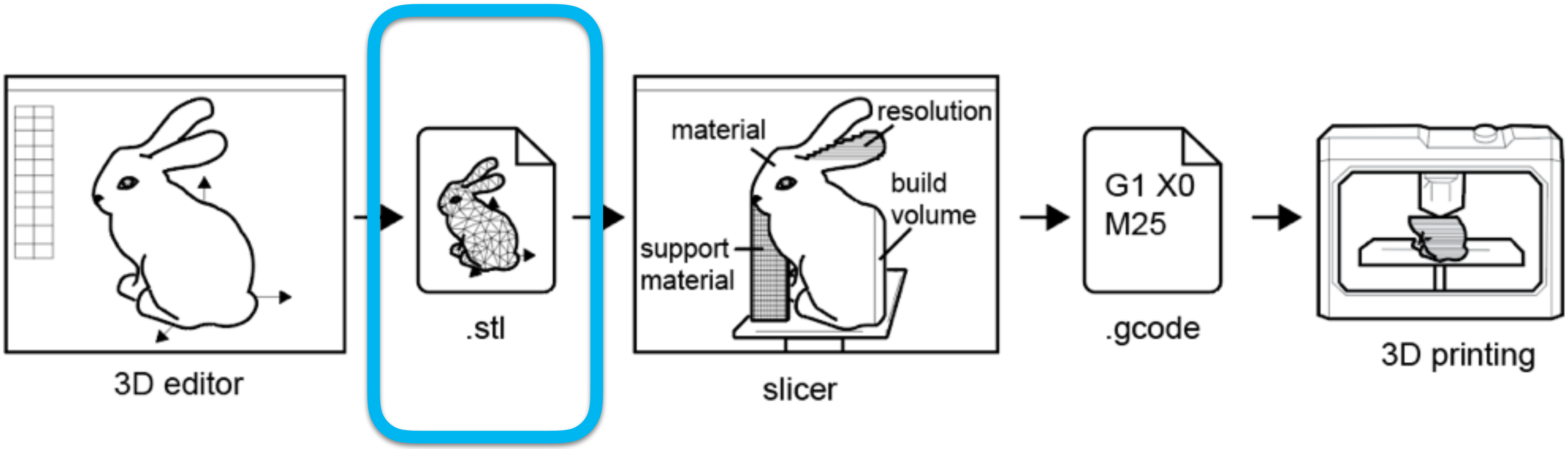
product company creates model

you get the 3D model in .stl, slice it locally (create gcode) and 3D print it



problem:

once you have the model,
you can give it to your friends and
they can print it too!

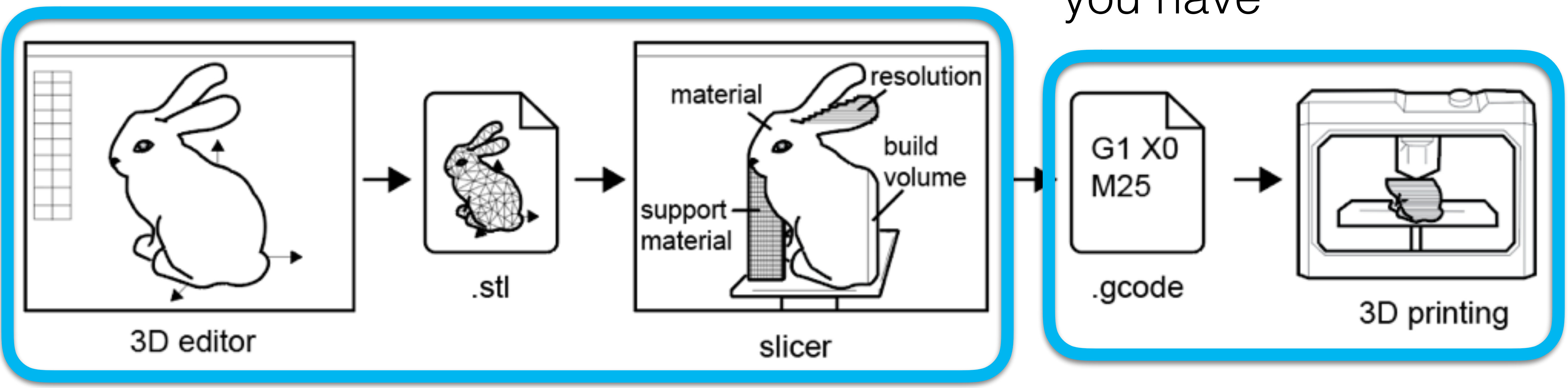


solution:

company asks you for your printer model, and gives you the machine specific code

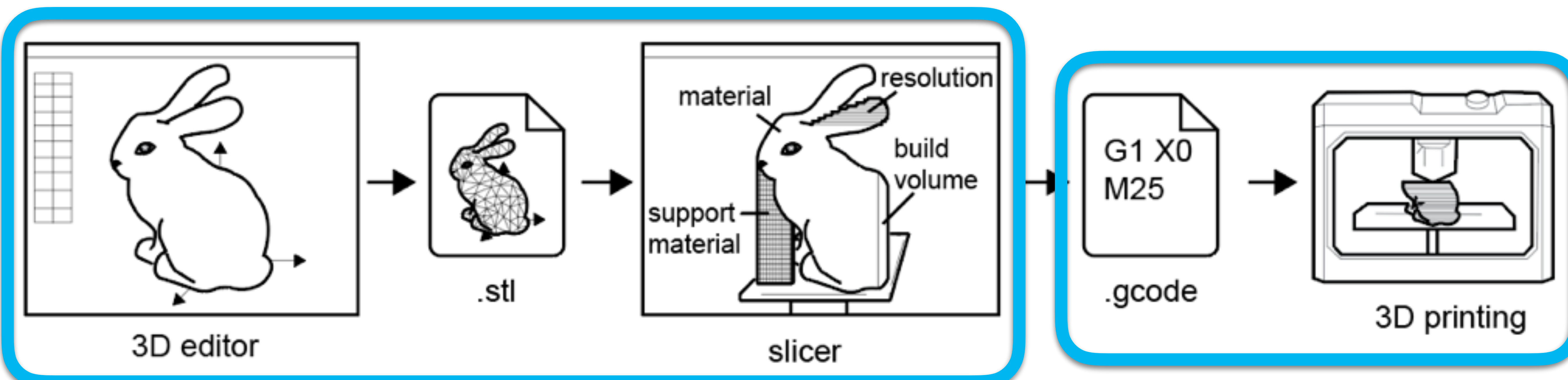
(you never get the 3D model, just the instructions on how to execute the layers)

can only be executed on the printer model you have



additional safety features:
gcode is streamed one command at a time, not downloaded
(so you would have to implement a listener to steal it)

similar to streaming music, but same side effects:
you always have to by connected to the server



add-ons:
encrypted streaming
embed printer ID, not just type

The Future of Law and eTechnologies pp 81-109 | Cite as

Intellectual Property Protection of 3D Printing Using Secured Streaming

Authors Authors and affiliations

Paula-Mai Sepp, Anton Vedeshin, Pawan Dutt

Chapter
First Online: 23 February 2016

Abstract

3D printing technology is a new and emerging technology which is capable of changing the world. However, an easy access to 3D printing technology makes a convenient way to illegally reproduce physical objects regardless of copyrights, license, and royalty payments. As 3D printing of physical things at home might become the "new normal," it will pose threats to traditional intellectual property laws, which were created in an era when copyright infringement of physical objects, or also defined as "physibles," was yet to come. The authors have brought forward the legal issues and have attempted to describe a unique technical solution—secured streaming which solves or at least partially solves the problem of copyrights in 3D printing. The proposed solution provides a possibility for a copyright owner to limit the number of 3D prints. He can specify the number of copies that are allowed for the manufacturer or an end user to produce. Moreover, secured streaming has detective and

2) certifying object authenticity:

how to make sure you really get the object you bought?

you think you are buying from company A,
but somebody interferes without you noticing it and gives you their 3D model…

any concerns regarding the product you just acquired?

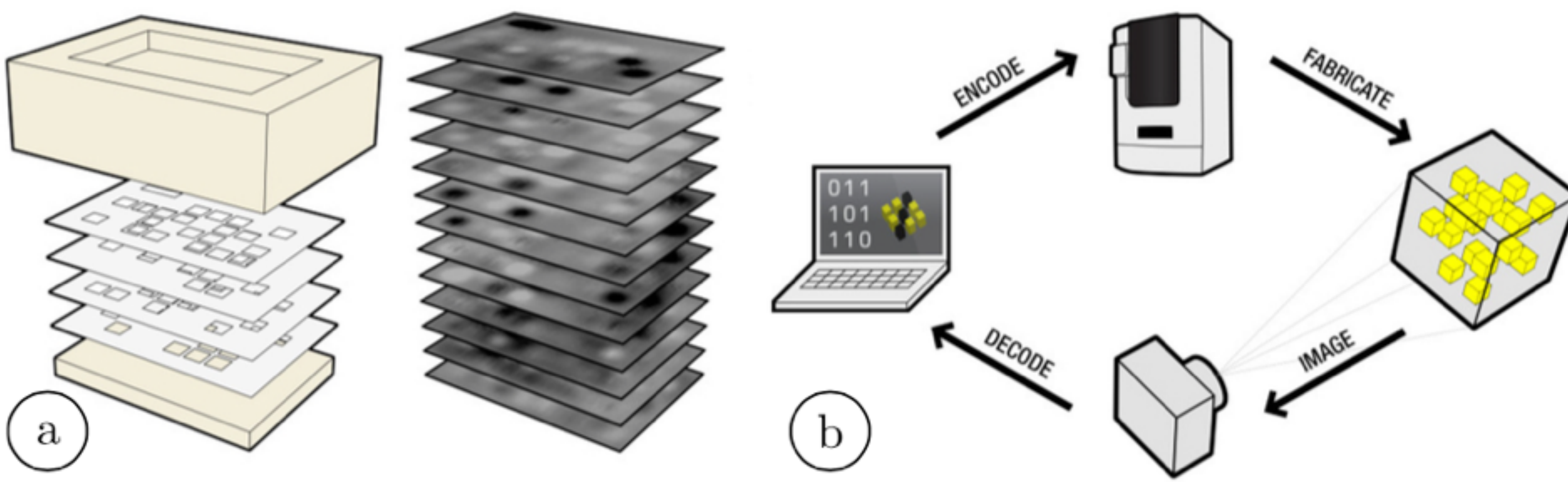
<30 sec brainstorming>

digital rights management protects the designer from theft,
certifying object authenticity protects the customer…

is the object really **from the declared source?**
does the object **function properly?**
(can have dangerous implications)

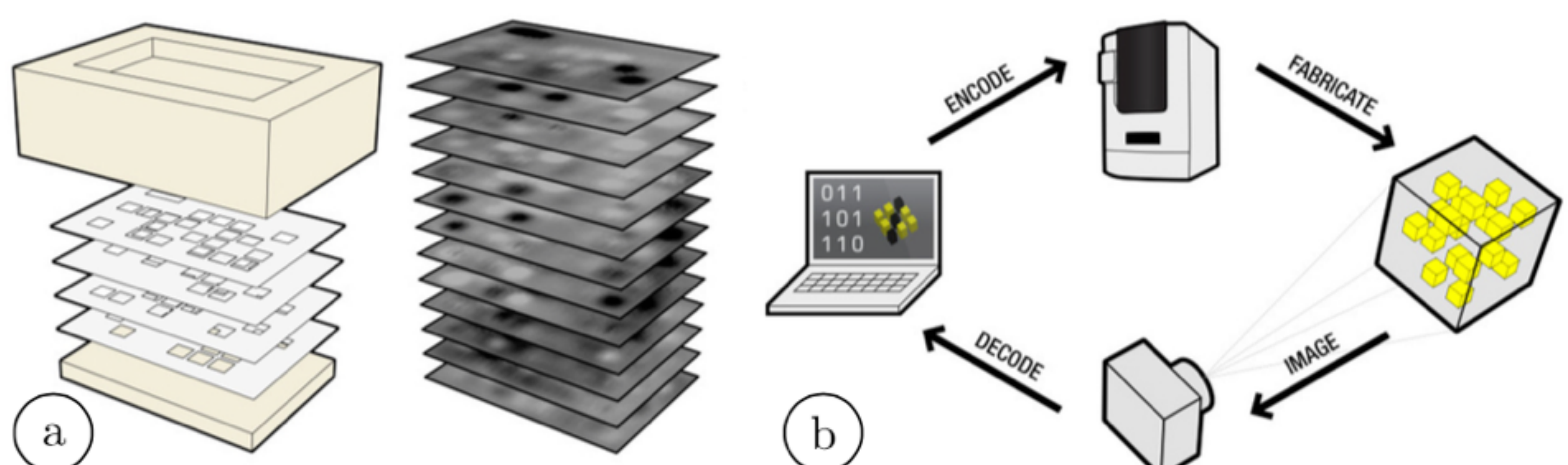
solution:
designers embed **hidden watermarks** into the 3D model
(if sb just replicates the appearance of the model to make it look like the original, we can detect this)

watermarks
e.g. via embedded markers, can be detected with Terahertz scanner (both cannot be seen from the outside)
e.g. print with invisible ink (infrared)



embed ID of manufacturer:
ensure that part is authentic

embed ID of customer during printing:
trace back illegal copies



InfraStructs: Fabricating Information Inside Physical Objects for Imaging in the Terahertz Region

Karl D.D. Willis
Carnegie Mellon University

Andrew D. Wilson
Microsoft Research

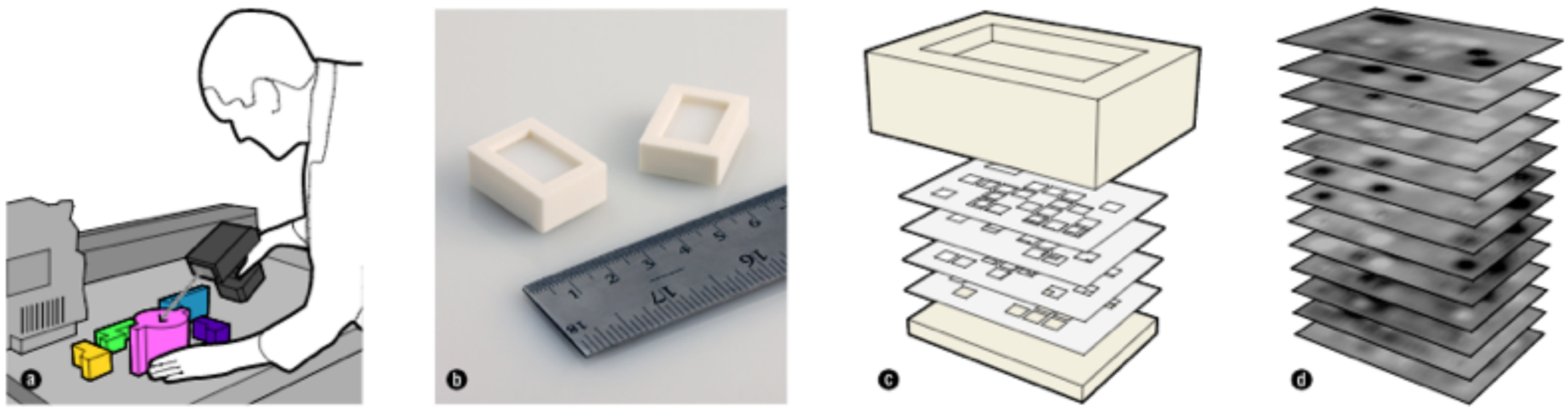


Figure 1: *InfraStructs are material-based tags that embed information inside physical objects for imaging in the Terahertz region. Terahertz imaging can safely penetrate many common materials, opening up new possibilities for encoding hidden information inside digitally fabricated objects. (a) InfraStruct tags are embedded during the fabrication process to immediately identify objects without additional labeling or packaging. (b) Inexpensive polymer materials are used to (c) create a layered internal structure. (d) The object interior is scanned to create a volumetric image that is decoded into meaningful information.*

Abstract

We introduce *InfraStructs*, material-based tags that embed information inside digitally fabricated objects for imaging in the Terahertz region. Terahertz imaging can safely penetrate many common materials, opening up new possibilities for encoding hidden information as part of the fabrication process. We outline the design, fabrication, imaging, and data processing steps to fabricate information inside physical objects. Prototype tag designs are presented for location encoding, pose estimation, object identification, data storage, and authentication. We provide detailed analysis of the constraints and performance considerations for designing *InfraStruct* tags. Future application scenarios range from production line inventory, to customized game accessories, to mobile robotics.

CR Categories: I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques I.4.1 [Image Processing and

1 Introduction

Computer-controlled digital fabrication technologies are rapidly changing how objects are manufactured. Both additive (e.g., 3D printing) and subtractive (e.g., laser cutting) techniques use digital information to programmatically control the fabrication process. Unlike conventional manufacturing, one individual object can differ significantly from the next. The ability to manufacture one-off objects has implications not only for product customization and on-demand manufacturing, but also for tagging objects with individualized information.

Object tagging systems have wide-ranging uses in logistics, point of sale, robot guidance, augmented reality, and many other emerging applications that link physical objects with computing systems. 1D and 2D barcodes have been successful due to their low cost, but are limited by their obtrusive appearance that is visible to the human

3) transferring a license

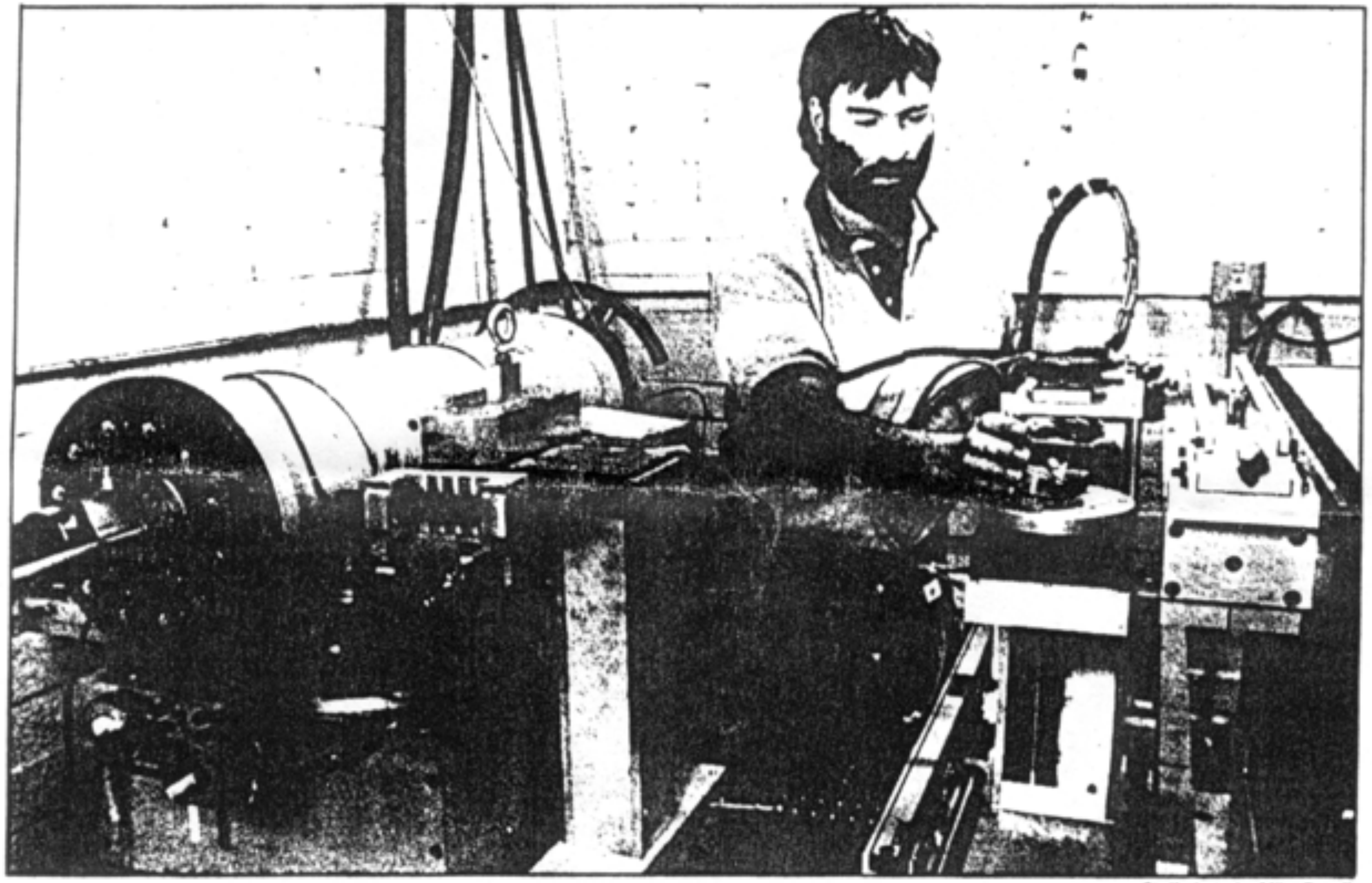
3D printing copyright for selling is already hard
when the **seller is the copyright owner (e.g. company)**

but how to **sell an object from customer to customer?**
-> think ebay, selling used goods

today’s online auction sites:

- adding a product: minutes
- electronic payment: seconds
- shipping: **…. days,…. weeks…. via physical mail.**

Thursday, August 15, 1991 Austin American-Statesman



Staff photo by Mike Boroff

Brett Simon, senior tomographic technician at Scientific Measurement Systems Inc., scans an automobile piston in a 420,000-volt scanner in the company's North Austin plant. The image was computerized and then transmitted by phone to a laser device in UT's mechanical engineering building, where researchers there called their advanced 3-D prototyping technology a success.

World's First '3-D Fax'

UT researchers take rapid prototyping a step further

By Kirk Ladendorf
American-Statesman Staff

University of Texas researchers, only partly joking, called it the world's first 3-D fax.

By linking two high-tech systems — an X-ray scanning device and a computer-driven laser — the researchers this week transmitted a 3-D copy of an automobile piston over the telephone line.

They joined with Austin-based Sci- basement of UT's mechanical engineering building.

The result of the first trial was imperfect, but it was rated a success.

"It worked," said UT mechanical engineering Professor Joe Beaman. "I wouldn't call it a pretty part, but it was definitely it" — the auto piston reformed in polycarbonate material and scaled down to about one-third its original size.

The copied part did not include all

tion, or as it is more commonly called, rapid prototyping.

UT is considered a leader in the field. Out of its mechanical engineering laboratory came the process called laser sintering — using a computer-driven laser to fuse together fine powder of material into precise 3-D prototypes made of polycarbonate.

DTM Corp., an Austin-based start-up owned by the B.F. Goodrich Co., has developed commercial versions of laser sintering devices targeted at in-

1991! awesome!

http://www.hitechmex.org/self/3D_fax.html

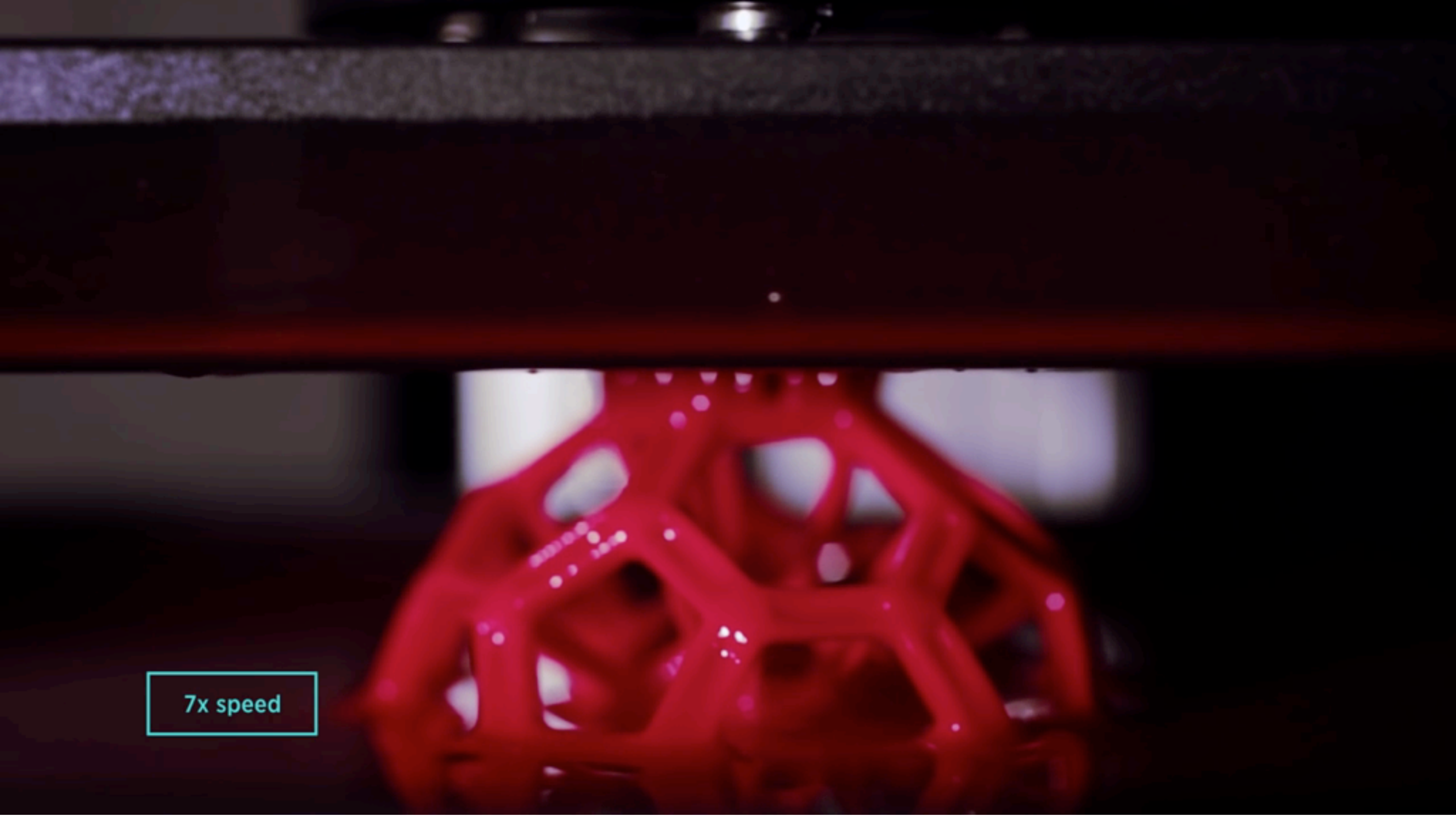
This 3D Printer Could Also Be the World's First 3D Fax Machine

nope,
it was actually already
done 22 years ago…

zewski
8/22/13 11 4am • Filed to: 3D PRINTING

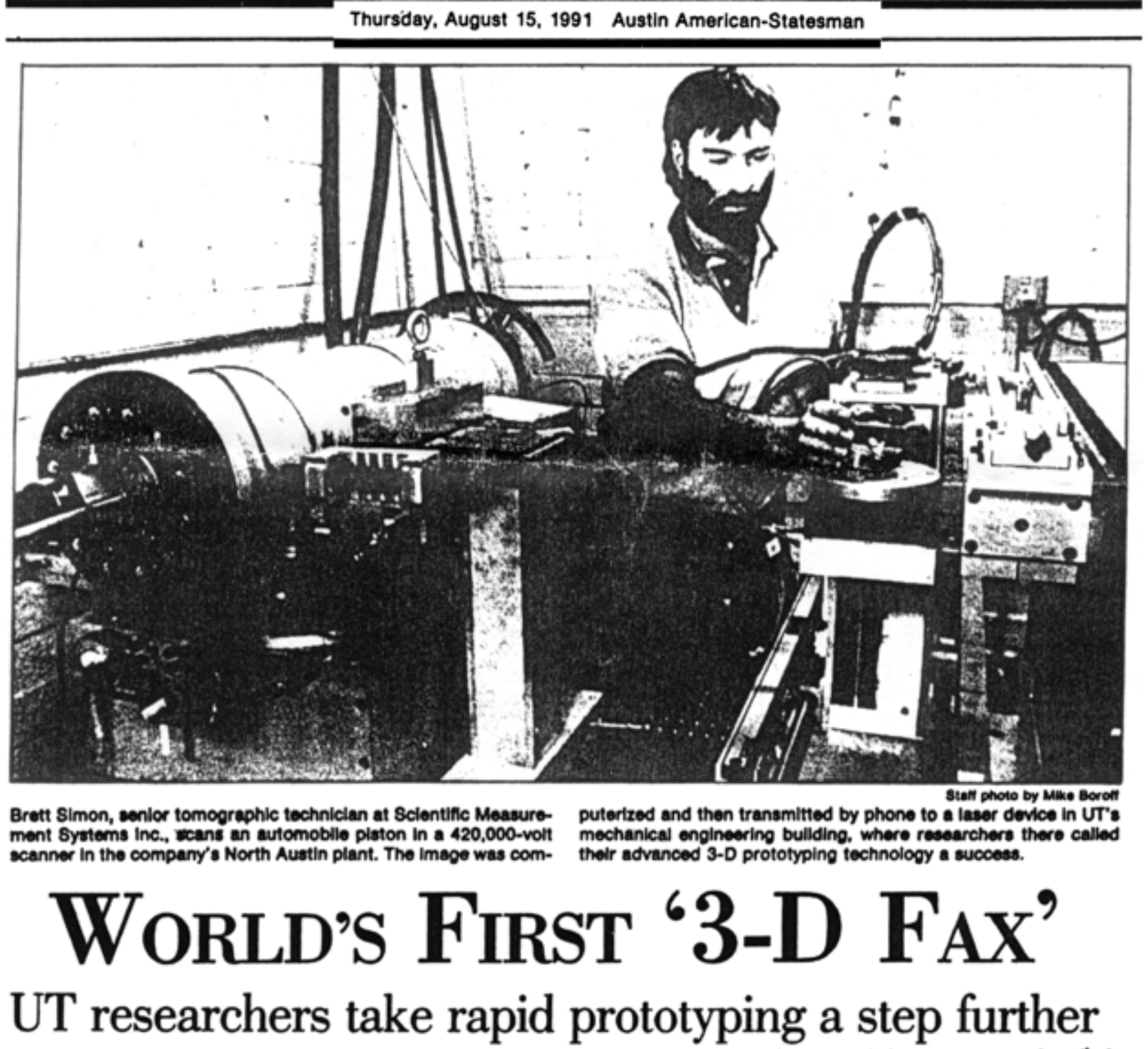
9.1K 30

As new models are announced every week, 3D printers are slowly but steadily becoming as common as iPhone cases. But thankfully there are a few standouts that boast features other than a cheaper price tag, like the Zeus from AIO



together with fast 3D printing (e.g. Carbon3D),
you could **deliver within minutes…**

[Carbon 3D]



Thursday, August 15, 1991 Austin American-Statesman

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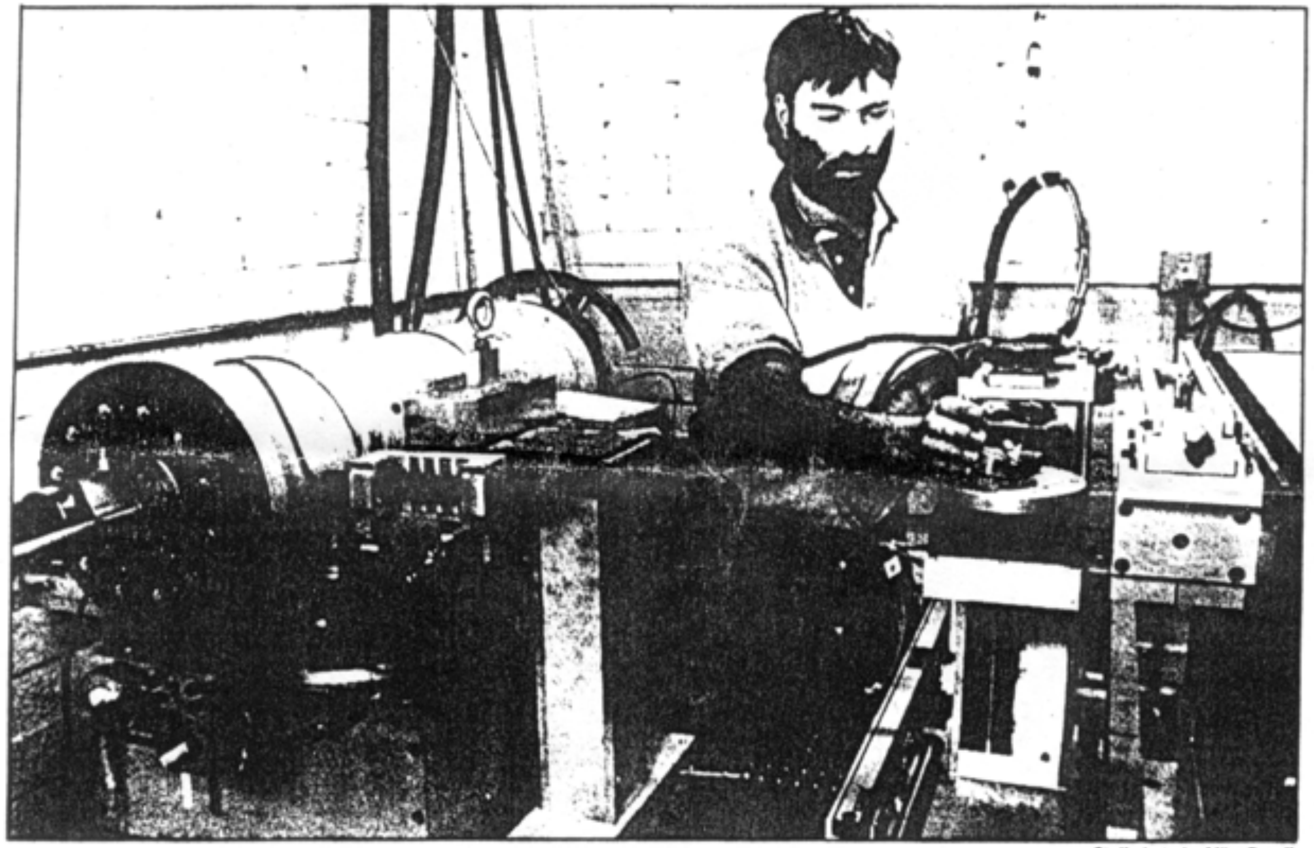
World's First '3-D Fax'

UT researchers take rapid prototyping a step further

do you see any copyright issues
with the 3D Fax Machine approach for sending objects?

<30 sec brainstorming>

Thursday, August 15, 1991 Austin American-Statesman



Staff photo by Mike Boroff

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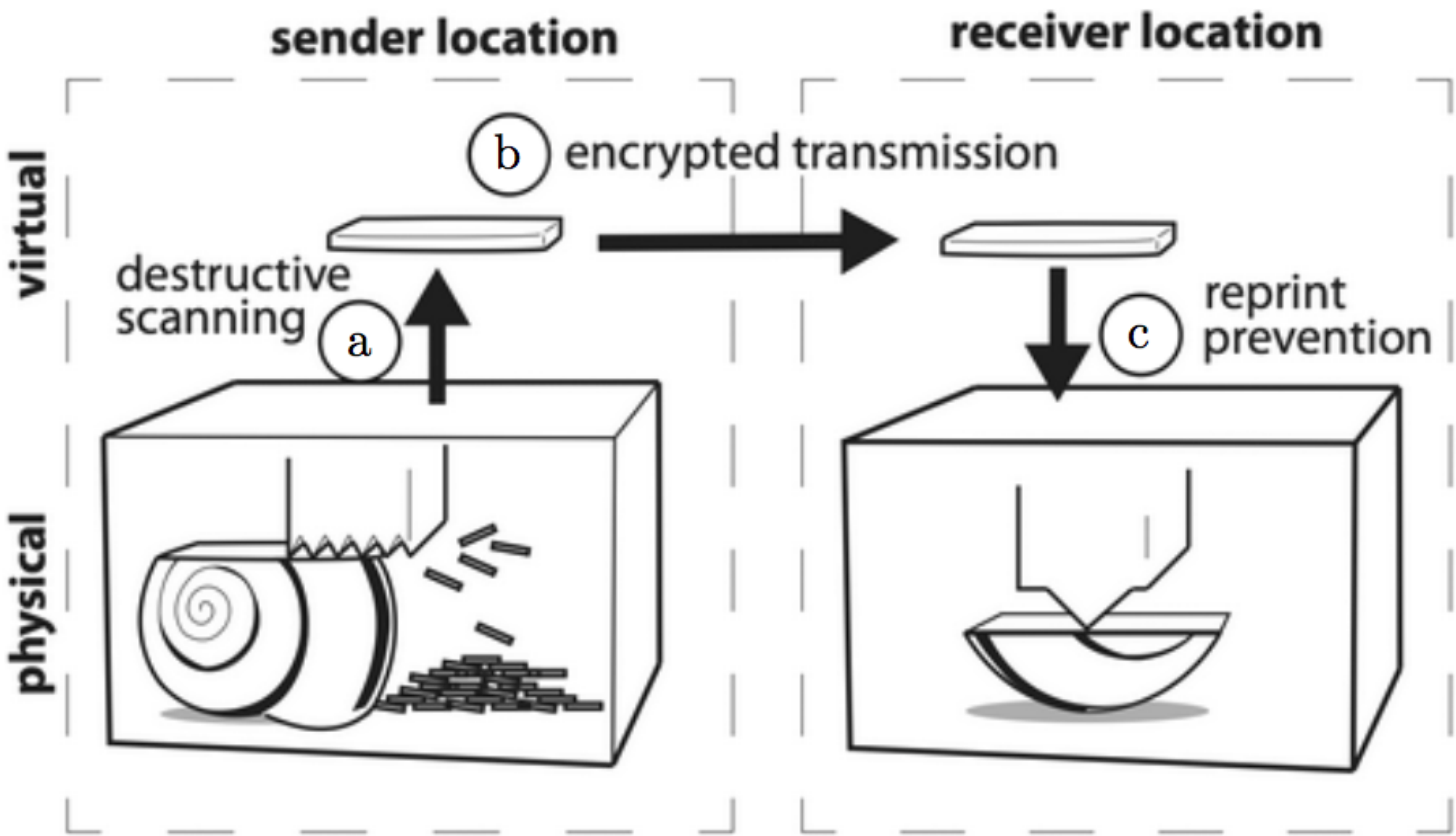
World's First '3-D Fax'

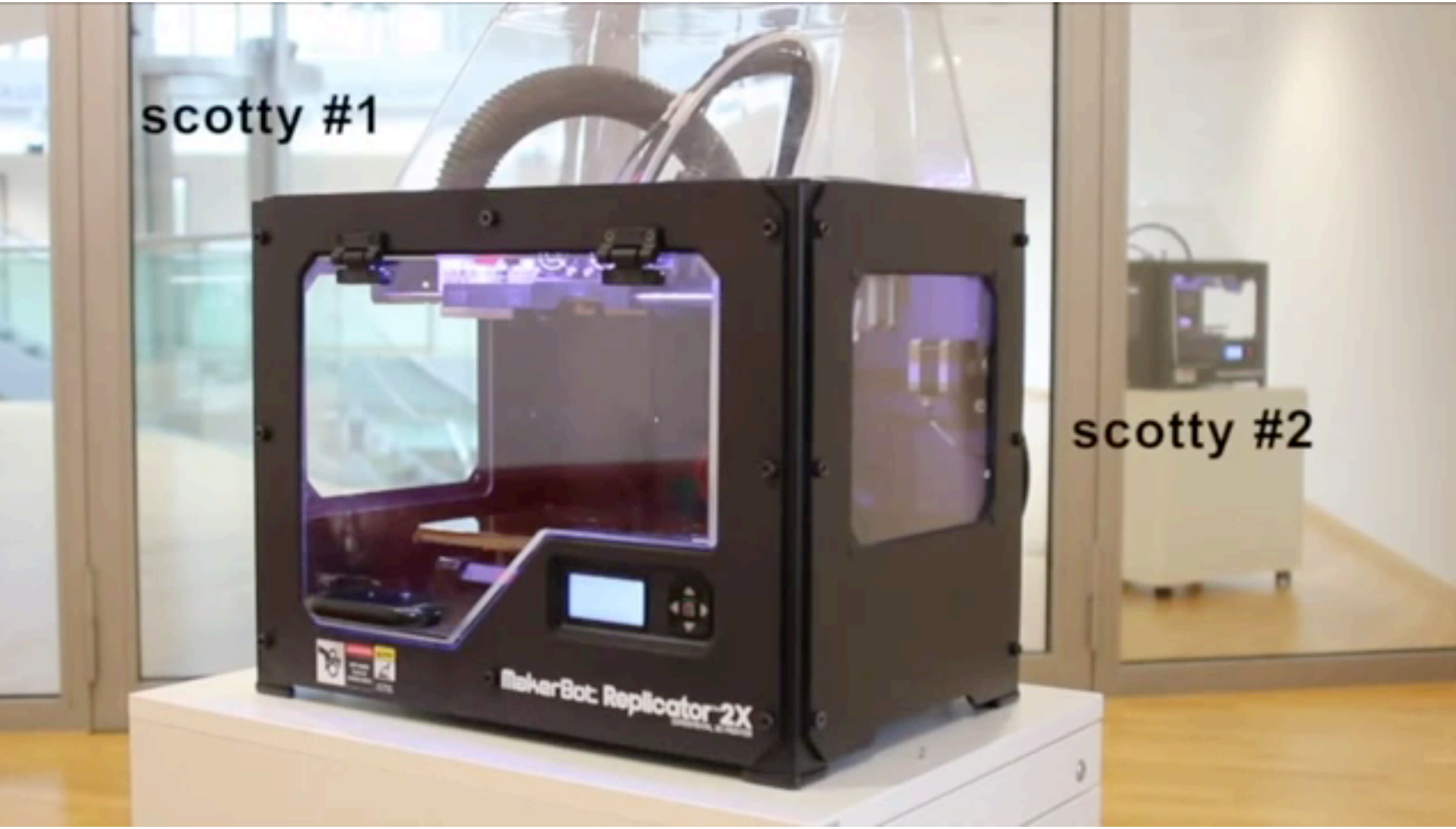
problem:
this creates an **illegal copy!**
now you have **two copies of the product.**

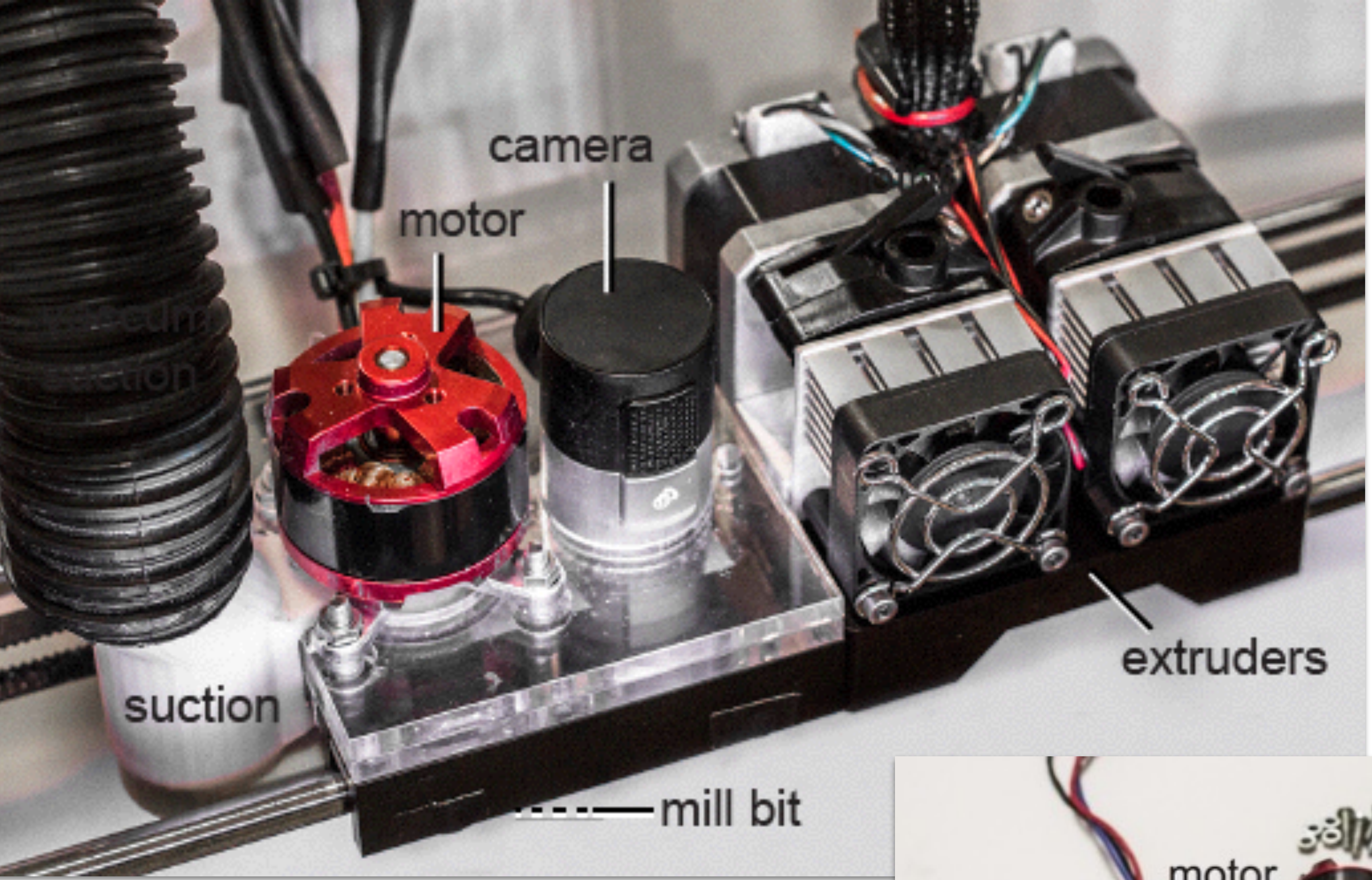
mh… wait… so can we make an object **disappear on the seller side** and **reappear on the receiver side?**

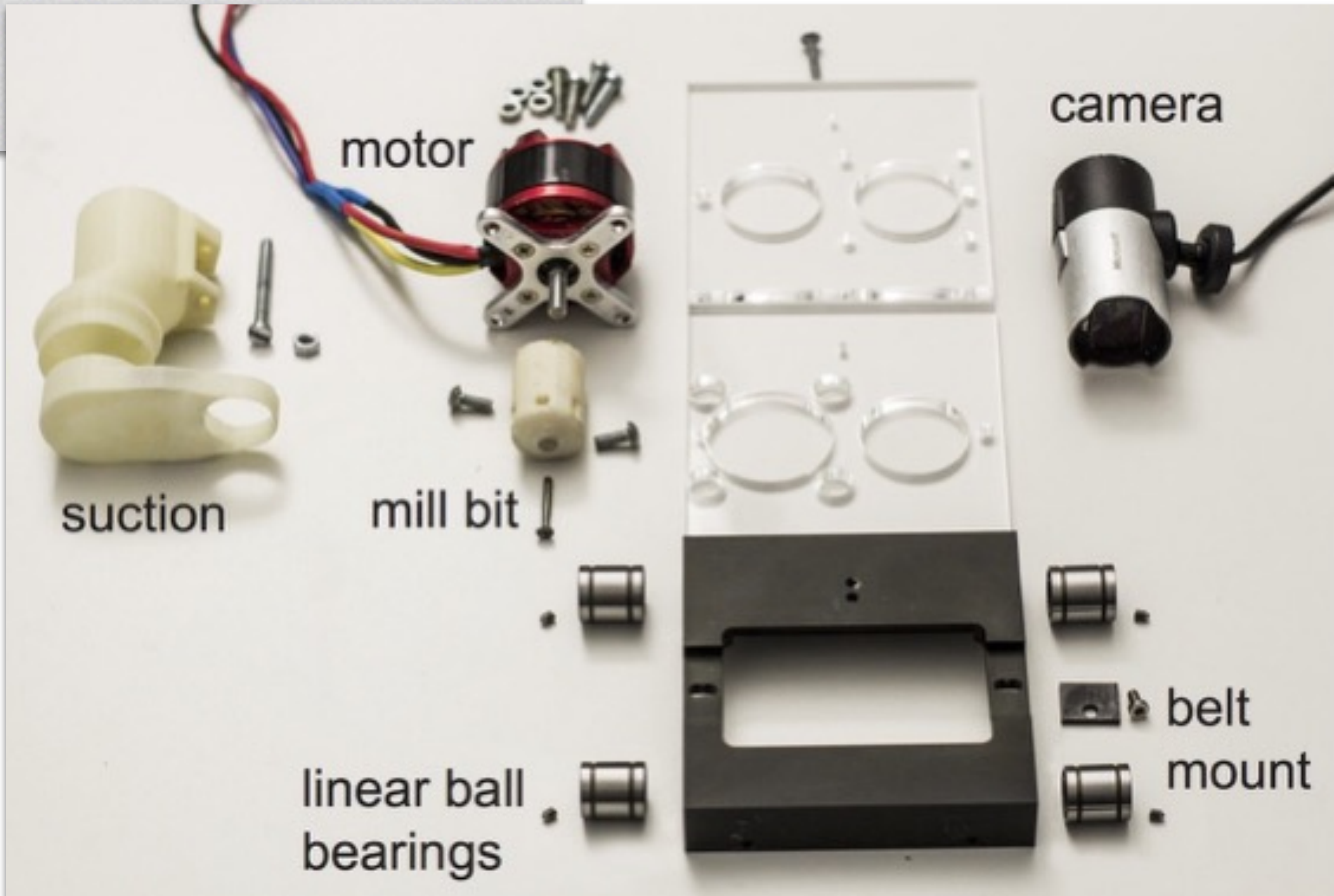
yes, we can!

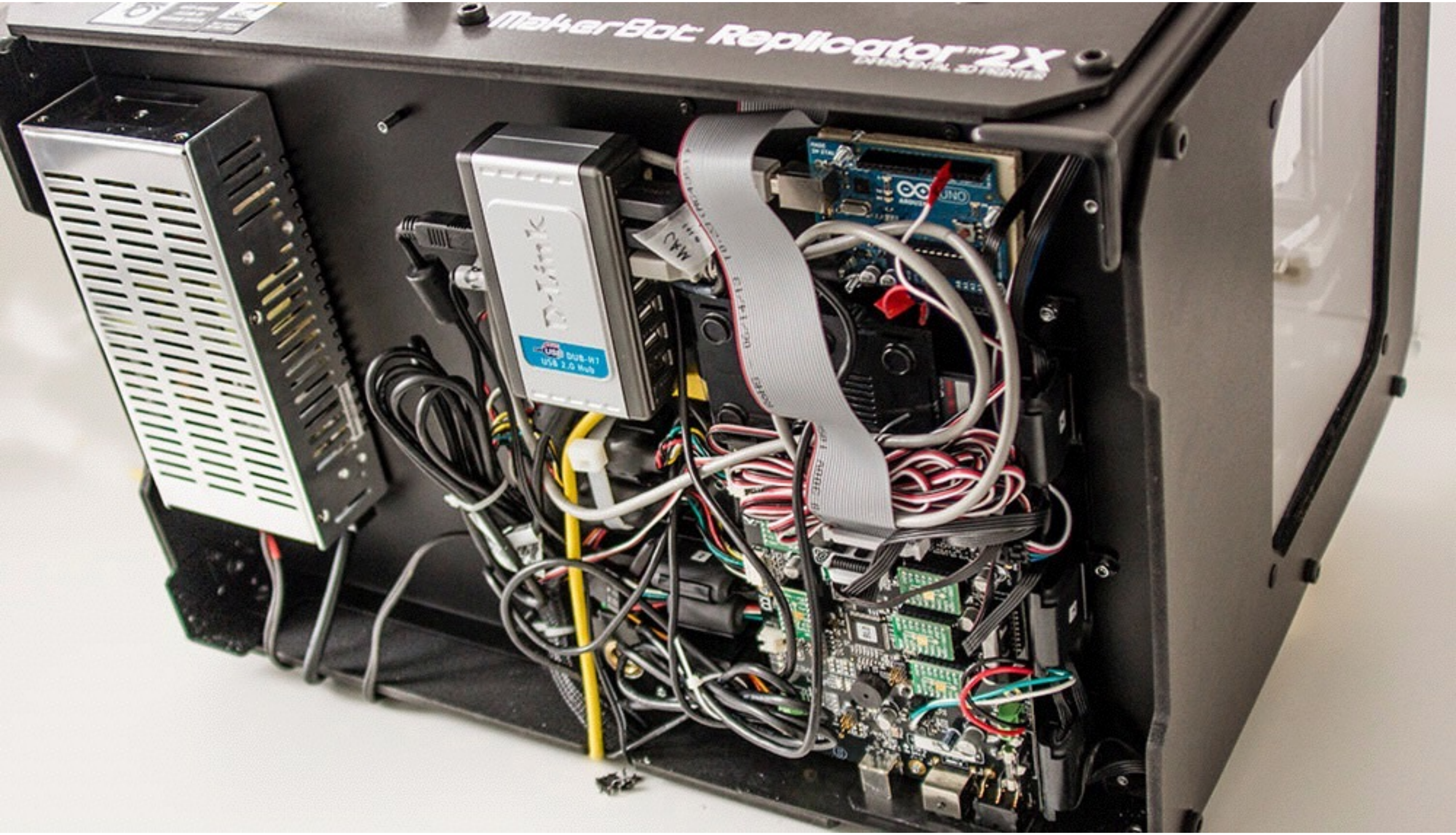


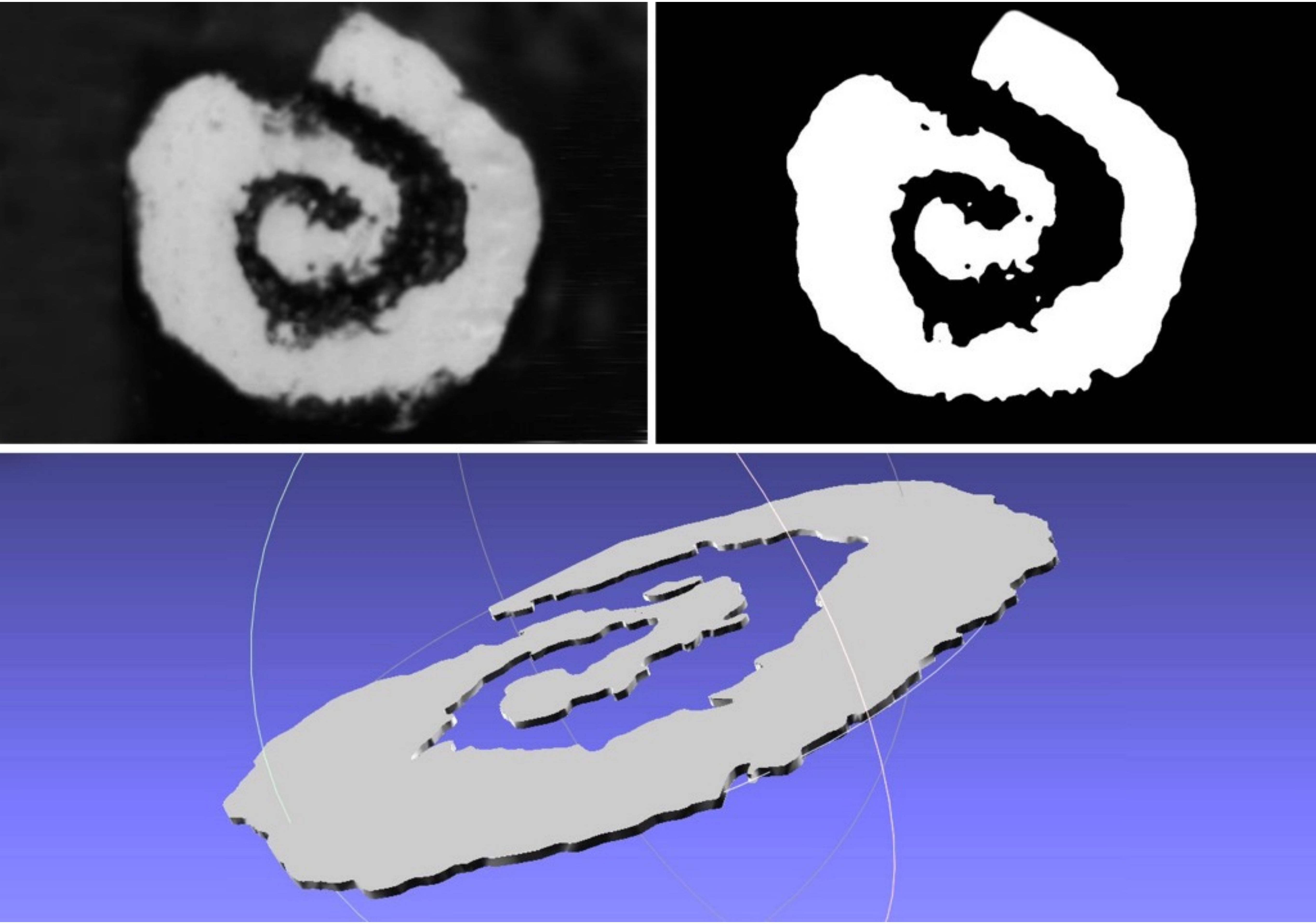
sender location
receiver location
virtual
physical
b
encrypted transmission
destructive
scanning
a
c
reprint
prevention

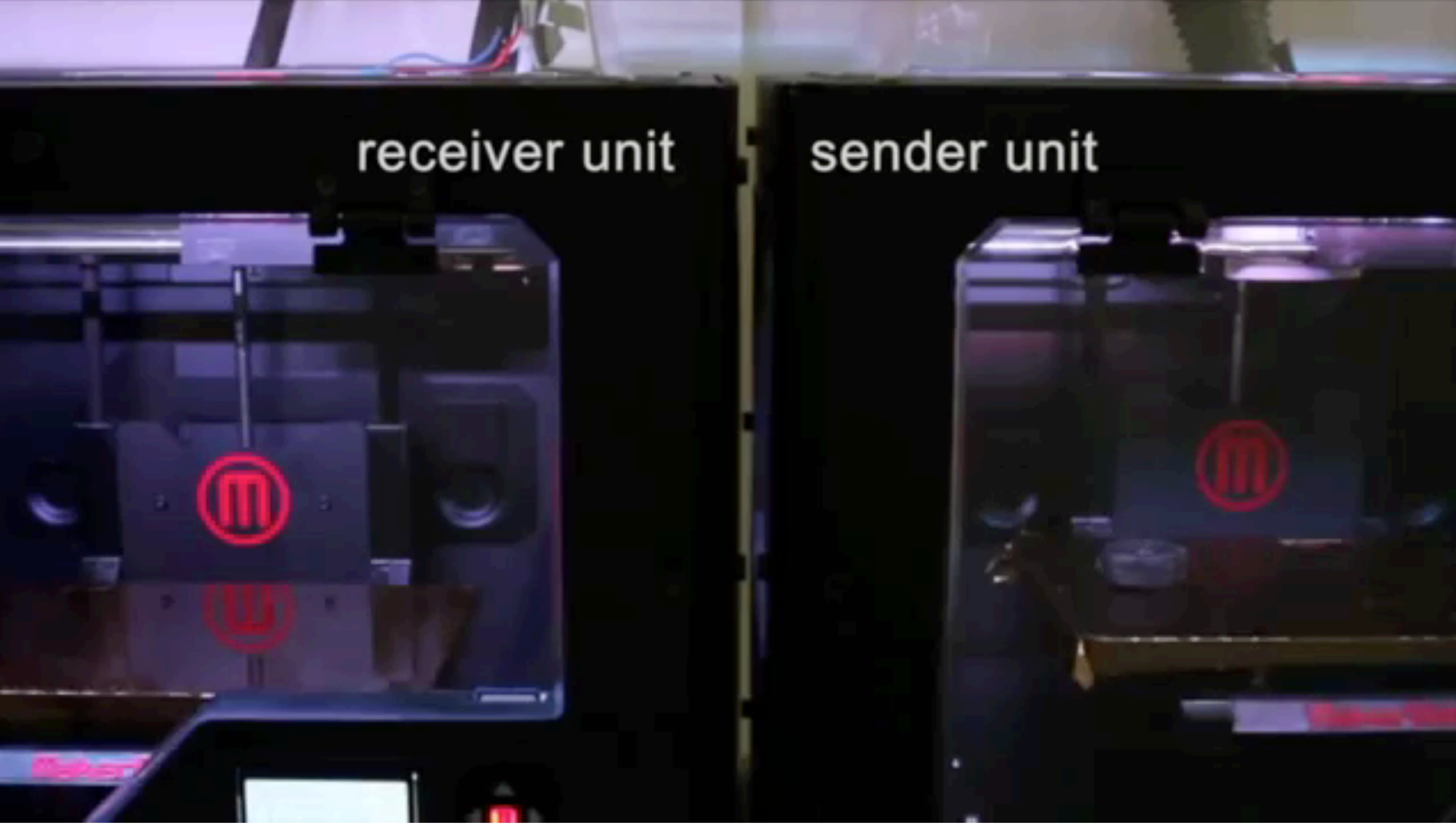

scotty #1
scotty #2
MakerBot Replicator 2X


camera
motor
extruders
suction
mill bit


motor
camera
suction
mill bit
belt
mount
linear ball
bearings

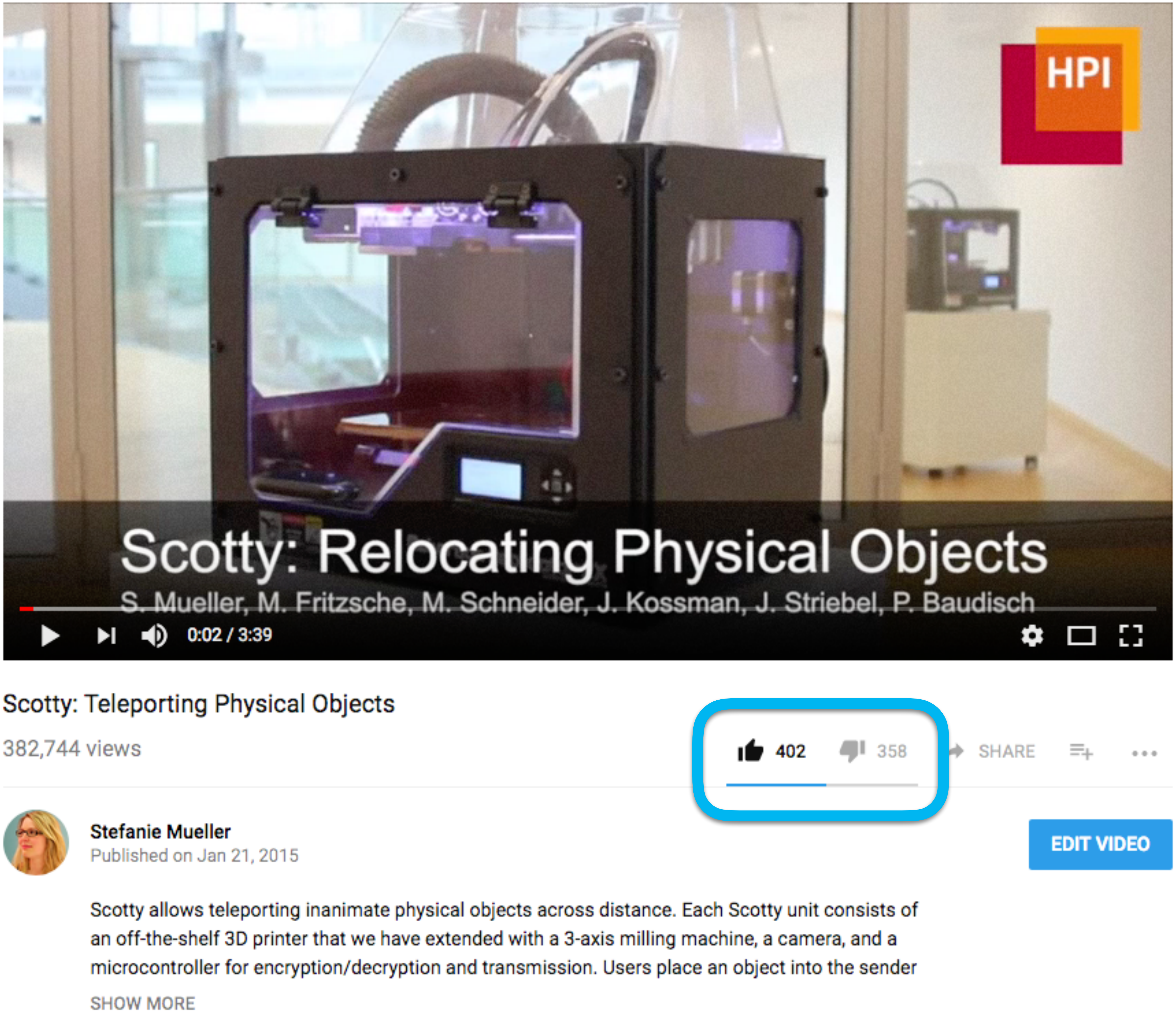

MakerBot Replicator™2X
D-Link
DUB-H7
USB 2.0 Hub





would you call this teleportation?
if yes, why. if no, why not?

<30 sec brainstorming>


HPI
Scotty: Relocating Physical Objects
S. Mueller, M. Fritzsche, M. Schneider, J. Kossman, J. Striebel, P. Baudisch
0:02 / 3:39
Scotty: Teleporting Physical Objects
382,744 views
402
358
SHARE
Stefanie Mueller
Published on Jan 21, 2015
EDIT VIDEO
Scotty allows teleporting inanimate physical objects across distance. Each Scotty unit consists of an off-the-shelf 3D printer that we have extended with a 3-axis milling machine, a camera, and a microcontroller for encryption/decryption and transmission. Users place an object into the sender
SHOW MORE

definitions of teleportation:

1. transport through a wormhole (continuum)
2. disassemble, transmit info about structure, reassemble

Scotty Relocating Physical Objects Across Distances Using Destructive Scanning, Encryption, and 3D Printing

Stefanie Mueller, Martin Fritzsche, Jan Kossmann, Maximilian Schneider, Jonathan Striebel, Patrick Baudisch
Hasso Plattner Institute, Potsdam, Germany
{firstname.lastname}@hpi.uni-potsdam.de

ABSTRACT

We present a simple self-contained appliance that allows relocating inanimate physical objects across distance. Each unit consists of an off-the-shelf 3D printer that we have extended with a 3-axis milling machine, a camera, and a microcontroller for encryption/decryption and transmission. Users place an object into the sender unit, enter the address of a receiver unit, and press the *relocate* button. The sender unit now digitizes the original object layer-by-layer: it shaves off material using the built-in milling machine, takes a photo using the built-in camera, encrypts the layer using the public key of the receiver, and transmits it. The receiving unit decrypts the layer in real-time and starts printing right away. Users thus see the object appear layer-by-layer on the receiver side as it disappears layer-by-layer at the sender side. Scotty is different from previous systems that *copy* physical objects, as its destruction and encryption mechanism guarantees that only one copy of the object exists at a time. Even though our current prototype is limited to single-material plastic objects, it allows us to address two application scenarios: (1) Scotty can help preserve the uniqueness and thus the emotional value of physical objects shared between friends. (2) Scotty can address some of the licensing issues involved in fast electronic delivery of physical goods. We explore the former in an exploratory user study with three pairs of participants.

Author Keywords: fabrication; rapid prototyping; 3D printing; 3D scanning.

While in digital form, users can vary the shape and design of objects (*OpenFab* [26]) or even more importantly share it with others [22]. As a result, many envision a future in which any object will be available to anyone anywhere anytime [9].

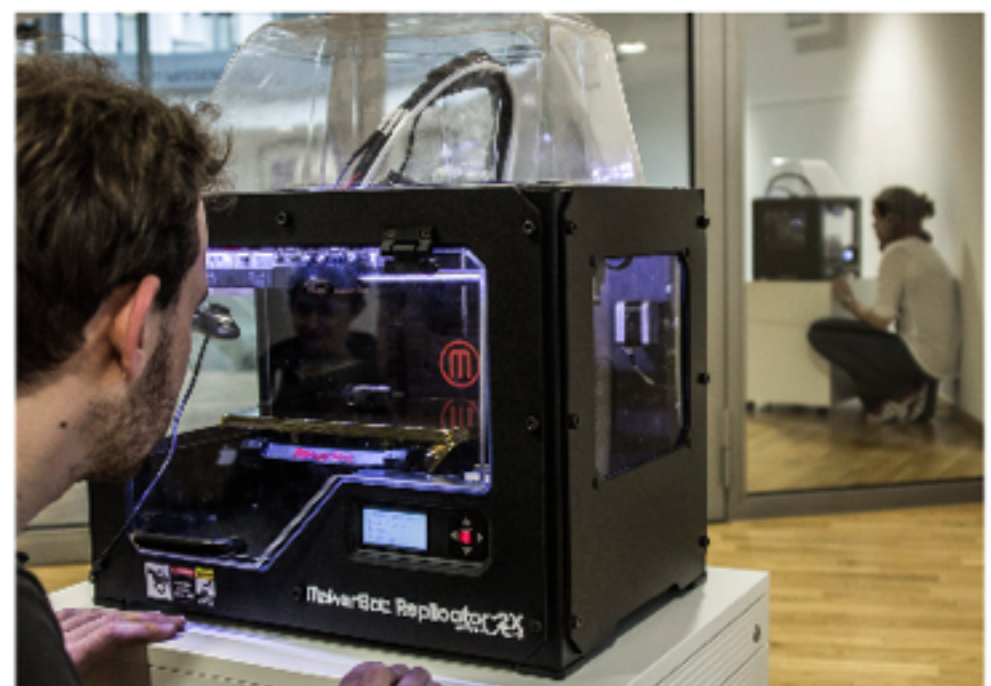


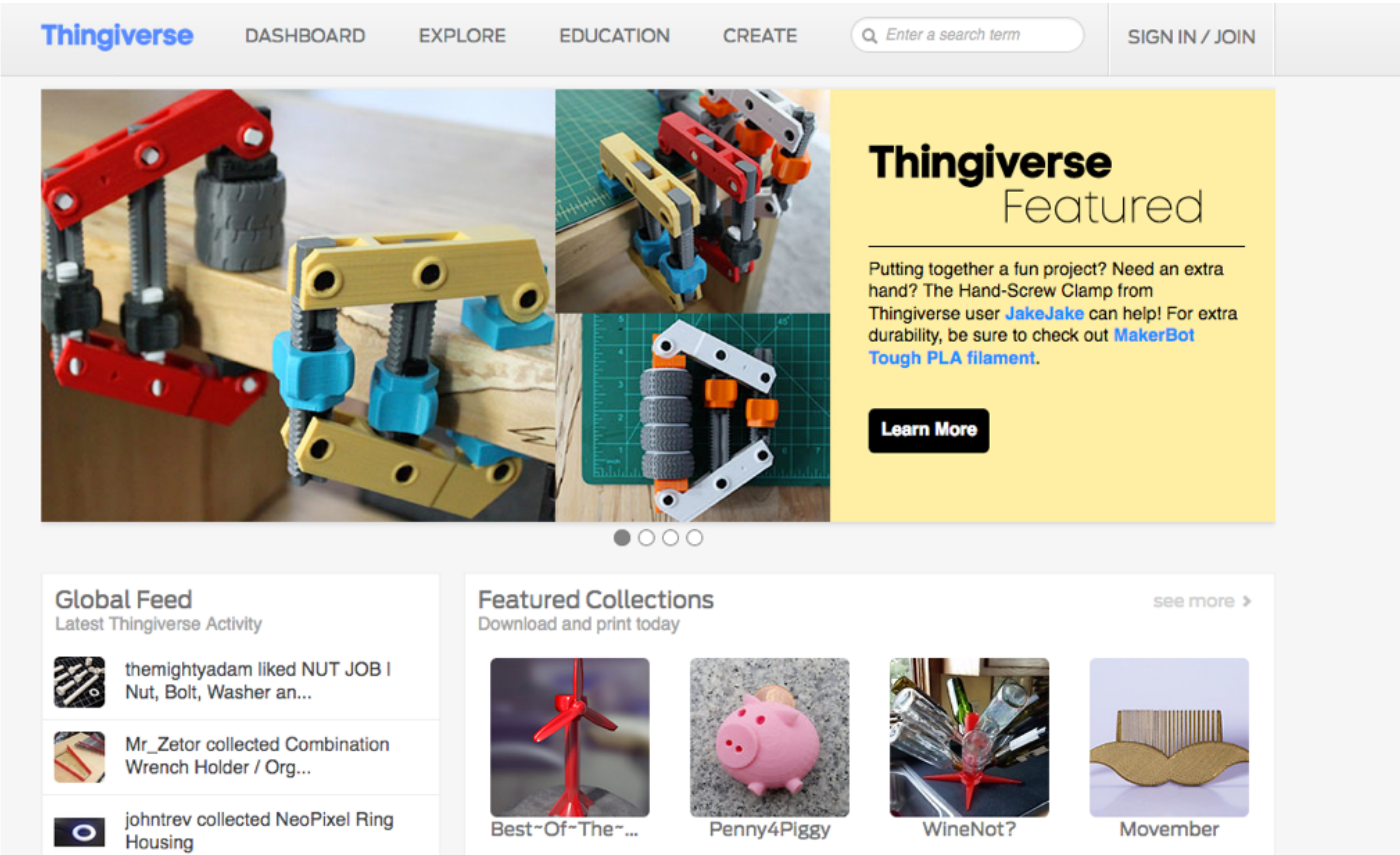
Figure 1: Johannes, (front) has placed a physical necklace pendant into his Scotty unit and is now sending it to Julia (back). Each Scotty unit consists of an off-the-shelf 3D printer (MakerBot) extended with a milling machine, a camera, and an additional processor. By destroying the necklace during scanning, encrypting it during transmission, and preventing reprinting, Scotty assures that never more than one pendant can exist, thereby preserving the

where will this go?

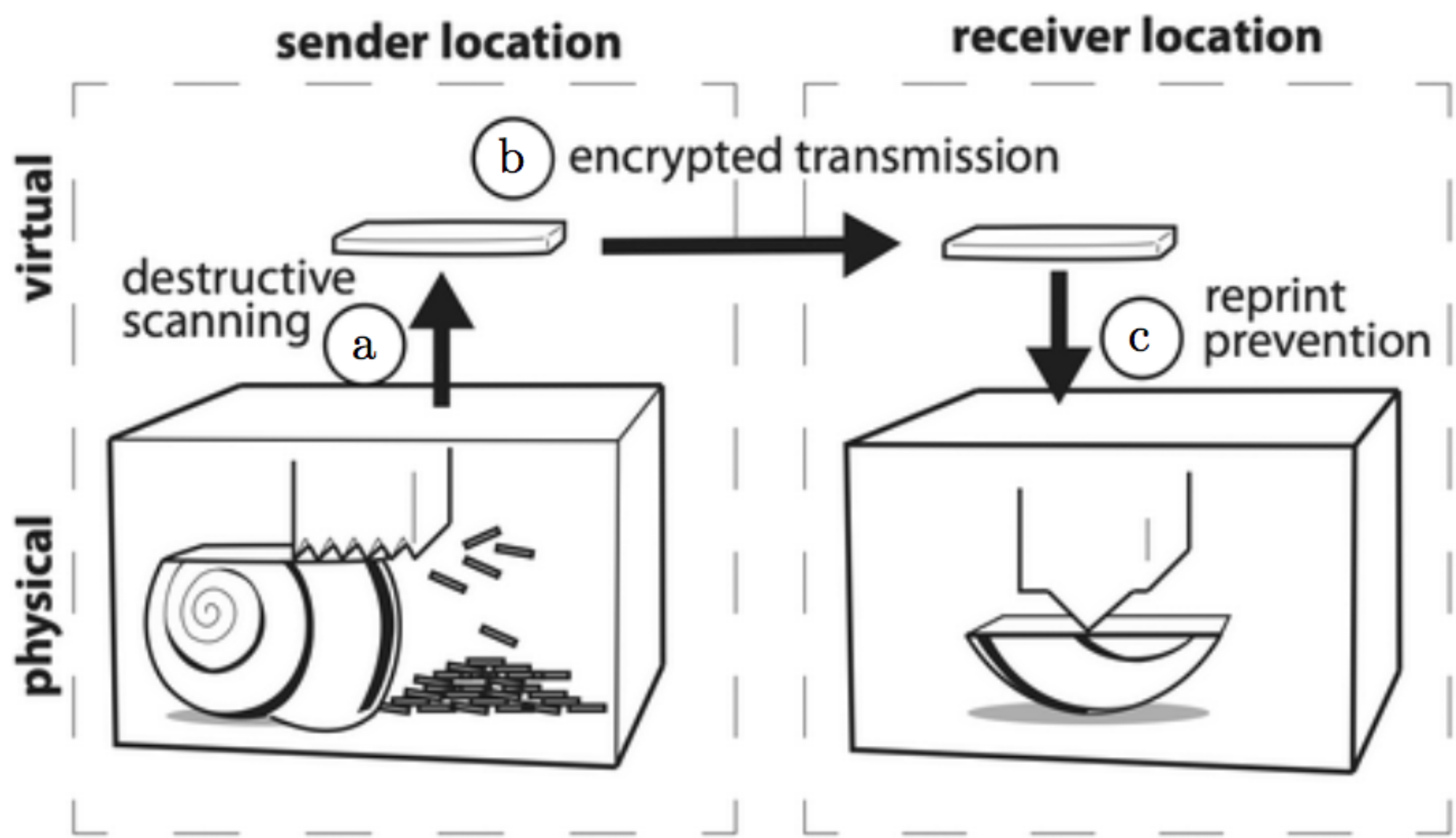
Spotify: flatrate for music
Netflix: flatrate for video
GettyImages: flatrate for photos
XX: flatrate for physical objects?

similar to Spotify, Netflix, GettyImages…
pay once, download as much as you want.

Thingiverse: flatrate for physical objects?
(but no payment model yet)



rent a movie…
rent an object?



will we really all **print at home?**

I think yes.
Today there's already a lot happening
to **bring 3D printing into the product delivery cycle.**

US 20150052024A1

(19) **United States**

(12) **Patent Application Publication**

Apsley et al.

(10) **Pub. No.: US 2015/0052024 A1**

(43) **Pub. Date: Feb. 19, 2015**

(54) **PROVIDING SERVICES RELATED TO ITEM DELIVERY VIA 3D MANUFACTURING ON DEMAND**

(71) Applicant: **Amazon Technologies, Inc.**, Reno, NV (US)

(72) Inventors: **Linda Knowlton Apsley**, Sammamish, WA (US); **Colin Ian Bodell**, Seattle, WA (US); **Jacob Conrad Danton**, Bellevue, WA (US); **Scott Randall Hayden**, Woodinville, WA (US); **SaiPrasad Kapila**, Redmond, WA (US); **Eric Lessard**, Goodyear, AZ (US); **Robert Benjamin Uhl**, Seattle, WA (US)

(73) Assignee: **Amazon Technologies, Inc.**, Reno, NV (US)

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(57) **ABSTRACT**

Methods and systems can be provided for providing items manufactured on demand to users. A user request for an item can be received. The item can have 3D manufacturing instructions associated therewith. A delivery method for the item can be determined. A manufacturing apparatus can be selected to manufacture the item based on the 3D manufacturing instructions. Instructions can be sent to the manufacturing apparatus to manufacture the item based on the 3D manufacturing instructions. Delivery instructions can be provided for delivering the item according to the delivery method.

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Apsley et al.

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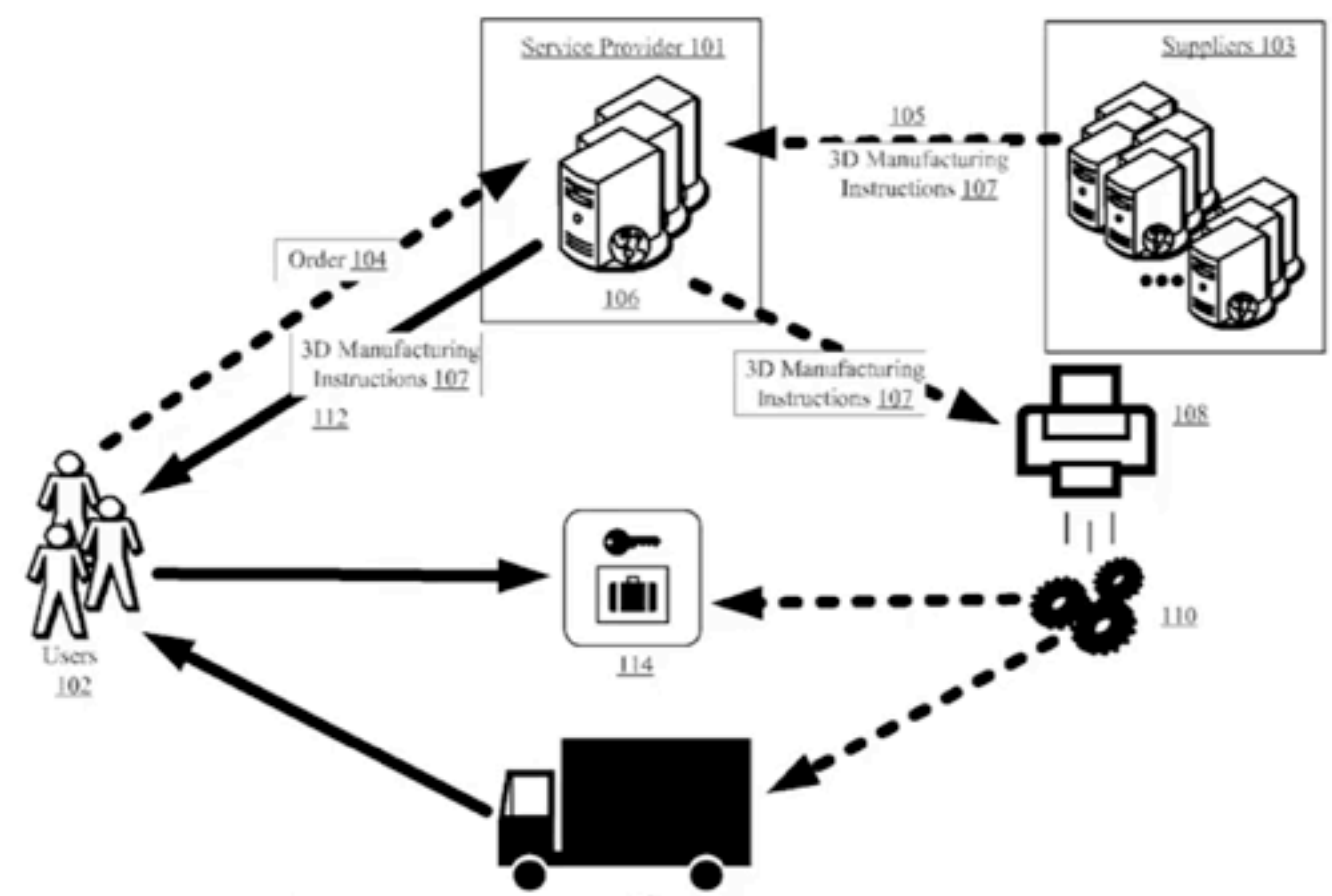


copyright issues have existed with all types of media:

illegal music copies
illegal movie copies
… next is objects….

product companies are very worried right now.

sustainability

<not part of nanoquiz since it was not lectured>

every access to a new type of media
came with huge sustainability problems…

text editing

photography

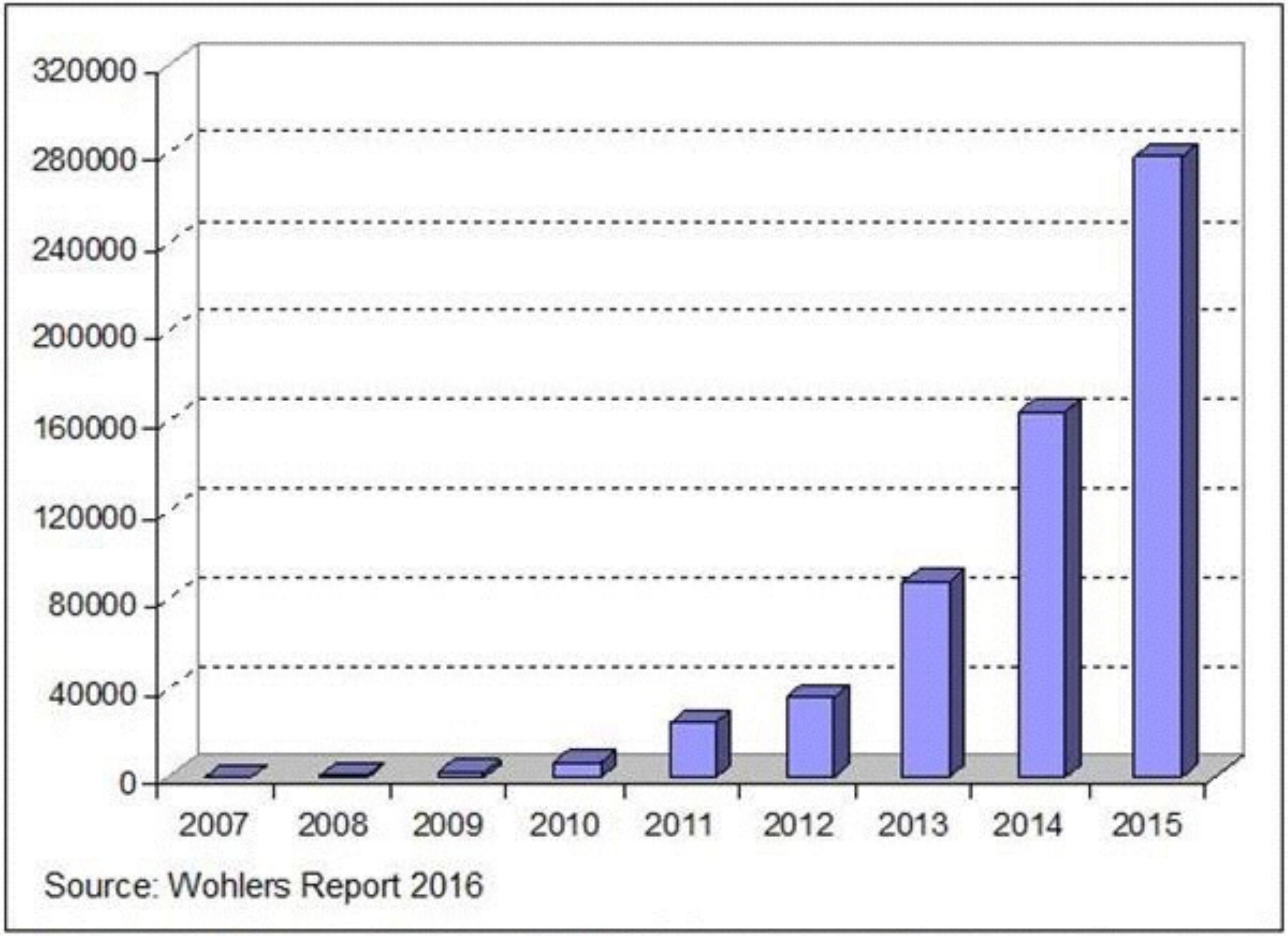
“**A wide variety of chemicals** are used in black and white photographic processing. Film developing is usually done in closed canisters. Print processing uses tray processing, with successive developing baths, stop baths, fixing baths, and rinse steps. Other treatments include use of **hardeners, intensifiers, reducers, toners, and hypo eliminators.”**

https://ehs.princeton.edu/health-safety-the-campus-community/art-theater-safety/art-safety/photography

but now we have **digital screens**
for displaying text…
for displaying photos…
so we don't need this anymore.

but objects need to be instantiate in the physical world in order to have value

objects



More than 278,000 desktop (under $5,000) 3D printers were sold worldwide last year

what will happen if **everyone** can produce physical objects?

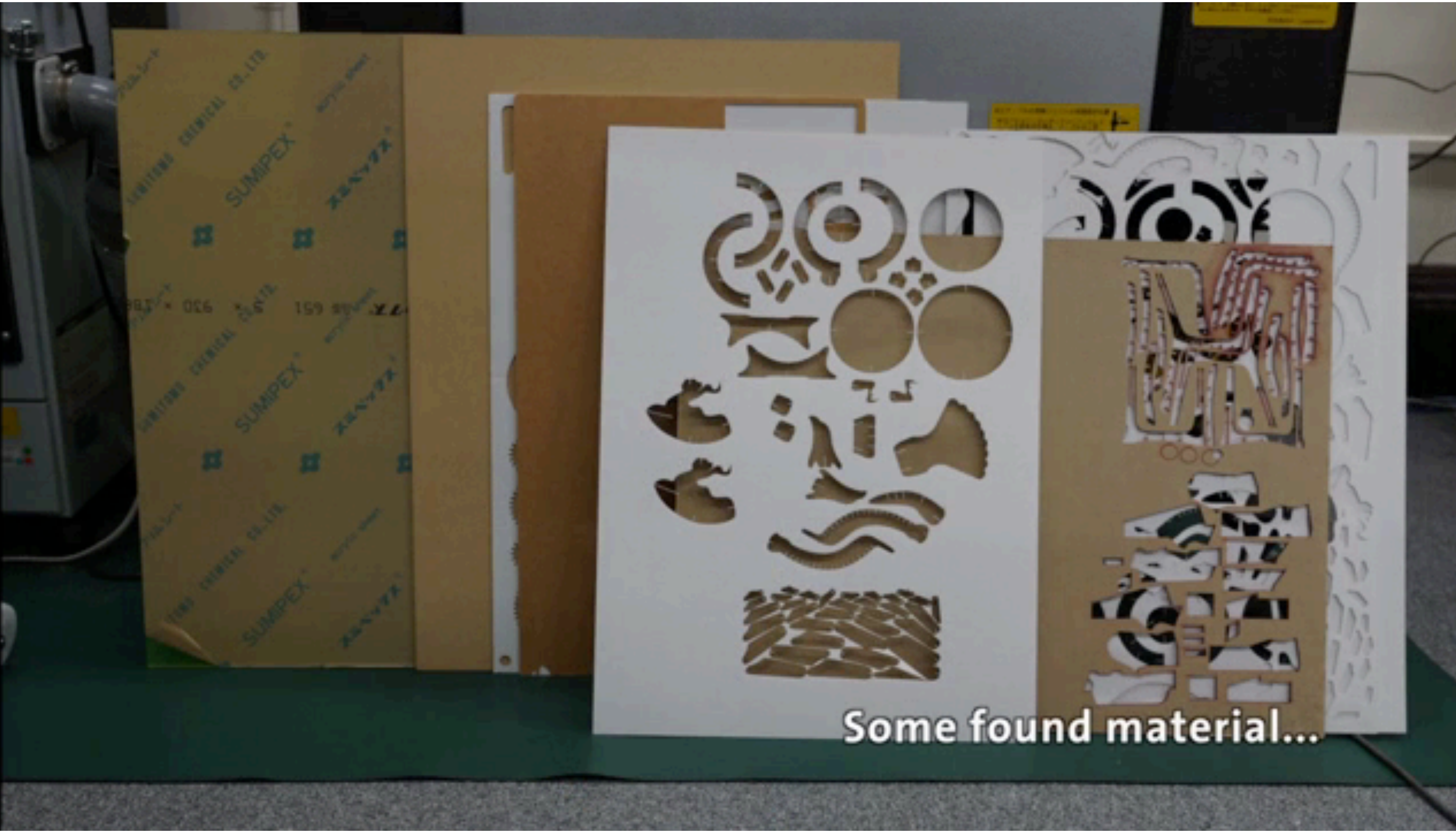
what will happen if **everyone** can produce physical objects?

many great things… but also more of this:
huge amounts of **material being consumed**
and **trash being generated**

can we reduce the consumption of material per object?
can we recycle?
[…]

there's not much material out there yet,
huge space for invention!

1) using material more efficiently


SUMIPEX
Some found material...

PacCAM: Material Capture and Interactive 2D Packing for Efficient Material Usage on CNC Cutting Machines

Daniel Saakes [1]
daniel@saak.es

Thomas Cambazard [1]
thomas.cambazard@epfl.ch

Jun Mitani [1,2]
mitani@cs.tsukuba.ac.jp

Takeo Igarashi [1,3]
takeo@acm.org

[1]JST ERATO Igarashi Design Interface Project [2]University of Tsukuba [3]The University of Tokyo

Figure 1. PacCAM supports users in packing 2D parts by capturing materials in a CNC machine (a) and using the captured materials (b) in a dedicated user interface based on 2D rigid body simulation and snapping (c), resulting in optimized utilization of material for efficient fabrication (d).

ABSTRACT

The availability of low-cost digital fabrication devices enables new groups of users to participate in the design and fabrication of things. However, software to assist in the transition from design to actual fabrication is currently overlooked. In this paper, we introduce PacCAM, a system for packing 2D parts within a given source material for fabrication using 2D cutting machines. Our solution combines computer vision to capture the source material shape with a user interface that incorporates 2D rigid body simulation and snapping. A user study demonstrated that participants could make layouts faster with our system compared with using traditional drafting tools. PacCAM caters to a variety of 2D fabrication applications and can contribute to the reduction of material waste.

INTRODUCTION

Many objects are composed out of raw materials that enter the fabrication process flat; as sheets or in rolls. Computer numerical control (CNC) fabrication devices such as plotters, routers, and cutters transform these materials into multiple

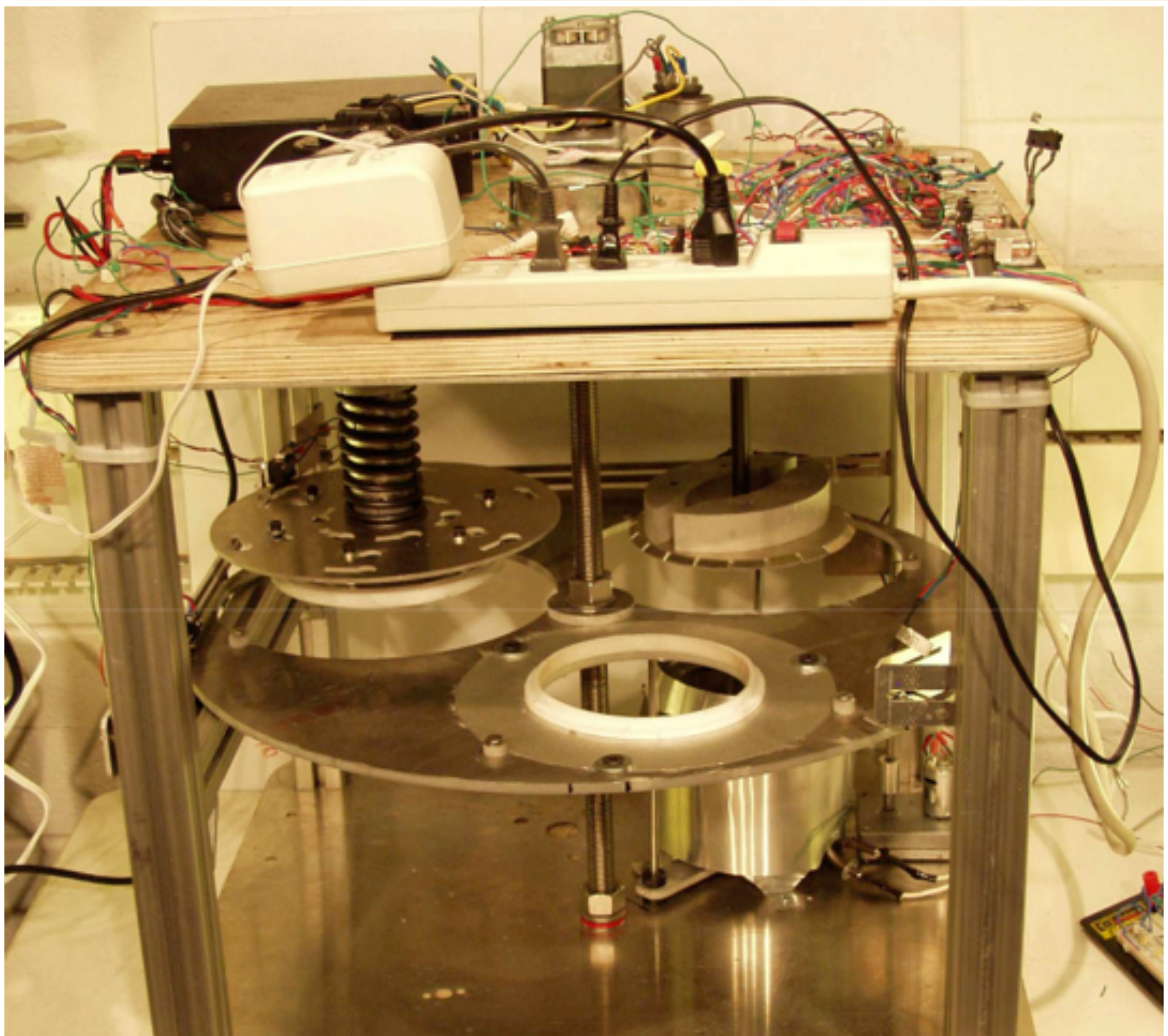
With the proliferation of decentralized [22] and personal [11] digital fabrication, new groups of occasional designers/makers are emerging. However, material usage is far from optimized in this emerging user community. We visited numerous fablabs, hackerspaces, and university labs and found piles of partly used materials as shown in Figure 1b. In this paper, we present a new system that is specifically aimed at manual packing of shapes to reduce material waste.

When designing physical objects that are composed of flat materials, designers encounter and switch between multiple representations: a) the intended 3D object, b) the decomposition of the object in 2D parts, and c) the layout and fitting of the 2D parts for actual fabrication on the sheets/rolls. A multitude of research and commercial software exists to support the user or automate the transition from step a to b [2, 14, 17, 18, 19, 23, 24]. However, the transition from step b to c is is currently overlooked. This final step from design to actual manufacturing is a one way process, only output. We ultimately aim to make this final step bi-directional: both output and input by using material features as a creative constraint

2) recycling

filament extruders:

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



thermoforming
is **reversible**

forming a plate,
then flattening it again,
then create new plate

Dishmaker: Personal Fabrication Interface

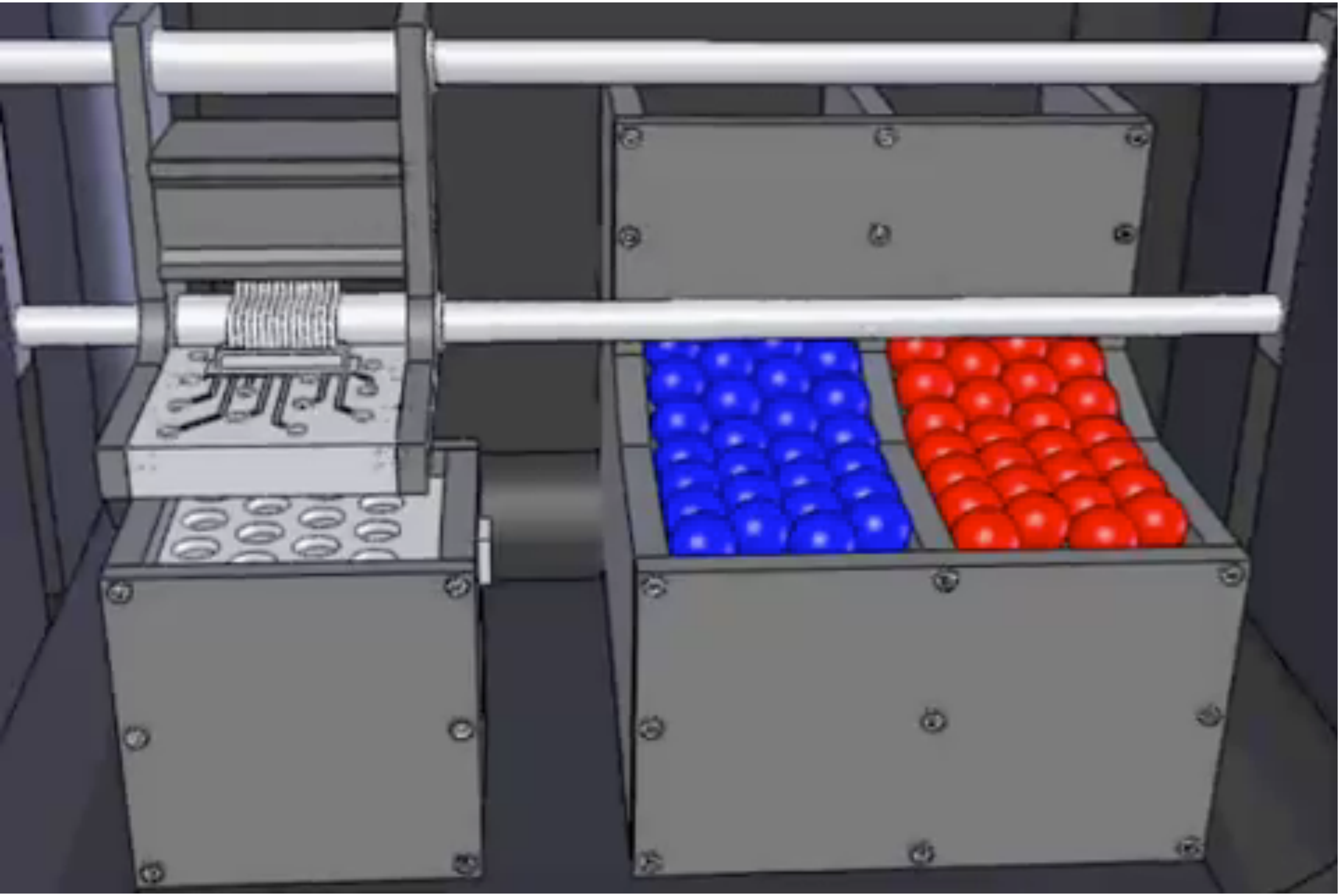
Leonardo Bonanni, Sam Sarcia, Subodh Paudel, Ted Selker
MIT Media Laboratory
20 Ames Street
Cambridge, MA 02139
+617 253 4564
amerigo@media.mit.edu, ssarcia@mit.edu, paudel@mit.edu, selker@media.mit.edu

ABSTRACT
People are tool-makers, but today we often depend on centralized fabrication for our tools. This paper explores the user experience opportunities demonstrated in a case study of a computer-controlled domestic fabrication system. Specifically we explore several approaches to creating a dish-maker that would create dishes on demand under computer control. The Dishmaker can create cups, bowls and plates and recycle them into their raw material when the user is finished eating. A graphic interface allows users to select between cups, bowls or plates that can be created in any volume. This paper describes several working prototypes and shows the approaches for defining your dishes for a meal.

Author Keywords
Tangible computing, Personal Fabrication, Machine Tool, Appliance, Product Design.

ACM Classification Keywords
J.7: Consumer Products.

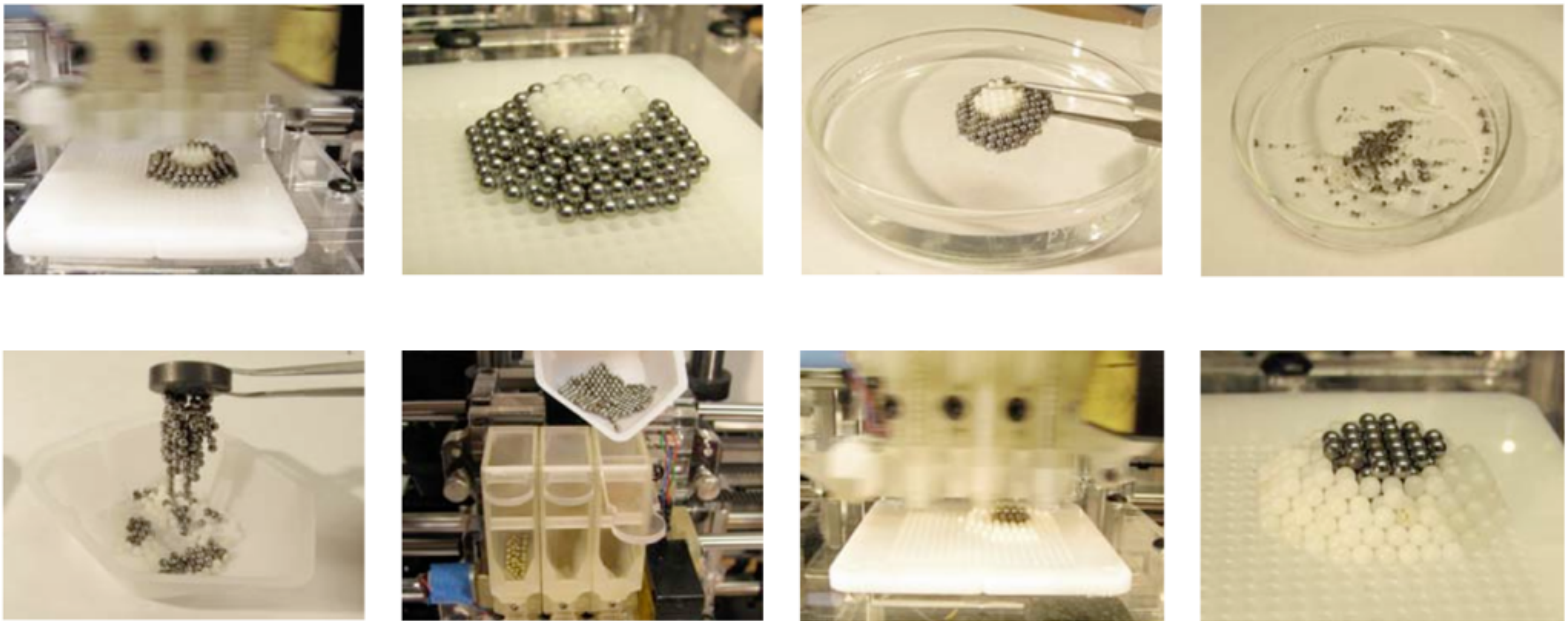
INTRODUCTION
Rapid prototyping techniques can produce an increasing variety of forms and materials based on 3-dimensional computer models. Personal fabrication could one day produce everything we need locally, replacing the with staples that we collect in case they one day serve their purpose. Dishes in the kitchen are one example of an object that actually wastes energy by having a long product life. Aside from the cost of production of infinitely durable plates and bowls, dishes require frequent washing for the duration of their lives – not to mention storage with its associated materials and space. By targeting this specific problem in the kitchen, we are seeking to produce a personal fabrication interface capable reducing the amount of things we live with. The scope of the idea is to obtain new dishes on demand for eating and to be able to recycle them back into the system. The term “dishmaker” was chosen to reflect the potential to replace a large part of what a dishwasher does with a more fundamental recycling effort. The mechanism is called a dishmaker because it produces the useful plates, bowls and cups that can be used for eating. It recycles them so that they can be re-produced for the next meal. By storing the dishes in their raw material, the dishmaker seeks to eliminate clutter as well as to replace storage spaces with productive space.



alternative approach:

- assemble object from voxels, then glue them together
- easy to recycle: just dissolve the glue

- magnetic + non-magnetic voxels
- after dissolve, use magnet to separate



FULLY RECYCLABLE MULTI-MATERIAL PRINTING

Jonathan D. Hiller, Hod Lipson
Mechanical and Aerospace Engineering
Cornell University
Ithaca NY, 14853, USA

Reviewed, accepted September 15, 2009

Abstract

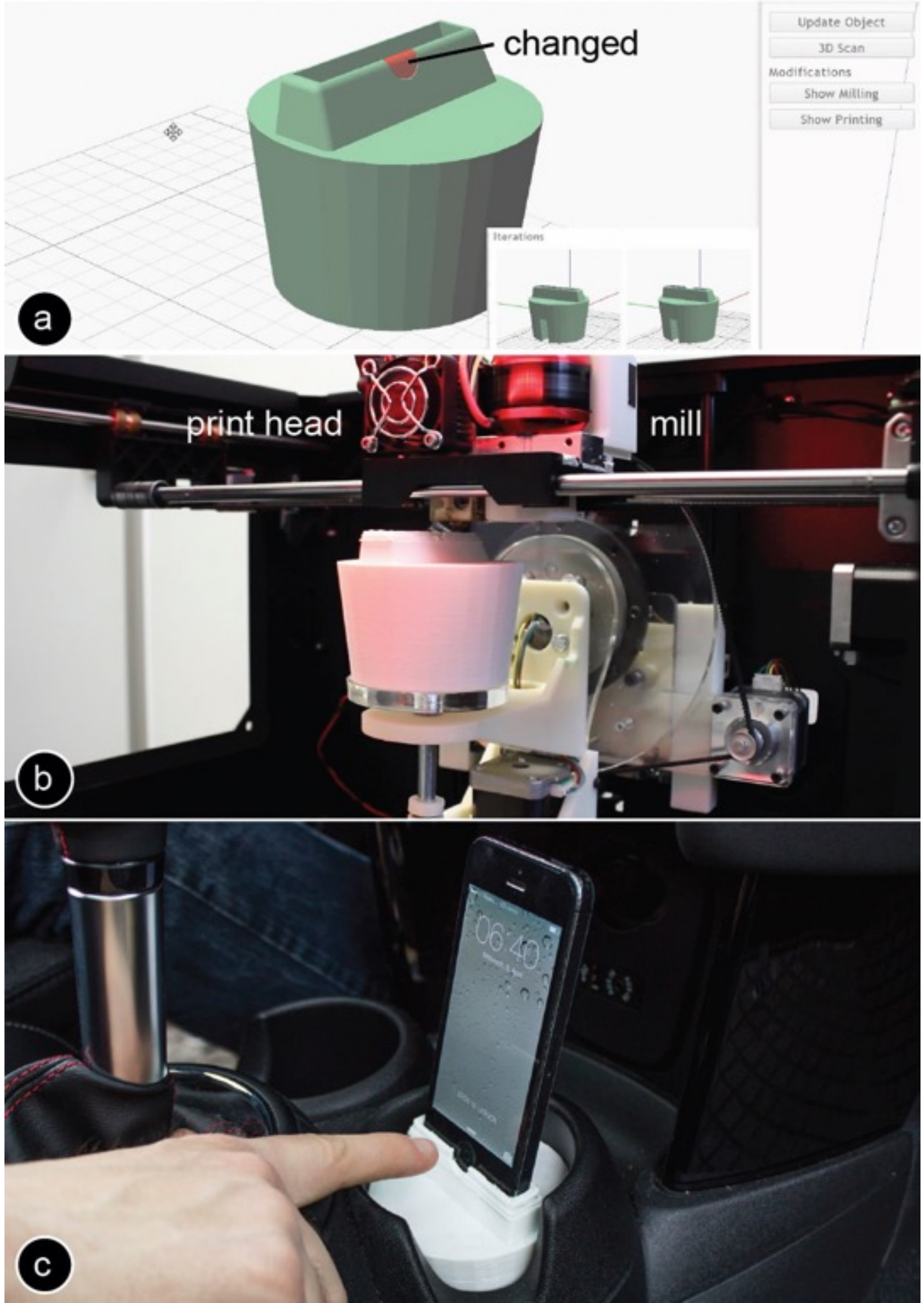
Recycling is often a costly and inefficient process, particularly for objects composed of multiple integrated materials. Here, we demonstrate a freeform fabrication system that prints with fully reusable physical voxels and minimal recycling effort. This new paradigm of digital (discrete) matter enables any number of materials to be printed together in any configuration. The individual voxels may then be reclaimed at will by dissolving the bonds holding the structure together. Coupled with a compatible voxel sorting process, we demonstrate multiple generations of freeform fabricated objects using the same physical material. This opens the door to a flexible desktop fabrication process in which 3D multi-material objects are fully recyclable and re-usable with minimal infrastructure.

Introduction

With the advent of multi-material additive manufacturing (AM) processes and the recent push for sustainability among developed nations, the need for recycling of additively fabricated 3D parts has become a critical need for future research (Bourell et al., 2009). The AM industry is growing steadily (Wohlers, 2008), but as AM parts see widespread adoption the potential impact has not been thoroughly considered (Yanchun et al., 1999). Here, we focus specifically on recycling end-use additively manufactured objects, not the full lifecycle analysis of additive manufactured parts (as in Jansen and Krause, 1995, Drizo and Pegna, 2006 and Hopkinson et al., 2006).

The vast majority of parts created with additive manufacturing processes today are not recycled. This is primarily for two reasons. First, in many AM processes the

3) patching rather than reprinting


changed
Update Object
3D Scan
Modifications
Show Milling
Show Printing
Iterations
a
print head
mill
b
c

#1 immediately because of failed 3D printing

Patching Physical Objects

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

[1]Hasso Plattner Institute
Potsdam, Germany
{firstname.lastname}@hpi.uni-potsdam.de

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

ABSTRACT

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

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

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

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

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

General Terms: Design; Human Factors.

INTRODUCTION

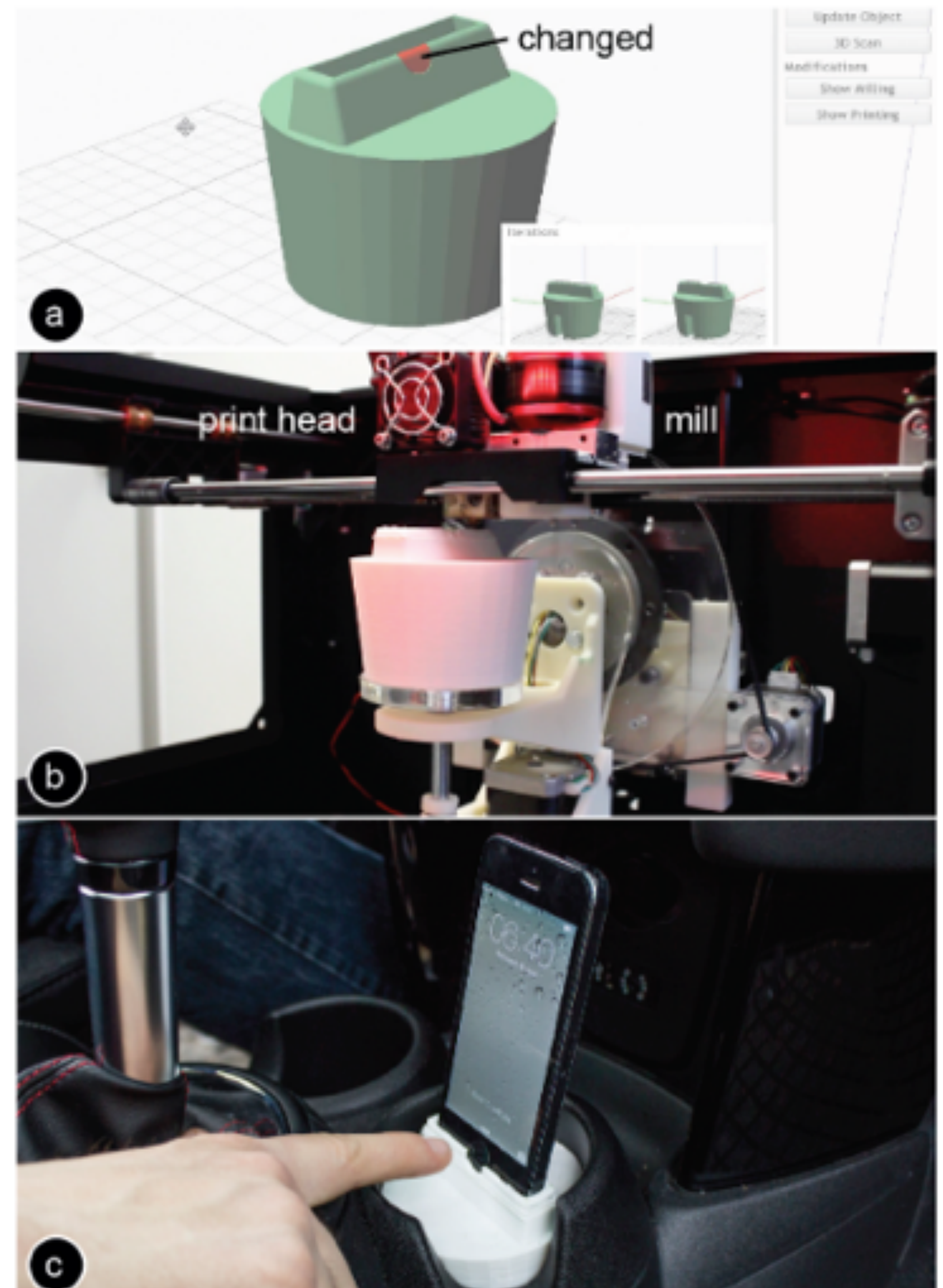


Figure 1: To minimize material consumption and to reduce waste during design iteration, we propose *patch-*

where will this lead?

maybe the main sustainability problem
are not the objects printed,
but the **3D printing hardware itself…**

rapid advances:

- new materials
- increased speed
- higher resolution

same was true in computing…
tons of electronic waste

Moore's law for 3D Printing?

a 3D systems stated in his 2014 keynote
that **3D printing speed** for their products on average
had doubled every 24 months over the last 10 years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The Moore's Law of 3D Printing... Yes it Does Exist, And Could Have Staggering Implications

KODAK enters 3D Printing
Early bird offer!

by Brian Krassenstein | Jun 28, 2014 | 3D Printing, Editorials / Opinions |

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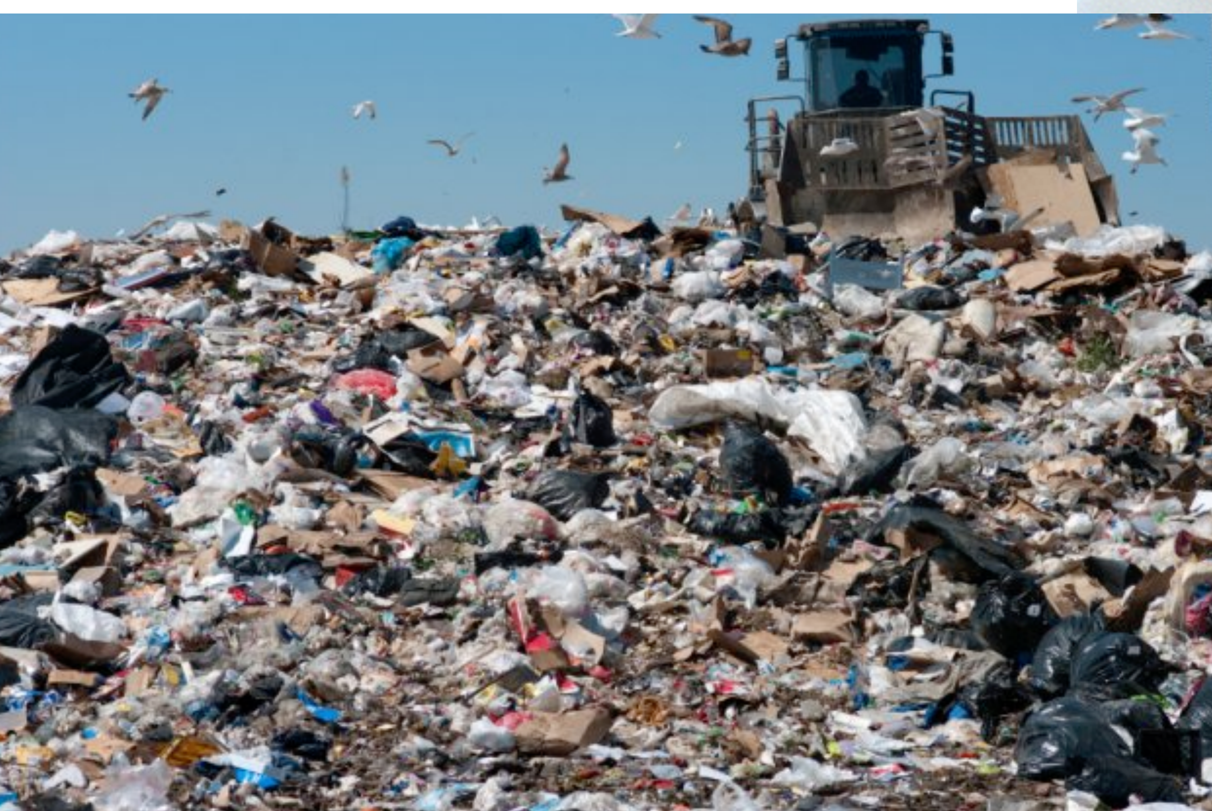
For those who follow technology, there isn't a single concept which embodies the incredible progress we have made over the last several decades, than that of Moore's Law. In a paper written in 1965, a man named Gordon E. Moore made a prediction, which at the time was mocked by many. The prediction stated that the number of transistors per square inch on integrated circuits would double every year, because it had done so up until that point in 1965. Since then the law has been modified, and many within the industry use the 12-24 month time frame for the doubling. Three years after Moore's famous prediction, he founded Intel, the semiconductor manufacturer, now worth in excess of $150 billion.

consumers will
trash old machines
and buy newer ones

modular hardware?
shared fabrication facilities?

huge space for potential innovation
to get it right this time (hopefully).



end.