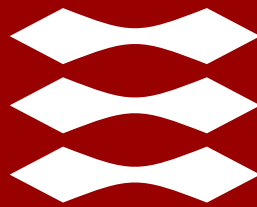


DTU



Ada-loana Bunea, Assoc. Prof. at DTU Nanolab

Miniaturized pH sensors fabricated by 4D printing



What is 3D printing?

- Also known as additive manufacturing
- A 3D object is constructed based on a digital CAD 3D model
- Objects are typically built layer-by-layer
- The additive manufacturing nature means less waste is generated in the process (vs. subtractive manufacturing)
- 3D design freedom, overhanging parts, hollow parts, ...
- Umbrella term for many different techniques

Date

DTU

Title

3



Creating the model for 3D printing

- 3D design
- 3D scanning of real-life object
- Photogrammetry from 2D image
- Stereolithography (STL) file – triangles – typical CAD format

- Full 3D design freedom!

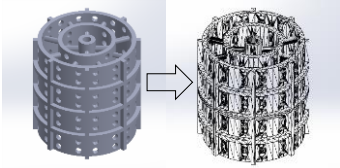
Date

DTU

Title

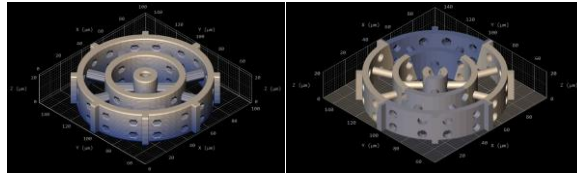
4

3D printing – steps



- Creating the model (CAD to STL file)

- Converting the model to a printable file format (G-code)



- 3D printing

- Post processing (Depending on the technique, material and purpose)

Materials

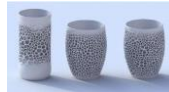
- Polymers – traditional material and the most used



- Metals



- Ceramics



- Wood



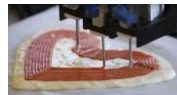
- Graphite, graphene, carbon fiber composites



- Wax



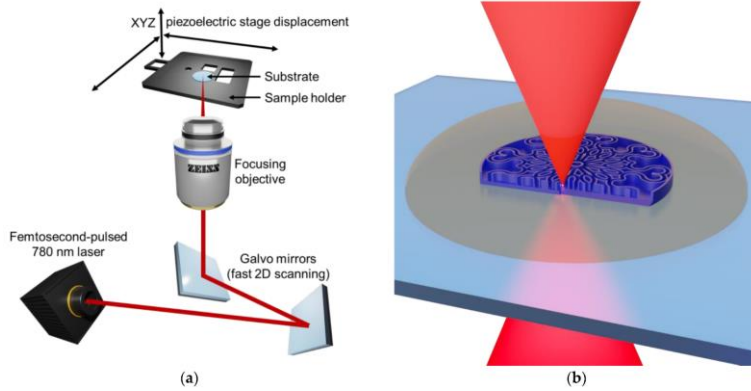
- Food



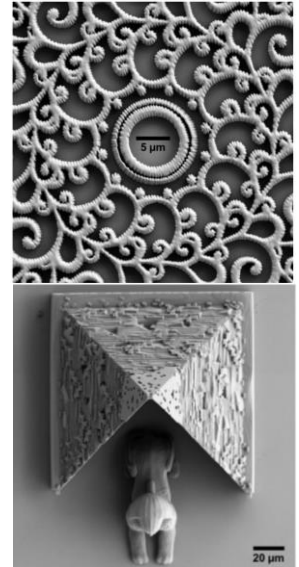
- Cells + hydrogel (Bioprinting)



Two-photon polymerization 3D printing



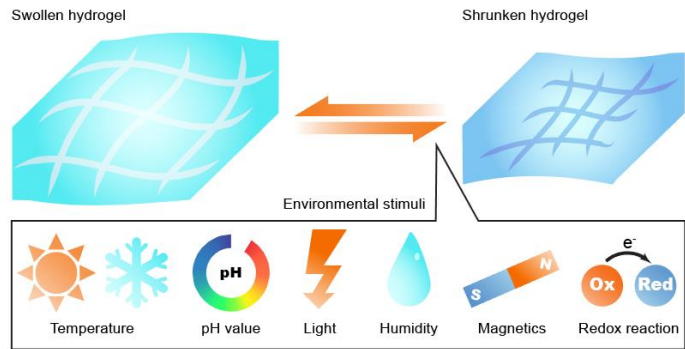
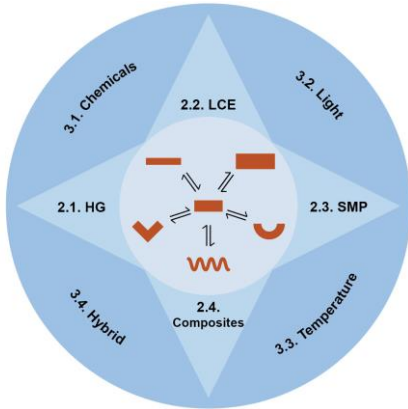
A.-I. Bunea et al, *Micro* 1, 164-180, 2021



4D printing

- 3D printing of shape-changing materials
- 4th dimension – time – the structures change in response to the environment
- Environmental cues: temperature, humidity, pH, light, etc.
- Materials: special polymers





- Pioneering a new generation of microrobots
 - High-resolution microfabrication
 - Smart materials
 - Remote actuation

- Proof-of-concept application: pH sensing in microfluidic channels
 - Reduced reagent consumption
 - Reduced waste
 - **Sustainable studies**



Robotics – a growing concept at all size scales

Industrial robots



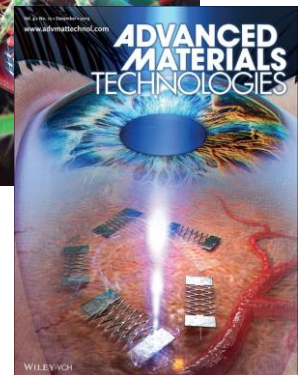
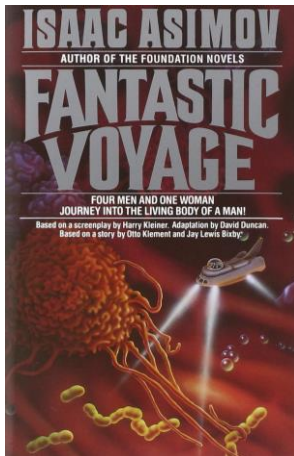
Prosthetics & androids



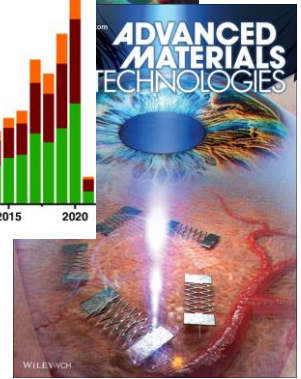
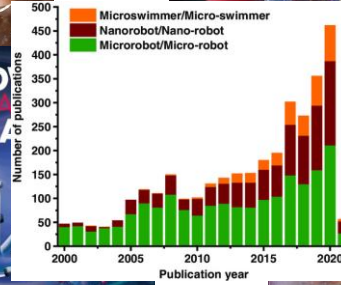
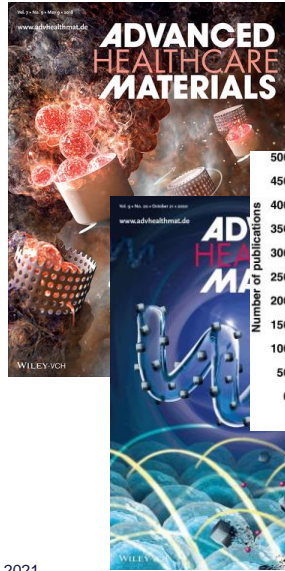
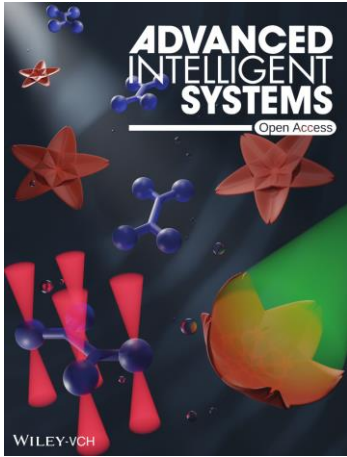
Household robots



Microrobots: from SF to research

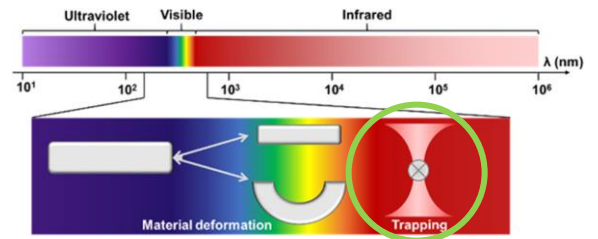
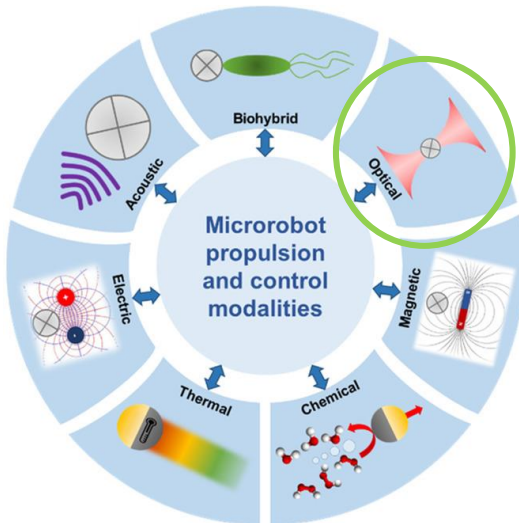


Microrobots: from SF to research



A.-I. Bunea et al, *Advanced Intelligent Systems* 3, 2000256, 2021

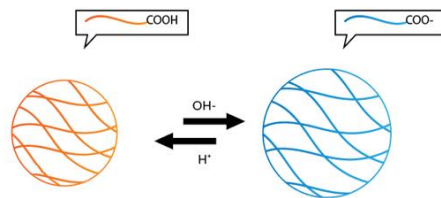
Microrobot control



A.-I. Bunea et al, *Advanced Intelligent Systems* 3, 2000256, 2021



- Acrylic acid-based hydrogel (carboxyl functional groups)
 - Monomer – Acrylic acid C=CC(=O)O
 - Crosslinker
 - Photoinitiator
- Rapid and reversible shape change in response to pH.
- Swells in pH above the material's pKa (~4.3)



Optical trapping

1. Three smooth optical trapping handles
2. Ø10 µm traps
3. Ø70 µm trapping area

Sensing

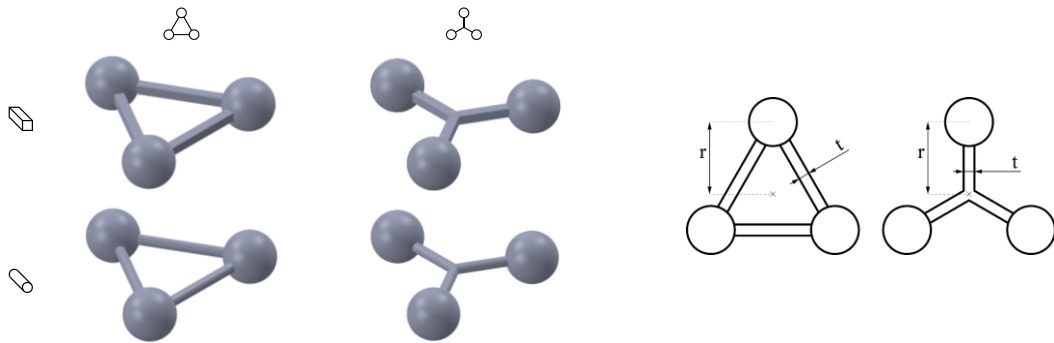
1. Qualitative visualization (acid/base)
2. Possibility to measure (pH value estimate)

2PP fabrication

1. Limited overhang
2. Rounded edges

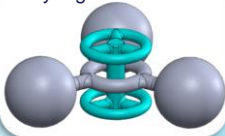
Structure

1. Integrity
2. Robustness
3. Easy to align

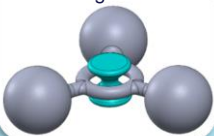


Reduced alignment need

EasyAlign

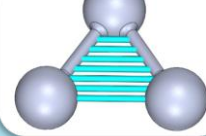


FallThrough

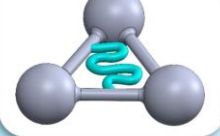


Small features

Fishnet

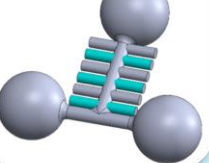


Snake

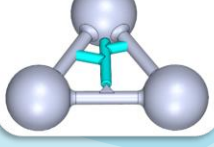


Qualitative change

Comb



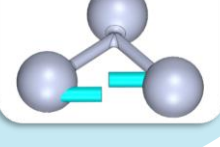
Hinge



Puzzle

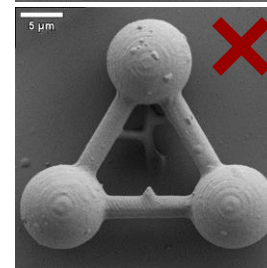
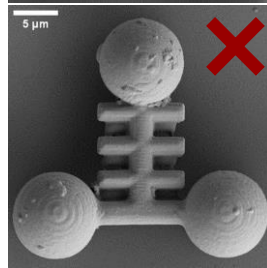
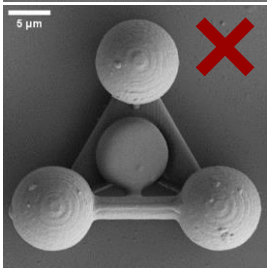
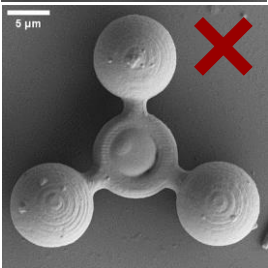
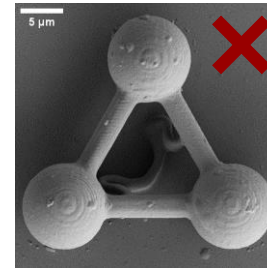
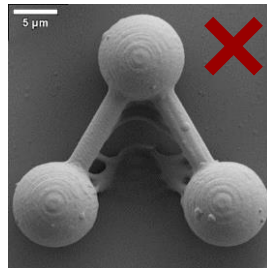
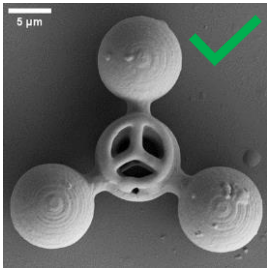
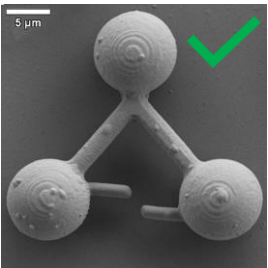
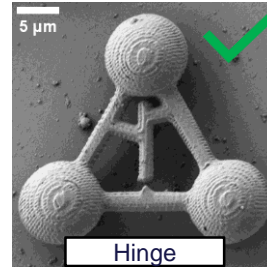
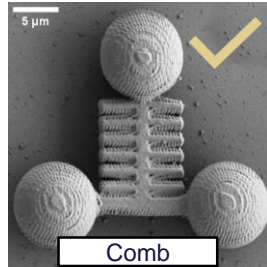
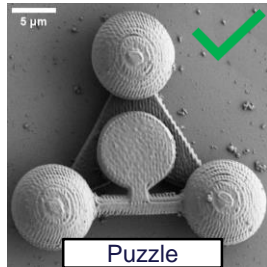
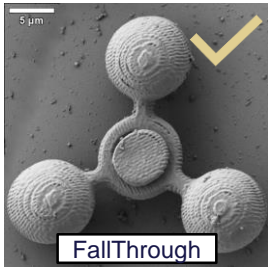
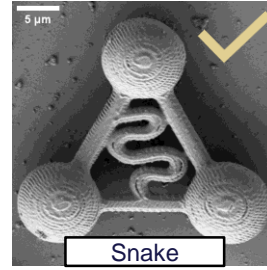
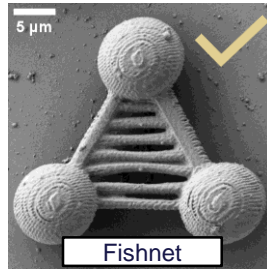
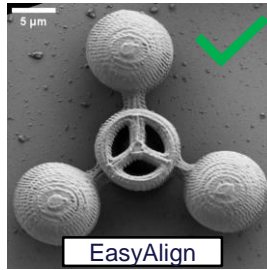
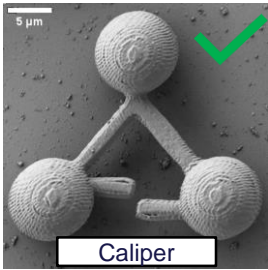


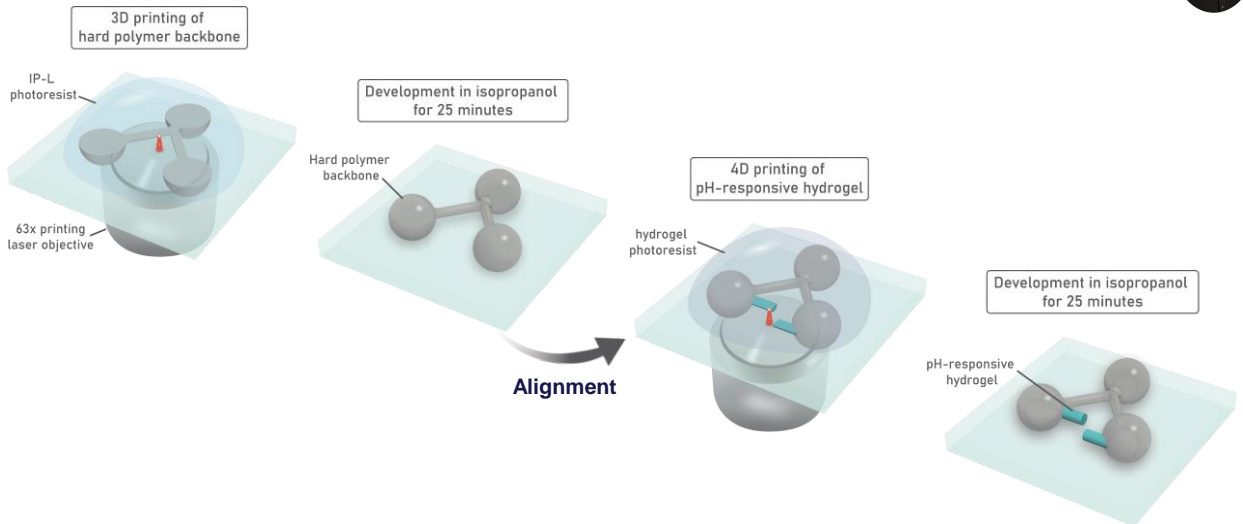
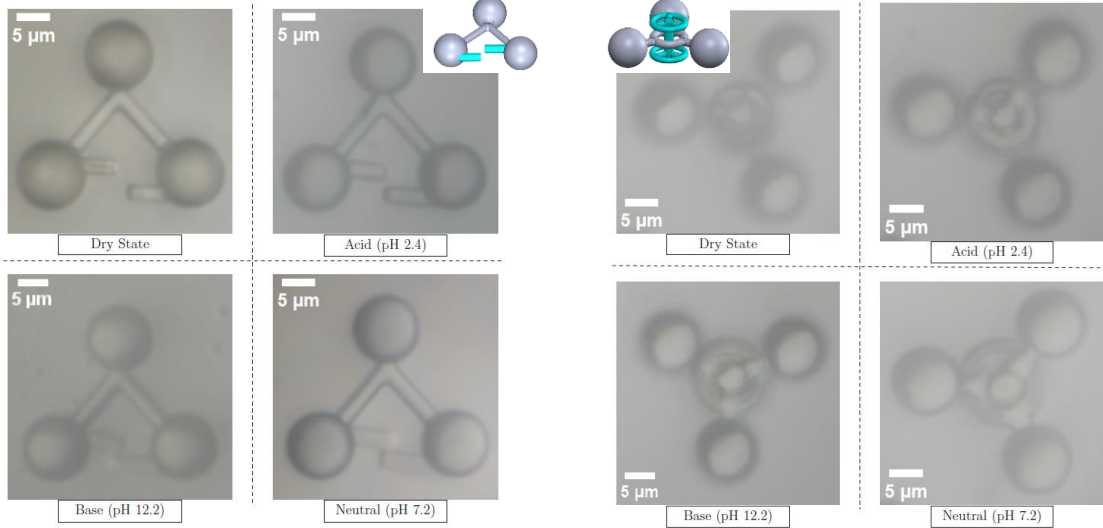
Caliper

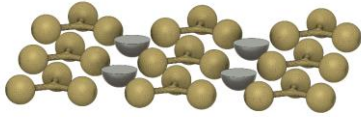


Complex actuation

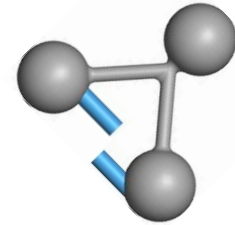
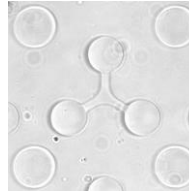
Height offset



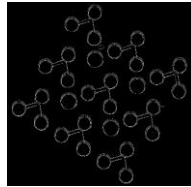
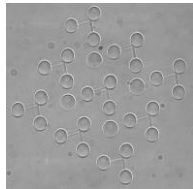




Hemispheres glare under microscope illumination => improved edge detection

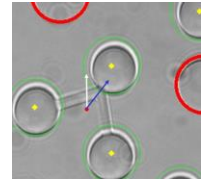
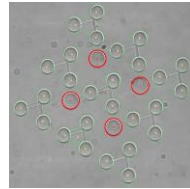


1. Original image from internal microscope



2. Canny edge detection gives contours

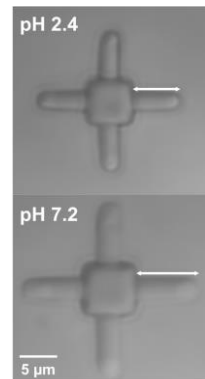
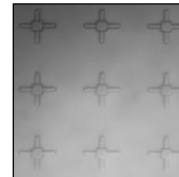
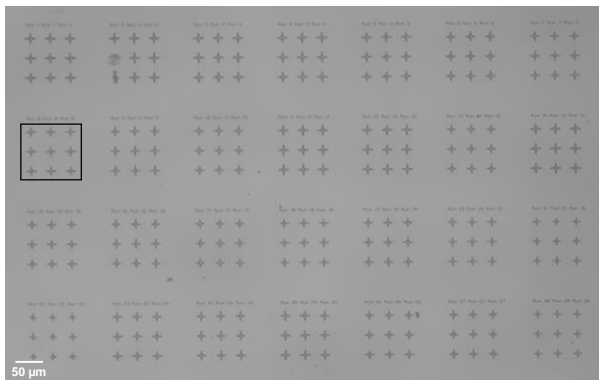
3. Hough transformation detects circles

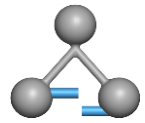


4. Compute alignment using detected circles



- Length increase % from pH 2.4 to pH 7.2
- 9 identical structures per batch
- 3 batches





4D printing can be used for fabricating smart responsive microstructures



Process optimization helps maximizing material actuation



The microrobots can be harvested and manipulated by optical trapping



Range for pH sensing is suitable for applications in food fermentation studies

Acknowledgements



DANMARKS FRIE
FORSKNINGSFOND

novo nordisk
fonden

VILLUM FONDEN



POLYMIC Group

