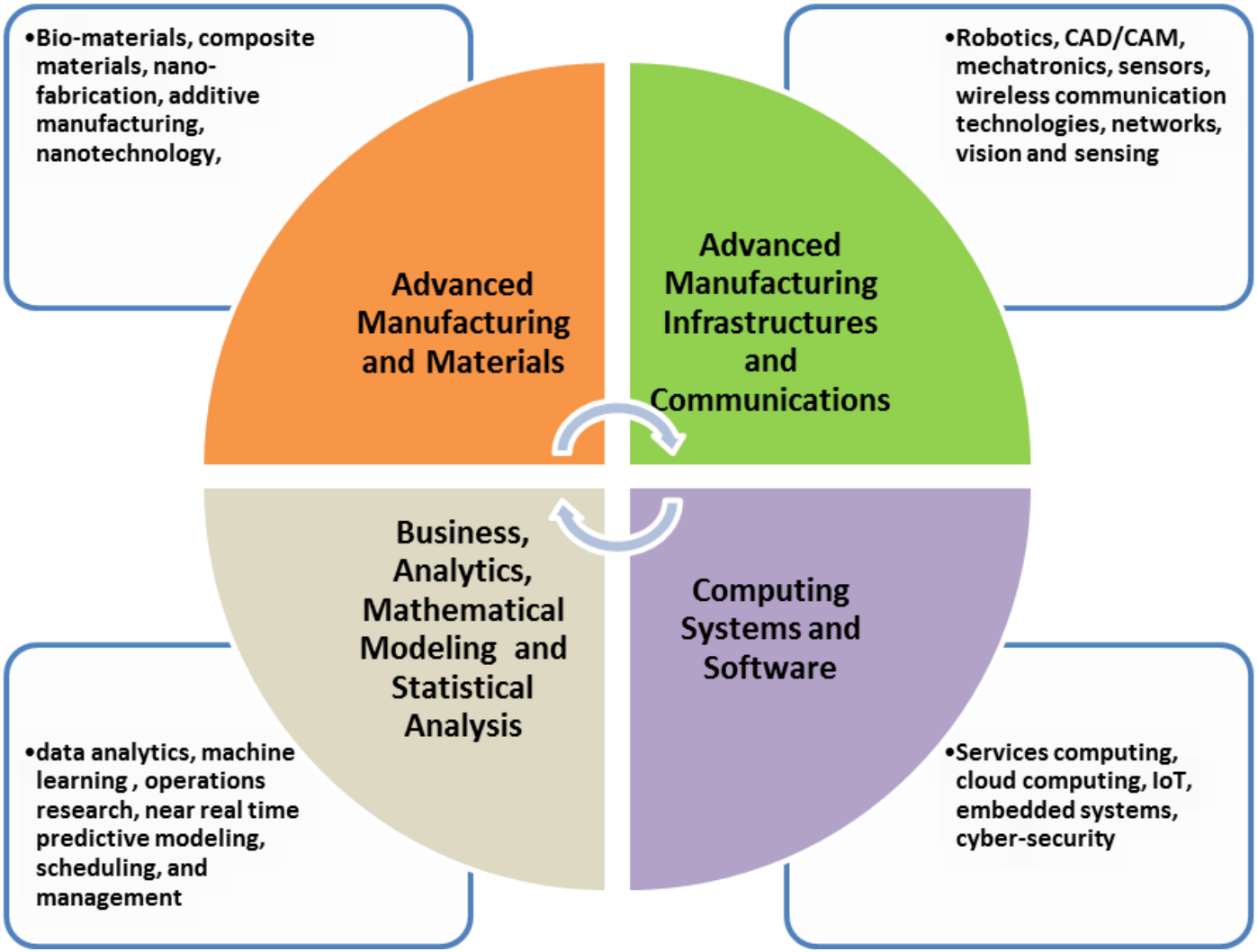
3D printing of bioplastics, bio-inspired 3D printing, bioprinting, and their biomedical applications

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Director, WIN 4.0 (Western's Industry 4.0 Network)
Western University (The University of Western Ontario)

July 26, 2018, 15th International Symposium on Bioplastics, Biocomposites and Biorefining (ISBBB 2018), Guelph, Ontario, Canada

WIN 4.0 (Western's Industry 4.0 Network)



~ 50 faculty members from Engineering, Science, Medicine, and Business and Management

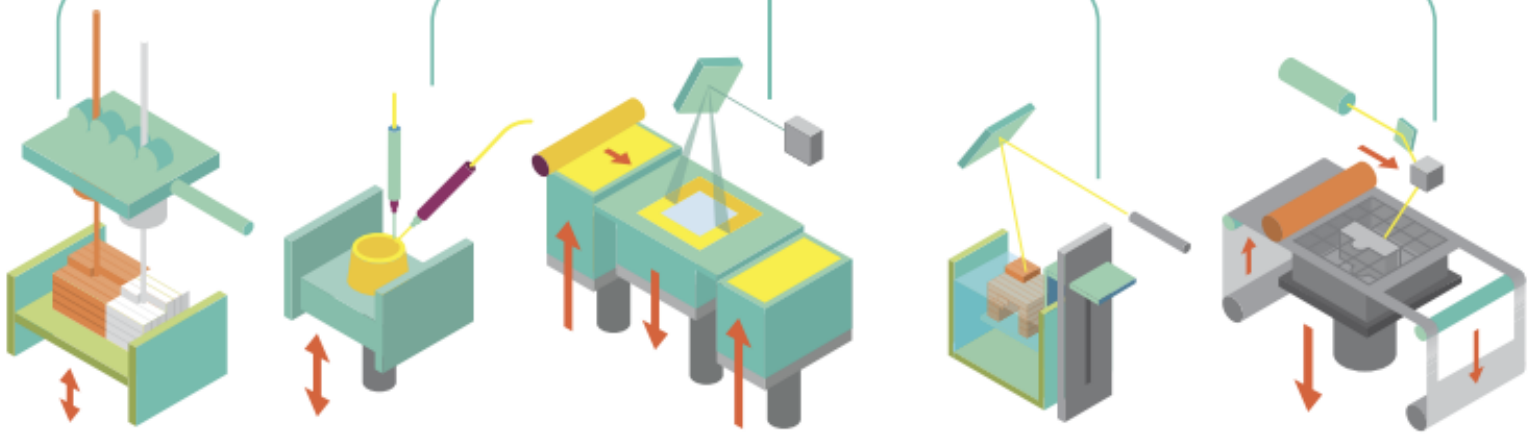
Outline

- 3D printing: applications, challenges and opportunities
- 3D printing of bioplastics
- Bio-inspired 3D printing
- Bioprinting

Outline

- **3D printing: applications, challenges and opportunities**
- **3D printing of bioplastics**
- **Bio-inspired 3D printing**
- **Bioprinting**

3D Printing



EXTRUSION
OF MOLTEN MATERIALS

DIRECT ENERGY DEPOSITION
MELTS METAL WITH A HIGH ENERGY POWER SOURCE

SOLIDIFICATION OF POWDER
FUSION OR JOINING OF PARTICLES

PHOTOPOLY-MERIZATION
SOLIDIFICATION OF A LIQUID POLYMER

SHEET LAMINATION
BONDING OF SHEETS

MATERIALS

POLYMERS

BIOBASED PLASTICS
PLA, PLL, PLGA, TPC, TPS, PA-11,...

METALS

METALS, CERAMICS POLYMERS

BIOBASED PLASTICS
PA-11, PLA, PLGA, PHBV,...

POLYMERS PHOTOCURABLE RESINS

HYBRIDS, PAPER, METALS CERAMICS

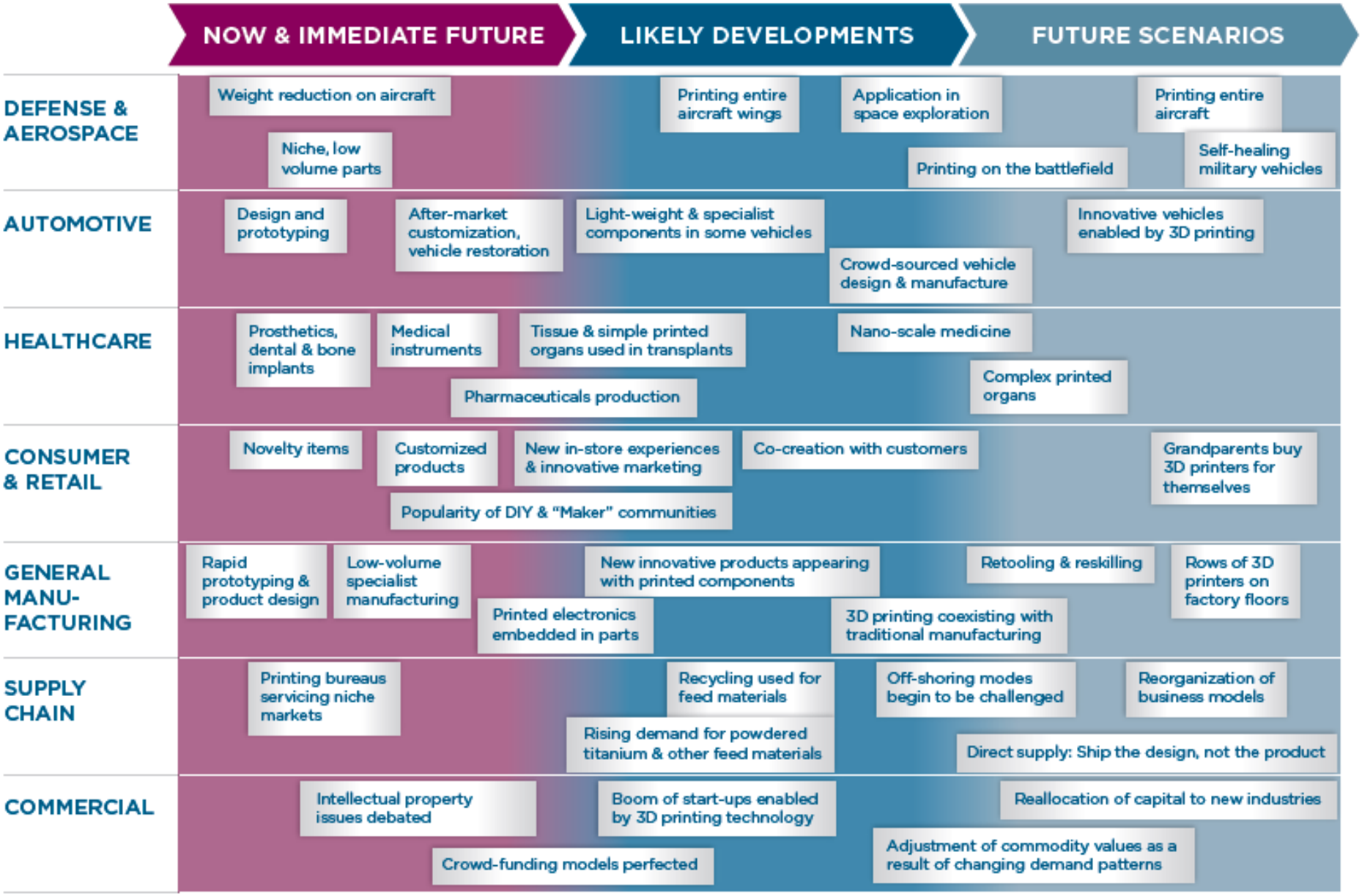
Image from: 3D PRINTING WITH BIOMATERIALS
Ad van Wijk & Iris van Wijk

3D Printing

An additive manufacturing process of making three-dimensional objects layer by layer from a digital model

- Vat Photopolymerization
  - -- Stereolithography (SLA)
  - -- Digital Light Processing (DLP)
- Material Jetting
- Binder Jetting
- Material Extrusion
- Powder Bed Fusion
  - -- SLS, SLM, DMLS, EBM, etc.
- Sheet Lamination
- Directed Energy Deposition

Challenges and Opportunities

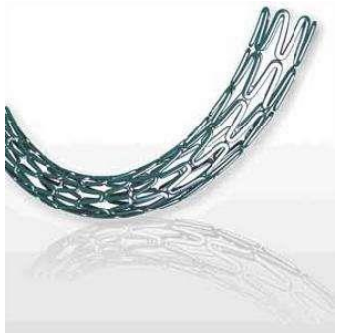


3D Printing is leading a revolution in manufacturing, increased flexibility, customization, features of Industry 4.0



Customized shoes/Jewelry
Fashion





Customized Medication
Time saving





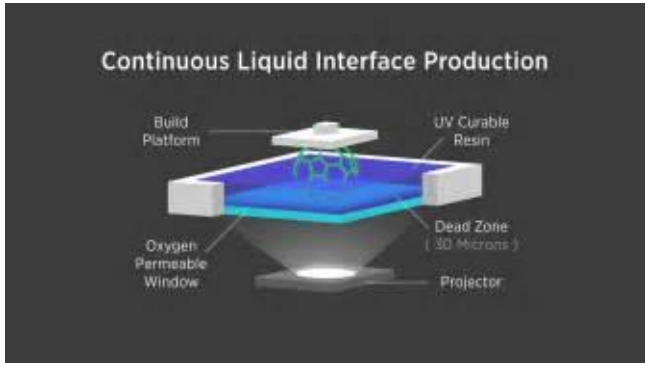
Customized Parts
Reduced weight



Image from internet

3D printing for Bio

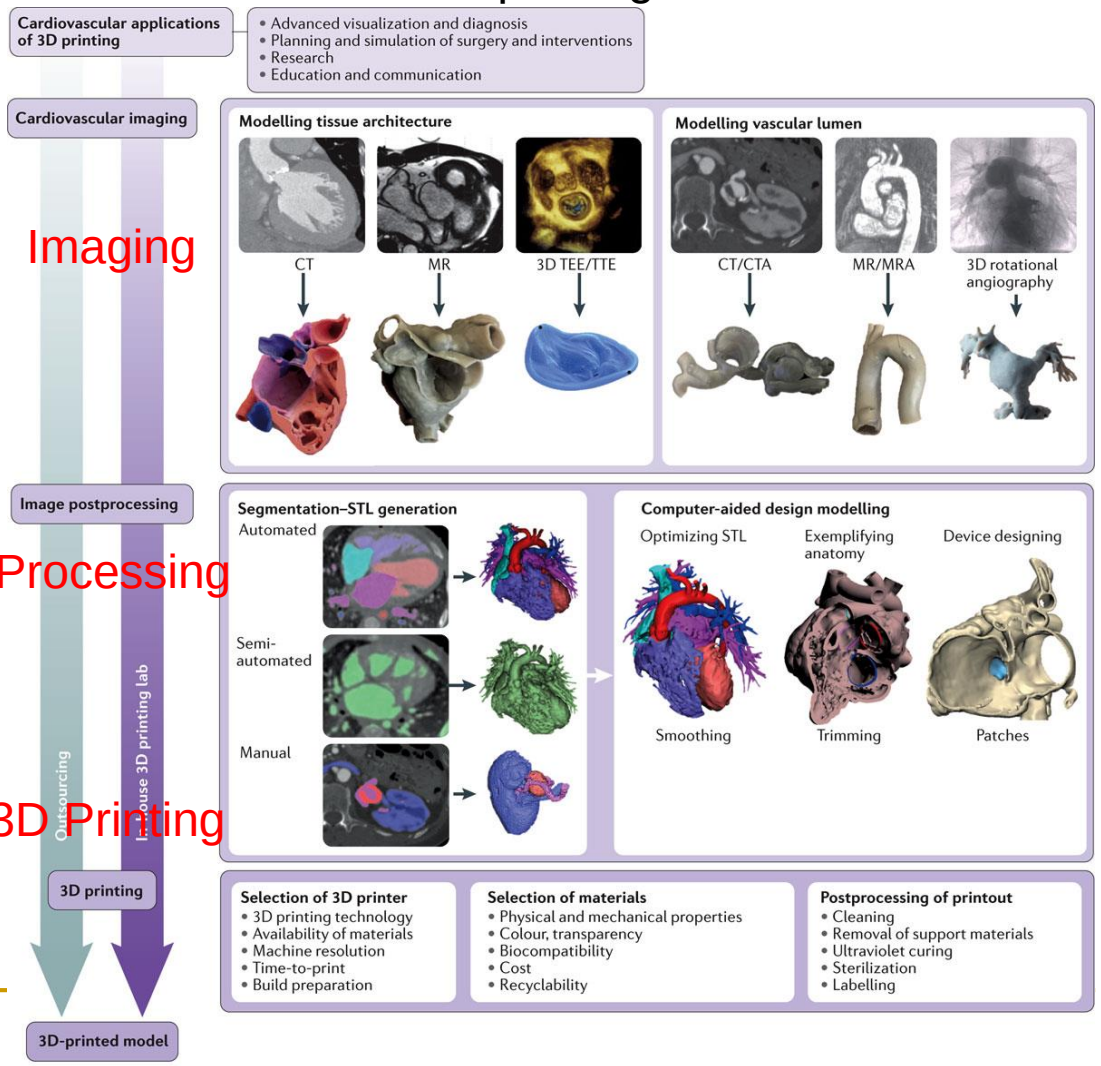
A typical application: Patient-specific medication



Why 3D printing?

- Patient specific
- One-of-a-kind
- Customized complex devices
- Cost saving
- Time saving

Cardiovascular 3D printing workflow



Nature Reviews | Cardiology

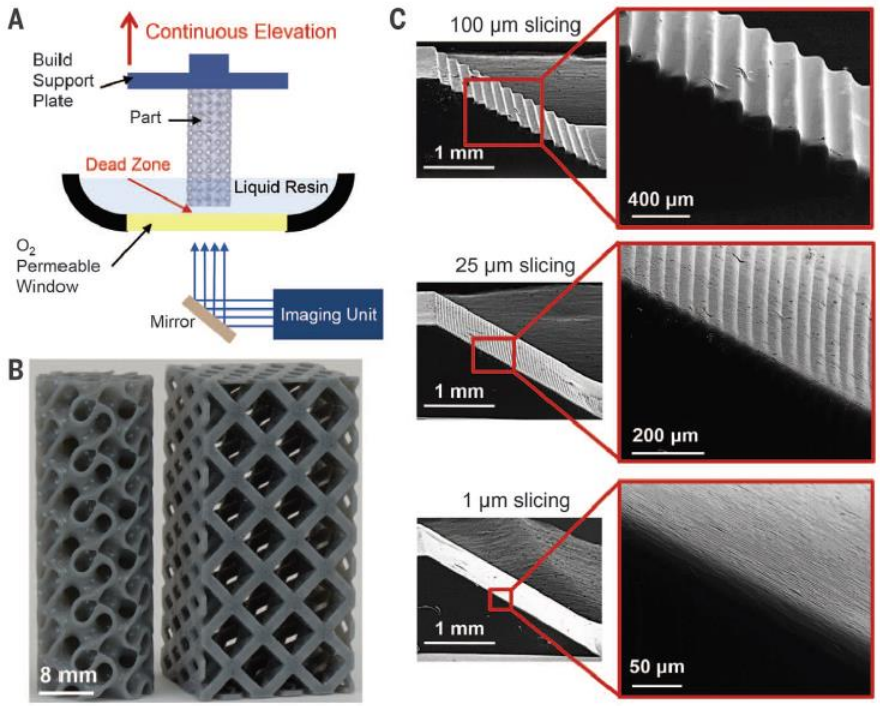
Nat. Rev. Cardiol. doi:10.1038/nrcardio.2016.170

Challenges and Opportunities

- Speed
- Resolution
- Large scale
- Mechanical Properties, e.g., strength
- Materials, e.g., functions

  -- polymer, metal, ceramic, glass, wood, powder based composite

3D Printing Speed can reach rates of hundreds of millimeters per hour.

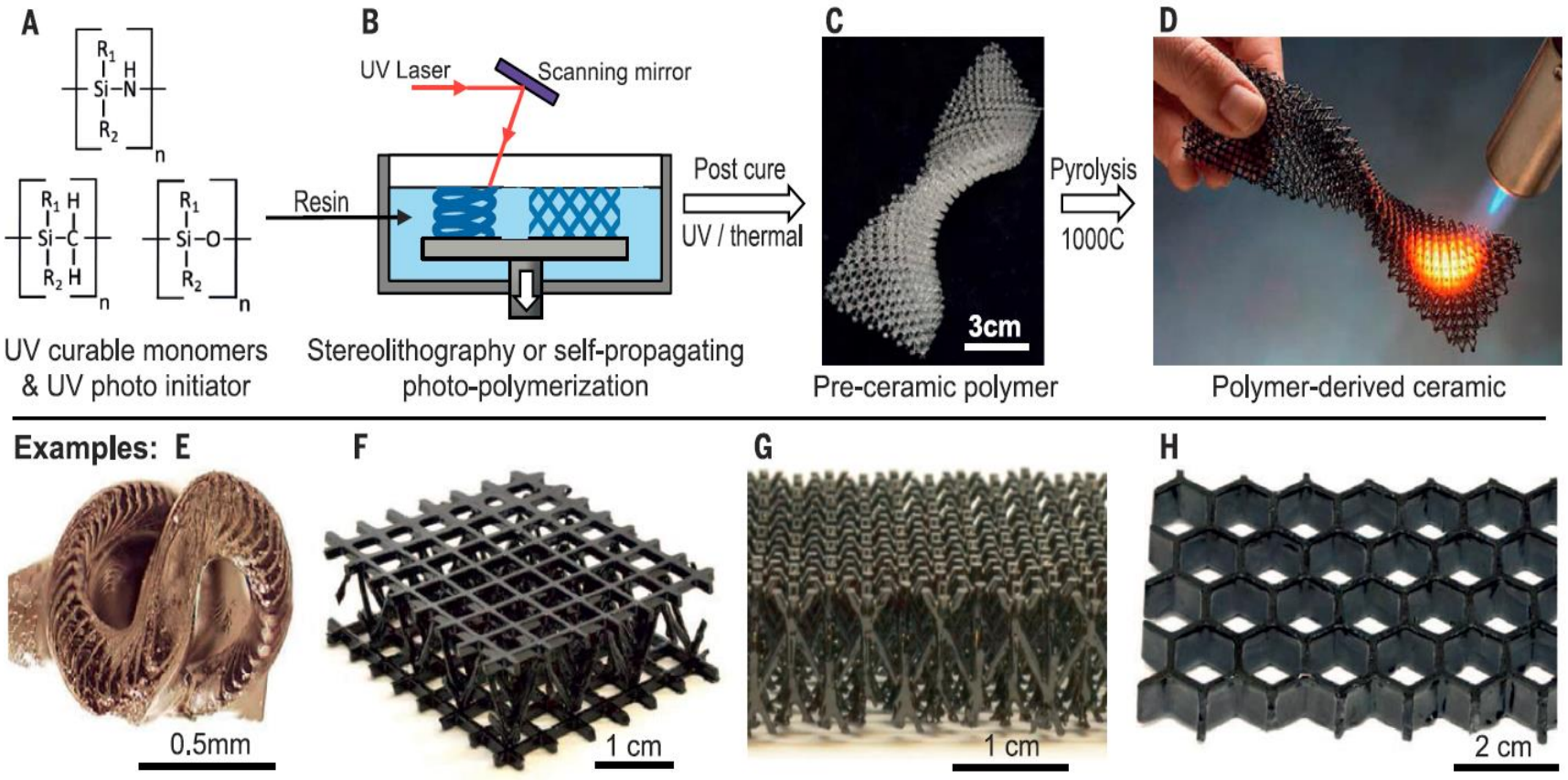






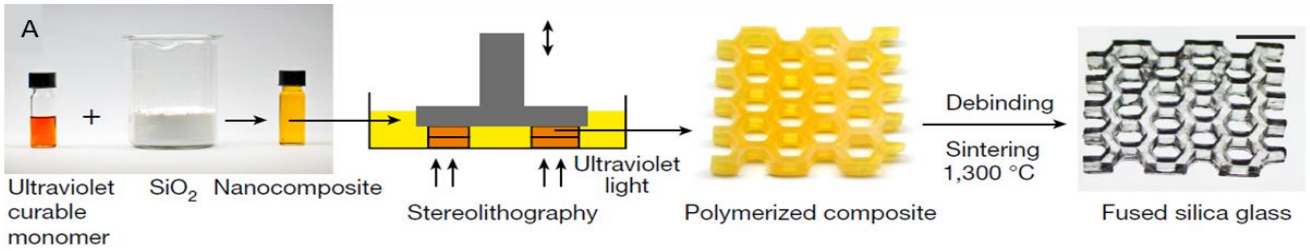
Continuous liquid interface production of 3D objects, Science, 20 MARCH 2015 • VOL 347 ISSUE 6228, 1349-1352

3D Printing of Ceramics



Eckel, Z.C., et al., *Additive manufacturing of polymer-derived ceramics.* Science, 2016. **351**(6268): p. 58-62.

3D printing of Glass





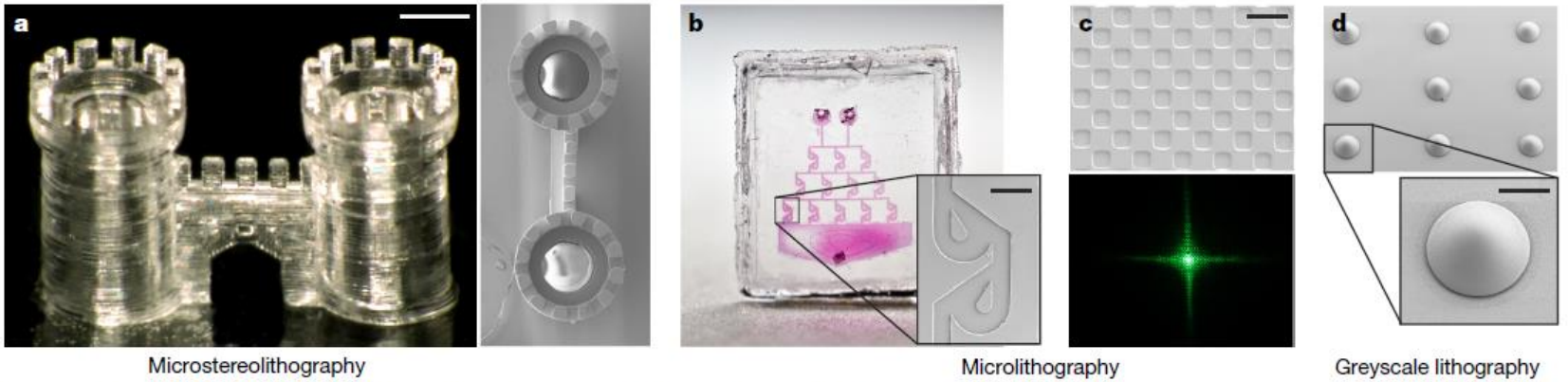


Figure 3 | Microstructuring of fused silica glass. a, Microstereolithography of a hollow castle gate (scale bar, 270 μm). **b**, Microlithography of an exemplary microfluidic chip (inset scale bar, 200 μm). **c**, Micro-optical diffractive structure creating the optical projection pattern shown at the bottom (illuminated with a green laser pointer; scale bar, 100 μm). **d**, Microlenses fabricated using greyscale lithography (inset scale bar, 100 μm).

Kotz, F., et al., *Three-dimensional printing of transparent fused silica glass.* Nature, 2017. **544**(7650): p. 337-339.

Outline

- 3D printing: applications, challenges and opportunities
- 3D printing of bioplastics
- Bio-inspired 3D printing
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Bio-based Plastics For 3D Printing

PROCESS	MATERIALS	FOSSIL BASED	BIO-BASED
EXTRUSION	Polymers (thermoplastics)	ABS, ABSi, ABS-M30, ABS-M30i, ABS-plus, ABS-ESD7, PC, PC-ISO, PA, PPSF/PPSU, ULTEM-9085	PLA, PLLA, PLGA, TPC, TPS, PA-11
DIRECT ENERGY DEPOSITION	Metals		
SOLIDIFICATION OF POWDER	Metals, ceramics, polymers (thermoplastics)	PC, PS, PMMA, PA-12, HDPE, POM, PCL, PEEK, HIPS, SAN	PA-11, PLA, PLGA, PHBV
PHOTOPOLY-MERIZATION	Photo-polymers (photocurable resins)	Epoxy/Acryl	**PLA**

PLA

- PLA is a typical bioplastic widely used

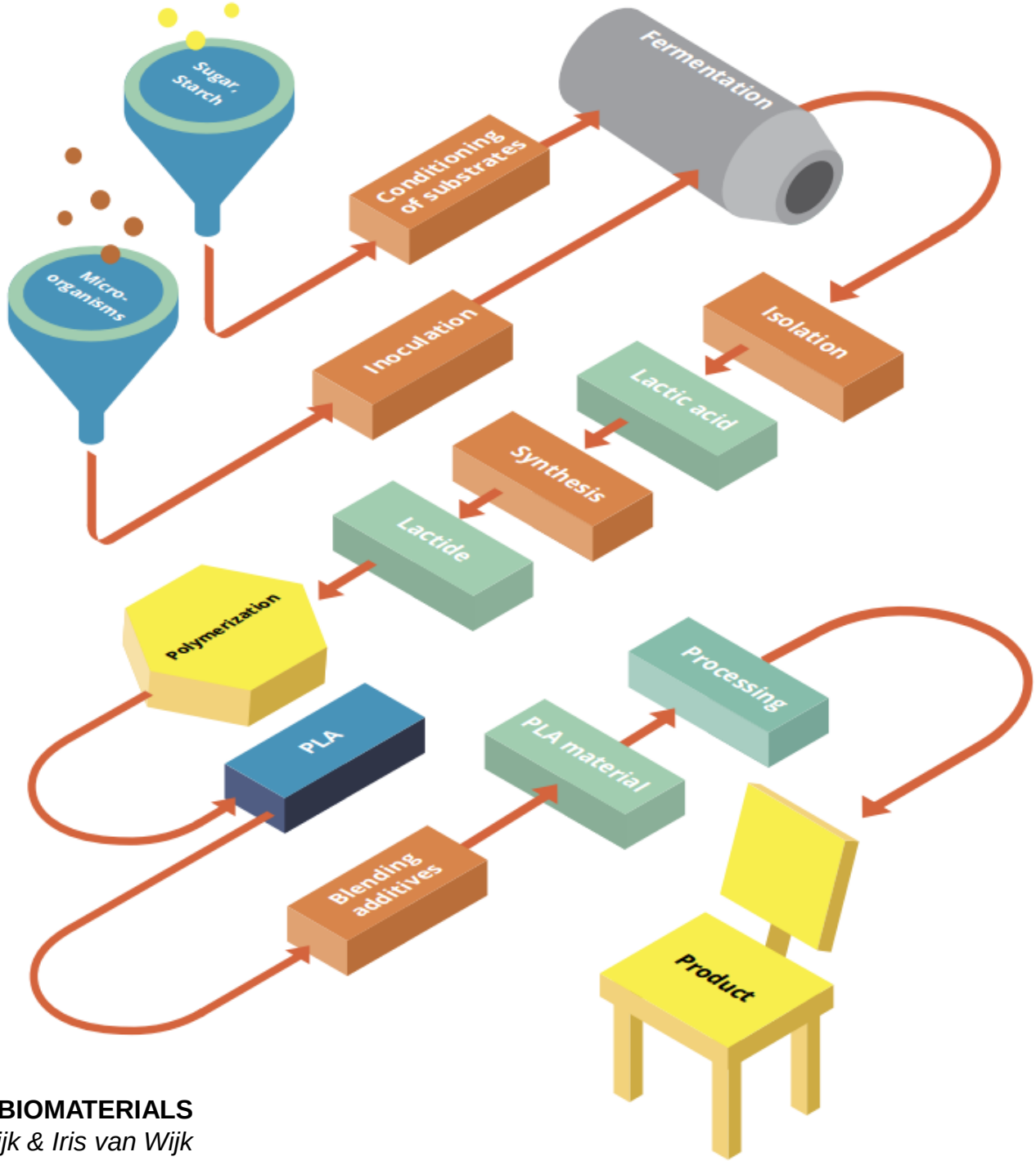


Image from: 3D PRINTING WITH BIOMATERIALS
Ad van Wijk & Iris van Wijk

Algae to bioplastics



Image from: https://www.dezeen.com

Outline

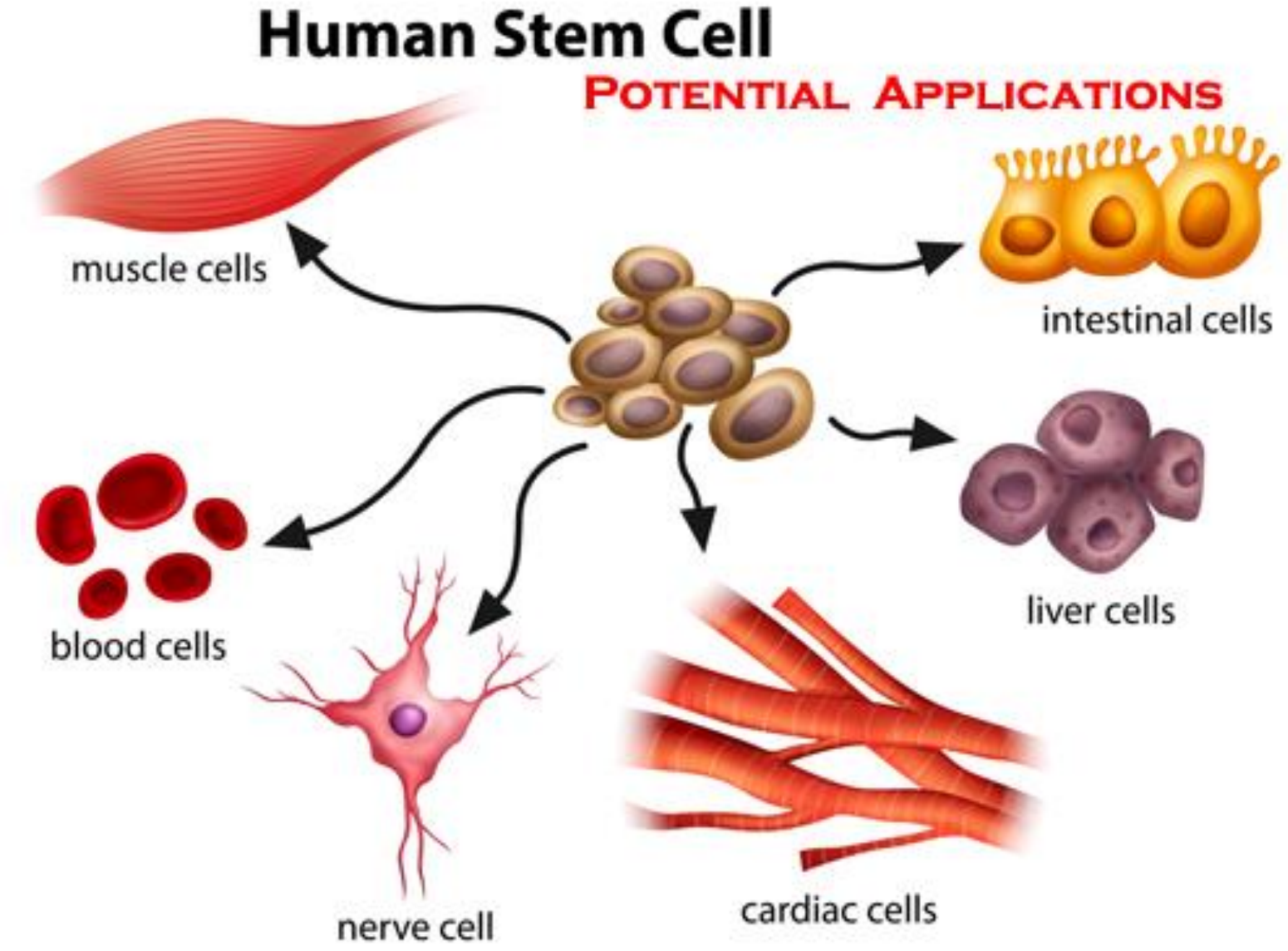
- 3D printing: applications, challenges and opportunities
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Challenges and Opportunities

- Speed
- Resolution
- Large scale
- Materials

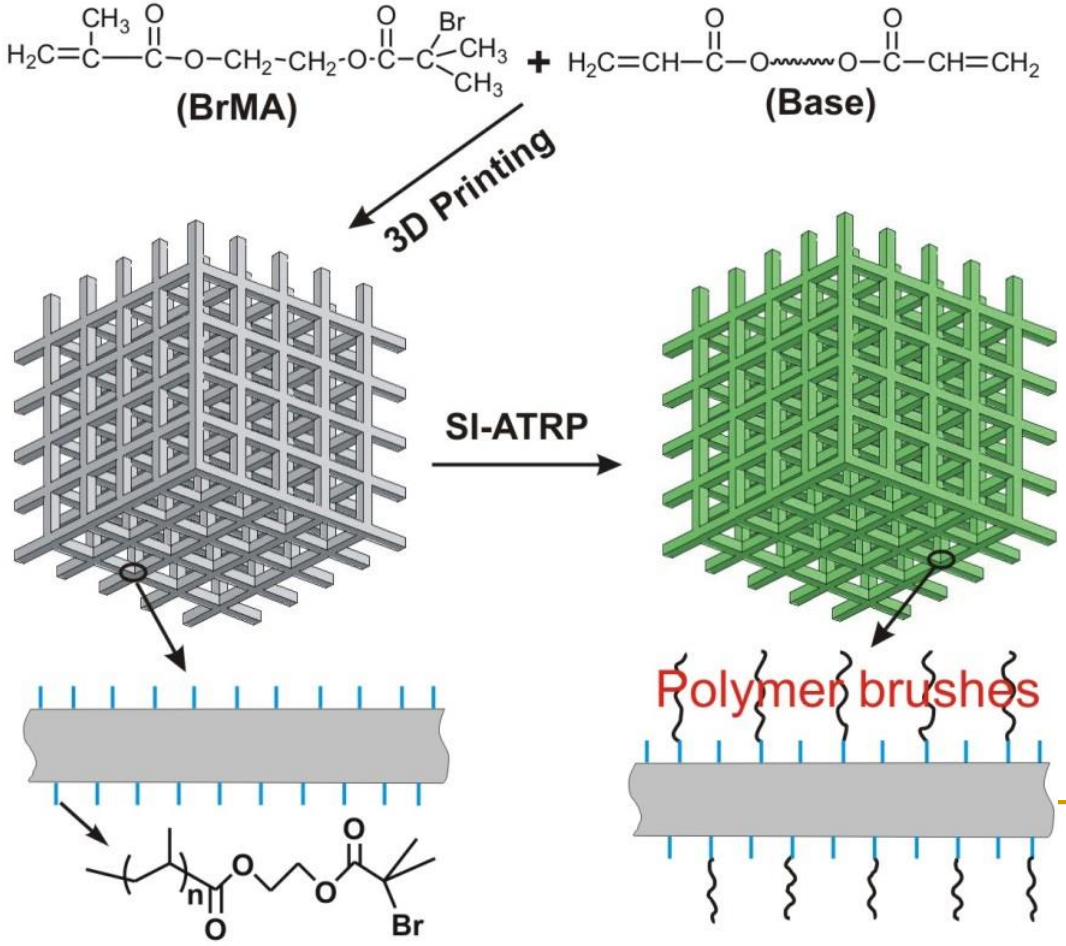
  -- polymer, metal, ceramic, glass, wood, powder based composite

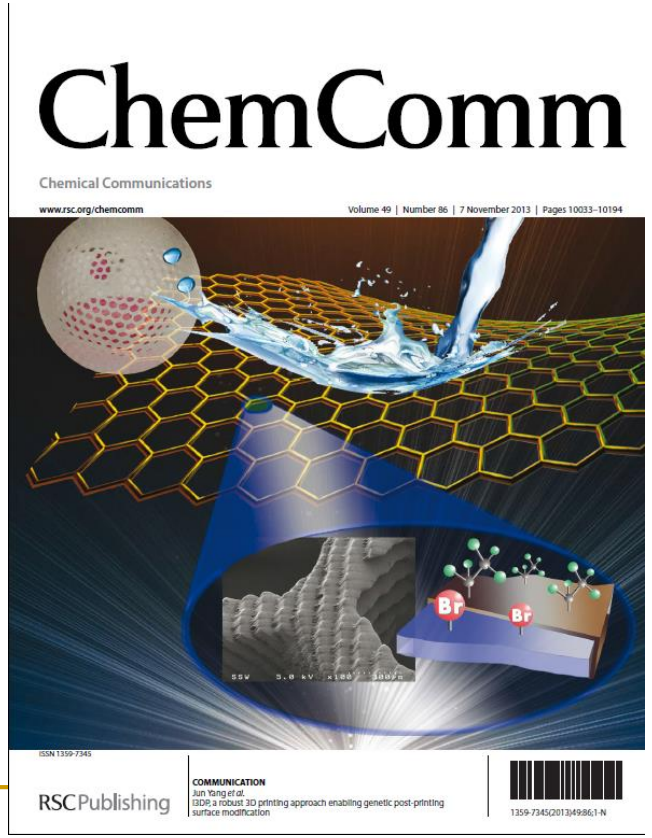
i3DP, bio-inspired 3D printing: extending 3D printing to 4D printing


Human Stem Cell
POTENTIAL APPLICATIONS
muscle cells
intestinal cells
liver cells
blood cells
nerve cell
cardiac cells

i3DP, a robust 3D printing approach enabling genetic post-printing surface modification

Our strategy (Extended Photopolymerization by Atom transfer radical polymerization (ATRP))

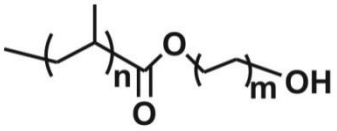




Chem. Commun., 2013,**49**, 10064-10066

Example 1: Superhydrophilicity & Superhydrophobicity

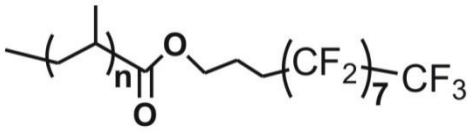
PEGMA brushes:

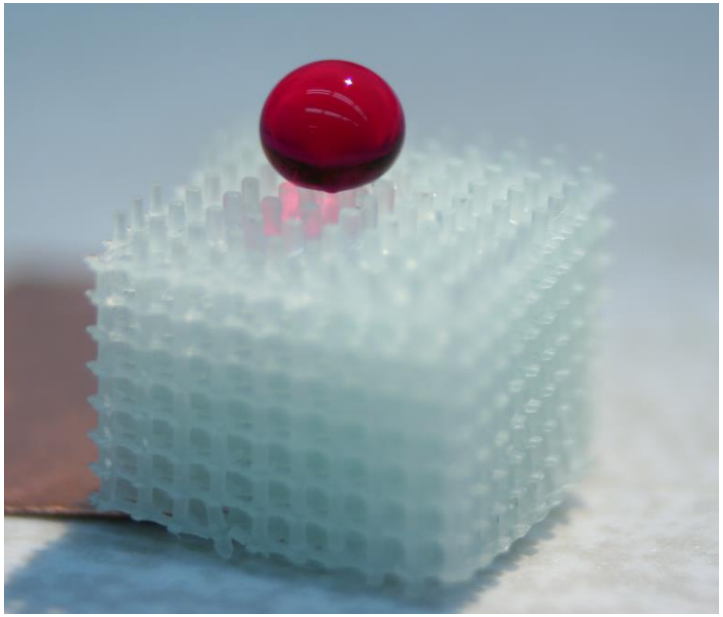




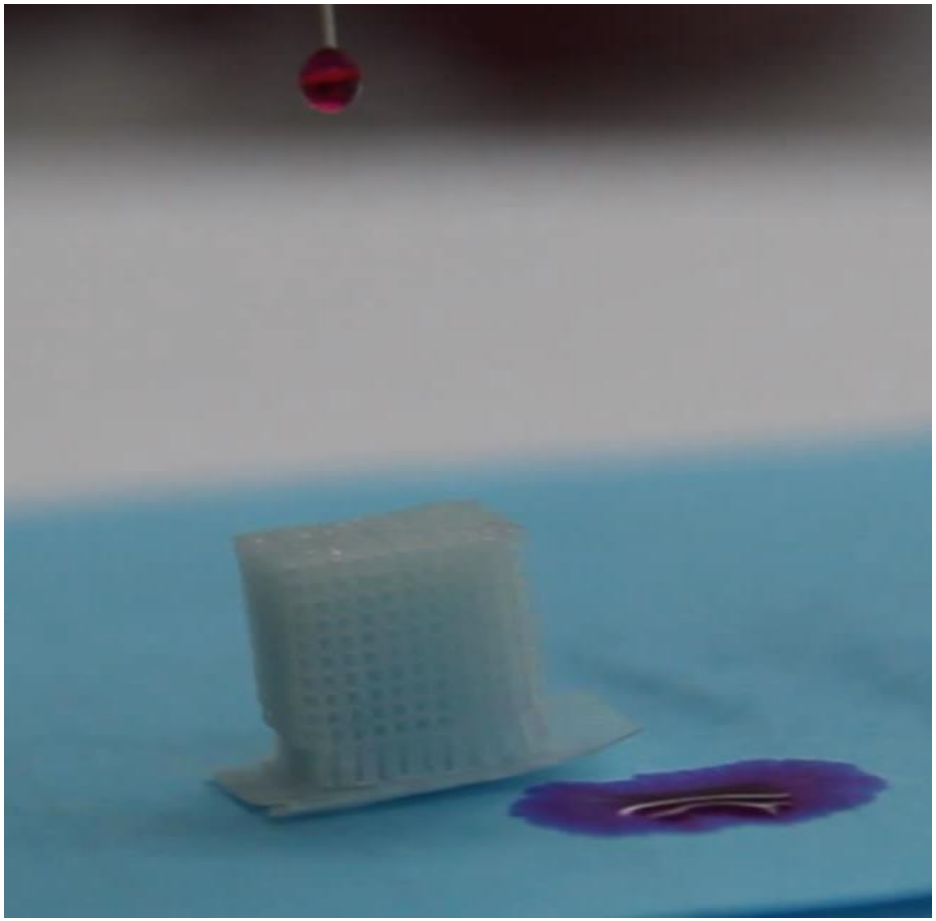
Video 1, superhydrophilic microlattice

PFMA brushes:

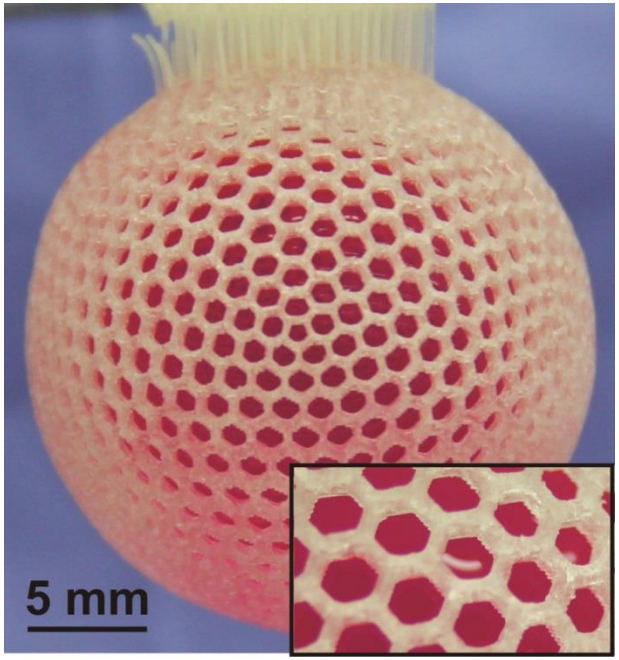




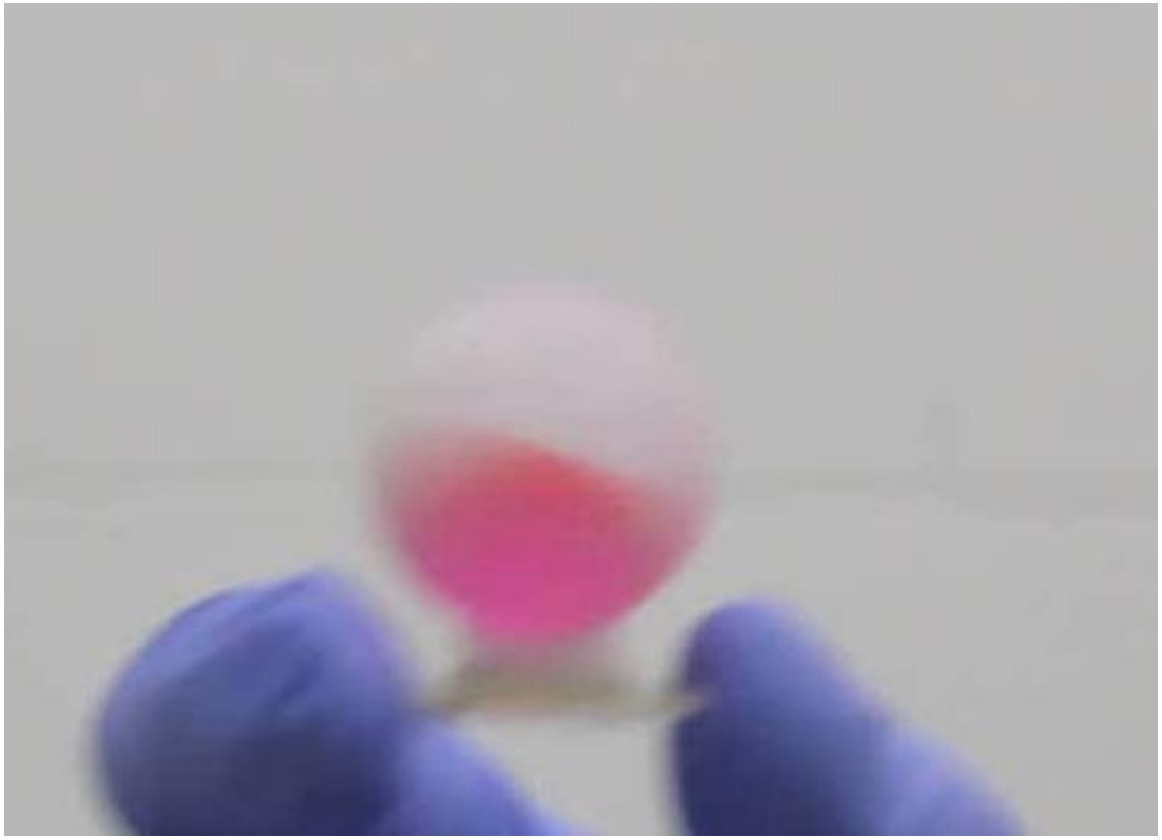
Video 2, superhydrophobic microlattice



Pouring water into a sieve

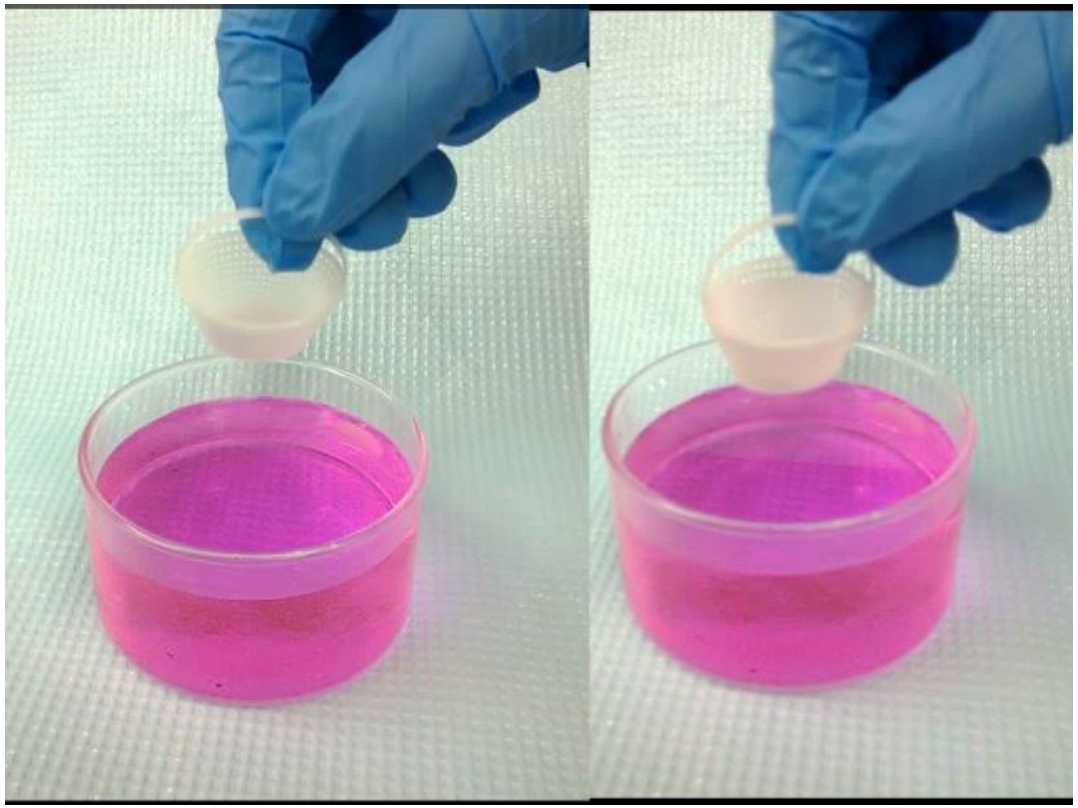


Video 3, superhydrophobic hollow ball

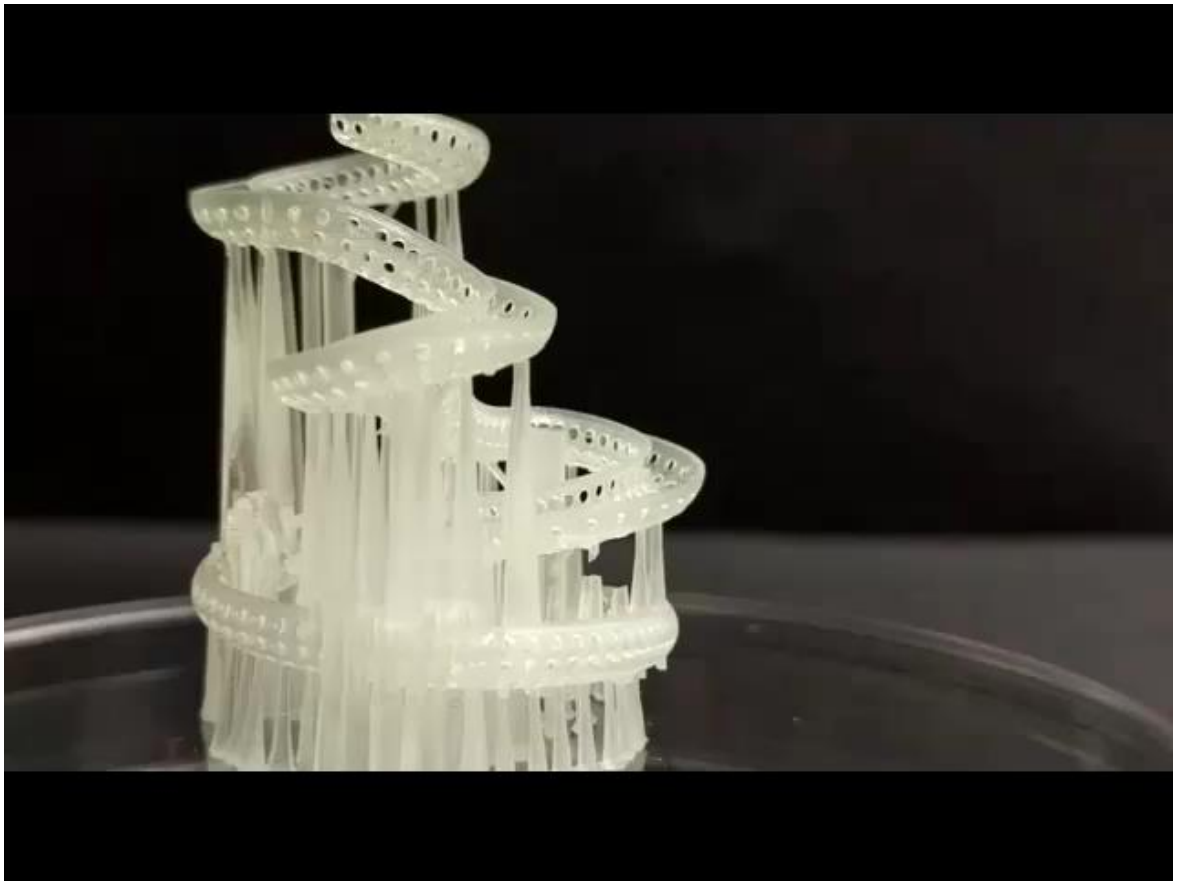


Draw water with a bamboo basket

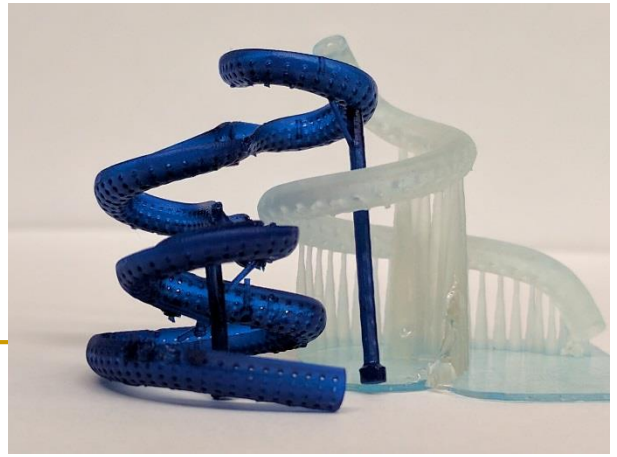




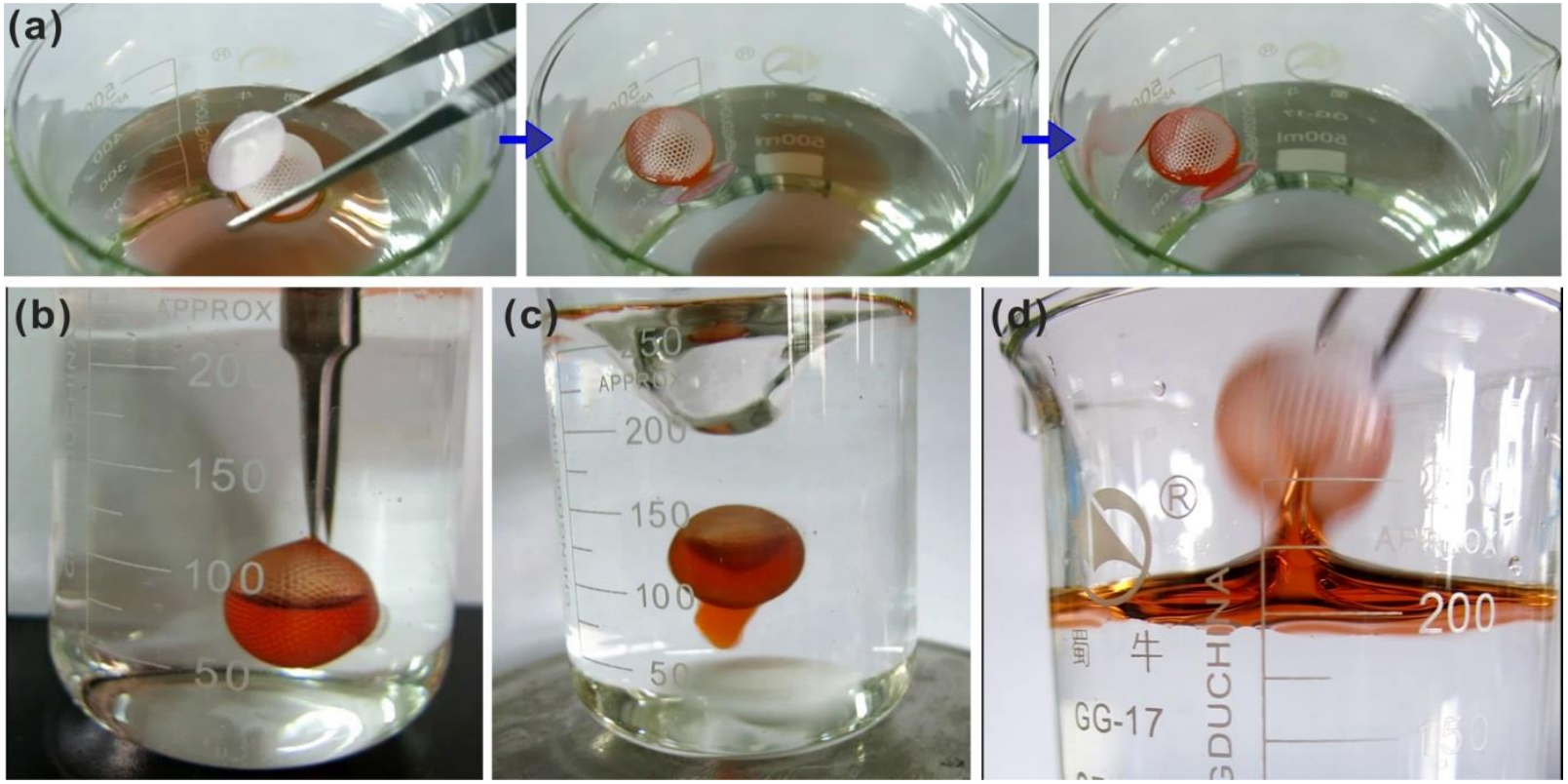
Hollow water pipe





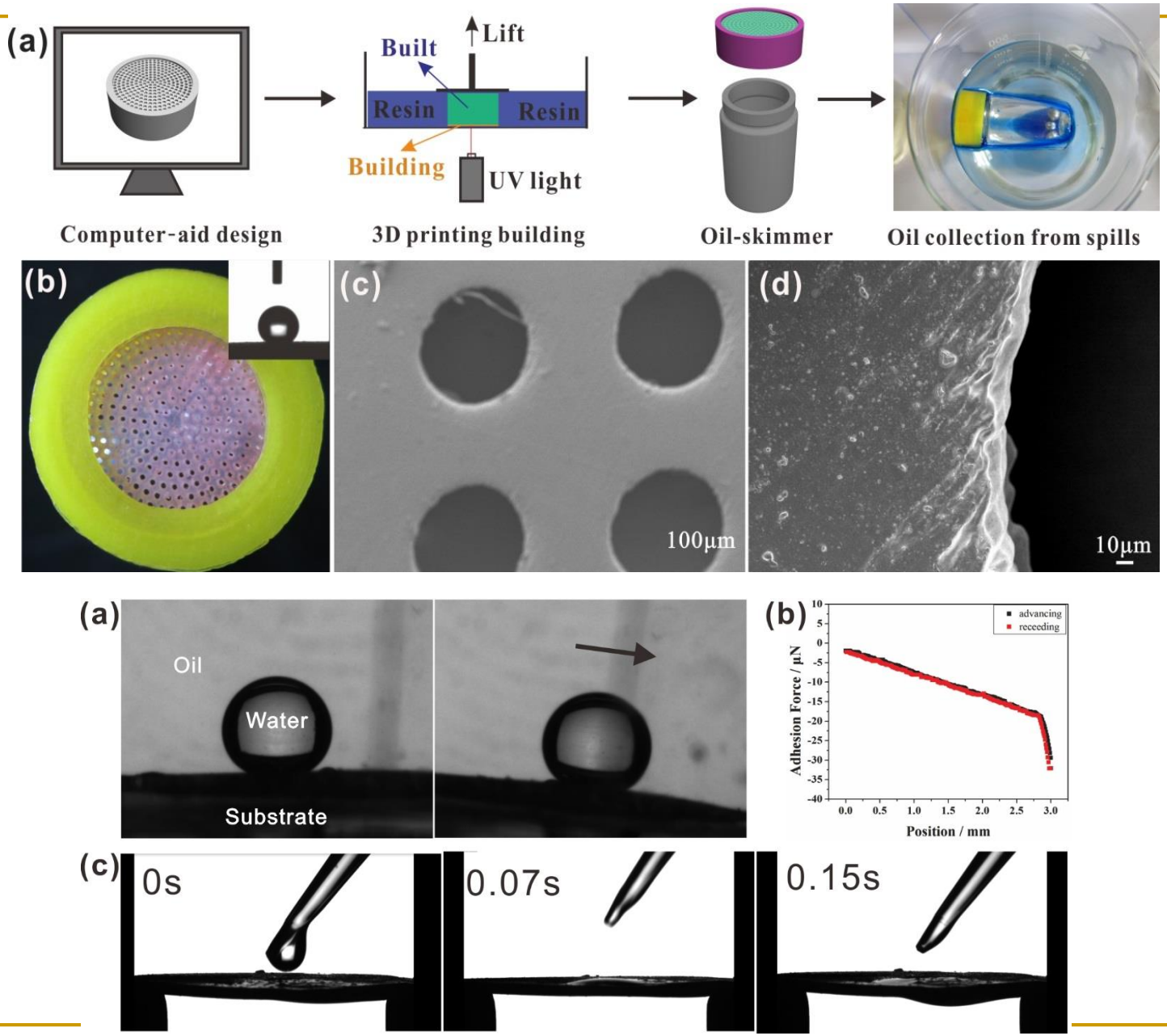


3D printing oil-skimmer for oil collection from spills

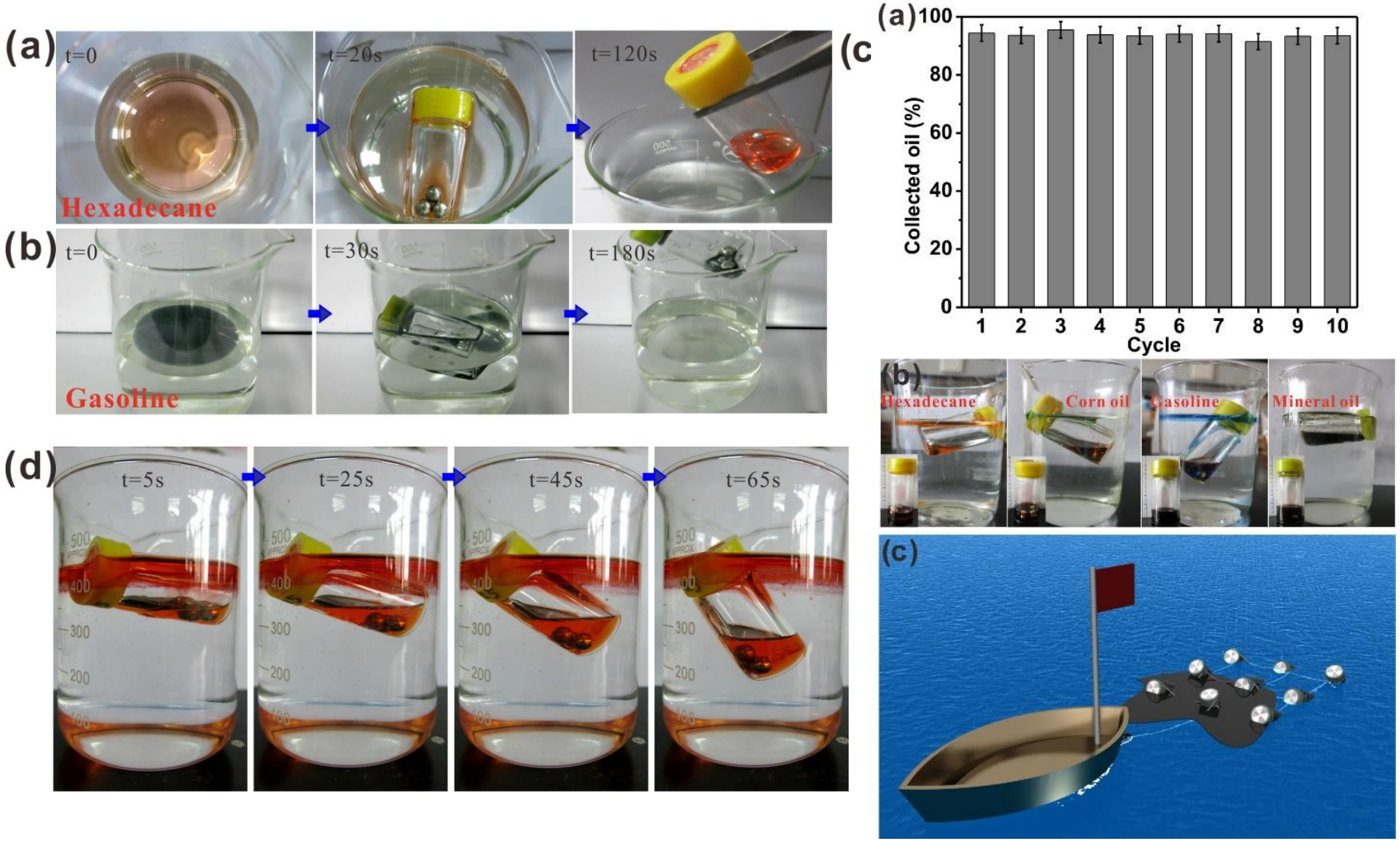


Floating oil was collected but leaked out when the ball was pulled out of water

X. L. Wang et.al., Adv. Mater. Interfaces, 2016, 1600015

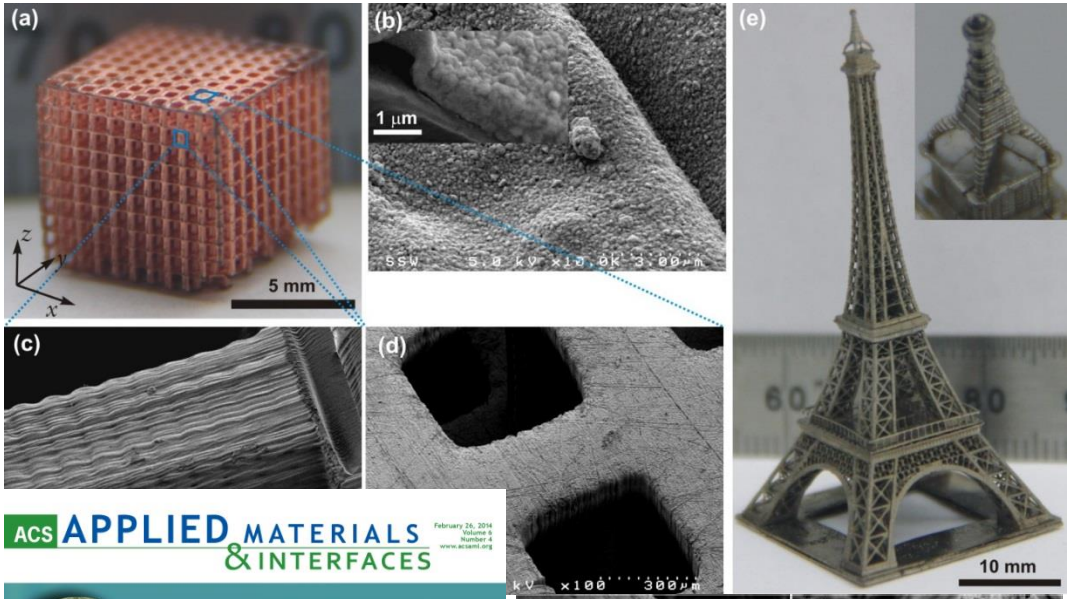


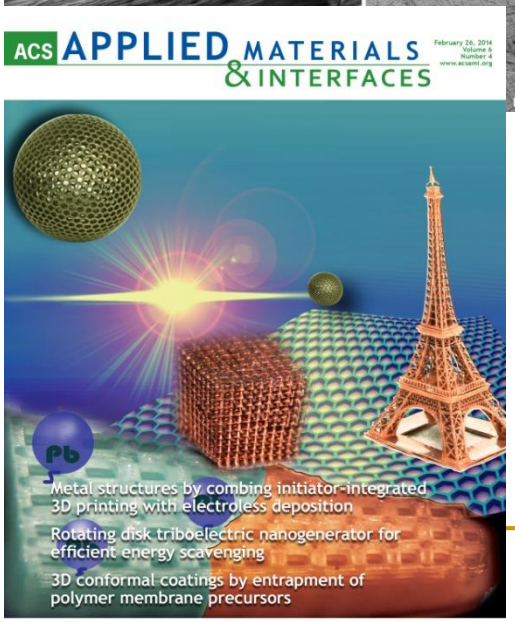
X. L. Wang et.al., Adv. Mater. Interfaces, 2016, 1600015

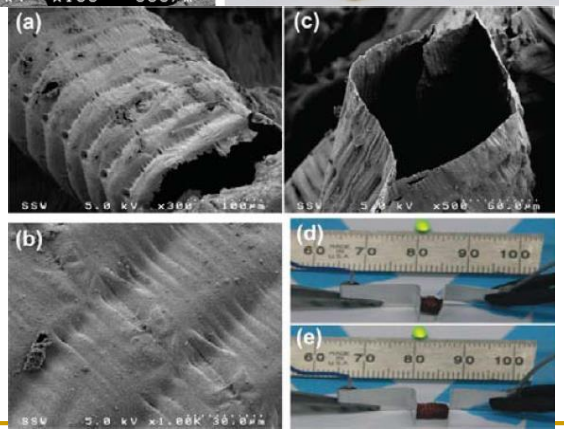

(a)
t=0
t=20s
t=120s
Hexadecane
(b)
t=0
t=30s
t=180s
Gasoline
(d)
t=5s
t=25s
t=45s
t=65s
(c
(a)
Collected oil (%)
Cycle
(b)
Hexadecane
Corn oil
Gasoline
Mineral oil
(c)

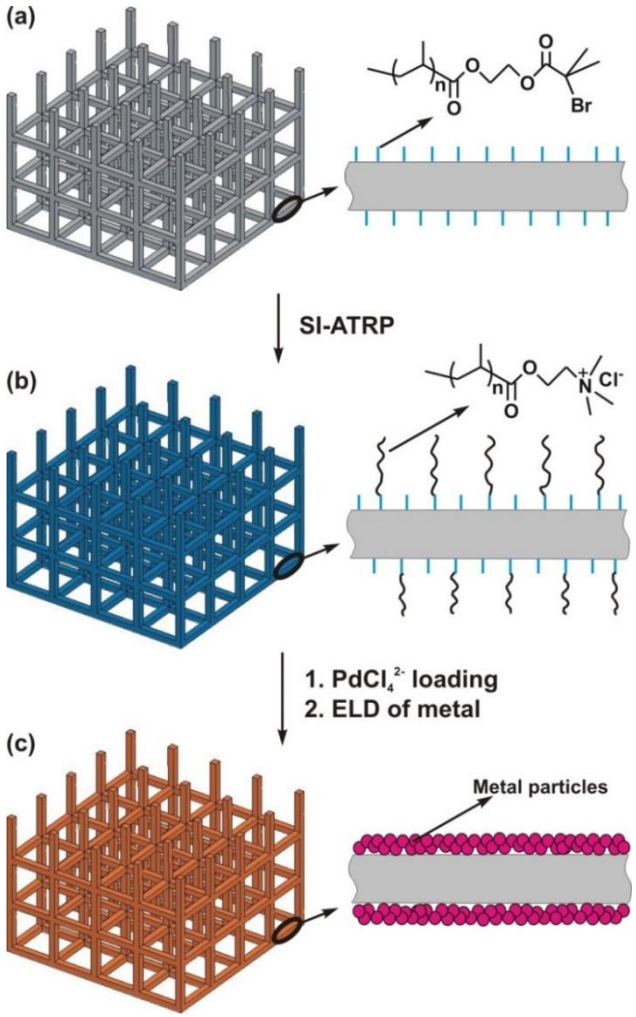
Example 2: Metallic Structures

Polyelectrolyte brushes:

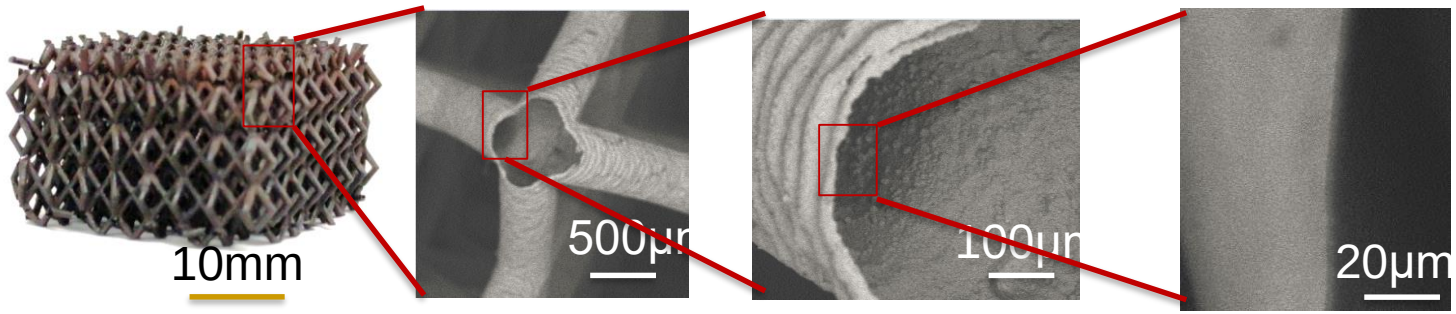


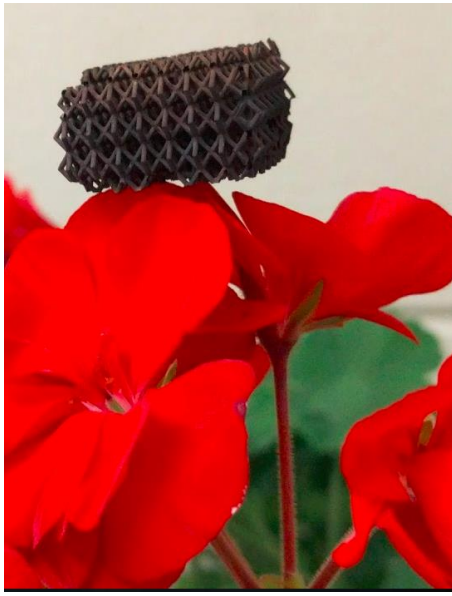




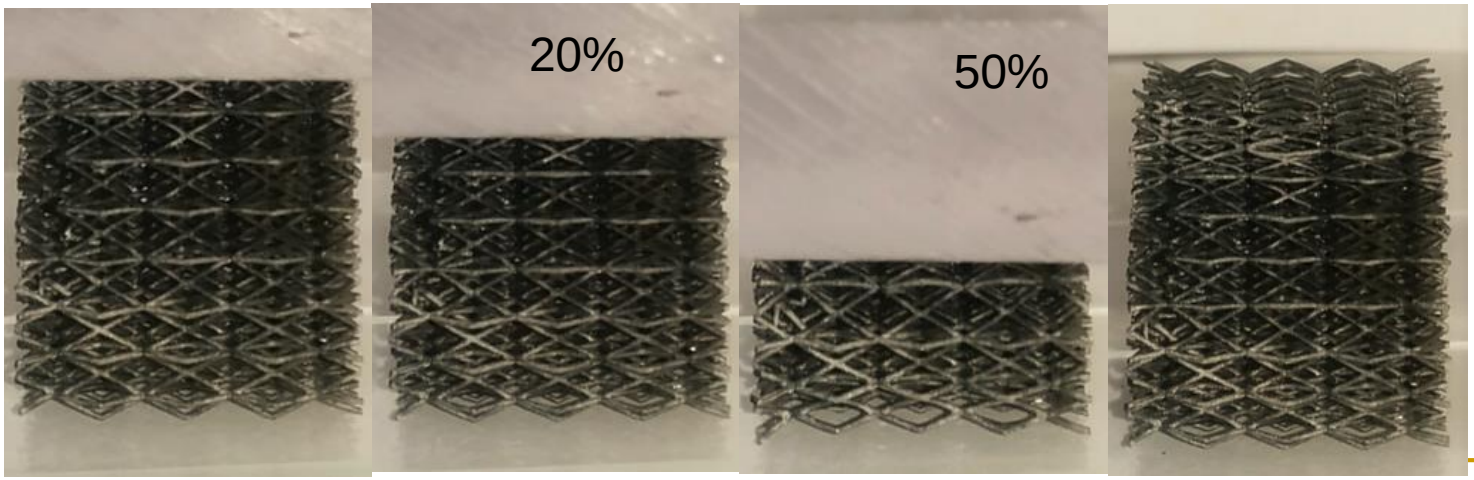


Example 2: Ultralight and Super-elastic Metallic Materials



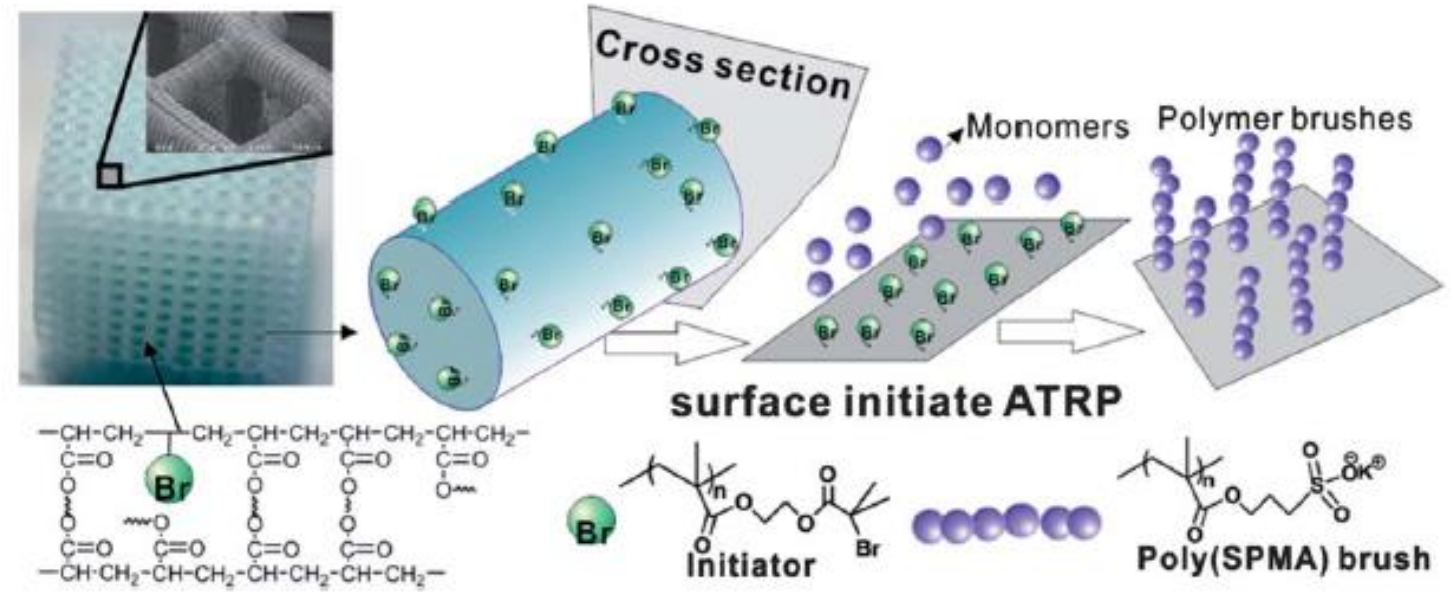


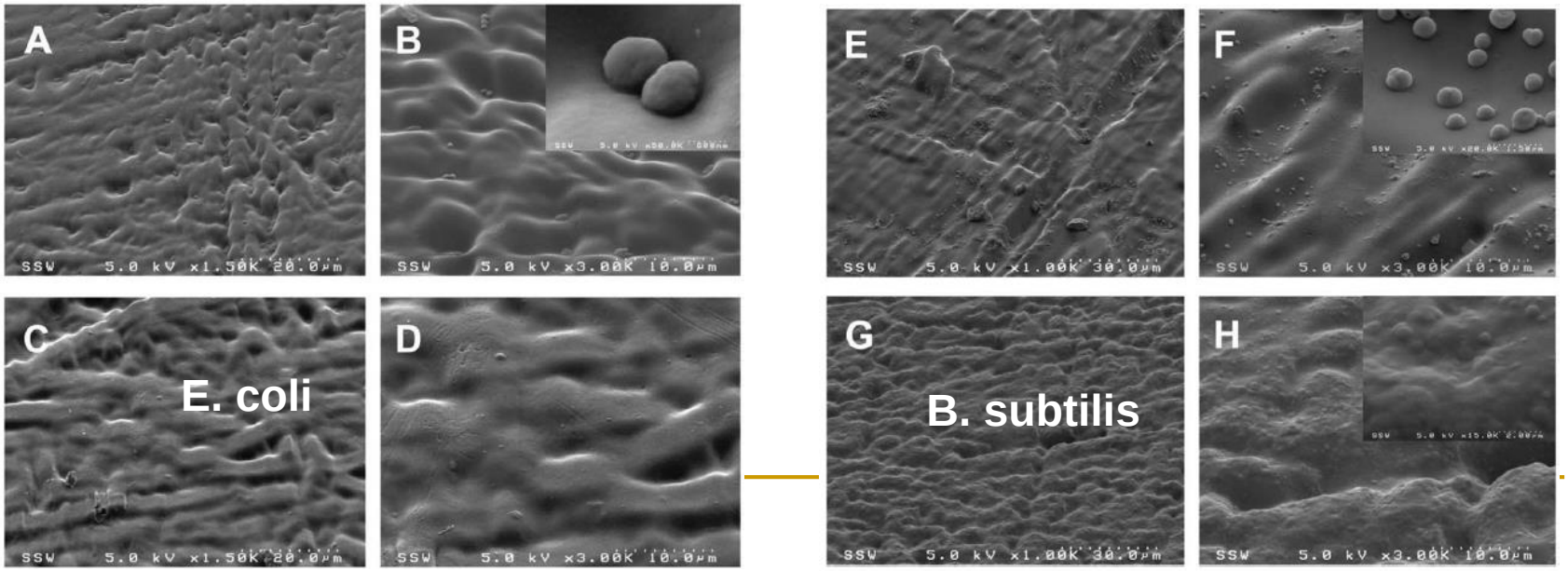
Ultralight Metallic Structures



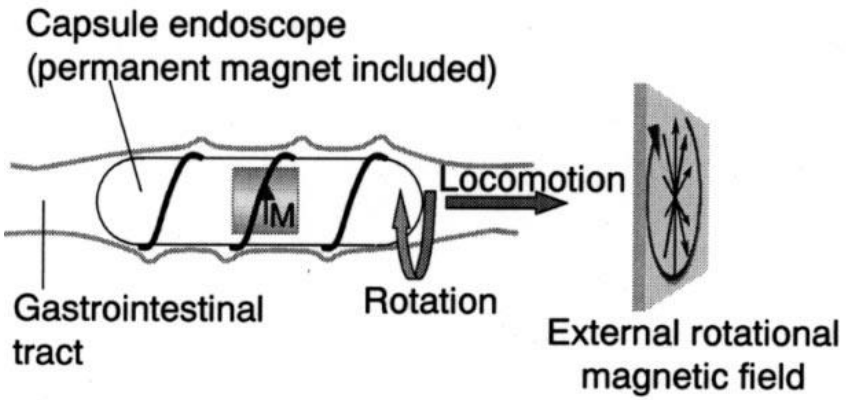
Super-elastic Metallic Metamaterials

Example 3: Antimicrobial Surfaces





Example 4: Functional Devices: helical structure actuator by magnetic manipulation

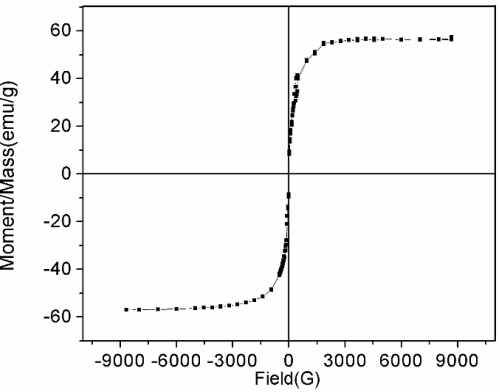




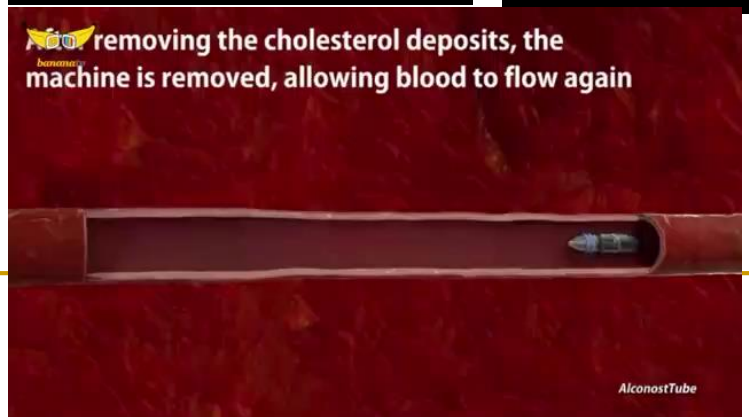






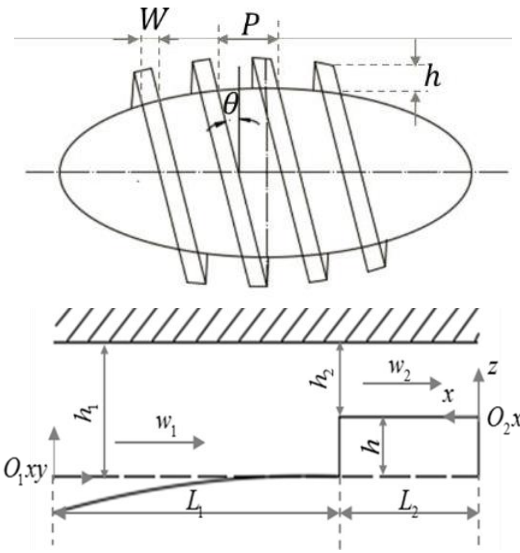


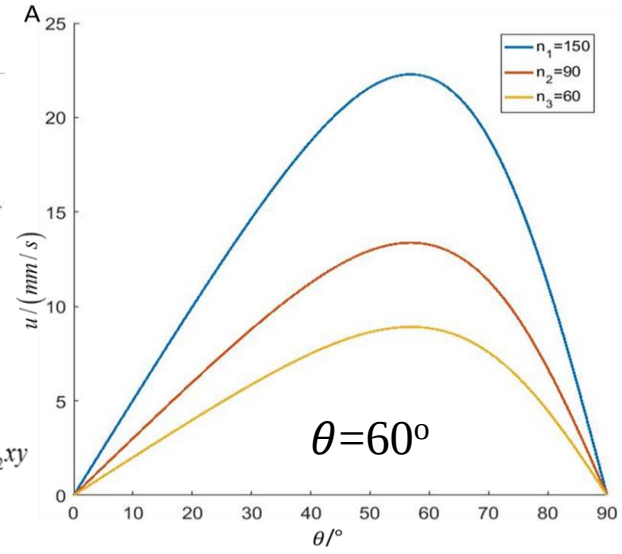


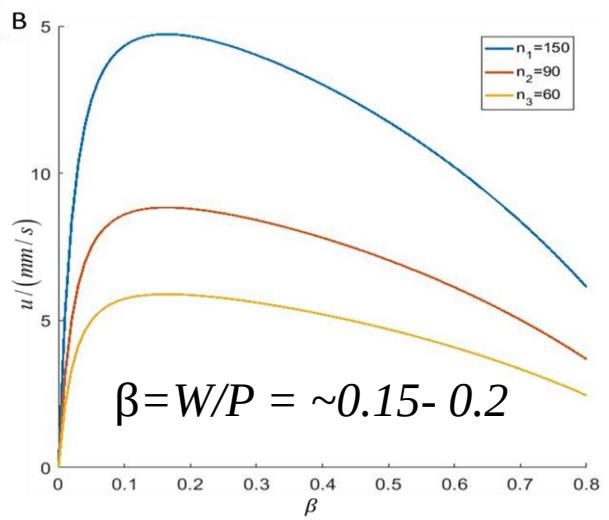


Vibrating sample magnetometer (VSM) measurement

Optimization of spiral structure



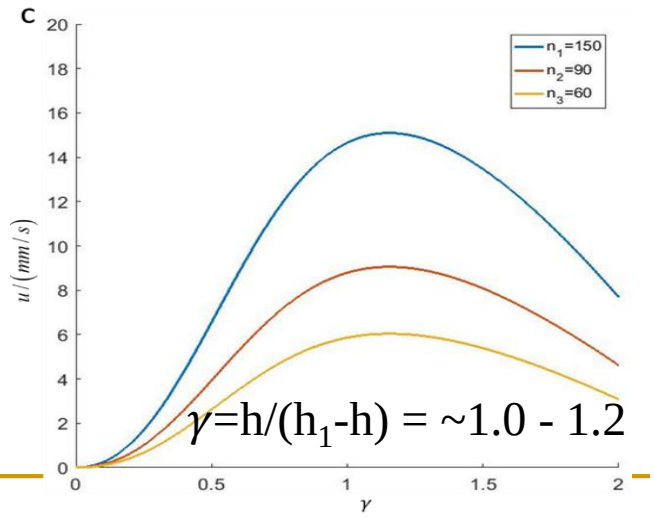




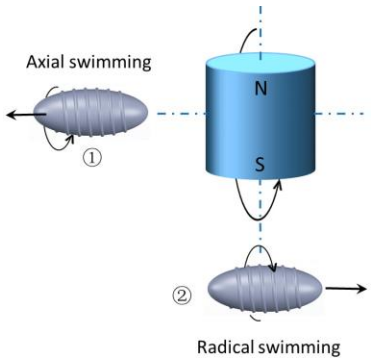
Fluidic Kinematics：

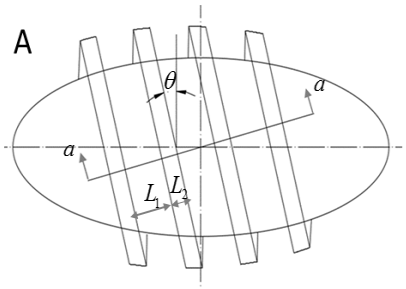
$$F_a = A\left(f_y \sin\theta - f_x \cos\theta\right)$$

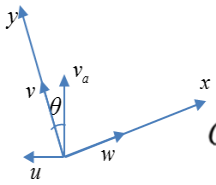
$$= \frac{2\pi\eta l}{h_2}\left(\frac{3\beta(1-\beta)\gamma^2\cos\theta\left(r - h_2(1-\gamma)\right)C_1C_2}{(1-\beta)C_1 + \beta R(1+\gamma)^3 C_2} - \frac{(1-\beta)(r-h_2\gamma)}{h_2(1+\gamma)}u - \beta u\right)$$



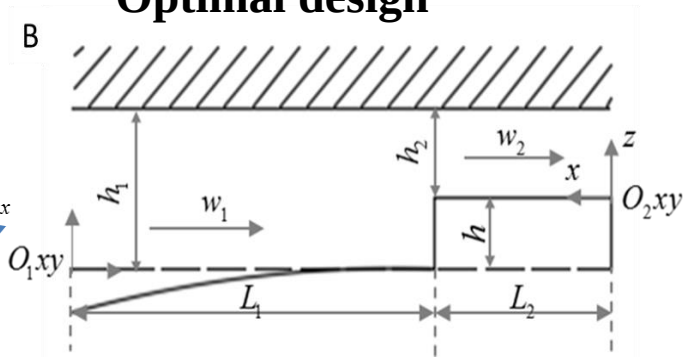
Effect of rotating magnetic field

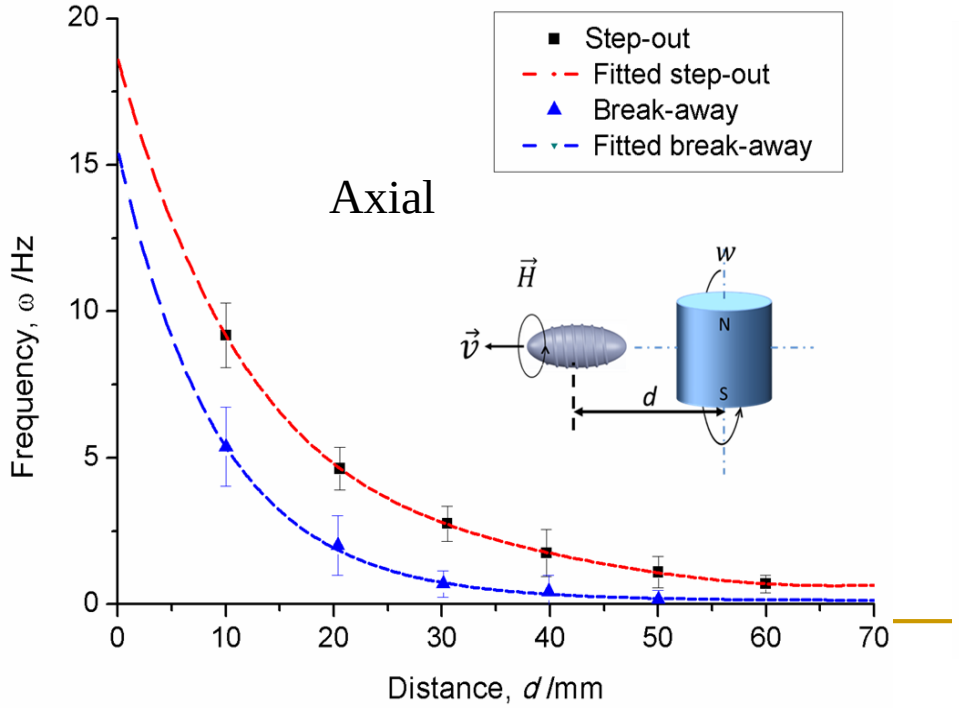


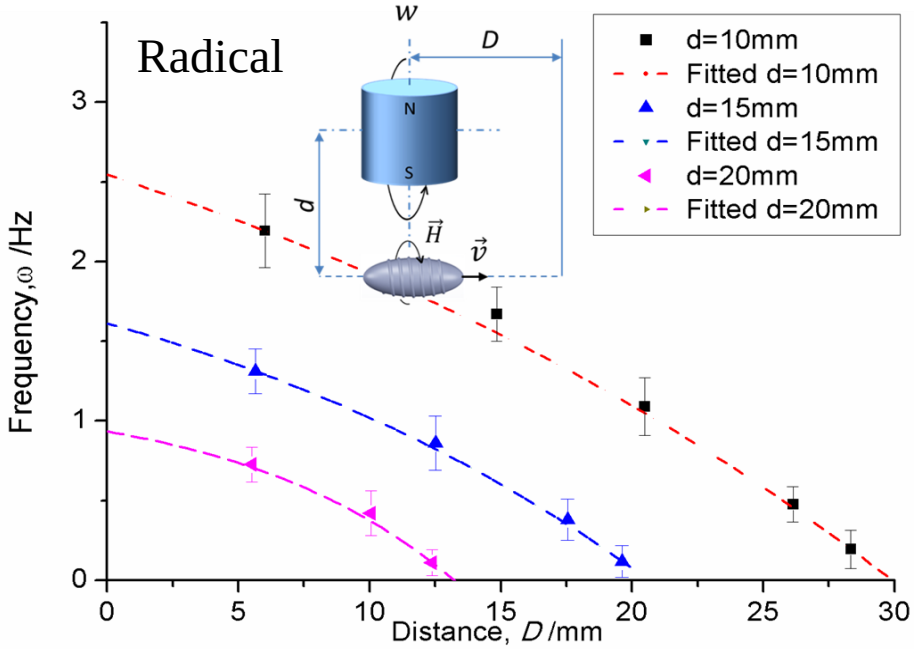




Optimal design







formi

A leader in functional 3D materials

www.formi3dp.com

Outline

- 3D printing: applications, challenges and opportunities
- 3D printing of bioplastics
- Bio-inspired 3D printing
- Bioprinting

Bioprinting

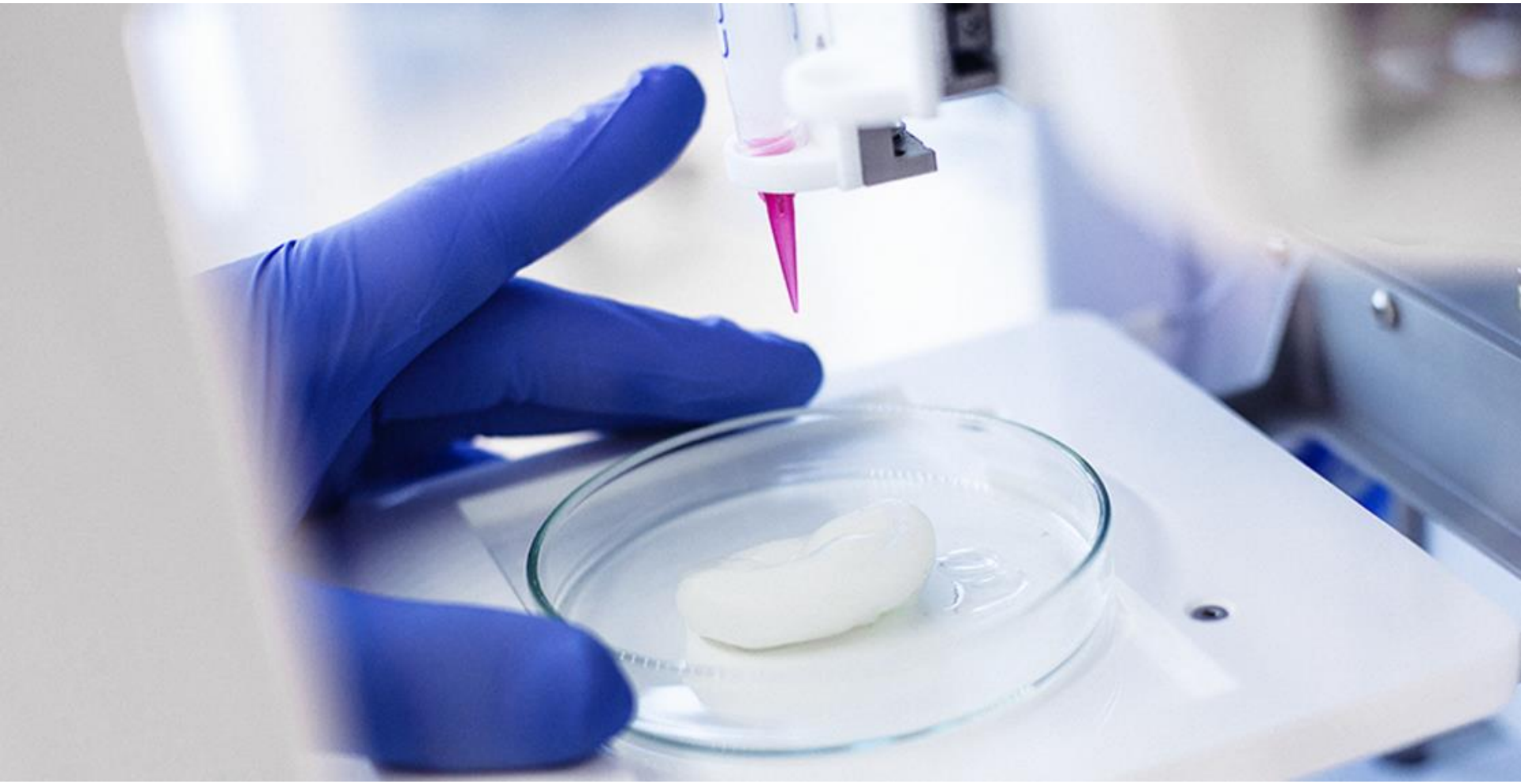
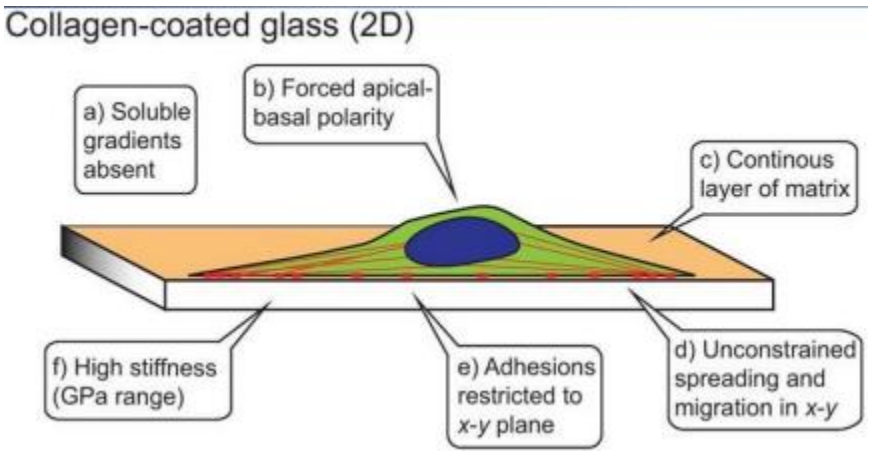
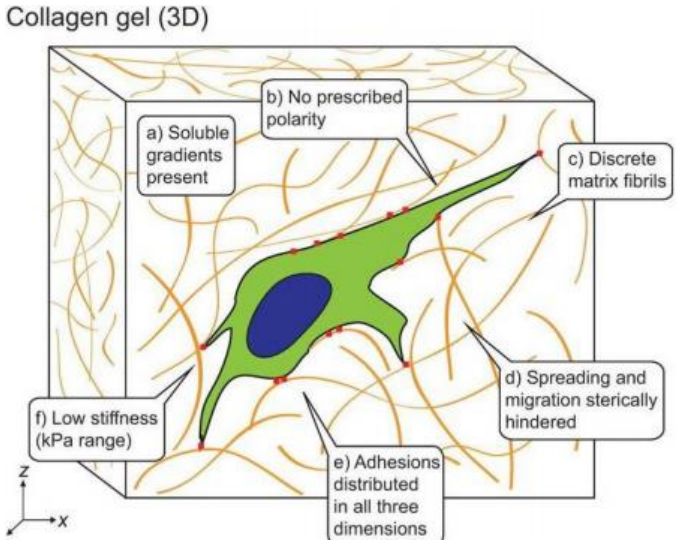


Image from: https://all3dp.com

Differences between 2D and 3D





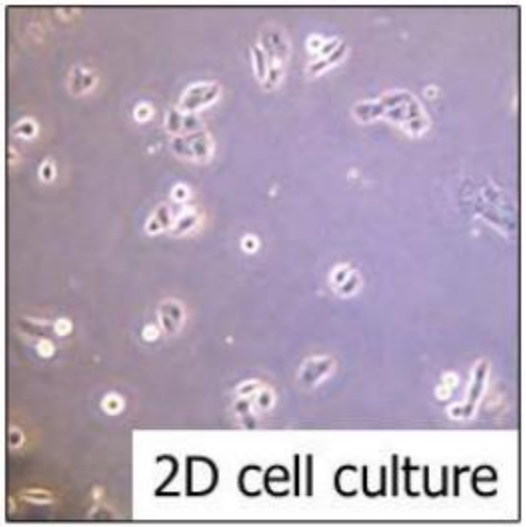
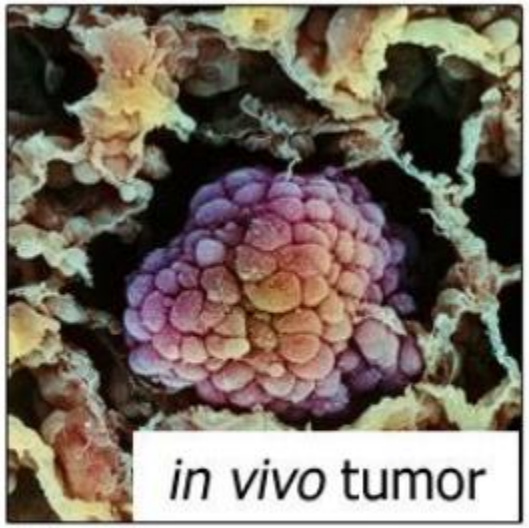


Image source: http://a549.com/



Photograph by Moredun Animal Health Ltd/Science Photo Library

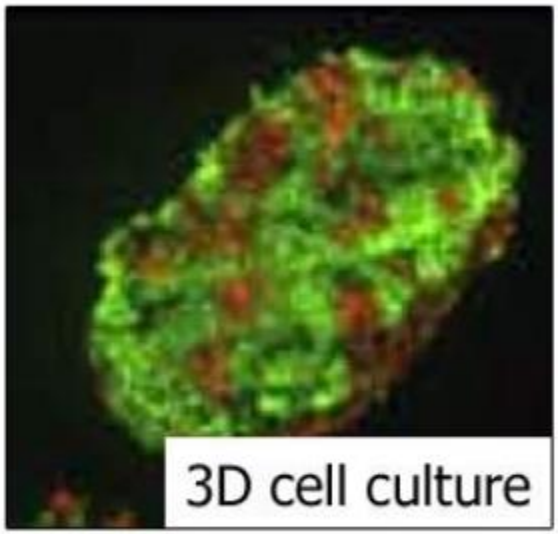
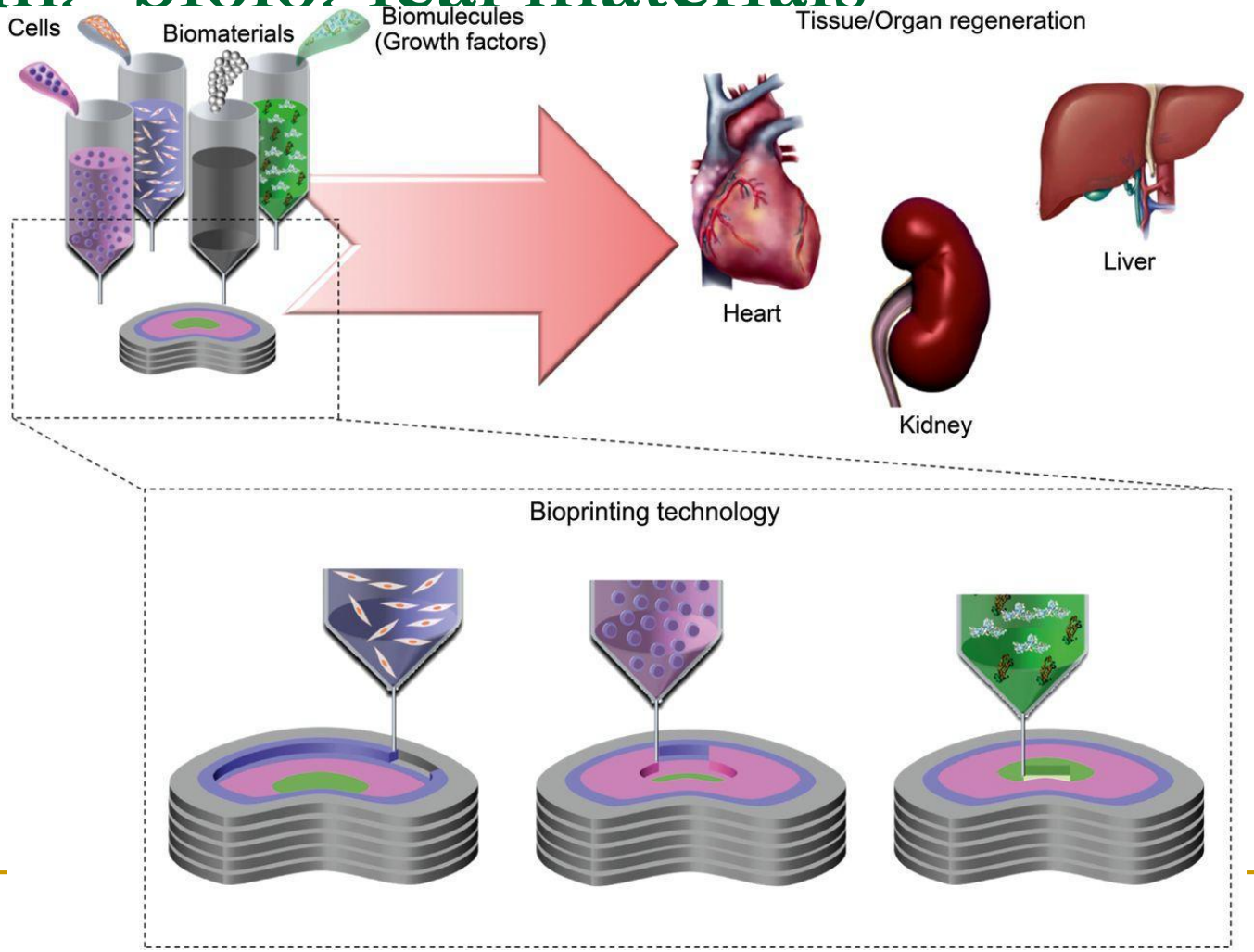


Image source: Osterholm et al., PLoS ONE. 2012: 7(7)

Bioprinting: 3D fabrication of tissues using biological materials



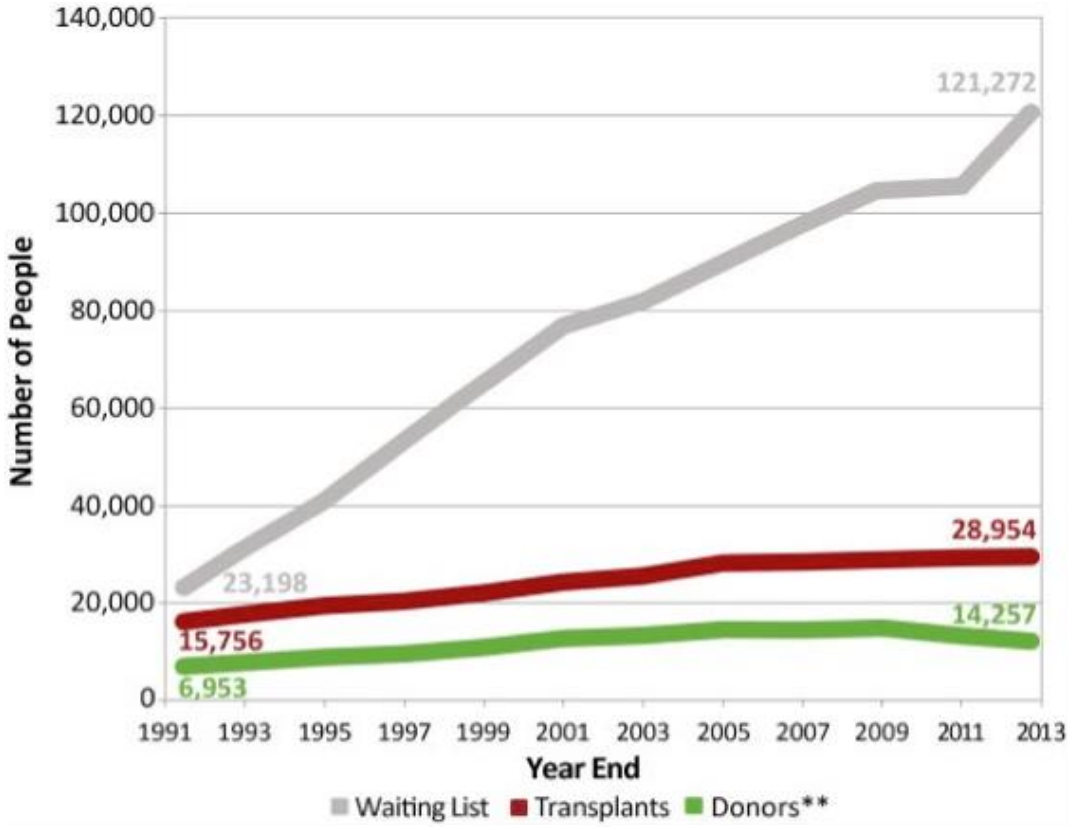
Applications of 3-D Bioprinting

Bioprinting applications include but are not limited to:

- Printing tissue for transplants
- Using printed tissue to research effects of drugs and pills (drug screening)
- Printed scaffolding to be used for the regeneration of joints and ligaments
- Bioprinting for cancer research

The Need For Organs Today

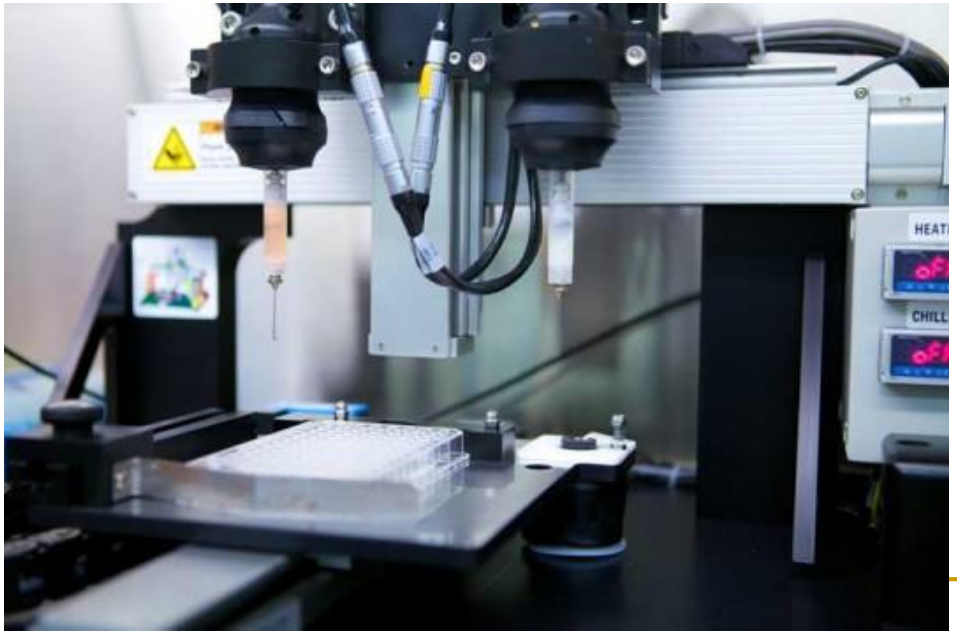
-117,521 people in United States in need of organ according to organdonor.gov
-Each day 79 receive organ each day while 18 will die from a lack of one
-Kidneys, hearts, livers, lungs are most needed organs



http://sitn.hms.harvard.edu/flash/2015/xenotransplantation-can-pigs-save-human-lives/
Data from: U.S. Government Information on Organ and Tissue Donation and Transplantation.

What is Organ Printing?

-Integrating biology and 3-D printing technology
-A process where an artificial organ can be created using a 3-D printer/bioprinter
-Currently NO real organ has been successful created, but scientists are currently working on this idea and are making progress



-First commercial bioprinter company is Organovo
-Printed blood vessels and cardiac tissue from chicken cells in 2008

https://www.rt.com, **Human organ transplants could be 3D-printed in 15 years – Russian researchers**

How Does It Work?

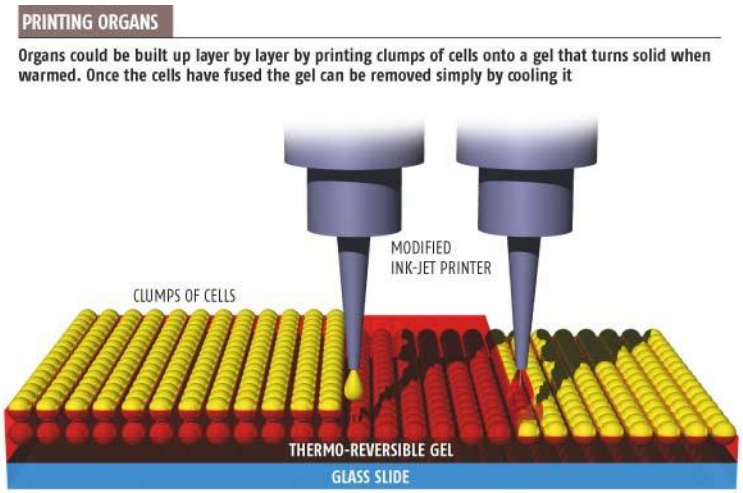
-Uses bioink, mixture of stem cells

-Printer moves back and forth dropping out one bioink particle at a time to form one layer

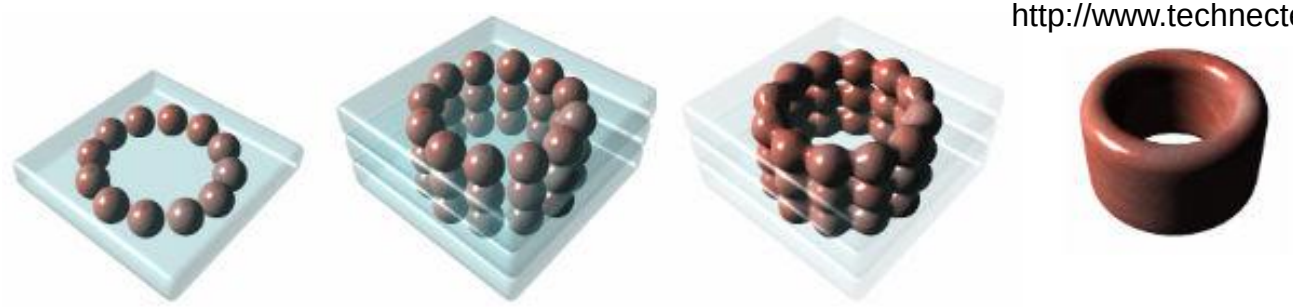
-Printer prints out one layer of cells at a time on biopaper, which is made up of collagen, water, and hydrogels

-Layers are printed one top of each other

-After cells fuse, biopaper is removed



http://www.technected.com/3d-printing-can-get-started-home



[A] Bioink spheroids printed into layer of biopaper gel

[B] Additional layers printed to build object

[C] Bioink spheroids fuse together and biopaper dissolves

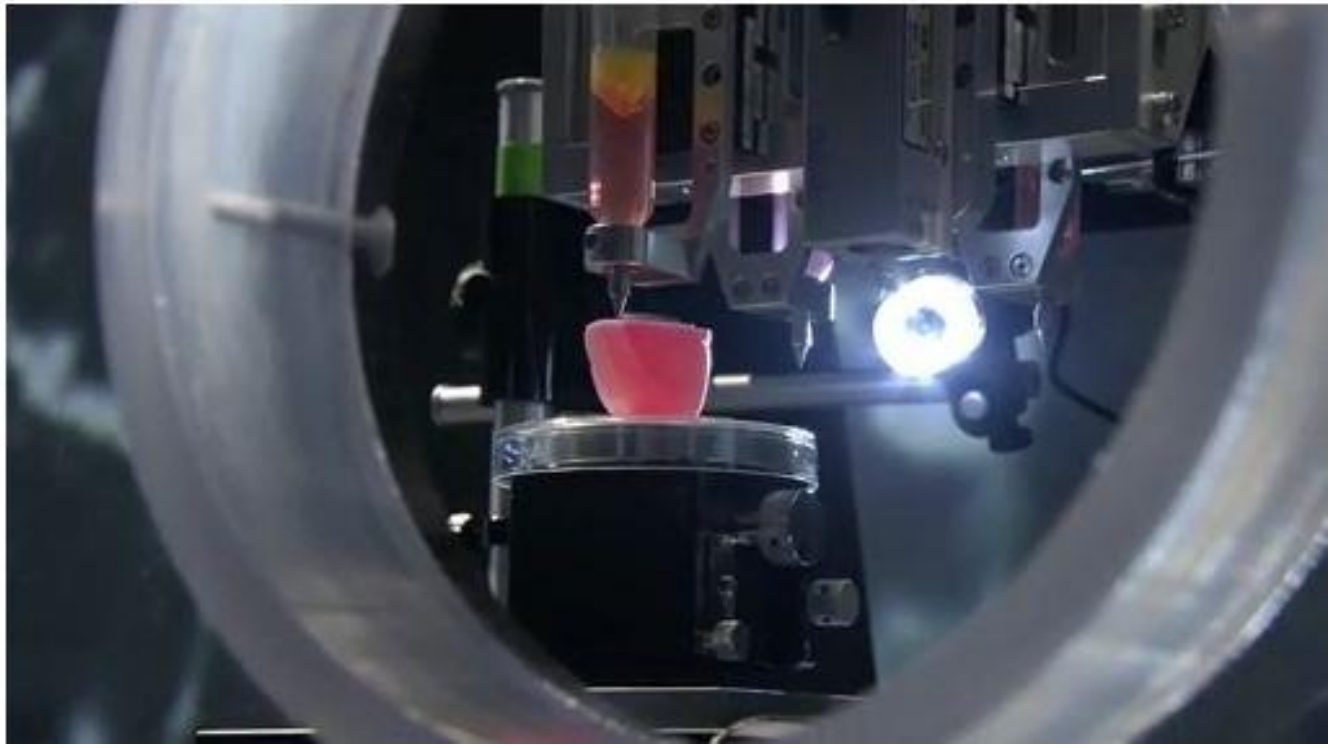
[D] Final living tissue

Jakab, K., et al., Three-dimensional tissue constructs built by bioprinting. Biorheology, 2006 43(3-4): p. 509-13.

Organ printing

-In 2011, Dr. Anthony Atala successfully printed a kidney from human cells

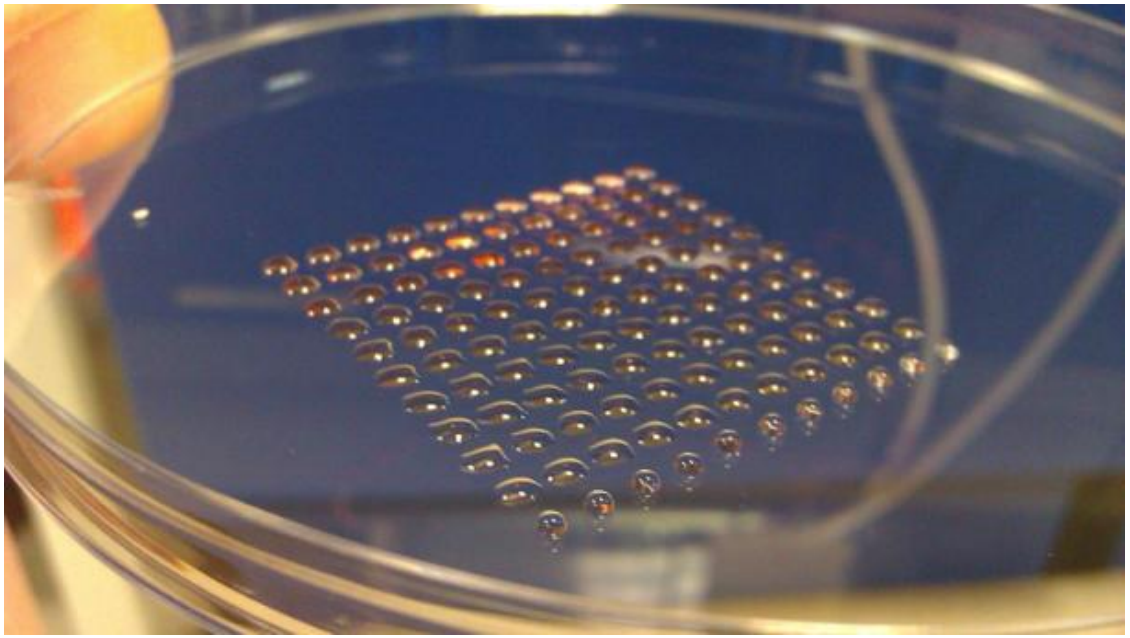
-Not functional in humans yet but such research is going on



Printing a human kidney - Anthony Atala

Why is challenging?

-Difficult to create blood vessels between tissue layers
-Organs have many specialized functions difficult to replicate



3D Printed Organ by Orlando MedelHaiku Deck

Benefits and Disadvantages

-Artificial organ personalized using patients own cells
-No DNA rejection
-Eliminate need for immunosuppressant drugs needed after a regular organ transplant
-Eliminate organ donation
-No waiting period

-Printers cost hundreds of thousands of dollars
-Possibly more expensive than regular organ transplant
-Use of stem cells is still controversial
-Cost of using stem cells
-Not successfully created yet

Biomedical applications



The (Not So Distant) Future Of Healthcare: AI, AR, Drones And Personalised Medicine
by Amalie Naustdal

Biobased Economy

- BioBased Economy (BBE) is about to change in our economy, based on **fossil feedstock** today, to an economy based on **biomass as feedstock**; from fossil-based to bio-based economy.
- The bio-based economy uses biomass for nonfood applications, such as chemicals, materials, transport fuels, electricity and heat.
- Instead of using fossil fuels, plastics can be produced from **renewable resources such as biomass**.

3d Printing with Biomaterials

TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY

- 3D Printing holds the promise to manufacture with less waste and energy.
- BIOMATERIALS: biomass is a renewable resource
- The 3D printing industry is developing rapidly. Not only in the 3D printing technology but also in the materials that can be used in 3D printers.

(Future) Biomaterials For 3d Printing

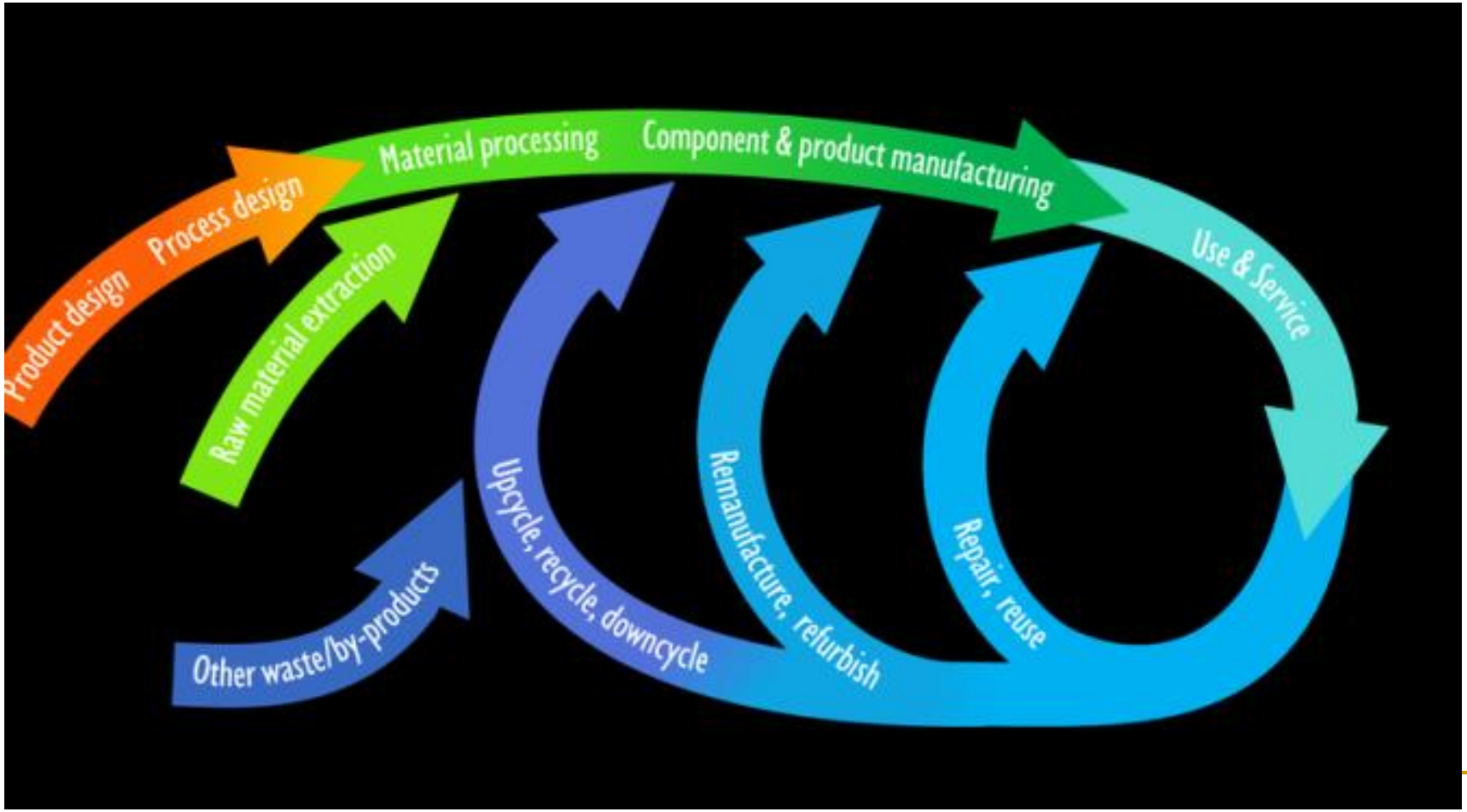
	PRODUCT MATERIAL	FEATURES
THERMO CHROME PLA	Regular PLA filament with thermo chrome feature	Changes color in response to temperature changes
FLEX PLA OR SOFT PLA (59)	Regular PLA filament mixed with unknown chemical to make it soft, though and rubbery	Similar to regular PLA filament, only more flexible
NYLON 11 (59)	Polyamide 11 (PA11) or Nylon 11 from vegetable oil from castor beans	Flexible, strong and self-lubricating
BIO RUBBER (56)	TPE; thermoplastic elastomer from Rapeseed Oil	Strong, UV resistant, chemicals and temperature resistant
ARNITEL® ECO (57)	TPC; thermoplastic co-polyester made partially of rapeseed oil	Flexible, strong, C2C certified
BIOME3D (58)	Thermoplastic from plant starches	Biodegradable
STRAW BASED (59)	Straw based plastic made from rice and wheat stalks mixed with plastic and additives	Low cost material
BAMBOO BASED (60)	Filament made of finely ground bamboo	Low cost material
LAYBRICK (61)	Filament made of finely ground chalk with a polymer binder	Feel like sandstone when printed, no layered look
LAYWOOD (59)	Filament made of 40% recycled wood with a binding polymer	Wooden look and smell, can also be handled like wood

3D Printing with Biomaterials

	PROMISES
3D PRINTING OR ADDITIVE MANUFACTURING	Design freedom Cloud- and community-based personalized design Faster product development cycle Low startup costs for production On-demand production Less transport and logistics
BIOMATERIALS	Material from biological origin instead of fossil fuels No CO_2 (short cycle) emissions Feedstock can grow everywhere Every plastic can be produced Specific and unique material characteristics for 3D printing
3D PRINTING WITH BIOMATERIALS	Local production of both biomaterials and products Zero greenhouse gas emissions Unique, innovative, new and sustainable products The realization of a sustainable and circular economy

3D Printing: Towards a Sustainable and Circular Economy

3D Printing can fit well in the concept of a circular economy



Unlocking value for a circular economy through 3D printing: A research agenda, Technological Forecasting and Social Change Volume 115, February 2017, Pages 75-84

Thank you



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