Universitätsmedizin Essen
Institut für KI in der Medizin (IKIM)

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Wahlfach Klinik - Info - Digitale Medizin und Künstliche Intelligenz

Medical 3D Printing

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Outline

- 3D Printing in General
  -history
  -types
  -how 3D printing works
  -3D printing applications
- Medical 3D Printing
  -special requirements
  -3D printing in medical applications
- Future of Medical 3D Printing
  -3D printing+artificial intelligence

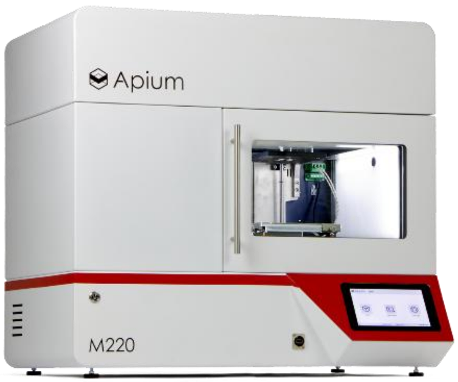
3D Printing in General

- 3D printing is also known as additive manufacturing (AM)
- motivated by easily and quickly creating **small** custom parts
- patents filed around the 1980s: **Stereolithography** (SLA), **Fused Deposition Modeling** (FDM)
- basic concept is similar: creates 3D objects by building successive **layers** of raw materials (polymer, ceramic, metal)

world‘s largest 3D printed building from “APIS COR” (as of Oct. 2019)

Fused Deposition Modeling (FDM)

also known as Fused Filament Fabrication



@ Apium M220 (~$60k, industrial level,1.2x0.6x0.64m)

filament

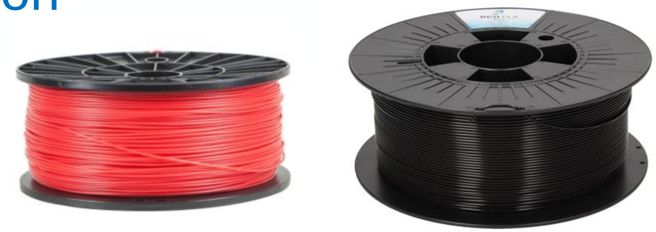
extruder

nozzle

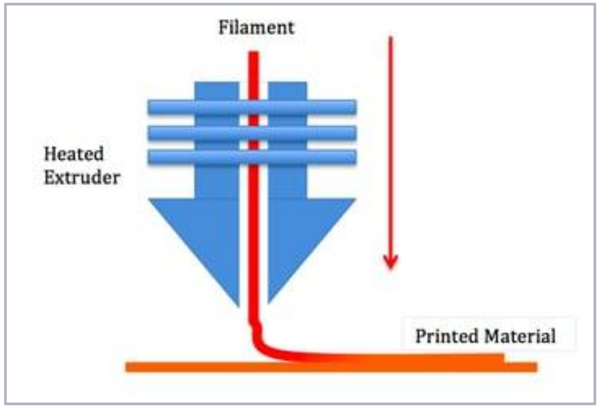
3D model

print bed

@VOXELAB Aquila (~$160, Desktop)



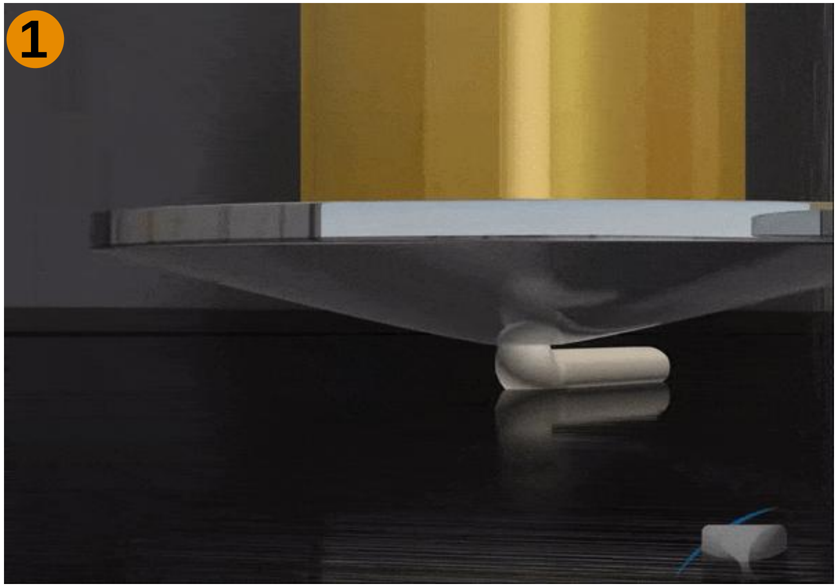
filament: color, material (polylactic, PLA)



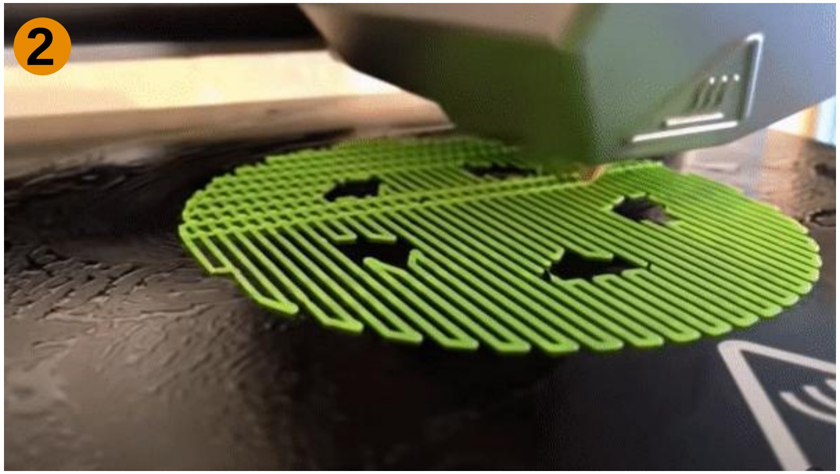
@Emmett Grames / All3DP

Fused Deposition Modeling (FDM)

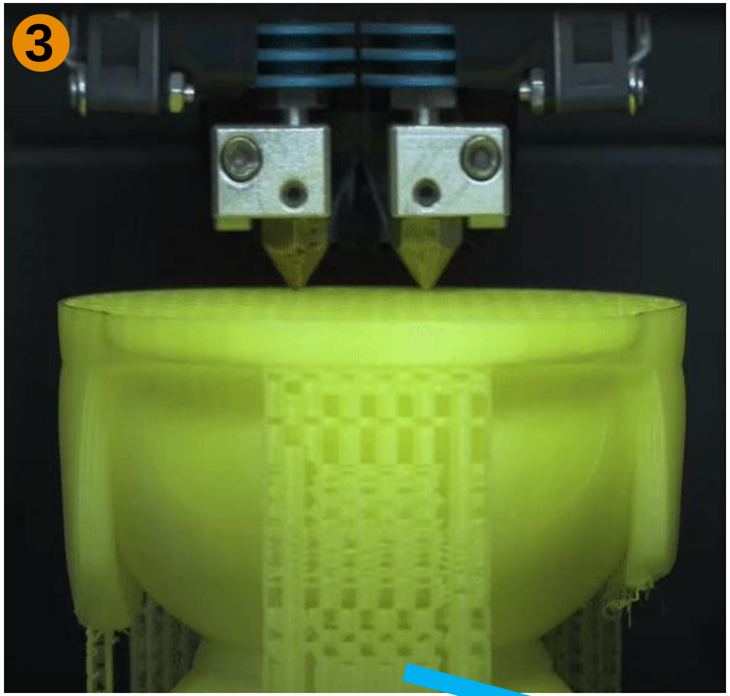
layer-by-layer printing



@Stratasys Direct Manufacturing



@ACAD Pte Ltd Singapore



@Product Design Online

support

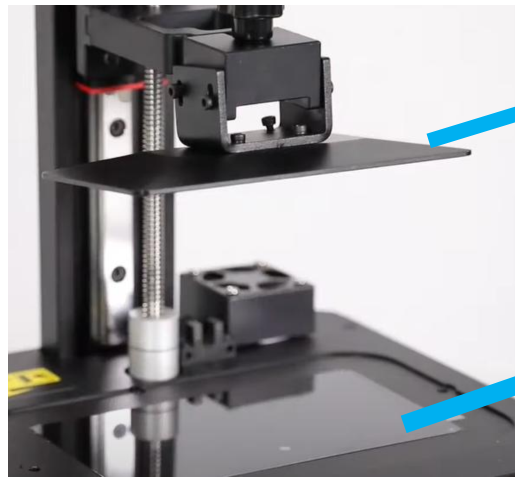
recap: a FDM printer prints a 3D model by melting the filament and fuse it in a layer-by-layer fashion.

Stereolithography (SLA)

also known as UV (ultraviolet) resin printer

- Use UV (Ultraviolet) light to solidify liquid resin/turn it into hardened plastic
- Resin is sensitive to UV light (photosensitive) and solidified when exposed
- Resin is toxic (wear mask and glove & cover the case during operation)

CREALITY LD-006
Desktop printer, ~$700



platform where the printed model will stick onto upside down

LCD (liquid-crystal display) screen, under which comes the UV light

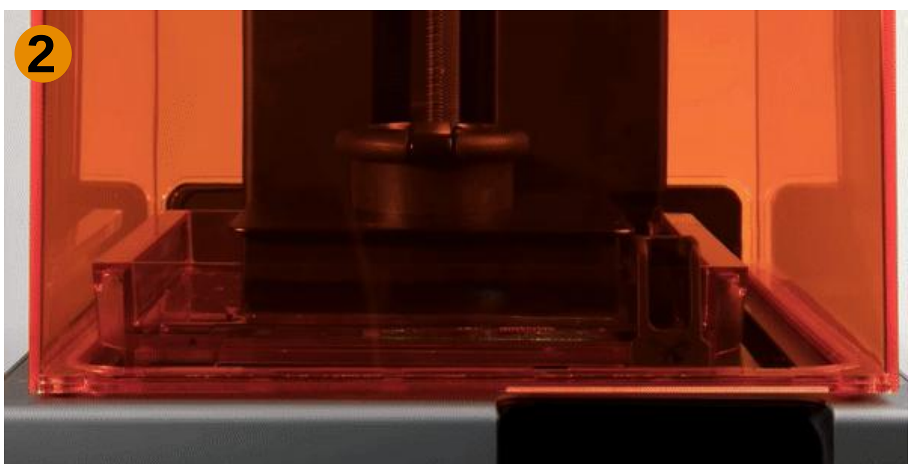
resin tank

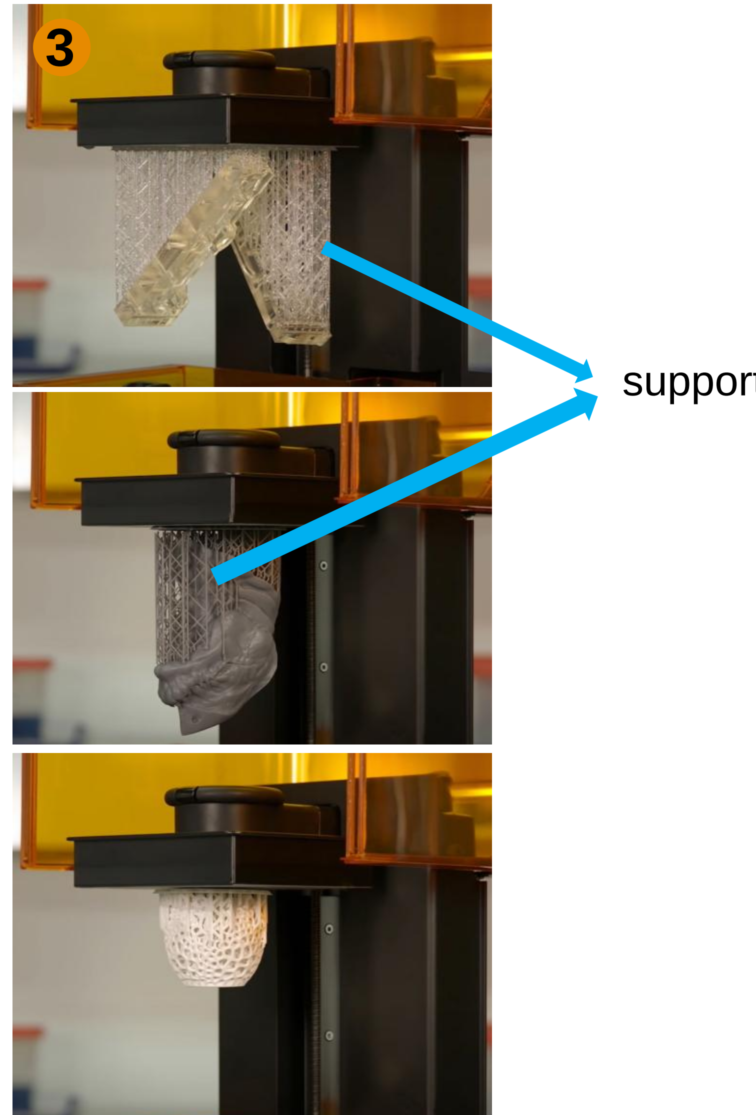
resin (different colors)

pour the resin into the tank

Stereolithography (SLA)

- UV light draws a cross section of the 3D model and selectively hardens the resin
- layer-by-layer printing
- when a layer is finished, the platform is lifted to let fresh resin flow beneath.
- the platform is lowered again
- repeat the above procedures until fully printed





@Formlabs

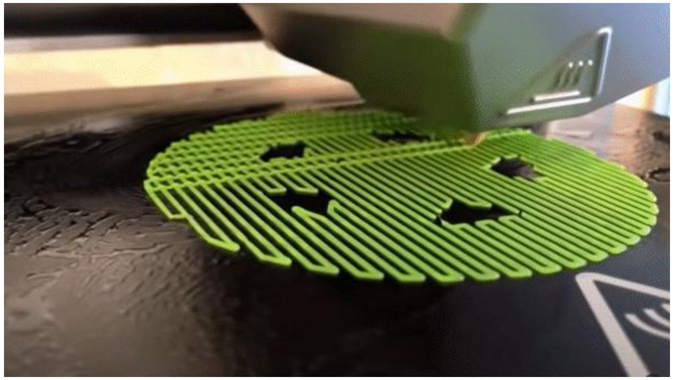
RECAP

Differences:

- FDM: melt solid material (filament). SLA: solidify liquid resin
- FDM uses heating (thermal) and SLA uses UV light
- SLA is more accurate than FDM (nozzle) and prints in higher resolution (fine details). SLA is suitable for printing complex parts that demands high precision.
- FDM is typically cheaper.

Similarities:

- **Need a 3D model to print**



RECAP

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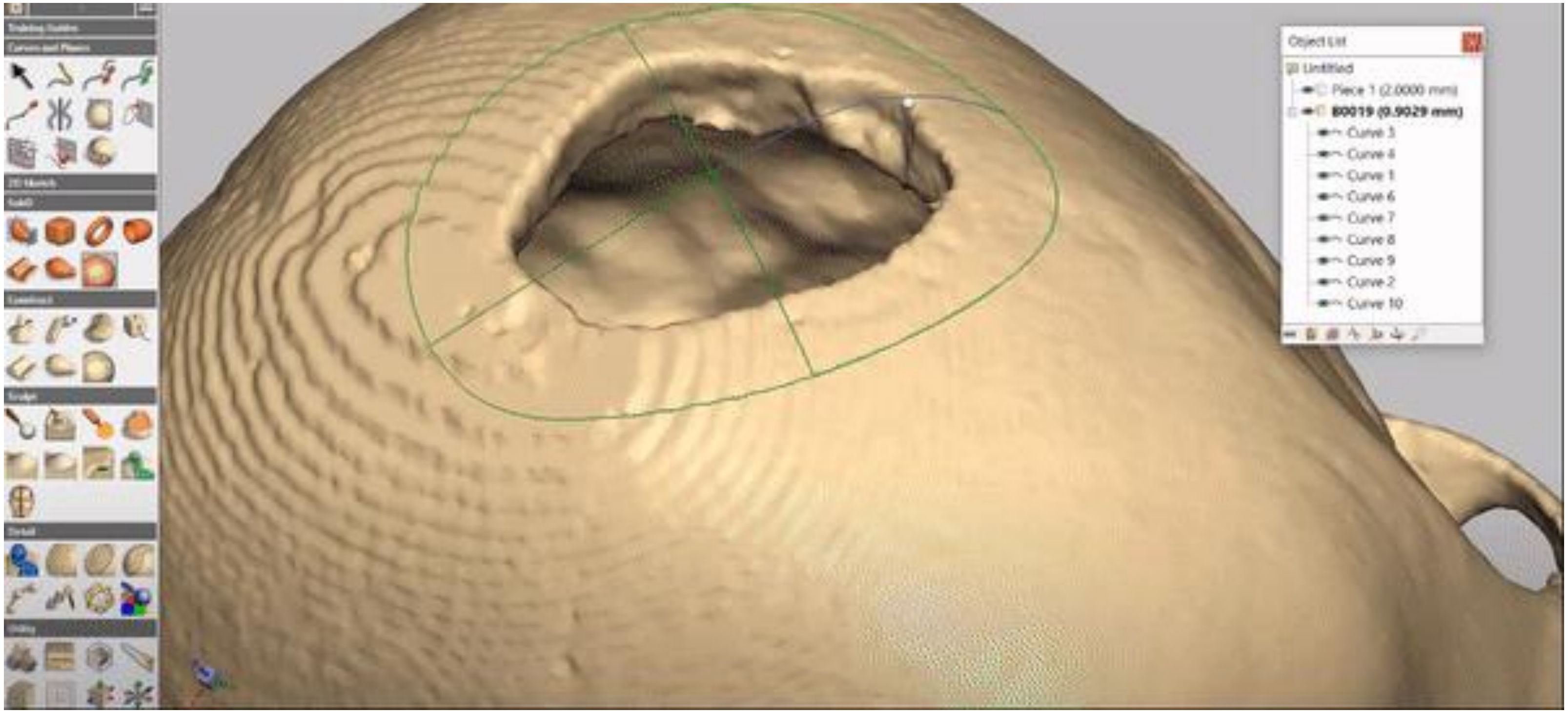
Similarities:

- **Need a 3D model to print**
- Print layer-by-layer
- Print in various materials (plastic, ceramic, metal[filament, iron resin - Ferrolite]) and color
- Both need post-processing (remove support, curing-exposing the model to light to make the material fully solidified/polymerized, cleaning- alcohol)

3D Printing Models

Step 1: Modeling (model format: .stl, .obj, AMF, 3MF, etc)

- Download model from internet
- Design your own model (dedicated CAD[1] software)



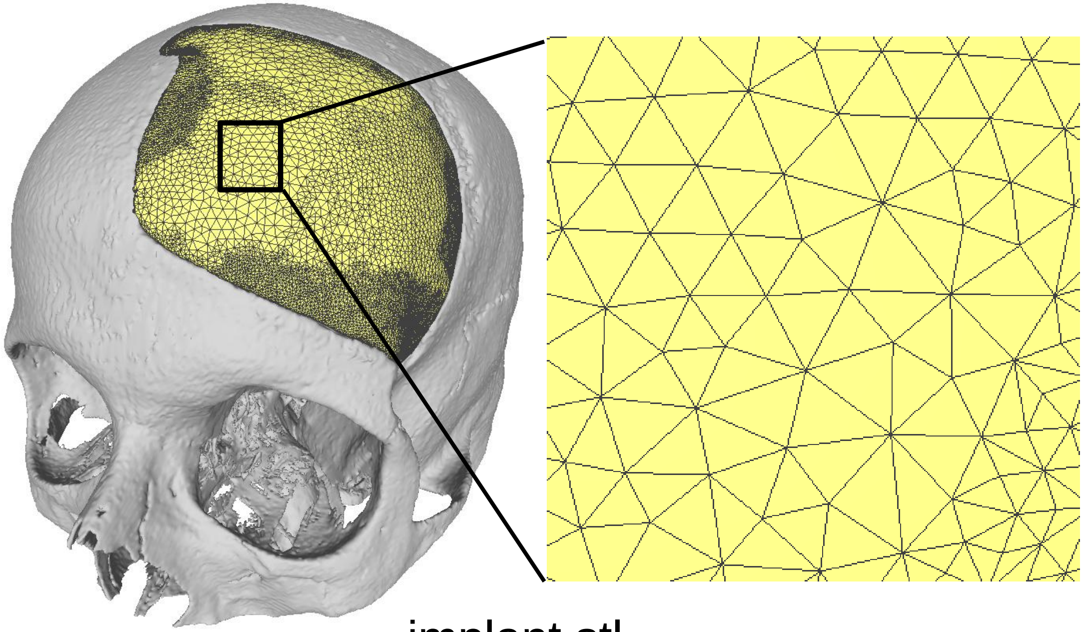
example: cranial implant design in neurosurgery

[1]CAD – computer-aided design

3D Printing Models

Step 1: Modeling (model format: .stl, .obj, AMF, 3MF, etc)

- Download model from internet
- Design your own model (CAD software)
- Post-processing: fill the holes/gaps and make the model surface watertight (can be done using many free software)



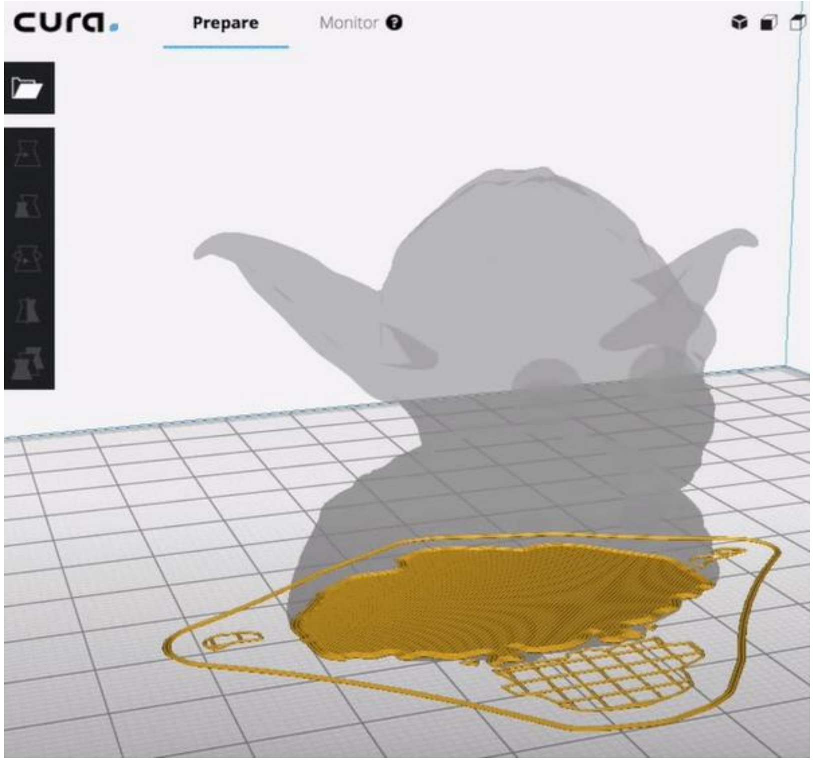
implant.stl

.stl files describe the surface geometry of a 3D model (e.g., an implant) using triangular meshes

3D Printing Models

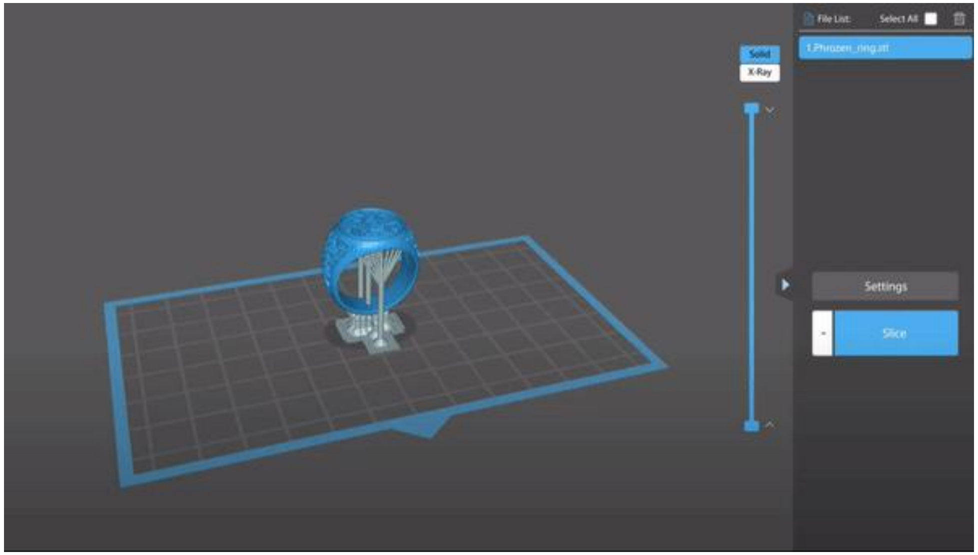
Step 2: Slicing (slice the 3D model into thin layers)

- Slicer software e.g., Ultimaker Cura 3D printing software (free)
- load the 3D model into the software
- set printing parameters (print size, speed, etc)
- generate G-code (i.e., instructions that a machine can understand)
- print



@3D Now

resin printer: ChiTuBox.
save the G-code to a USB drive

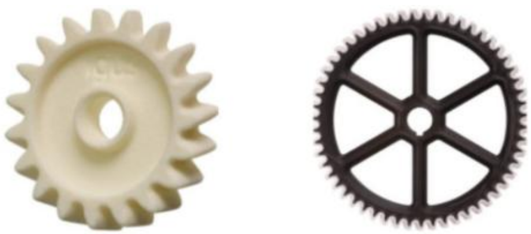


@Phrozen LCD 3D Printer

you can make use of the freely available software to **design** and **print** your own 3D model easily!

3D Printing Applications

- Functional spare parts & tools & utilities



gears

wheels

chairs

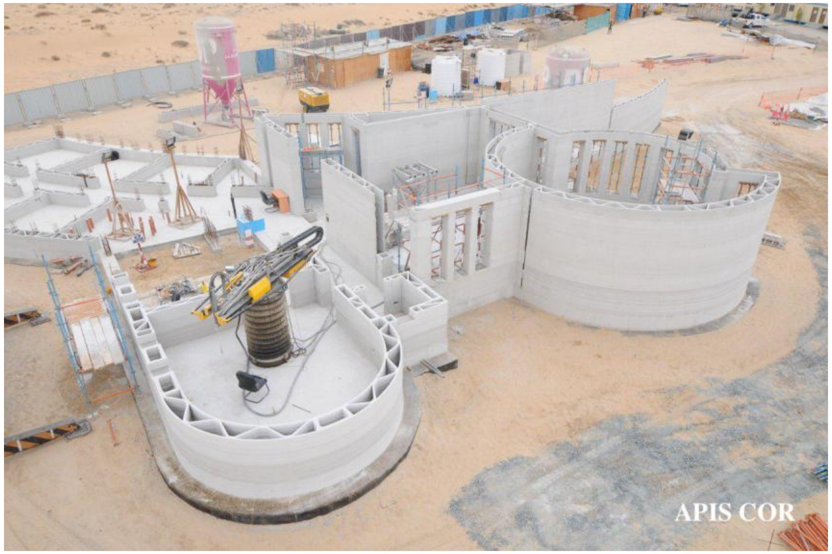
wrench

toys

3D Printing Applications

- Construction & automotive & …

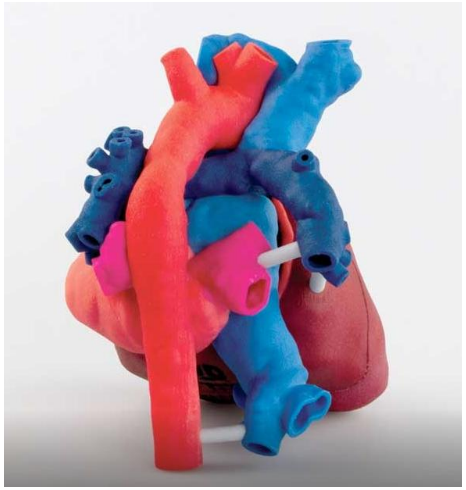
@Divergent Microfactories



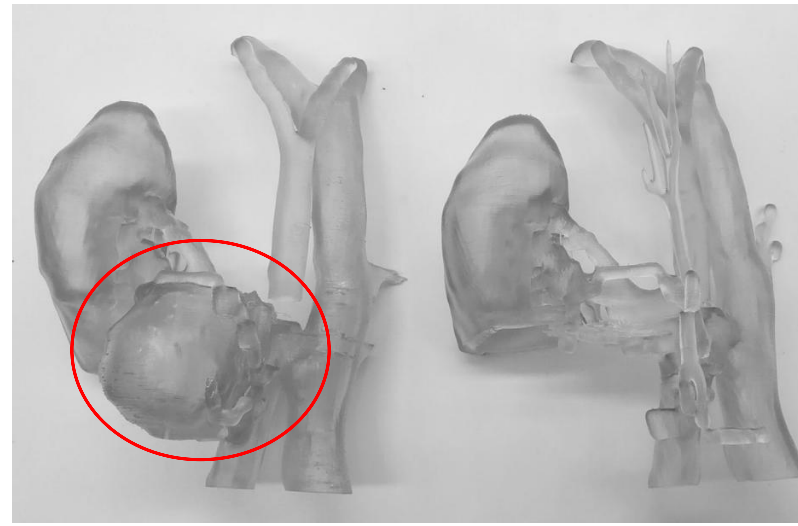
@APIS COR

3D Printing Applications

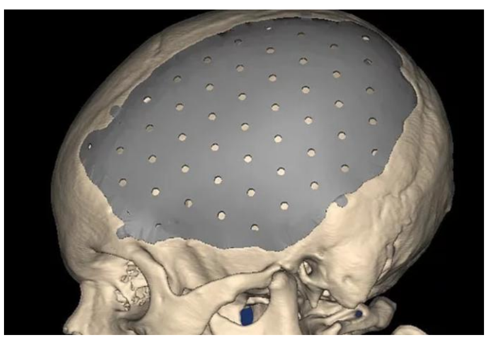
- medical 3D printing



anatomy education



preoperative surgical planning: visualize the tumor and the anatomical references around it[1]



implant

hearing aid

[1]Tejo-Otero, A., Buj-Corral, I. and Fenollosa-Artés, F., 2020. 3D printing in medicine for preoperative surgical planning: a review. Annals of biomedical engineering, 48(2), pp.536-555.

3D Printing Future Perspectives and challenges

nowadays,3D printing has wide and in-depth applications across manufacturing, industries, medicine and so on (low cost, fast, high flexibility)

Future perspectives:

digital warehouse + manufacture on demand + localized production

Challenges:

The development of new materials is relatively slow

Top 3D Printing Challenges by Industry

Consumer Electronics	Healthcare	Heavy Equipment
1. Cost of pre- and post-processing 2. Cost of materials 3. Limited material selection	1. Limited material selection 2. Cost of pre- and post-processing 3. Cost of system equipment	1. Cost of pre- and post-processing 2. Cost of materials 3. Limited material selection
Automotive	**Industrial Machines**	**Plastics & Packaging**
1. Limited material selection 2. Cost of pre- and post-processing 3. Technology limitations	1. Cost of pre- and post-processing 2. No in-house expertise 3. Cost of system equipment	1. Limited material selection 2. Cost of pre- and post-processing 3. Technology limitations

@Tim DeRosett

RECAP

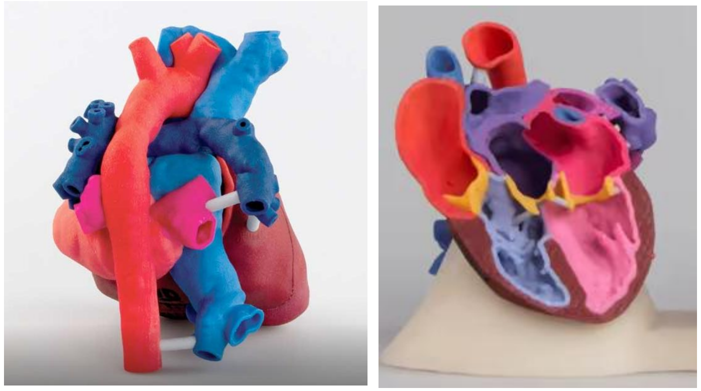
- you need to design your own 3D model for a specific purpose
- 3D models are stored in the format of triangular meshes
- various free software can be used to process and print the model. main steps include: hole filling, slicing, generate G-code, print
- 3D printing has nowadays been used widely across industries, to print both small and large objects
- development of new materials is one of the main challenge for future 3D printing

Medical 3D Printing

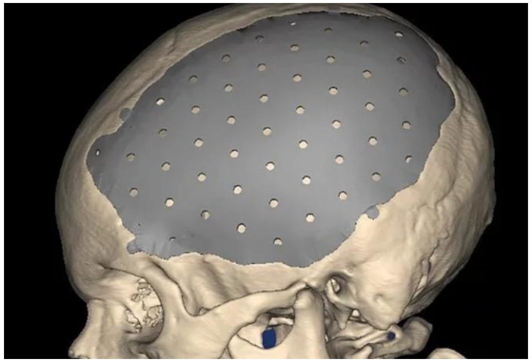
-----3D printing in medical/healthcare applications

types of medical 3D printing

- 3D model rendered from imaging data (1)
- 3D model custom-designed based on imaging data (2)

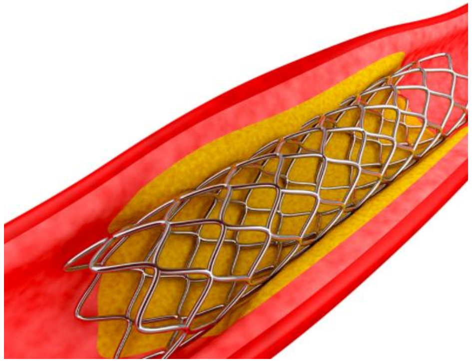


anatomy education (MRI/CT) (1)

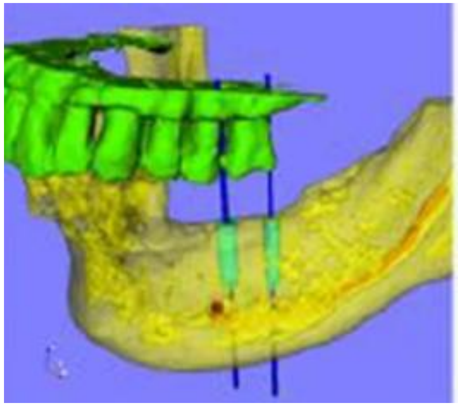


cranial implant (CT) (2)

orthopedic implant (CT/X-ray) (2)



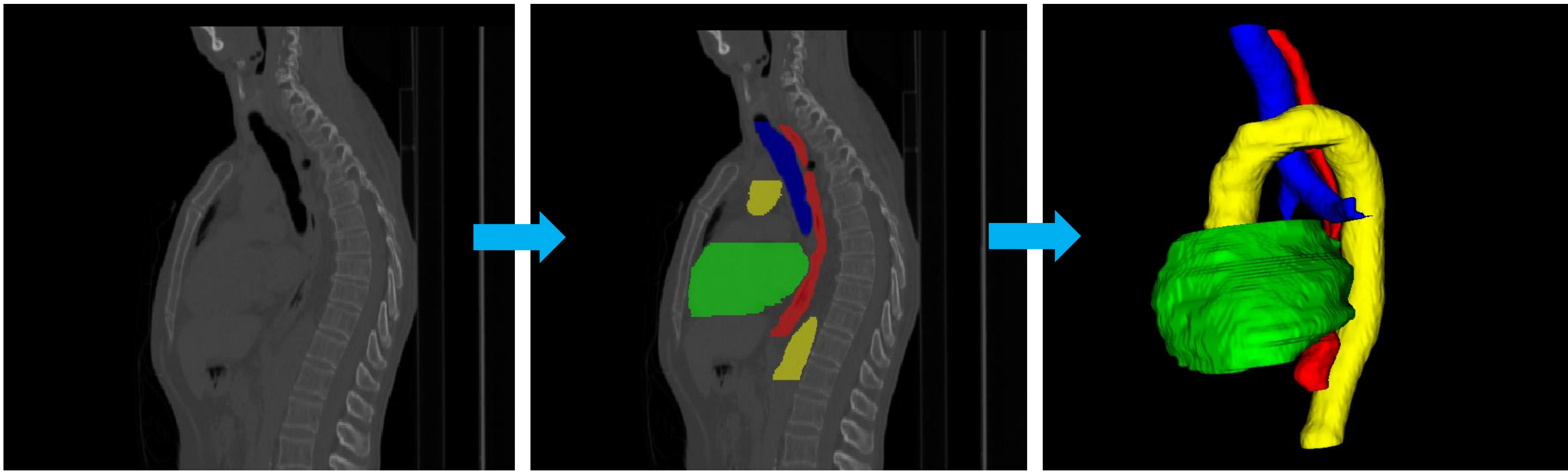
vascular stent-graft (2)



teeth implant (CBCT) (2)

○ 3D model rendered from imaging data

- not directly applied on patients[1]
- for anatomy education or surgical planning purposes
- segmentation determines the anatomical precision of the 3D model



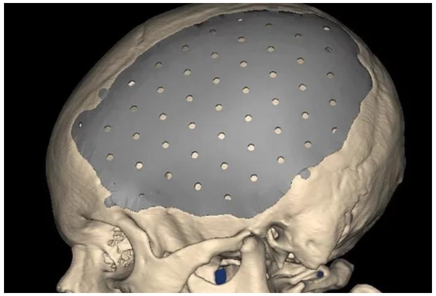
thorax CT | segmentation | 3D model

heart | trachea | aorta | esophagus

[1]excluding 3D printed organs as replacements of the original organs

○ 3D model custom-designed based on imaging data

- directly applied on patients/ implanted into patients' body
- 3D printed medical implants, e.g., cranial implant, teeth implant, vascular stent-graft, etc

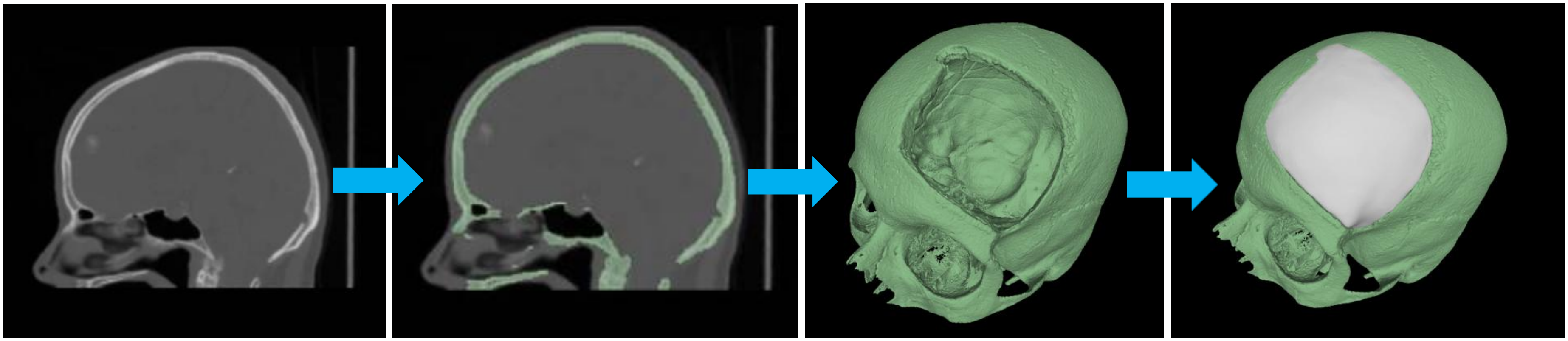


<u>special requirements/issues:</u>

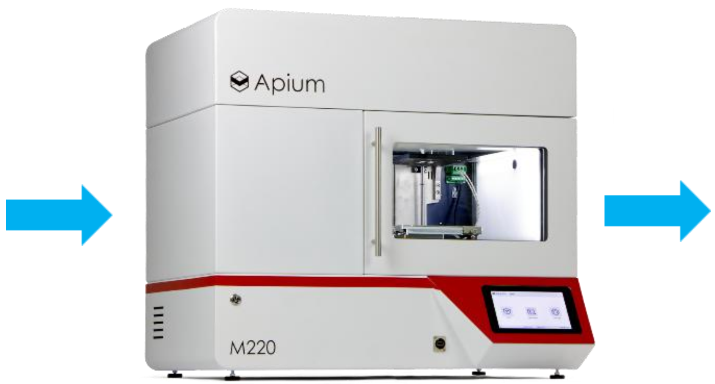
- **optimally should be patient-specific (geometry)**
- biocompatibility, e.g., no chemical reactions (material)
- thermostability, e.g., remain resilient in different thermal conditions (material)
- diagnostic compatibility, e.g., minimal radiological artifacts in CT/MRI (material)
- mechanical properties, e.g., resistant to force (material)
- FDA clearance (regulated medical devices)
- ethical issues (e.g., artifical heart[1])

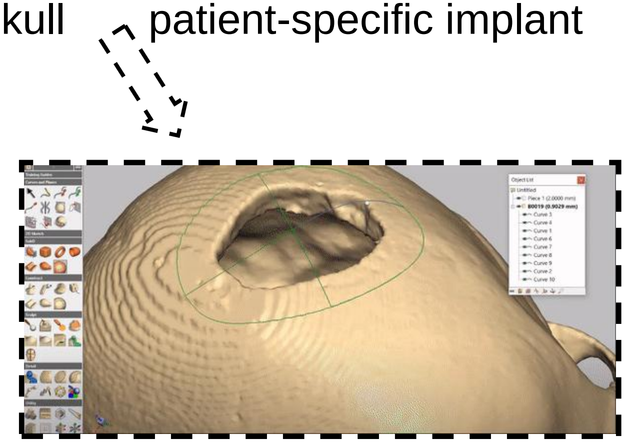
[1]Simmons, P.D., 1986. Ethical considerations of artificial heart implantations. Annals of Clinical & Laboratory Science, 16(1), pp.1-12.

3D model custom-designed based on imaging data



head CT — segmentation — patient-specific skull — patient-specific implant



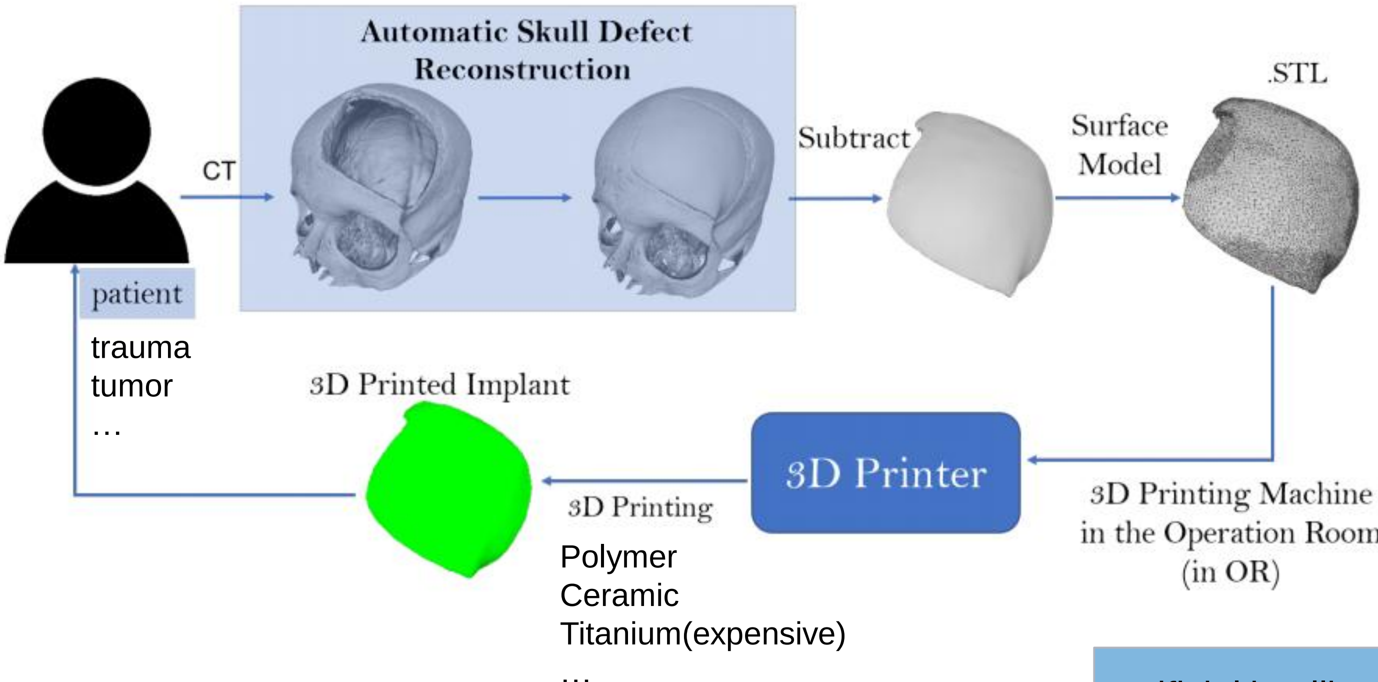


metal (titanium) or biocompatible plastic polymers (PEEK)

custom model design is a tedious and expensive (professional designer/commercial software) task!

Future of medical 3D printing

-- combining 3D printing with artificial intelligence



In comparison to current practice of cranial implant design[1]:

- low cost & fast
- in operation room (in-OR) design & manufacturing
- no secondary surgeries required (cranioplasty can be performed hours after craniectomy)

artificial intelligence (AI) algorithms (particularly deep learning) learn to generate the implant model directly

[1]Li, J., Pepe, A., Gsaxner, C. and Egger, J., 2020. An Online Platform for Automatic Skull Defect Restoration and Cranial Implant Design. *arXiv preprint arXiv:2006.00980*.

Future of medical 3D printing – Further reading

-- combining 3D printing with artificial intelligence

AI for automatic 3D model design:

- Li, J., von Campe, G., Pepe, A., Gsaxner, C., Wang, E., Chen, X., Zefferer, U., Tödtling, M., Krall, M., Deutschmann, H. and Schäfer, U., 2021. **Automatic skull defect restoration and cranial implant generation for cranioplasty**. *Medical Image Analysis*, *73*, p.102171.

- Kodym, O., Španěl, M. and Herout, A., 2021. **Deep learning for cranioplasty in clinical practice: Going from synthetic to real patient data**. Computers in Biology and Medicine, 137, p.104766.

AI for material science:

- Vasylenko, A., Gamon, J., Duff, B.B., Gusev, V.V., Daniels, L.M., Zanella, M., Shin, J.F., Sharp, P.M., Morscher, A., Chen, R. and Neale, A.R., 2021. **Element selection for crystalline inorganic solid discovery guided by unsupervised machine learning of experimentally explored chemistry**. *Nature communications*, *12*(1), pp.1-12.

- Bessa, M.A., Glowacki, P. and Houlder, M., 2019. **Bayesian machine learning in metamaterial design: Fragile becomes supercompressible**. *Advanced Materials*, *31*(48), p.1904845.

- Sha, W., Guo, Y., Yuan, Q., Tang, S., Zhang, X., Lu, S., Guo, X., Cao, Y.C. and Cheng, S., 2020. **Artificial intelligence to power the future of materials science and engineering**. *Advanced Intelligent Systems*, *2*(4), p.1900143.

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