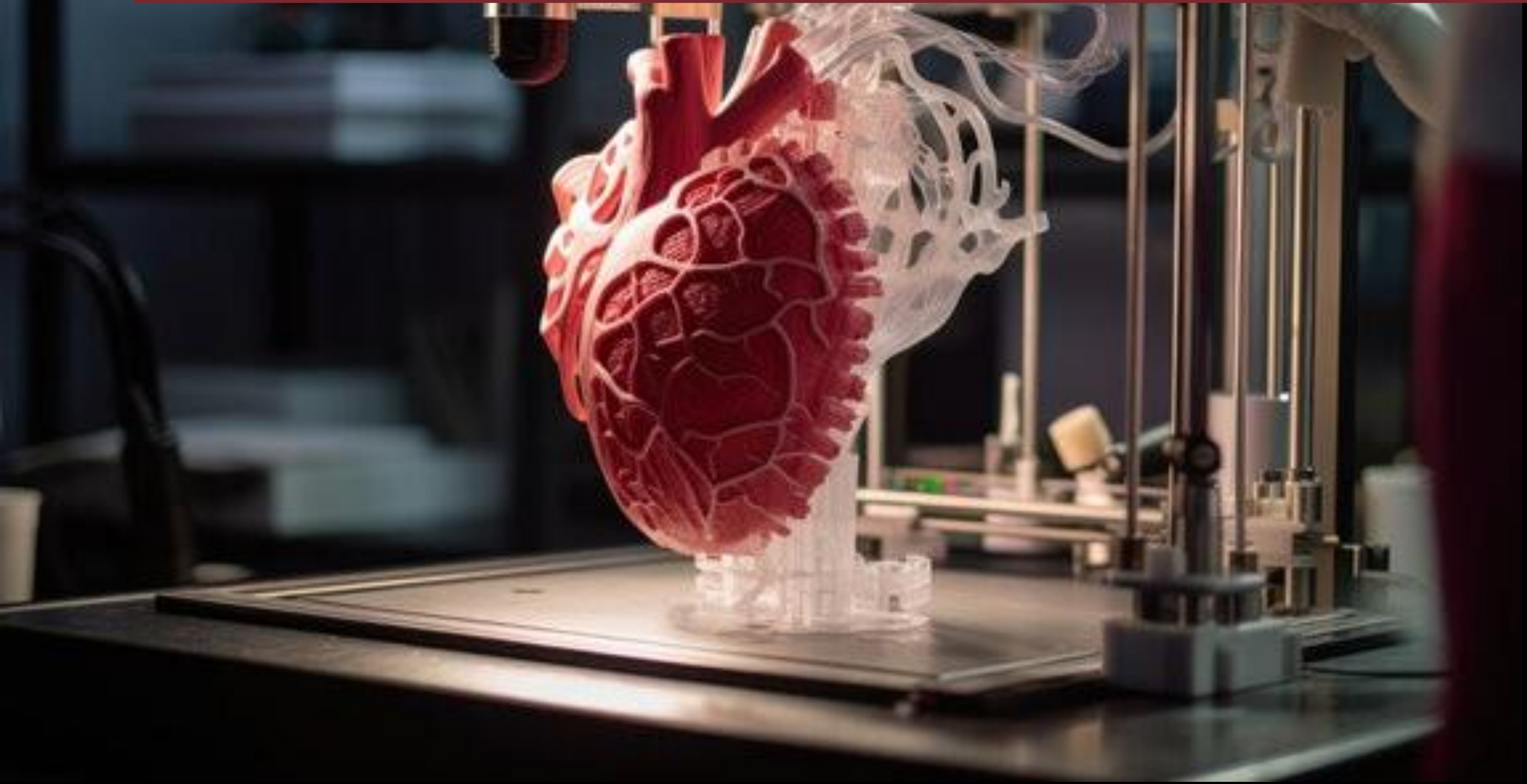
Printable Biomaterials

MAX-PLANCK-INSTITUT
FÜR POLYMERFORSCHUNG

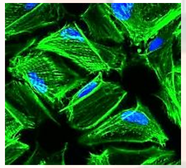


BIOFABLAB

QUESTIONS

Join at menti.com | Code: 7744 9634

http://patreon.com/crashcourse



USES OF BIOMATERIALS

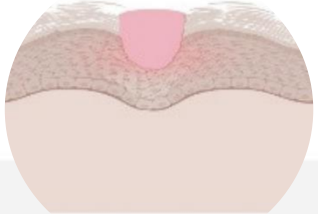
Medical Implants

Drug Delivery

Biosensors

Food Tissue Engineering

Wound Healing



Tissue Engineering

http://patreon.com/crashcourse

BUILDING BLOCKS

BIO MATERIALS

Ceramics:

Calcium Phosphate..

+ Ideal for Bone regeneration

Clay:

Laponite

Natural Polymers:

Collagen, Gelatin…

+ Biocompatible

- Variable

Hydrogels:

PEG, Alginate…

+ Cell friendly

+ Perfect for tissues

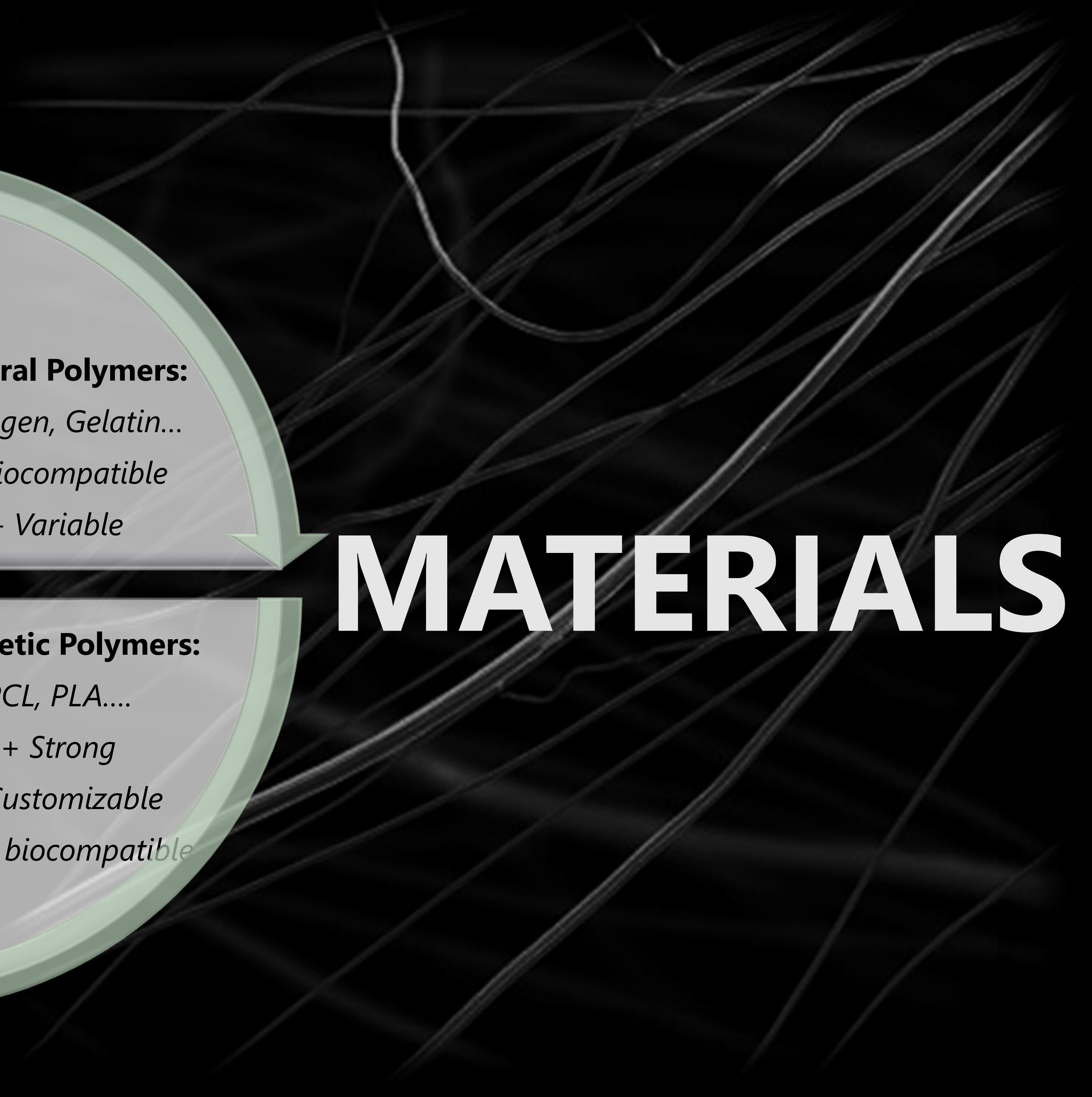
Synthetic Polymers:

PCL, PLA….

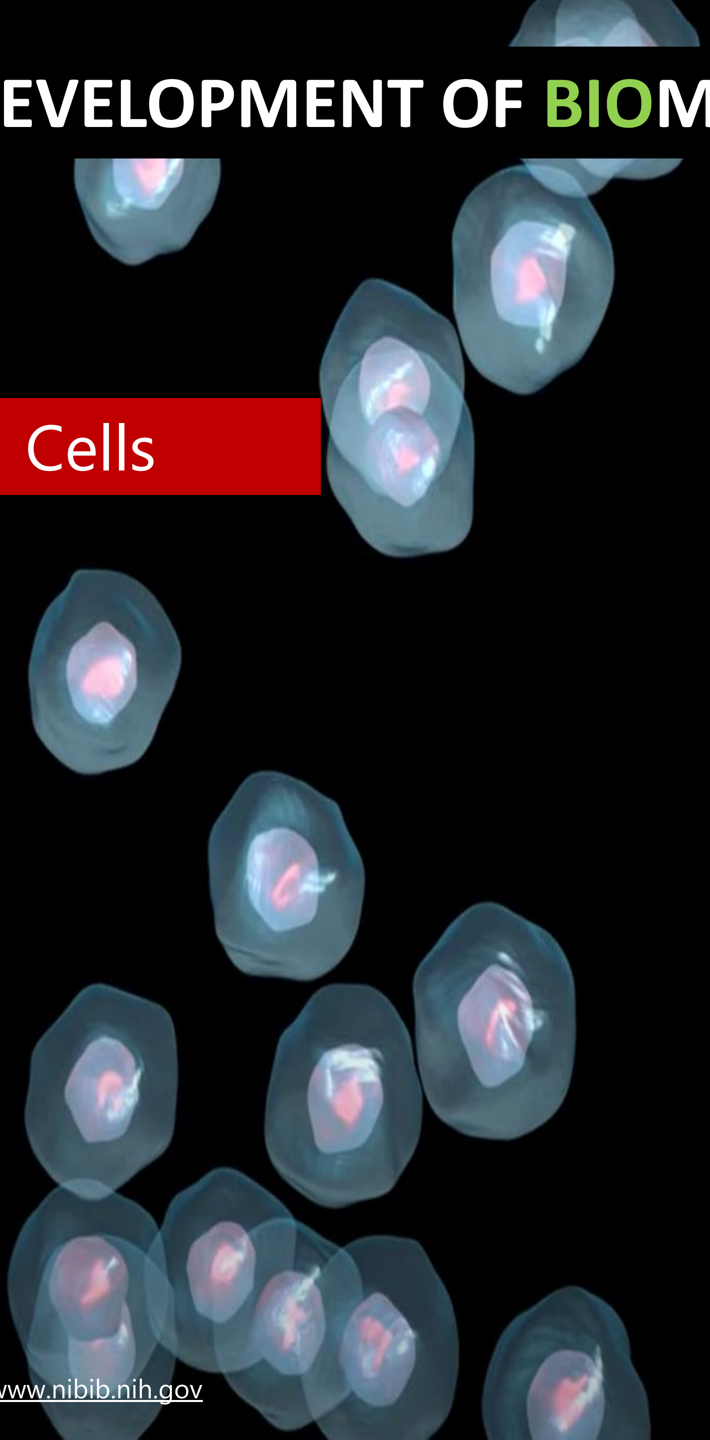
+ Strong

+ Customizable

- Less biocompatible



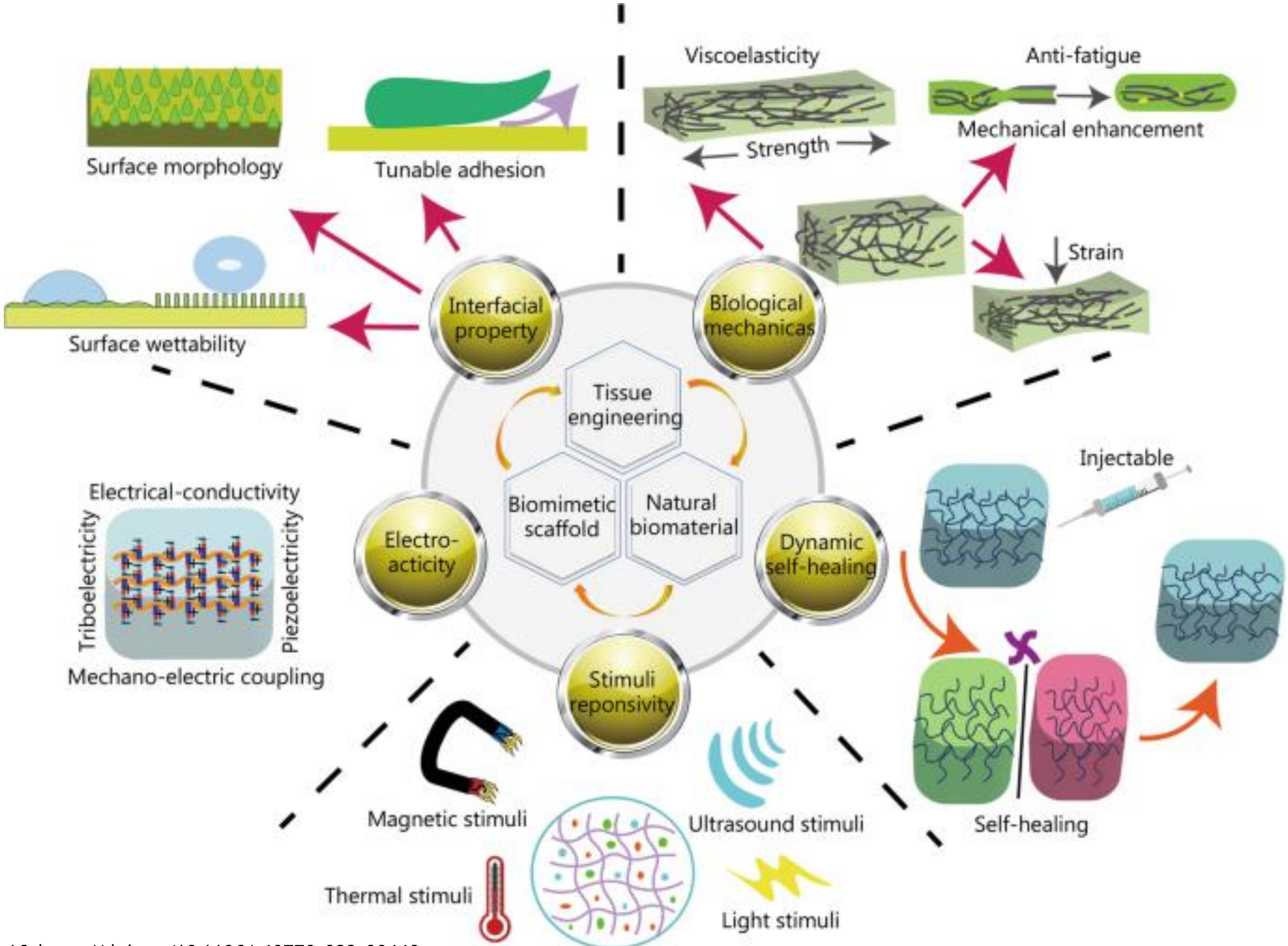
DEVELOPMENT OF BIOMATERIALS RELIES ON 4 IMPORTANT FACTORS



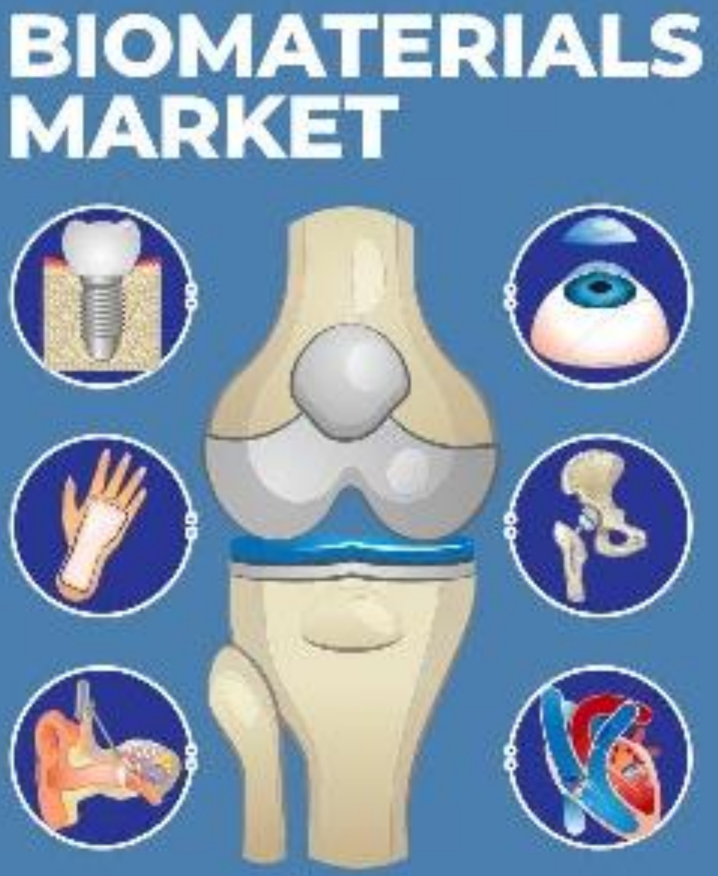
Cells

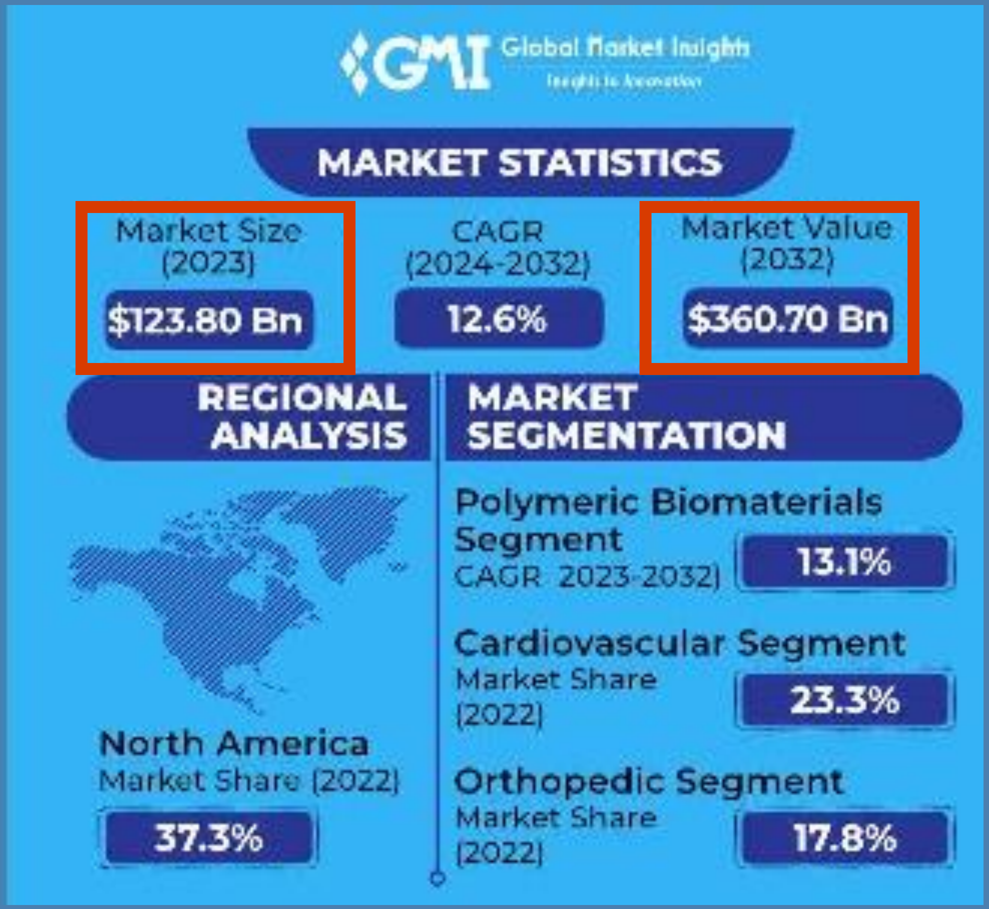
https//www.nibib.nih.gov

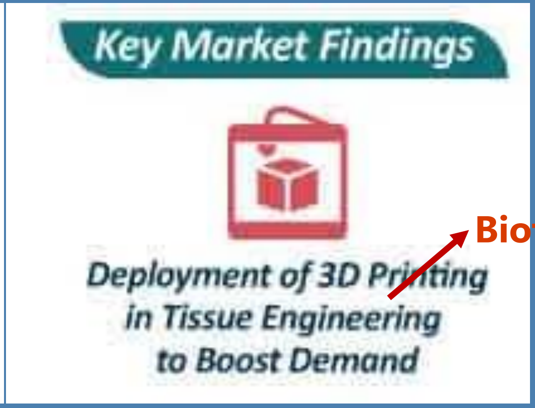
DESIGN & FUNCTIONALITIES OF BIOMATERIALS



Military Med Res, **2023**, 10, 16. https://doi.org/10.1186/s40779-023-00448-w

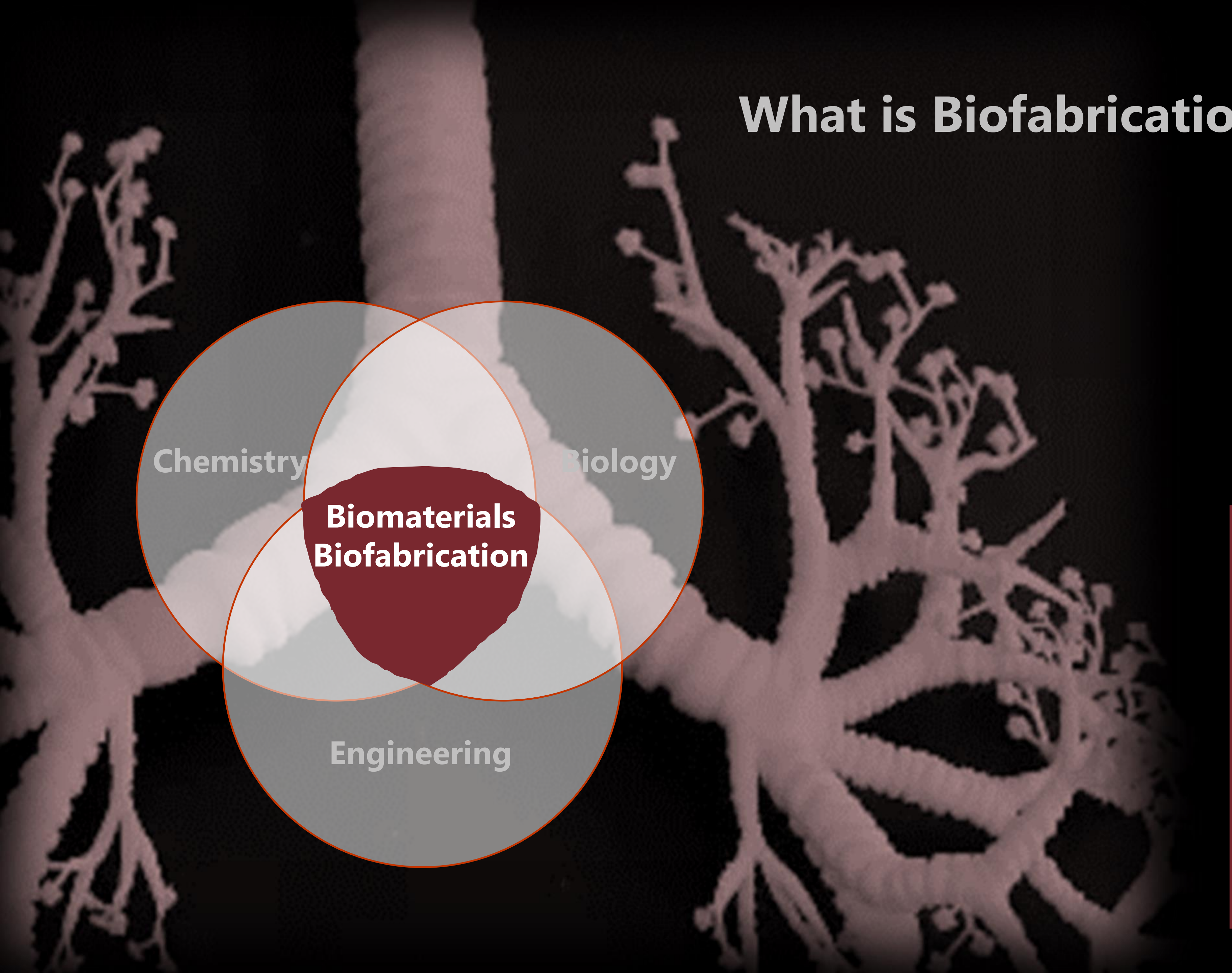




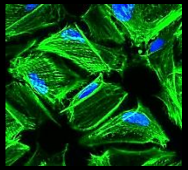


Biofabrication

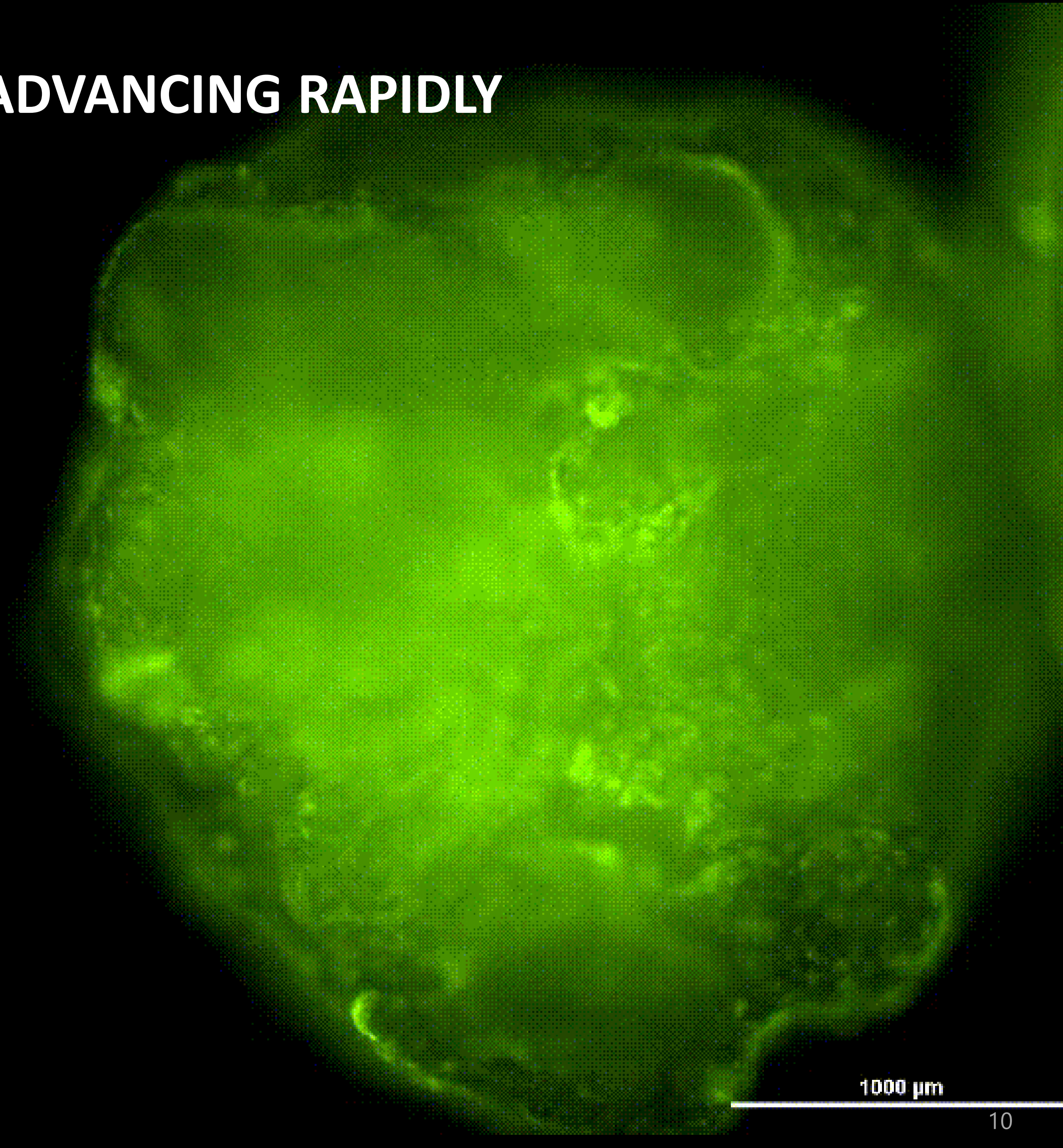
What is Biofabrication?

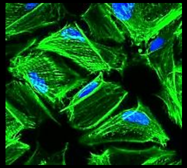


Biofabrication is the production of complex biological products, tissues, and organs through 3D printing, electrospinning, and other advanced techniques.



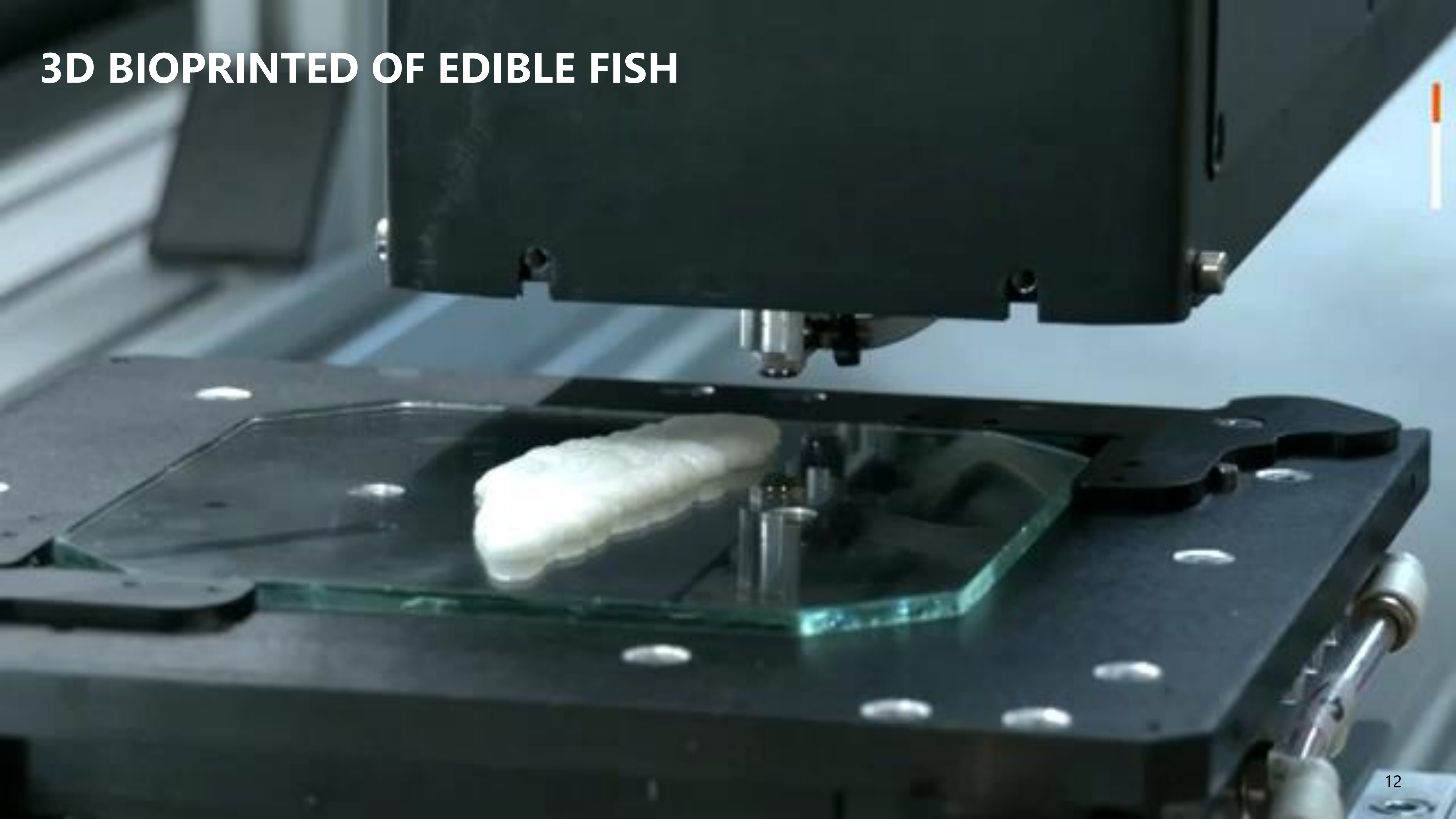
BIOENGINEERING RESEARCH: ADVANCING RAPIDLY



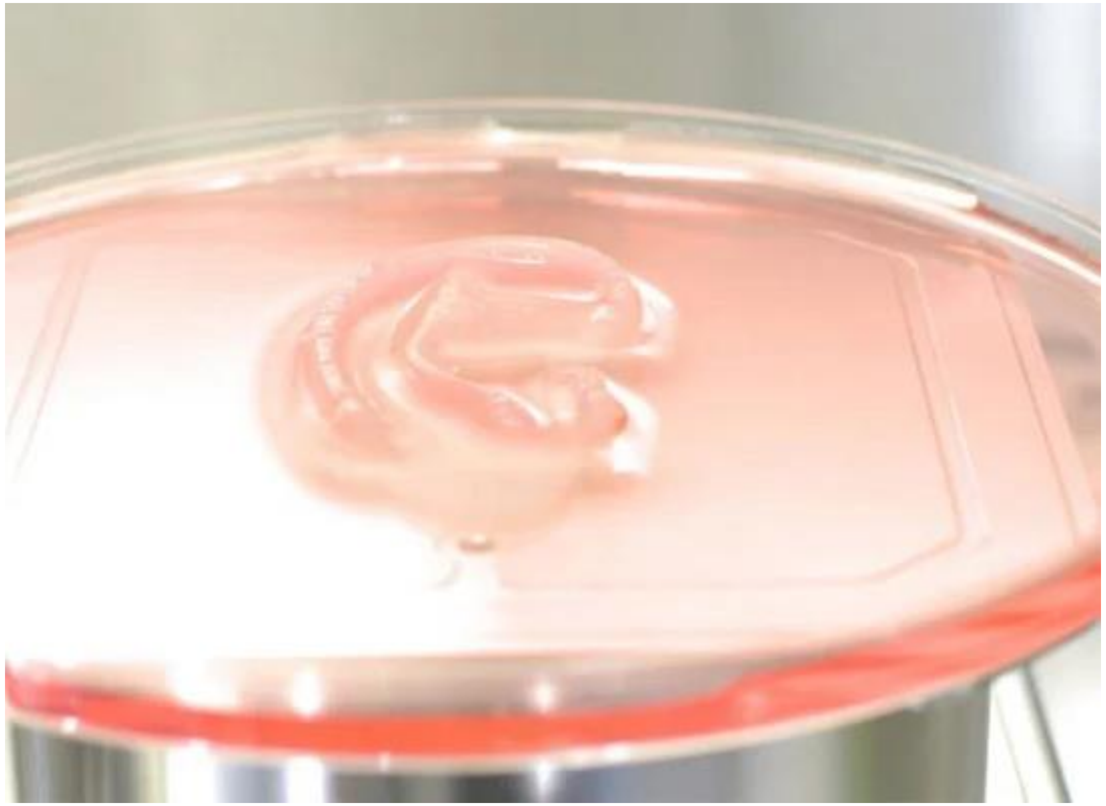


BIOENGINEERING RESEARCH: ADVANCING RAPIDLY

3D BIOPRINTED OF EDIBLE FISH



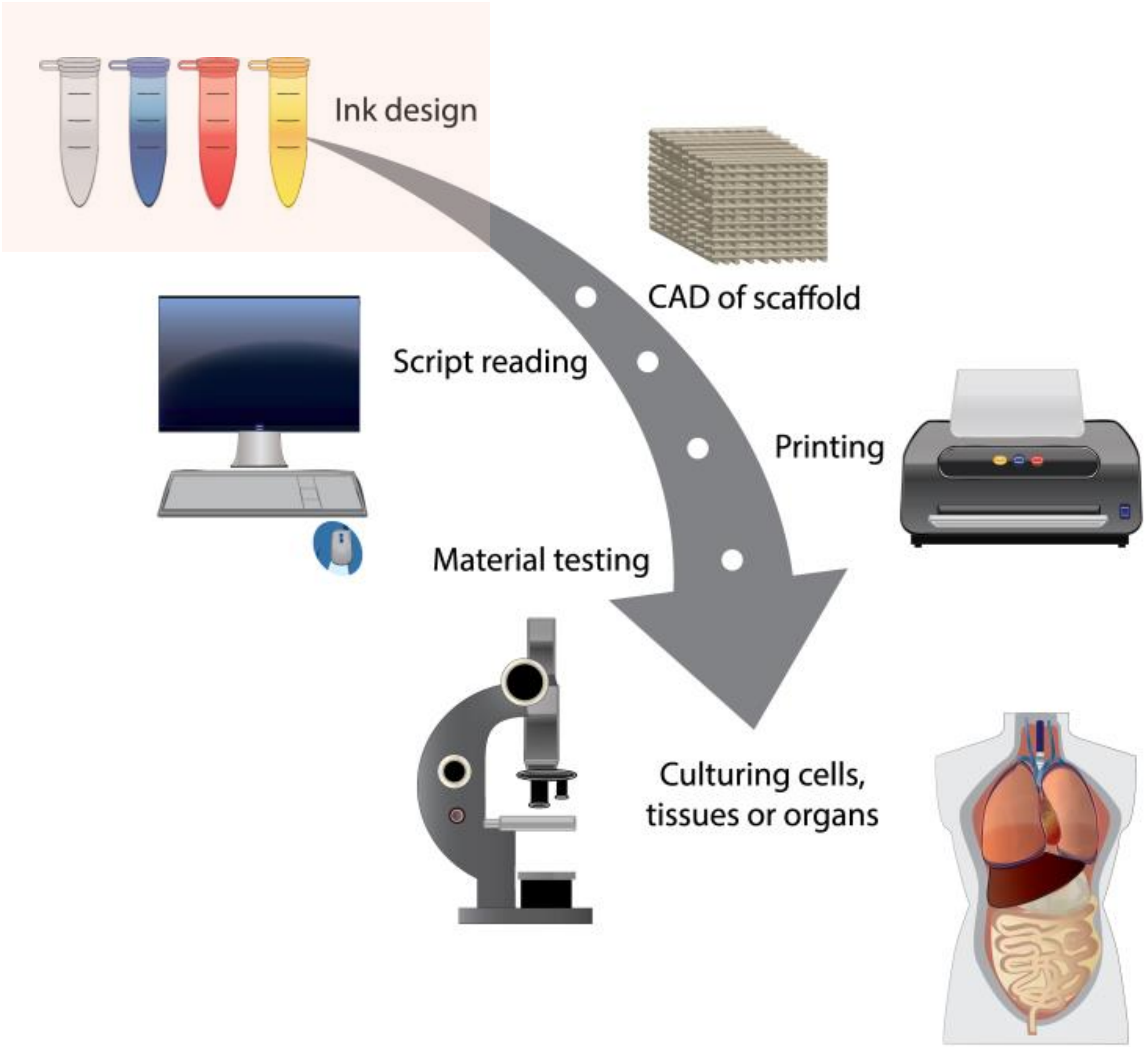
(BIO)PRINTING IN KLINICS



Photos: Microtia-Congenital Ear Institute and 3DBio Therapeutics, **2022**

3D BIOPRINTED HEART CONSTRUCT

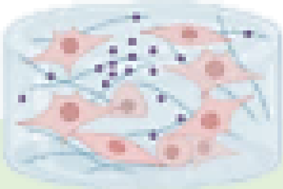
3D (BIO)PRINTING PROCESS



Polymer Nanocomposites in Biomedical Engineering, **2019**, pp.205-233.

(BIO)INK FROM POLYMERS

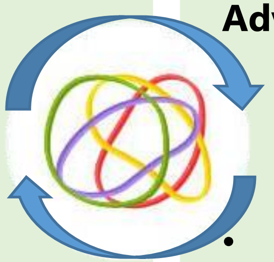
Biomaterial



Natural polymers are large, organic molecules derived from living organisms, such as proteins, polysaccharides, and nucleic acids, that play essential roles in biological processes.

Advantages:

- Biocompatibility
- Biodegradability
- Renewability
- Versatility
- Enhanced cell interaction



Rubber

Synthetic polymers are man-made compounds created through chemical processes that combine small molecules (monomers) into long, repeating chains, enabling a wide range of applications.

Advantages:

- Control over properties
- Consistency in production
- Tailored functionalities
- Cost-effectiveness
- Durability

Cellulose

DNA

Epoxy

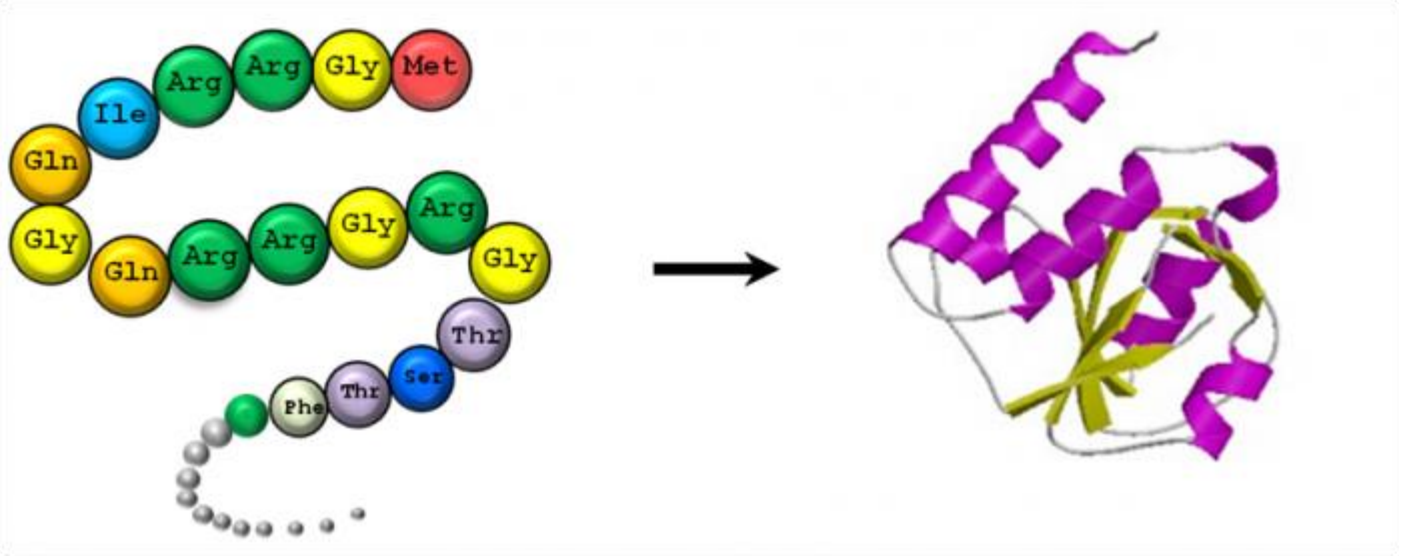
Polyester

Bioactive Mat. **2023**, 28, 511-536

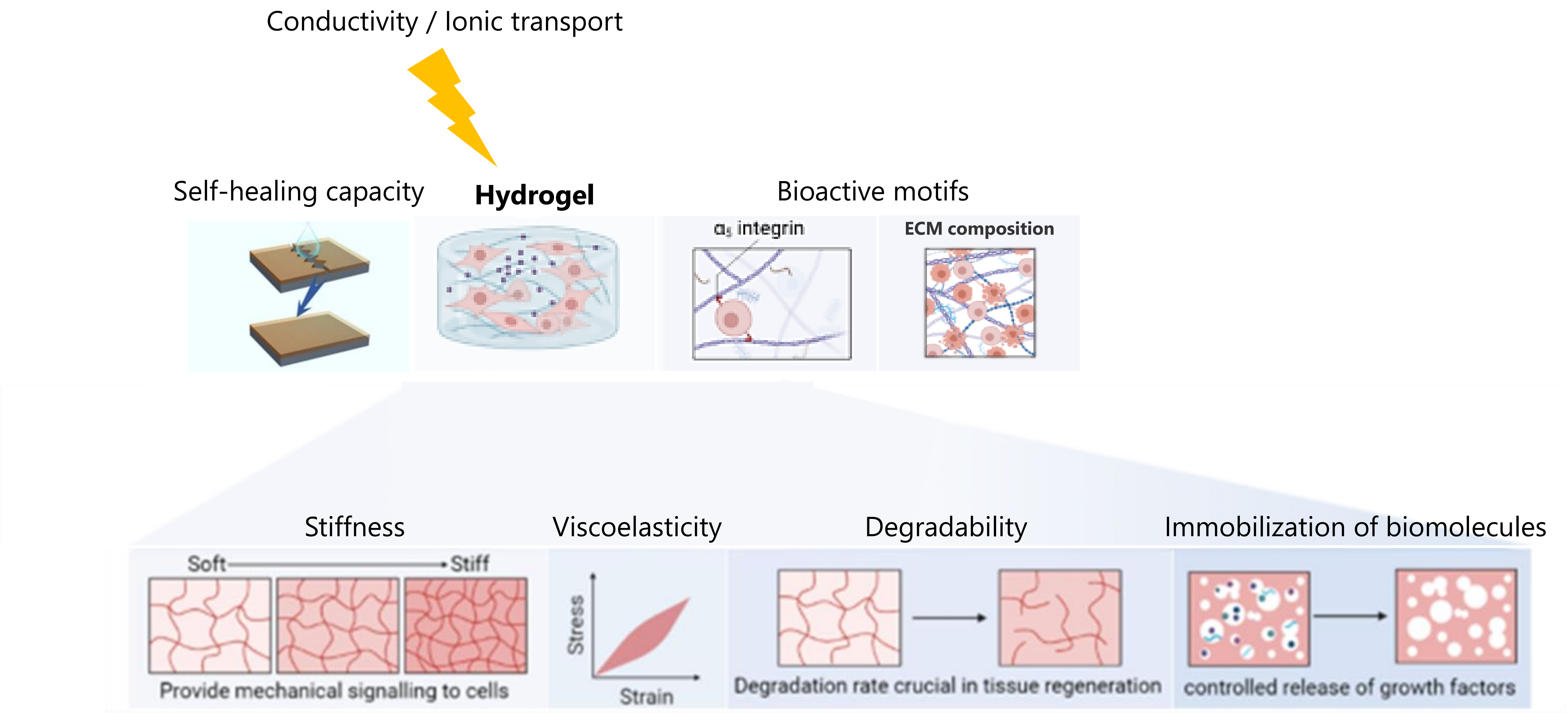
USE OF BIOINFORMATICS TO BIOMATERIAL DESIGN

Bioinformatics can reveal:

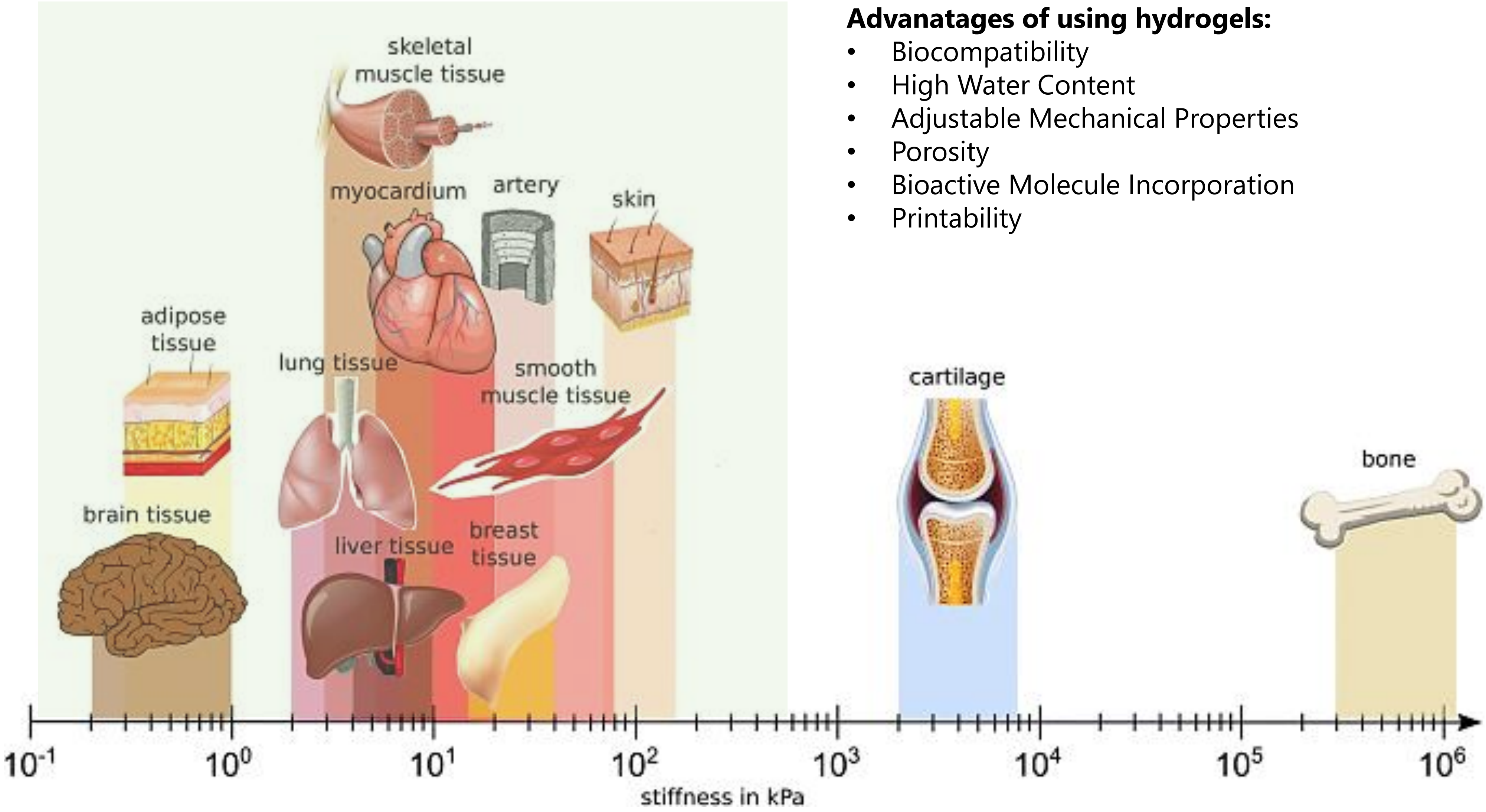
- **Protein sequences** for biomaterial scaffolds (e.g., silk, collagen, elastin-like polypeptides)
- **Cell–matrix interaction motifs** (RGD, YIGSR, IKVAV) obtained from protein databases
- **Enzyme cleavage sites** to design degradable hydrogels
- **Gene expression data** to tailor biomaterials for specific cell types
- Material **biomechanics and processability**



(BIO)INK : MODULAR DESIGN



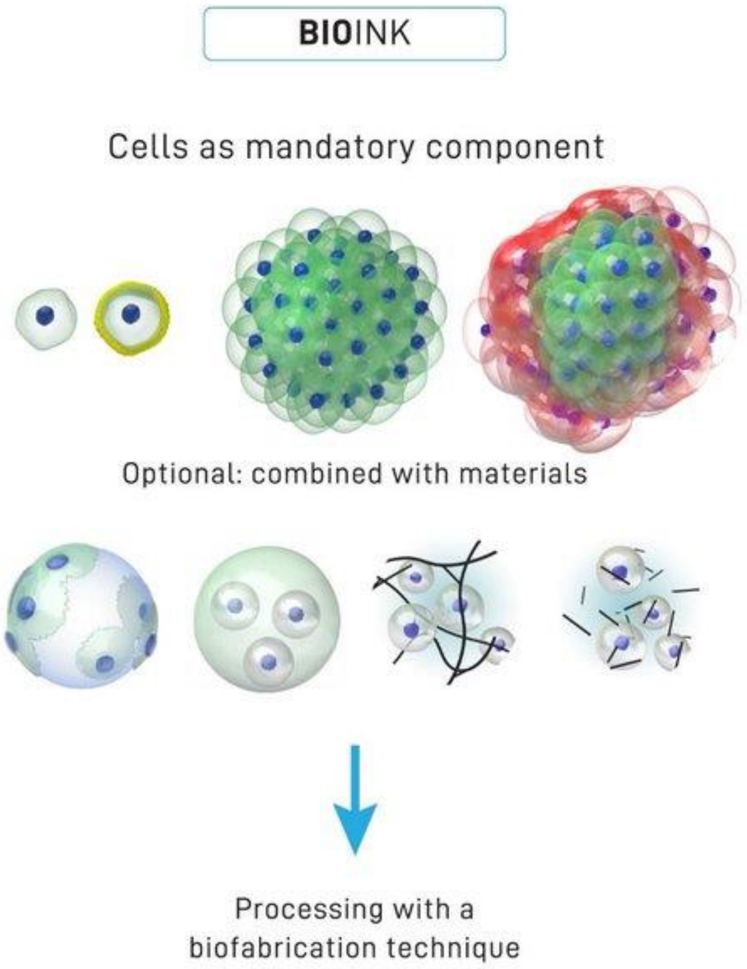
(BIO)INKS: HYDROGELS

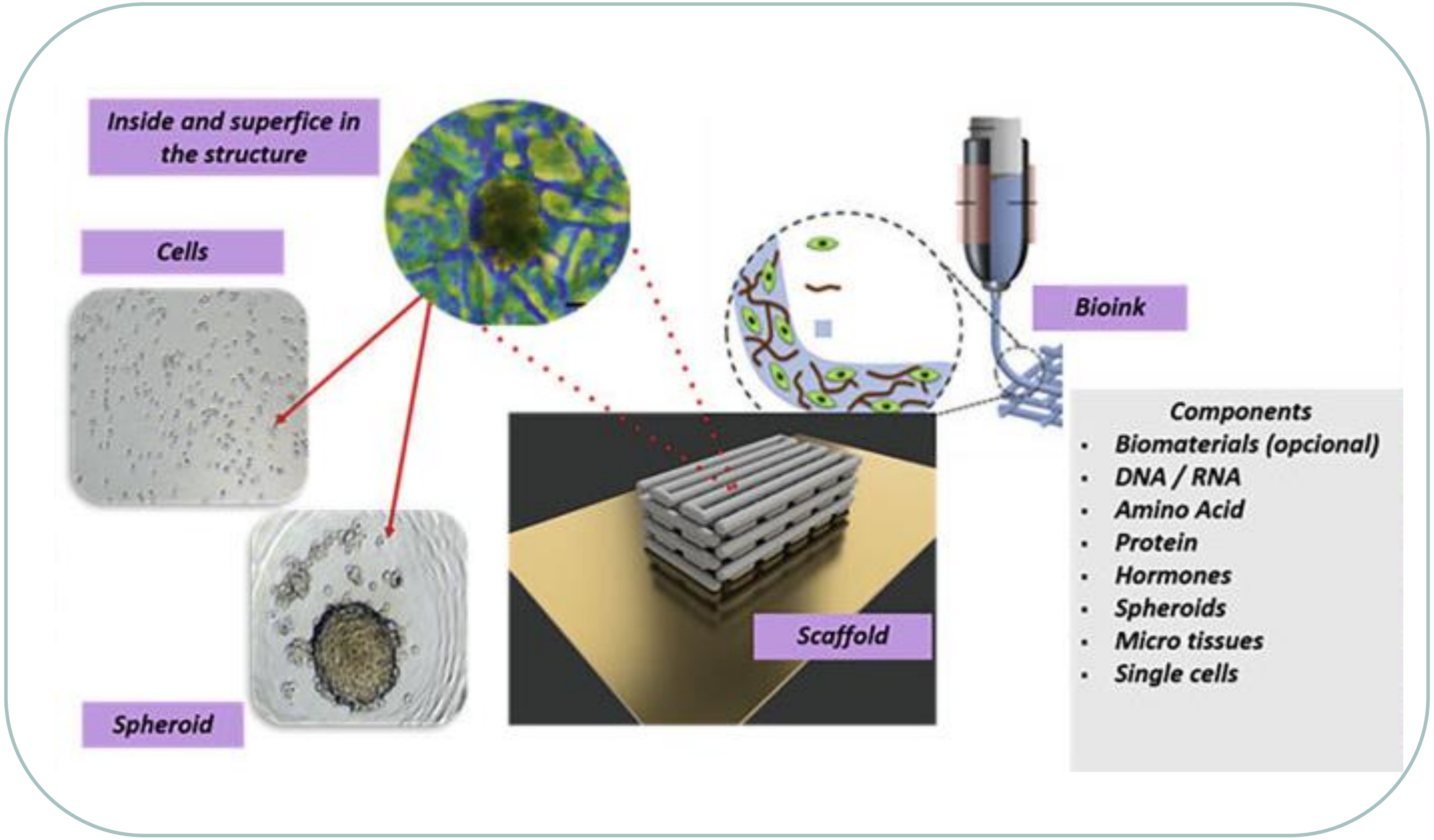


Advanatages of using hydrogels:
- Biocompatibility
- High Water Content
- Adjustable Mechanical Properties
- Porosity
- Bioactive Molecule Incorporation
- Printability

Arch. Computat. Methods Eng. **2020**, 1187–1230.

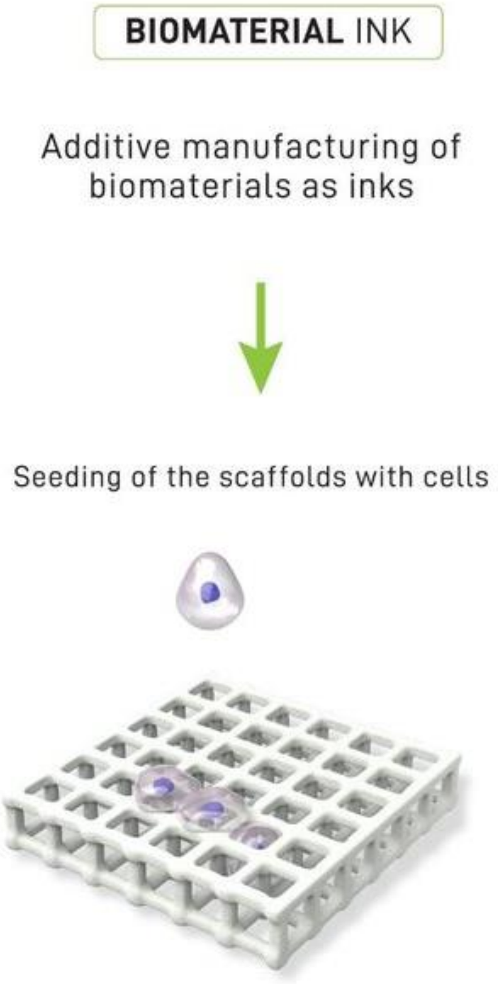
BIOINK VS BIOMATERIALS INK

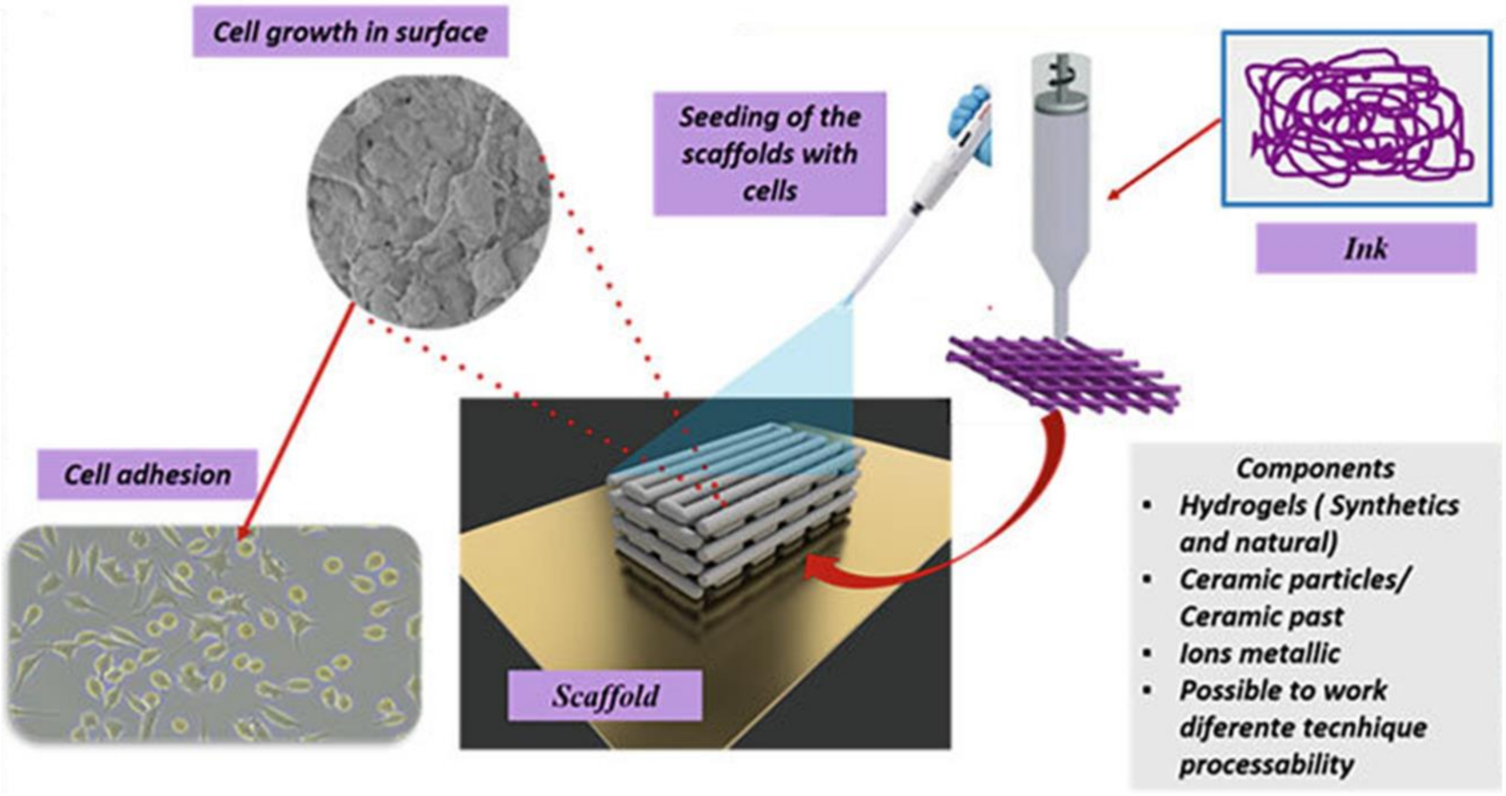




Biofabrication, **2018**, 11. 10.1088/1758-5090/aaec52.
Current Trends in Biomedical Engineering. **2023**, Springer, Cham. https://doi.org/10.1007/978-3-031-38743-2_11.

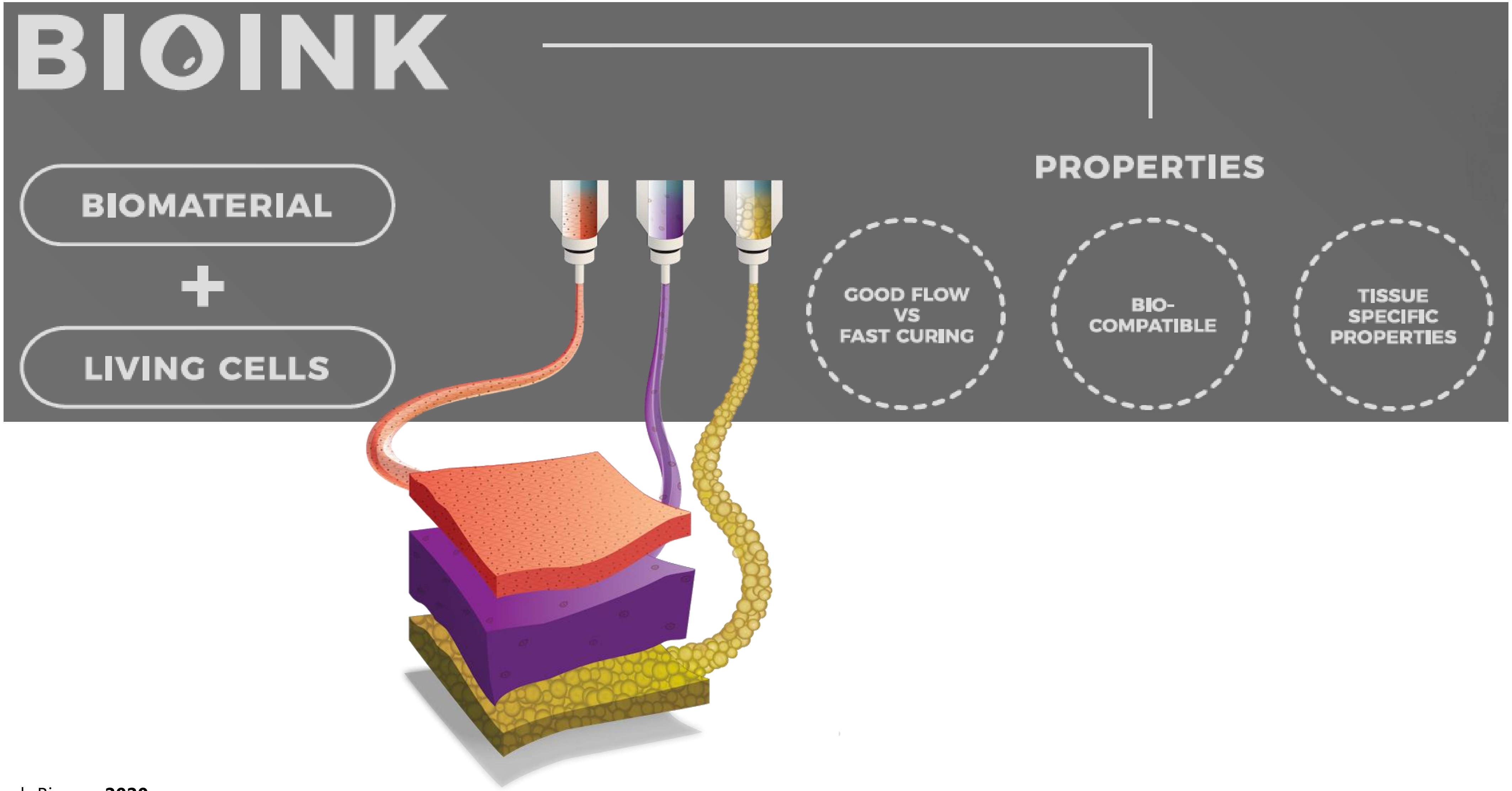
BIOINK VS BIOMATERIALS INK





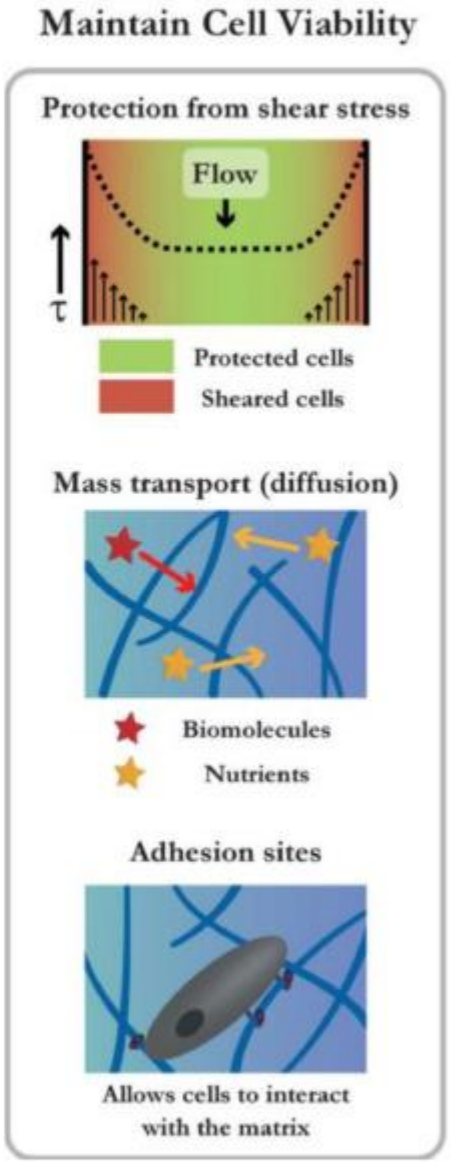
Biofabrication, **2018**, 11. 10.1088/1758-5090/aaec52.
Current Trends in Biomedical Engineering. **2023**, Springer, Cham. https://doi.org/10.1007/978-3-031-38743-2_11.

BIOINK

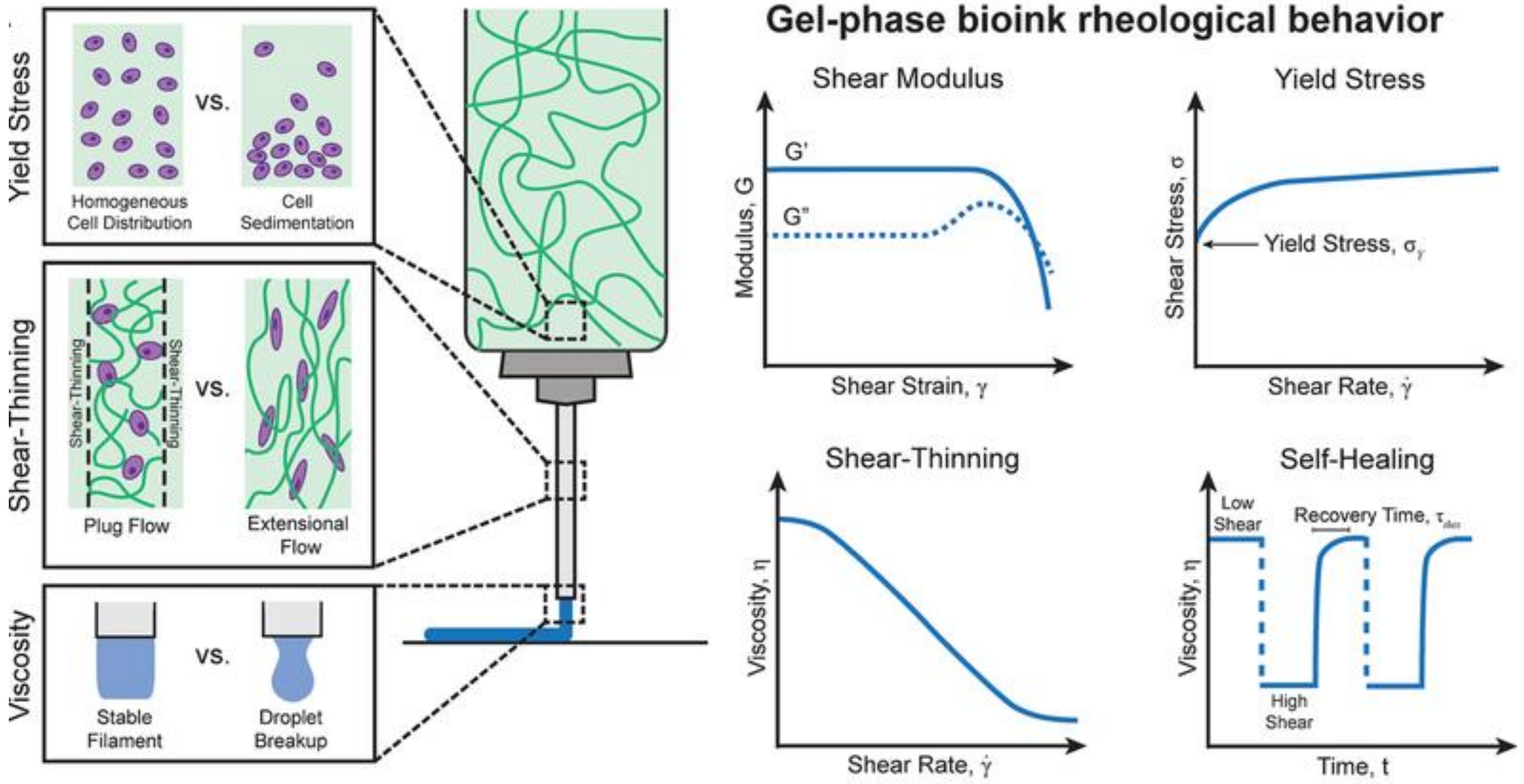


BIOINK
BIOMATERIAL
+
LIVING CELLS
PROPERTIES
GOOD FLOW
VS
FAST CURING
BIO-
COMPATIBLE
TISSUE
SPECIFIC
PROPERTIES

BIOINK CHARACTERISTICS

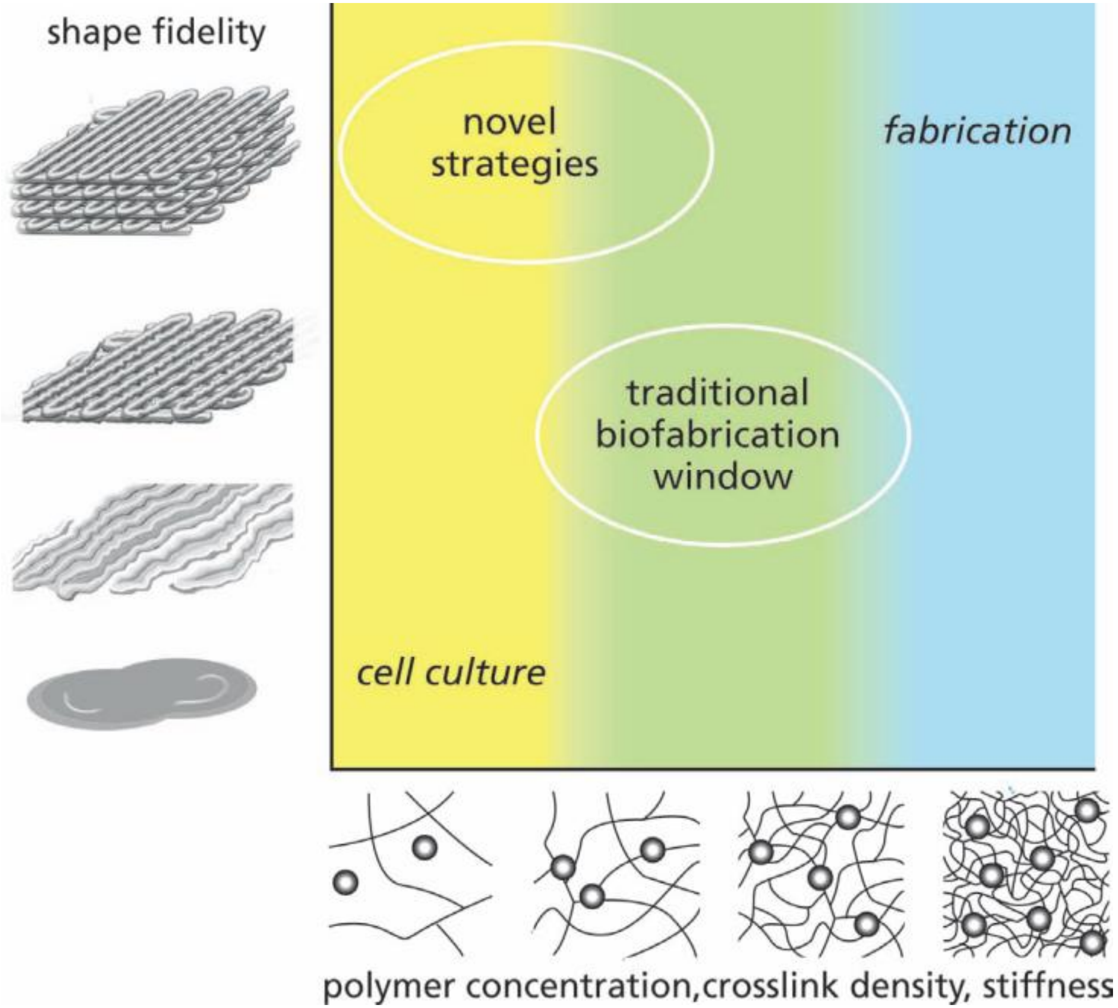


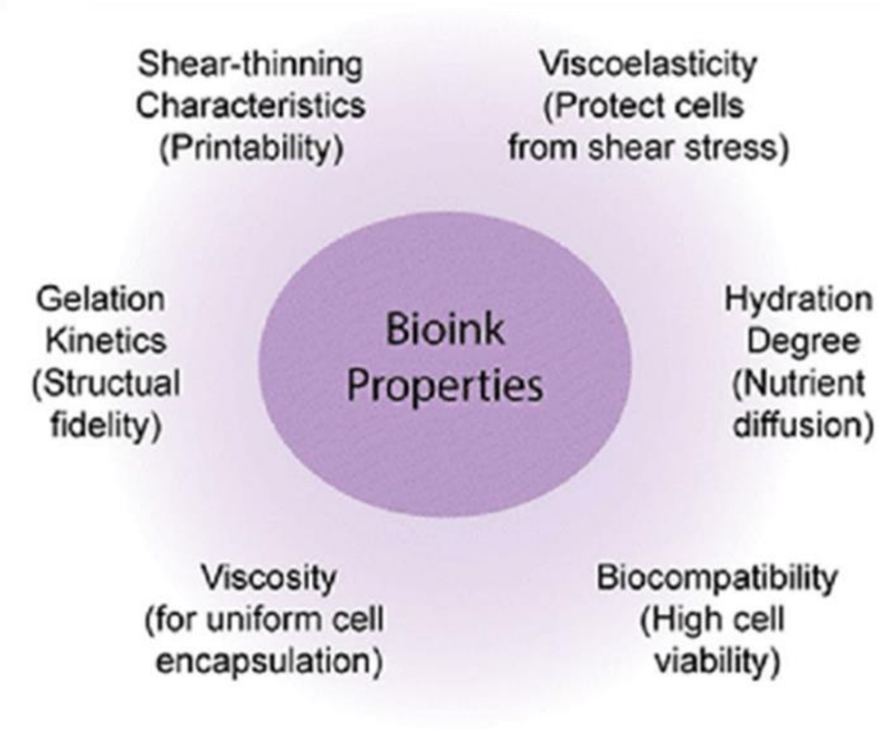
DESIGN CONSIDERATIONS FOR HYDROGEL-BASED BIOINKS



Advanced Materials, **2022**, 34(2), p.2103691.

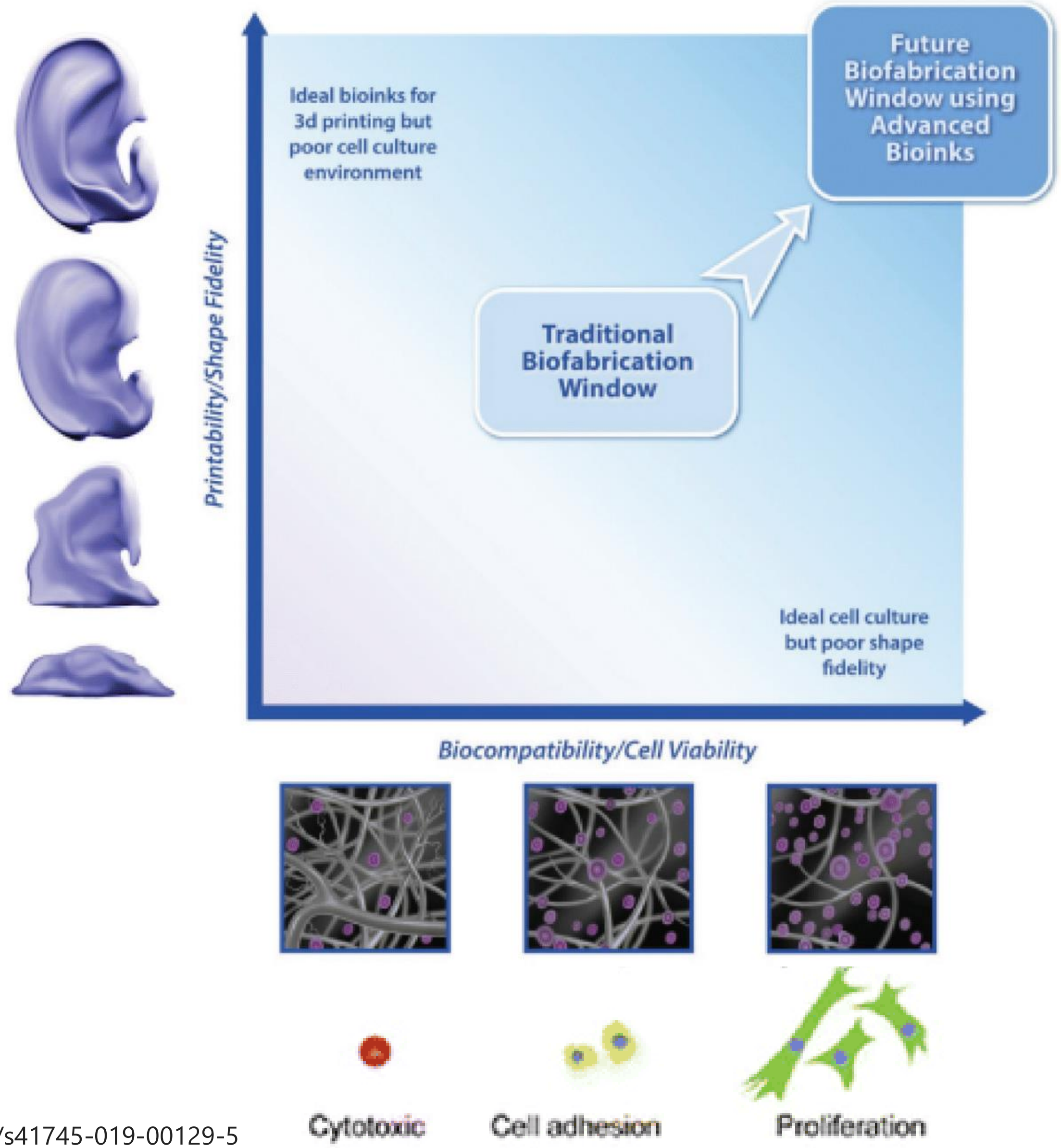
BIOINK DEVELOPEMENT





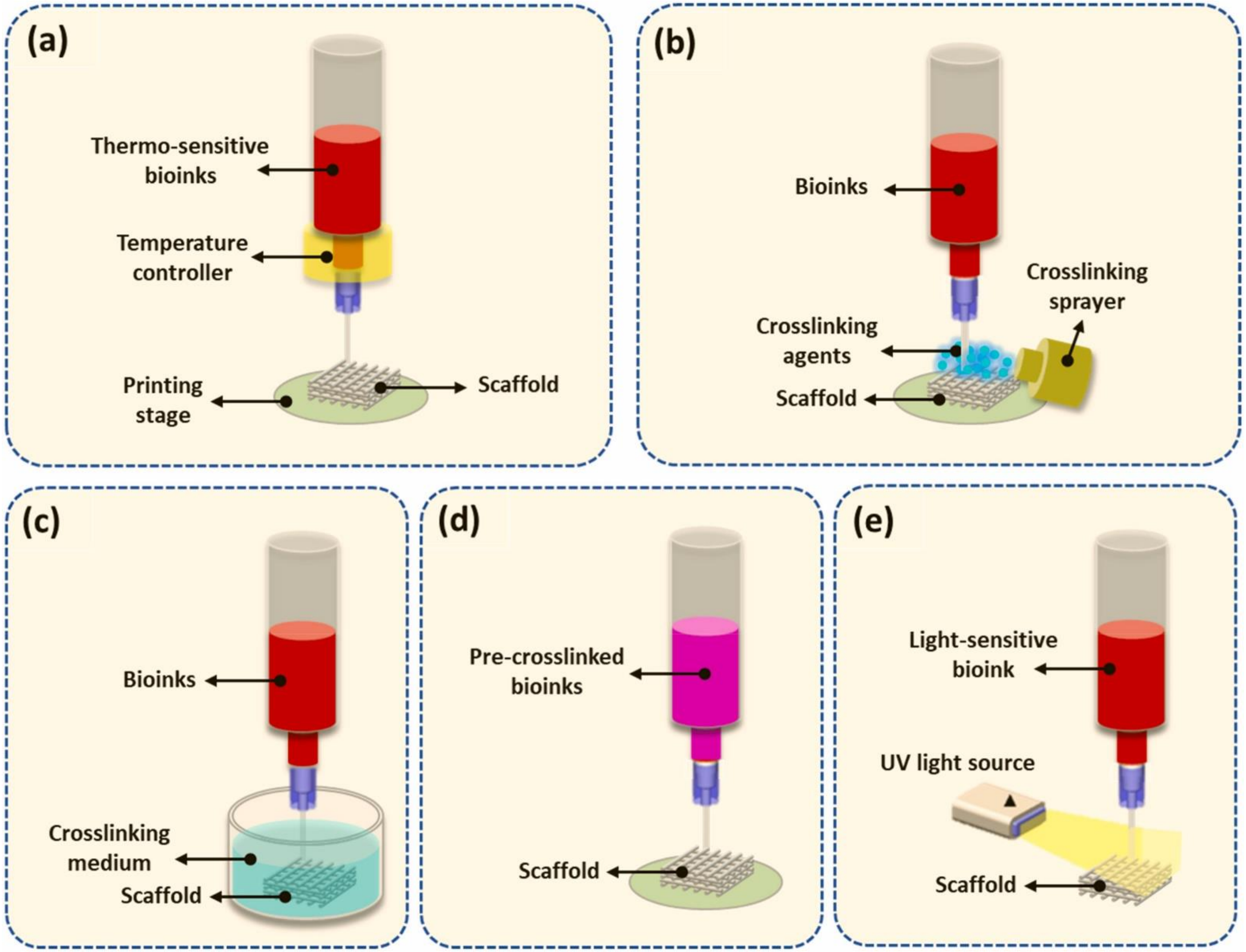
Adv. Mater. **2013**, 25, 5011–5028
Biomanuf. Rev. **2020** 5, 2. https://doi.org/10.1007/s40898-020-00008-y

IDEAL BIOFABRICATION WINDOW

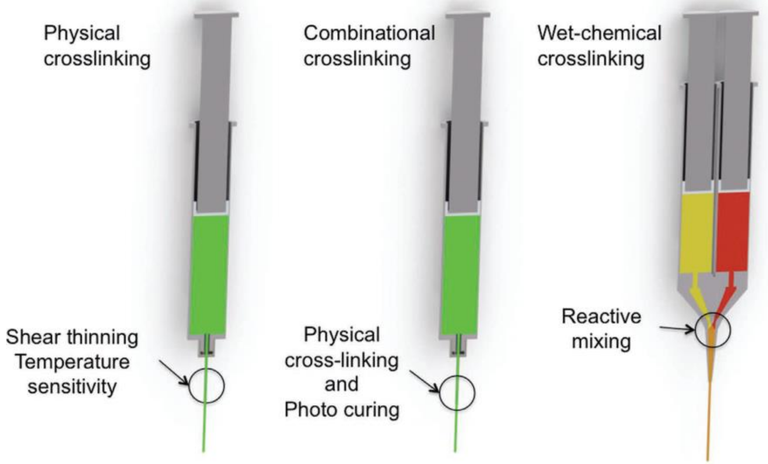


J. Indian Inst. Sci., **2019**, 99, 405–428. https://doi.org/10.1007/s41745-019-00129-5

(BIO)INKS CROSSLINKING

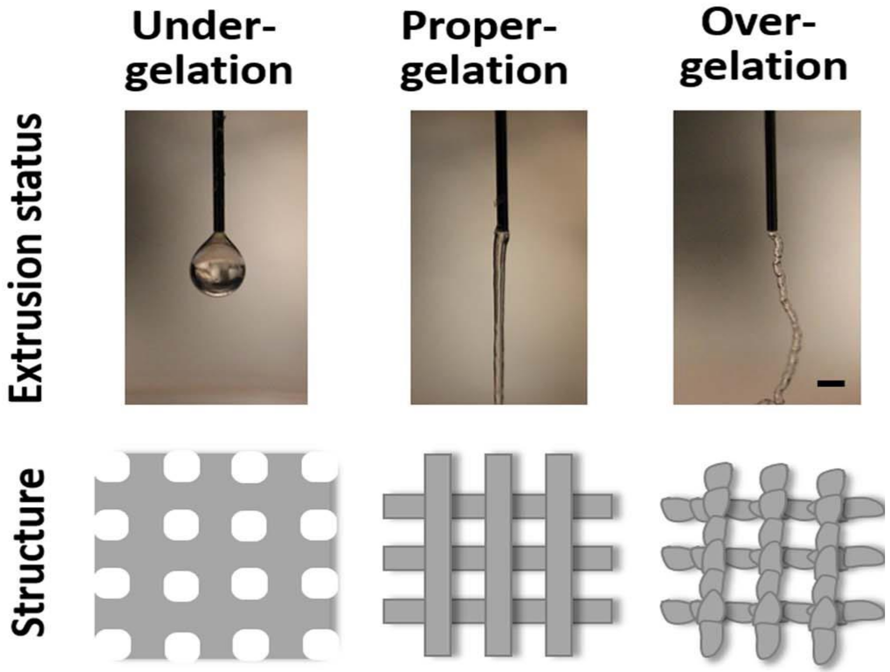


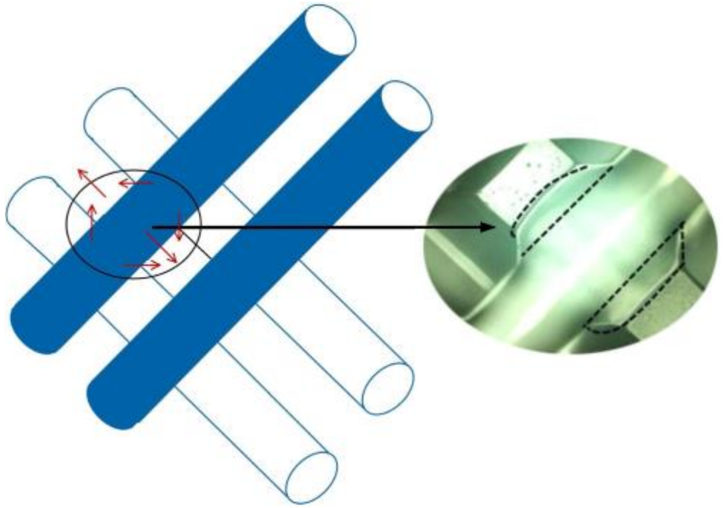
Bioactive Mat. (2023), **28**, 511-536



Adv. Mater. (2013), ***25***, 5011–5028

(BIO)INK CHARACTERIZATION: PRINTABILITY VALUE

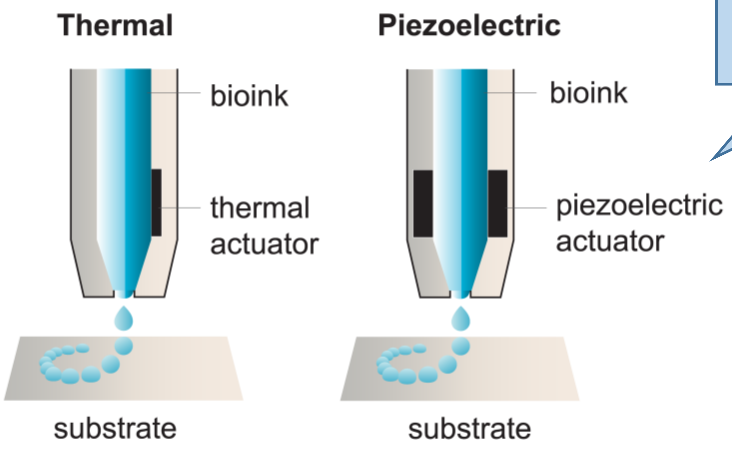




Biofabrication, **2016**, 8, 035020

3D (BIO)PRINTING TECHNIQUES

INKJET



A tiny heater rapidly vaporizes a small portion of bioink to form a droplet.

A piezoelectric actuator generates pressure pulses to eject droplets.

AK Bloom

Characteristics:

•**Droplet-based deposition**, highly controlled.

•**High resolution** (tens of micrometers).

•**Low viscosity bioinks** are required.

•**Non-contact printing**, reducing contamination risk.

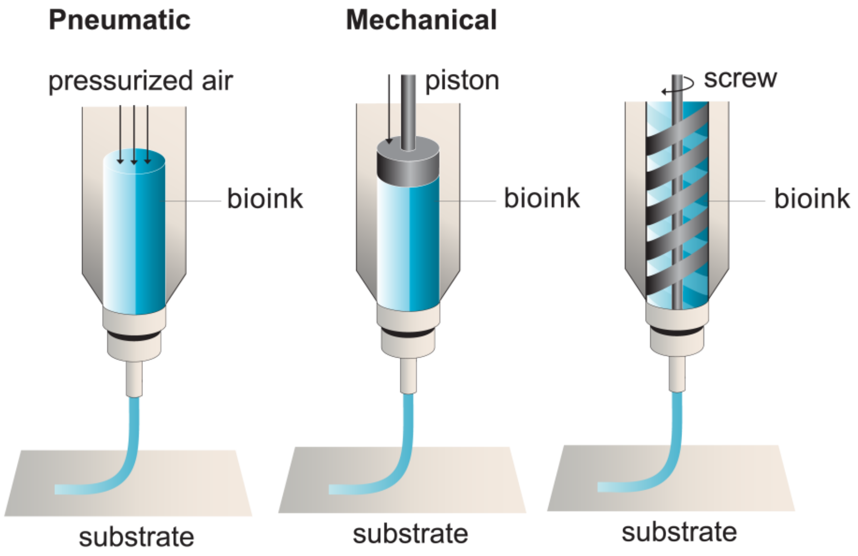
•**Limited to low cell density**, as high viscosity or cell density can clog the nozzle.

Modified: Materials & Design. **2018**, 159, pp.20-38.

3D (BIO)PRINTING TECHNIQUES

EXTRUSION

AK Landfester
&
AK Weil



Pressurized air pushes bioink through a nozzle.

A piston pushes the bioink.

A rotating screw pushes bioink.

Characteristics:

•**Continuous filament deposition**, rather than discrete droplets.

•**Compatible with higher viscosity bioinks** and higher cell densities.

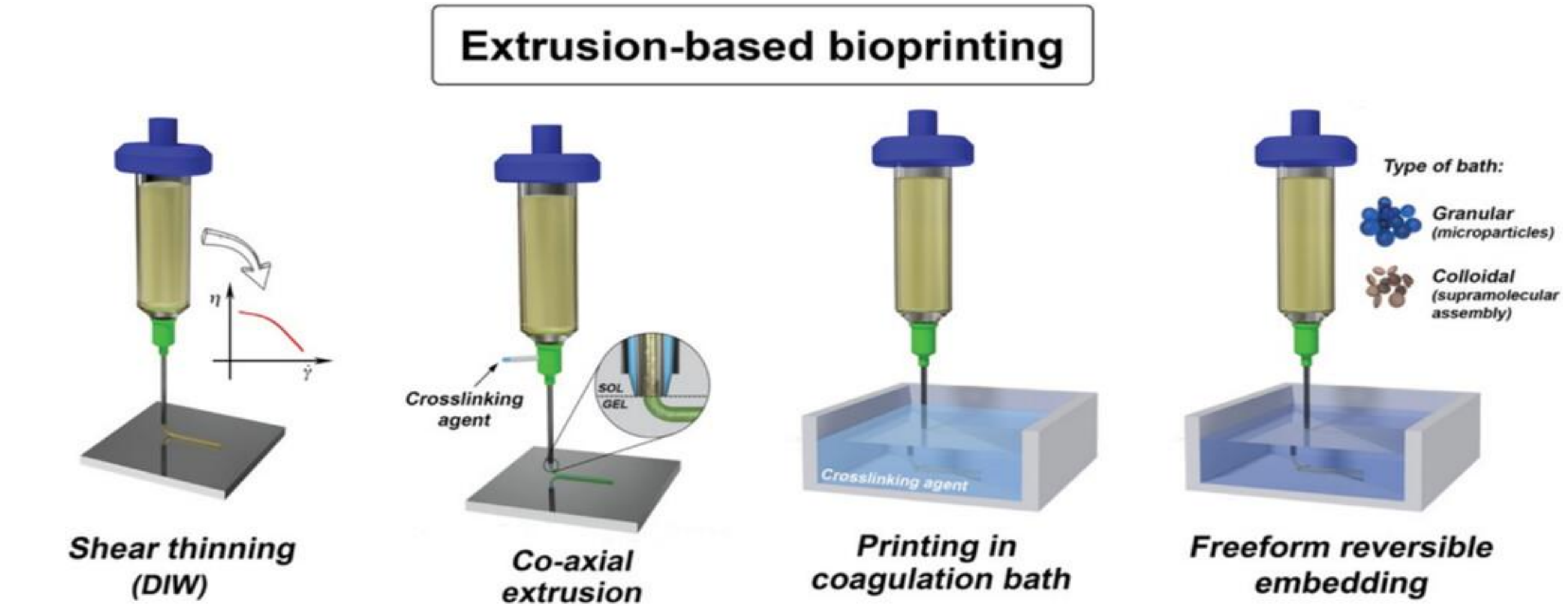
•**Lower resolution** than inkjet (100–500 µm).

•**Shear stress** on cells can be higher, potentially affecting cell viability.

•Can print **larger 3D structures**.

Modified: Materials & Design. **2018**, 159, pp.20-38.

EXTRUSION BASED (BIO)PRINTING

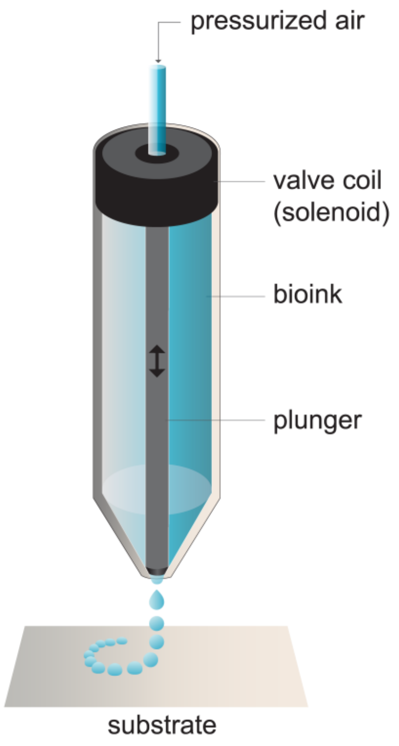


Pressure based extrusion of bioink through a syringe.	Deliver bioink and a crosslinking solution using separate nozzle.	Extruding bioink directly into a coagulation bath that triggers its gelation.	Extruding bioink into a pseudoplastic or granular bath.

Adv Materials Technologies, **2020,** 5(8), doi: 10.1002/admt.201901044

3D (BIO)PRINTING TECHNIQUES

MICRO-VALVE



Solenoid-controlled plunger or valve releases bioink droplets under pressure.

Characteristics:

•**Droplet-based**, similar to inkjet but can handle higher viscosities.

•**Moderate resolution**.

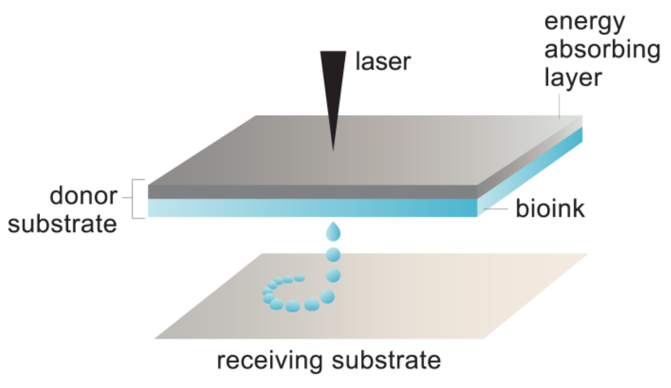
•Non-contact, reducing contamination risk.

•Good for **cell-laden bioinks**, as shear stress is lower than extrusion.

Modified: Materials & Design. **2018**, 159, pp.20-38.

3D (BIO)PRINTING TECHNIQUES

LASER



Laser-Induced Forward Transfer (LIFT)

A laser pulse hits an energy-absorbing layer, propelling a droplet of bioink from a donor substrate to a receiving substrate.

Characteristics:

•**High resolution** (10–50 µm).

•**Non-contact**, avoiding nozzle clogging.

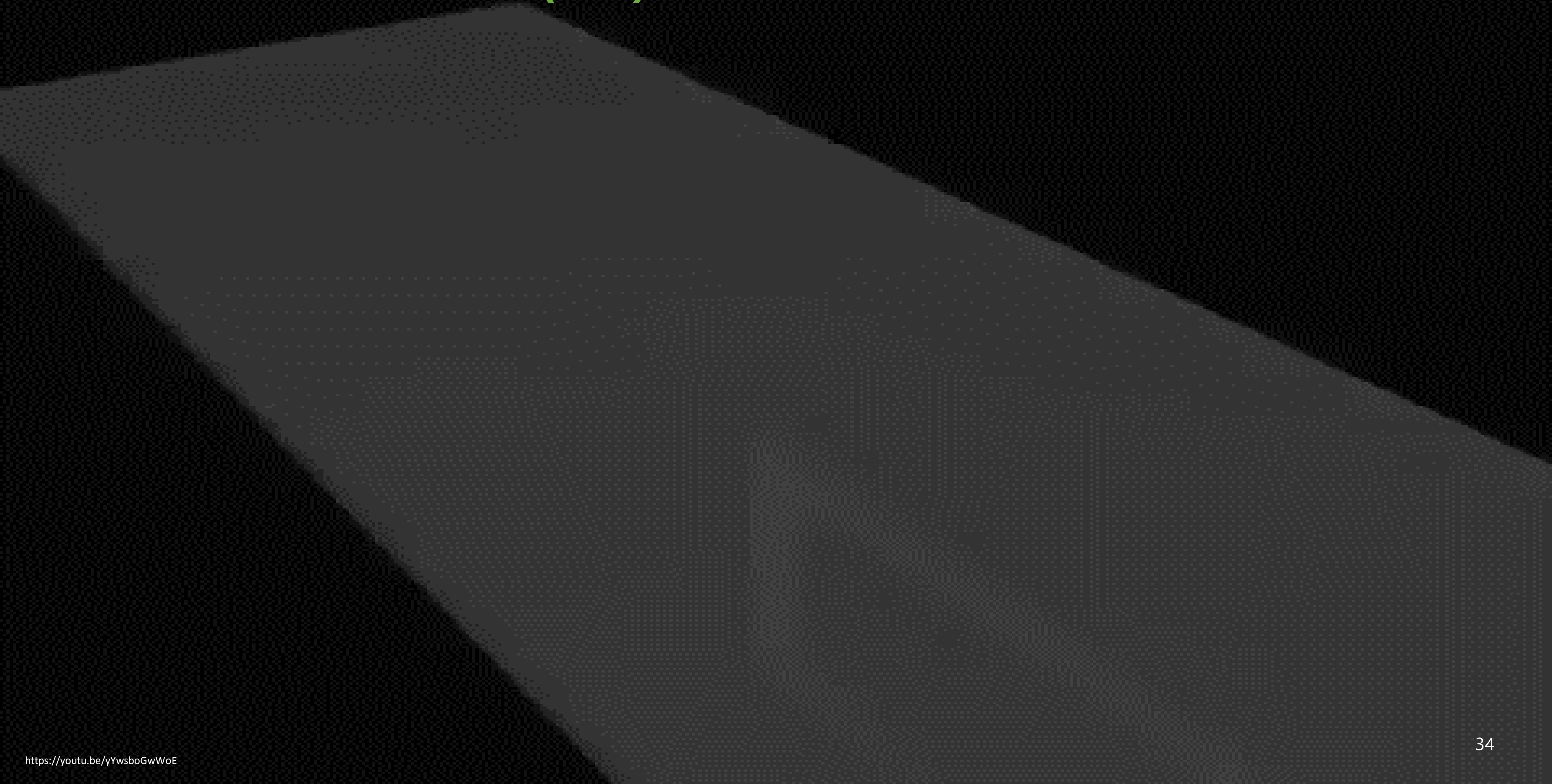
•Can handle **very viscous bioinks**.

•Can deposit **single cells or small cell clusters** with high precision.

•More complex and expensive than other methods.

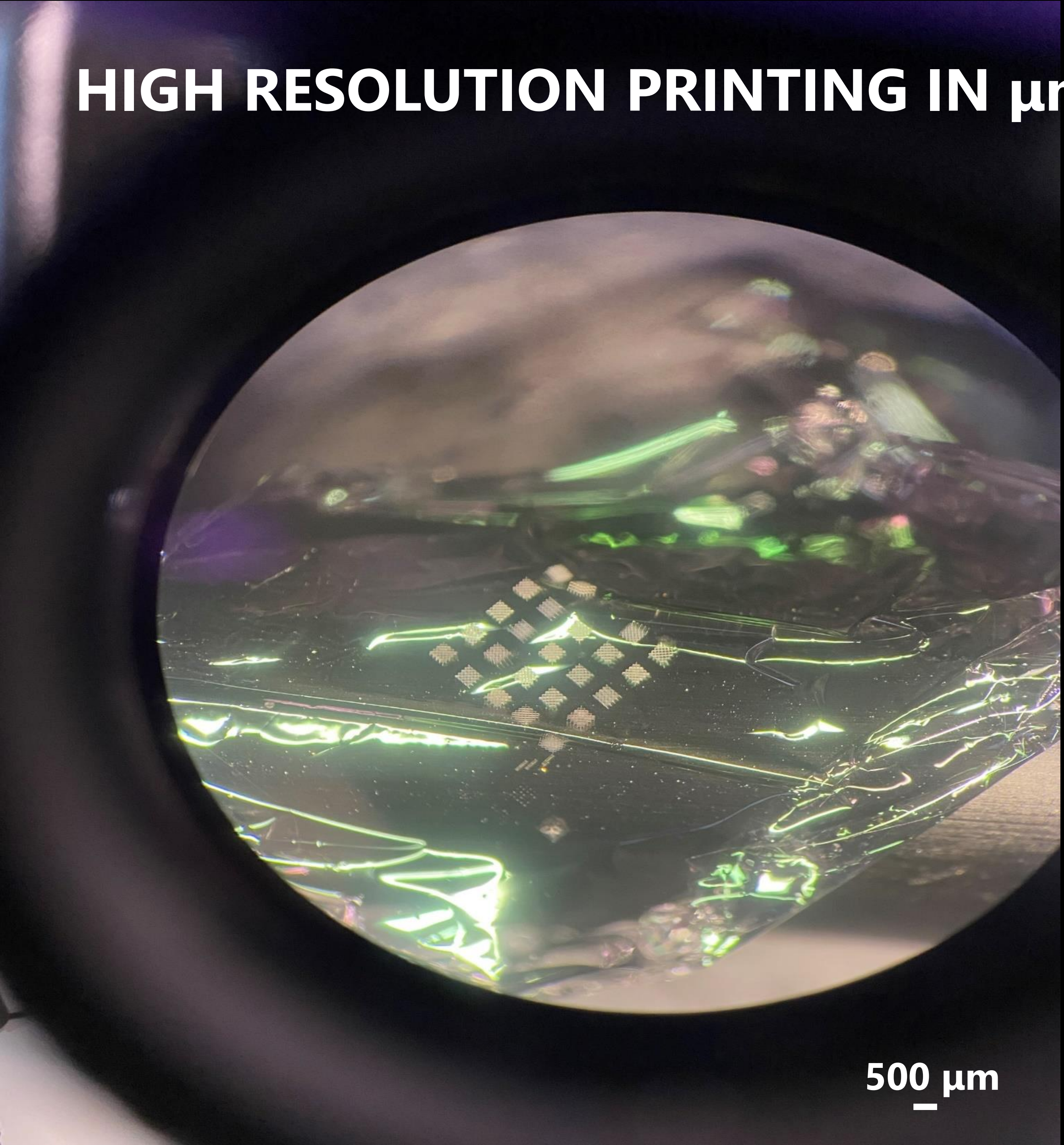
Modified: Materials & Design (2018), **159**, pp.20-38.

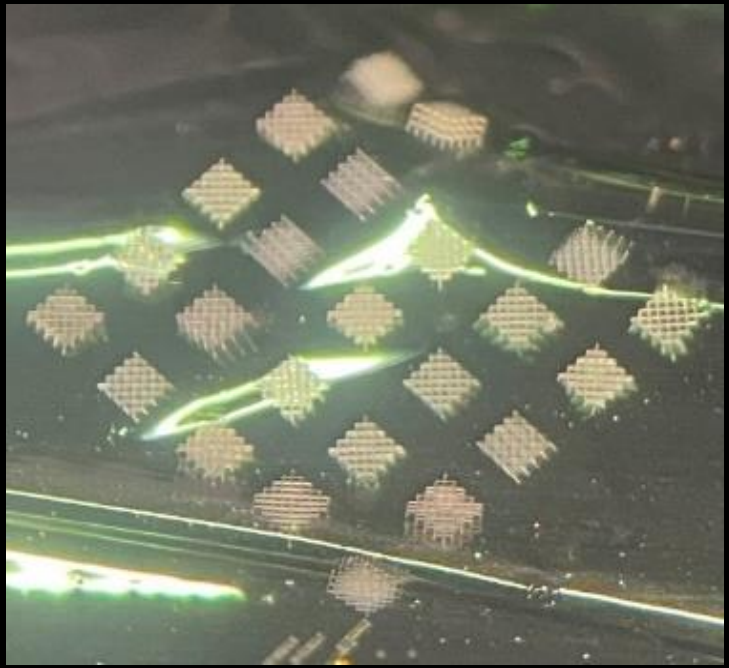
2-PHOTON 3D MICRO(BIO)PRINTING

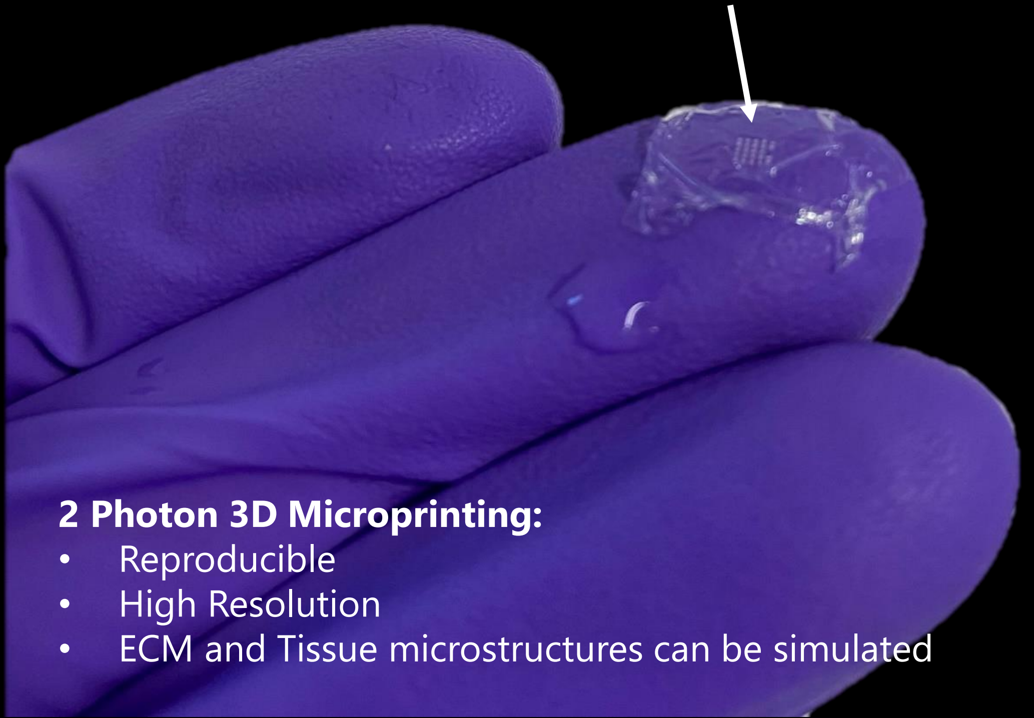


https://youtu.be/yYwsboGwWoE

HIGH RESOLUTION PRINTING IN µm SCALE



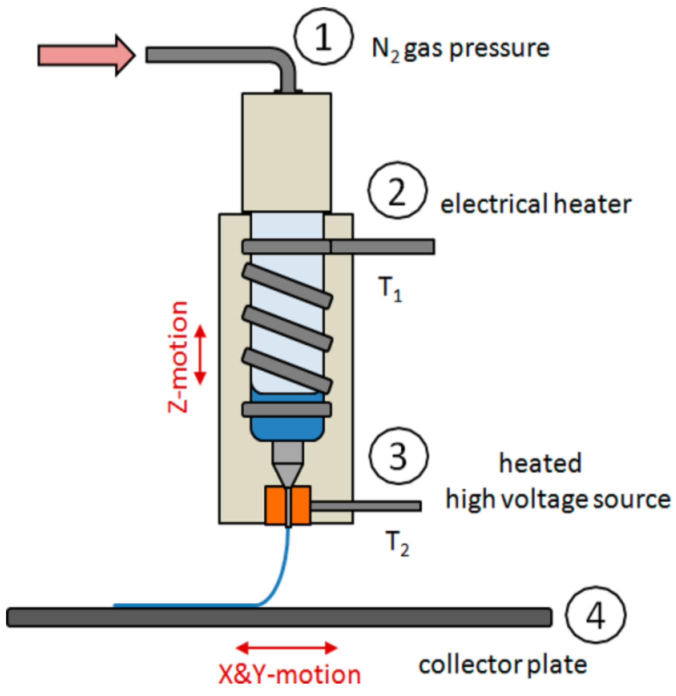




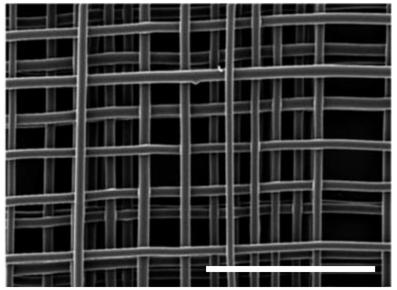
2 Photon 3D Microprinting:
- Reproducible
- High Resolution
- ECM and Tissue microstructures can be simulated

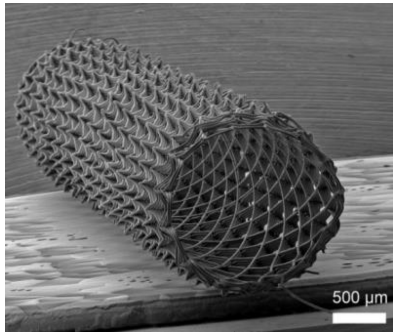
3D (BIO)PRINTING TECHNIQUES

Melt Electro-Writing (MEW)



Molten polymer is extruded under high voltage and precisely controlled stage movement, allowing fibers to be deposited in defined patterns.





Characteristics:

•**Fiber-based**, typically 1–50 µm in diameter.

•**Highly controlled fiber placement**, enabling 3D microstructures.

•**Solvent-free**, safer and environmentally friendly.

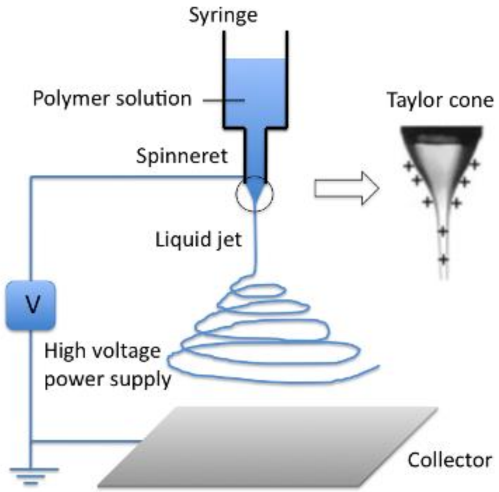
•Produces smooth, **uniform fibers with tunable porosity**.

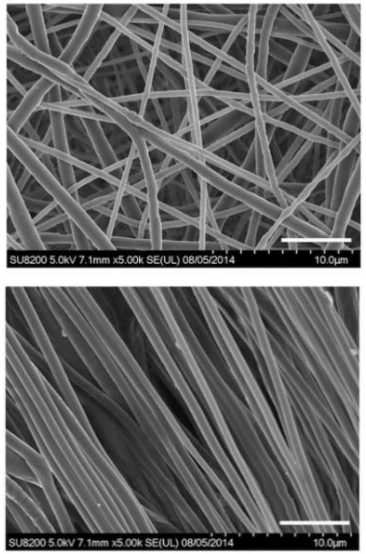
•Ideal for tissue engineering scaffolds and microstructured biomedical devices.

ACS applied Materials & Interfaces, **2017**, 9(44); 38187-38200.
Materials & Design, **2018**, 155; 46-58.

3D (BIO)PRINTING TECHNIQUES

Electrospinning





High-voltage electrostatic field draws a polymer solution or melt from a needle tip toward a grounded collector, forming fine fibers.

AK Landfester

Characteristics:

•**Fiber-based**, mainly nanoscale fibers (100 nm – few µm).

•Fibers are usually **randomly oriented**, but alignment possible with special collectors.

•**Solution-based**, requires solvent evaporation.

•High porosity, **limited control over exact fiber placement**.

•Suitable for filtration, drug delivery, wound dressing, and scaffolds.

Food Hydrocolloids, **2015**, 51; 227-240.
Stem Cell Research, **2016**, 16(3); 740-750.

BIOFABLAB RESEARCH FOCUS

We develop **life-inspired biomaterials**, by organizing molecules into higher-order assemblies and tuning their interfaces!

Multifunctional Biomaterials

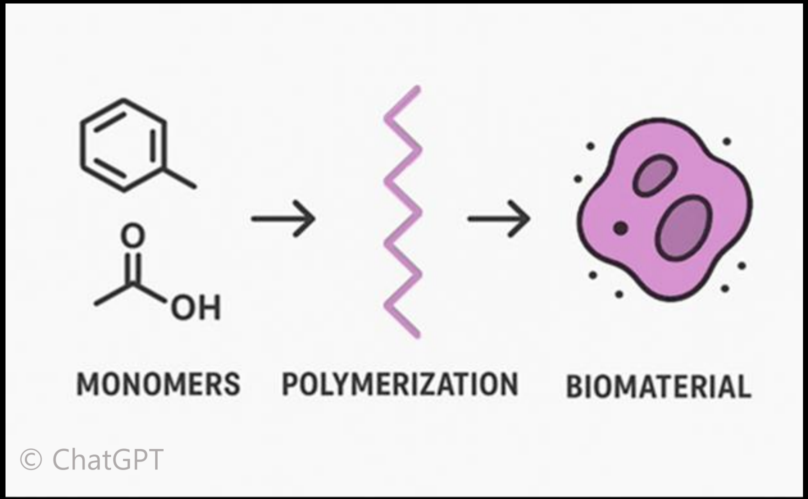
We develop **dynamic environments** that protect and interact with cells, ensuring survival and functionality during and after printing!

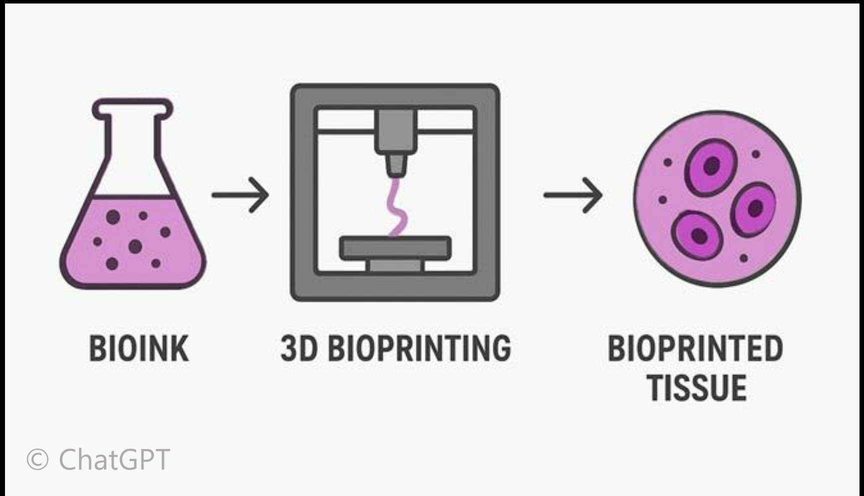
Dynamic Bioinks

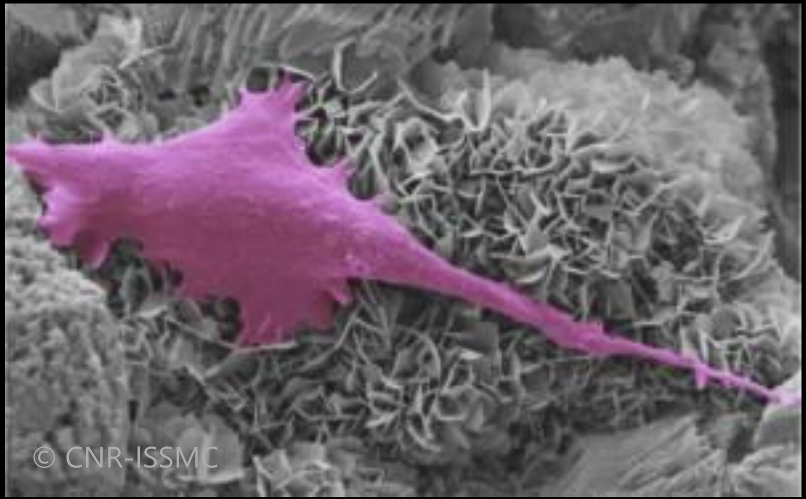
We develop **adaptive molecular systems** that evolve from molecular design into functional, **3D life-like model systems**, that do not only host cells but also communicate, respond, and evolve with them!

Adaptive Prototypes of Life

BIOMATERIALS AND BIOAPPLICATIONS



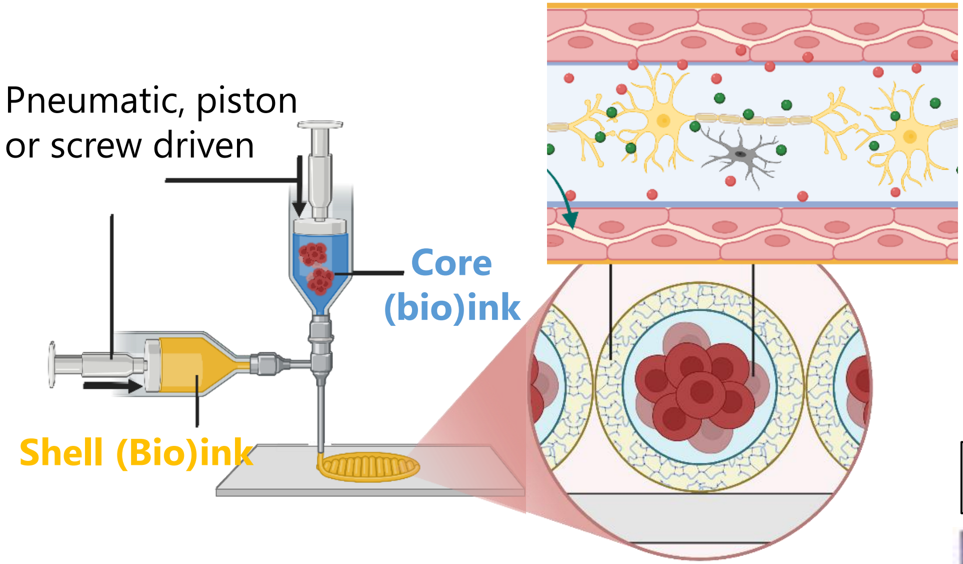




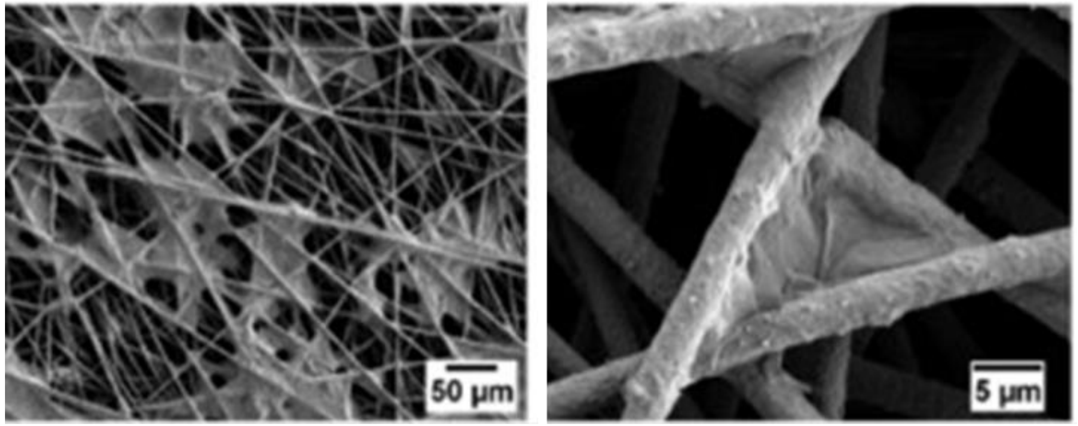
Biomaterials	(Bio)Fabrication	Bioapplications
Synthesis of Nature-Inspired Materials	Extrusion Bioprinting	Cell-Material Interactions
Physicochemical Characterization	Microprinting	Cell/Tissue Adhesion
Rheological - Mechanical Characterization	Light-assisted 3D printing	Biomolecule Release
Electrical Characterization	Electrowriting/Electrospinning/Electrospraying	*In vivo* Experimentation

3D PRINTABLE HYDROGELS: TISSUE ENGINEERING

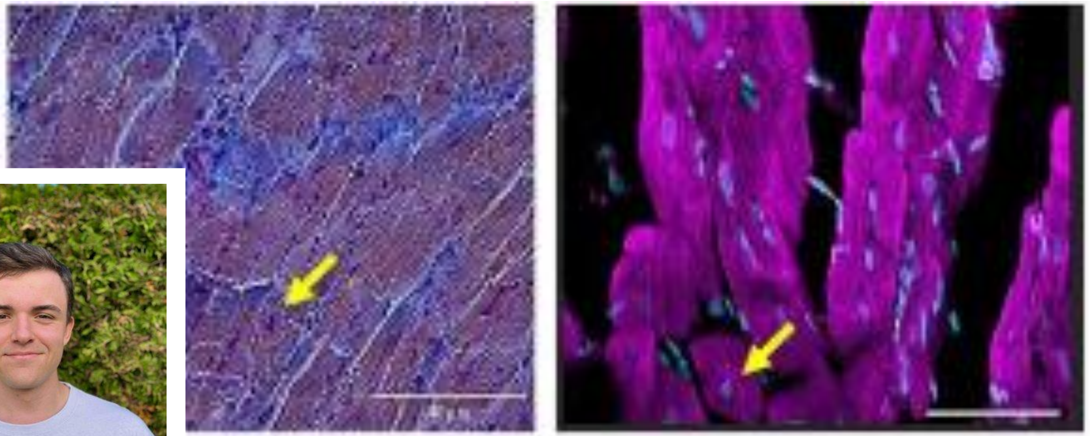
(Bio)printing



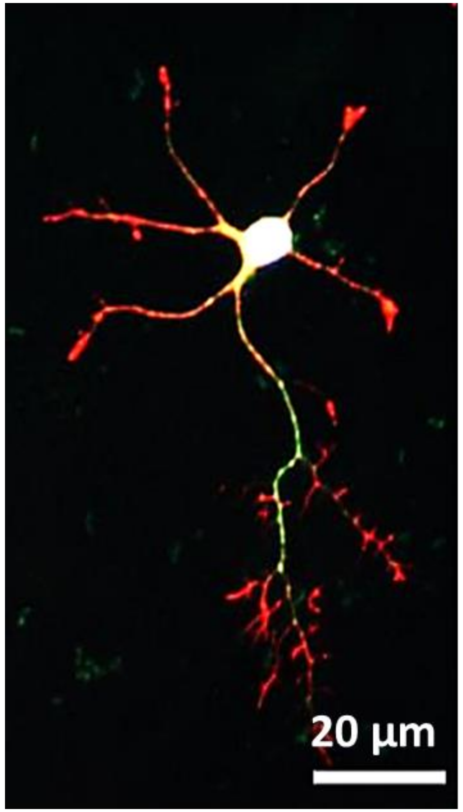
Bone Engineering



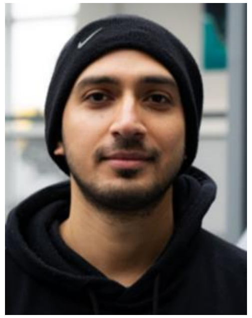
Heart Engineering



Neural Engineering



Xin Wei



Ayaan Khan

Till Grandjean

Alex Reitz

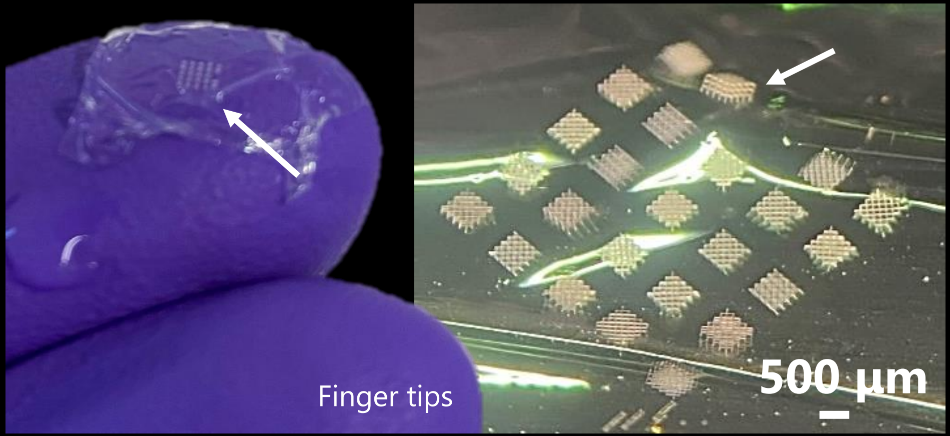
Feng; Zheng; Bhusari; **Villiou,** *et. al.*, Adv. Funct. Mater. **2020**
Włodarczyk-Biegun; Paez; **Villiou,** *et al.* Biofabrication **2020**
Włodarczyk-Biegun; **Villiou,** *et al.* ACS Biomater.Sci.Eng. **2022**

Wei; Grandjean; Reitz, Ritz, Landfester*, **Villiou***. Manuscript in preparation **2025**

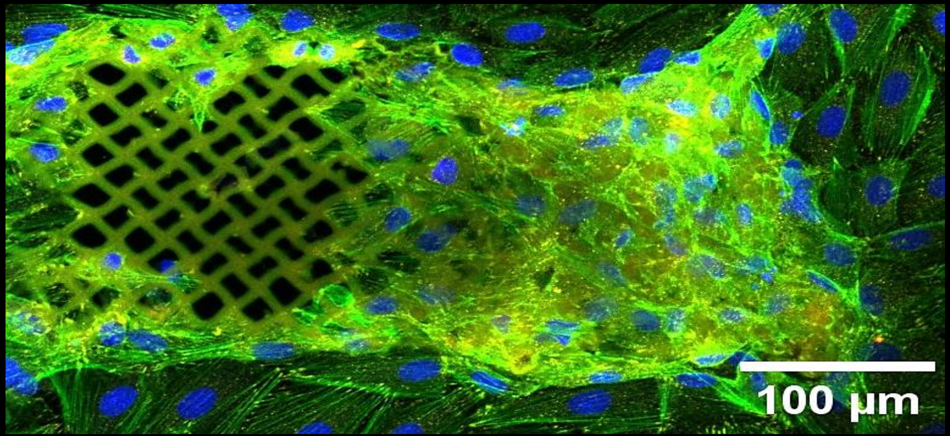
3D PRINTABLE HYDROGELS: CELL-MATERIAL INTERACTIONS

Xin Wei

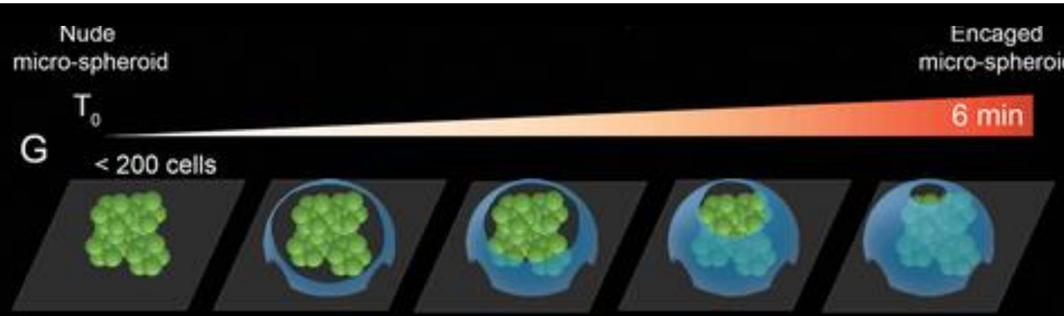
Light-assisted 3D printing

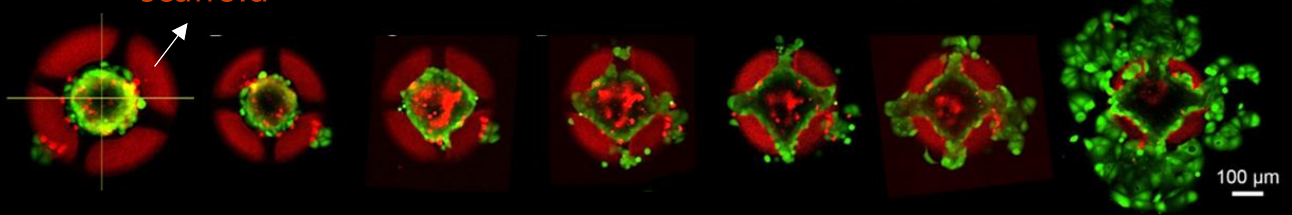


Cell – materials Interactions



Cell Migration

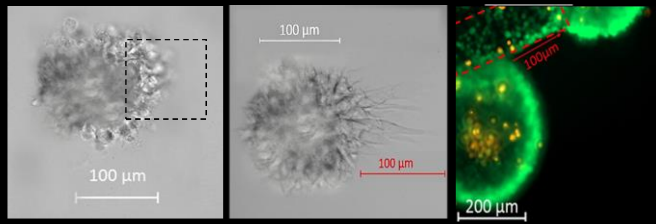




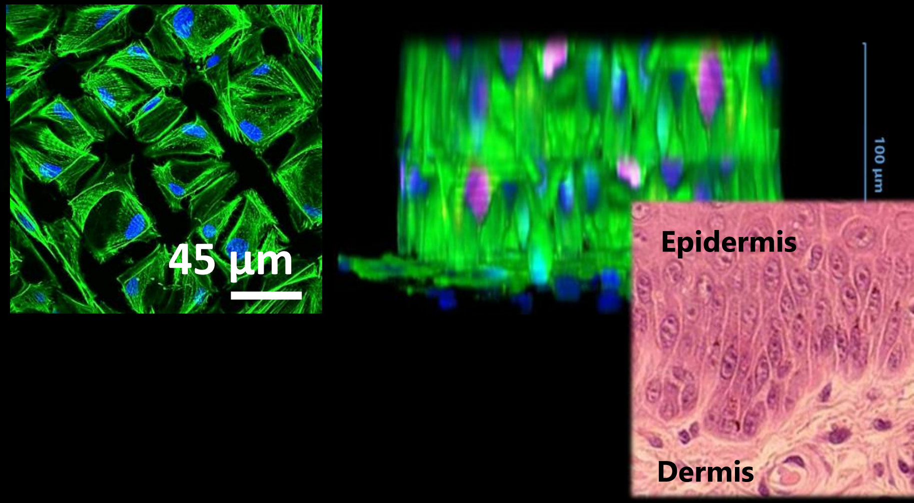
Manipulation-Migration

Day 0 Day 5 Day 9

Manipulation

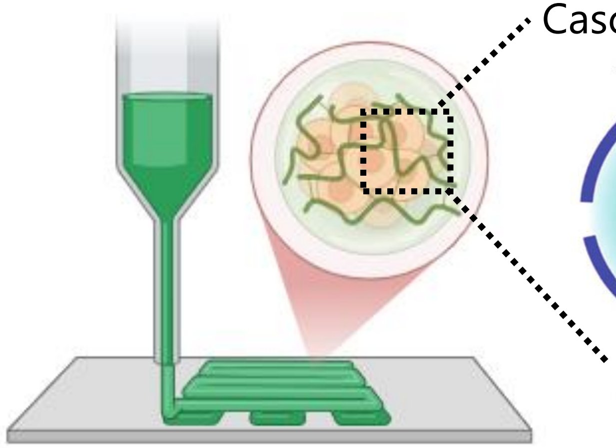


3D Cell Reconstruction

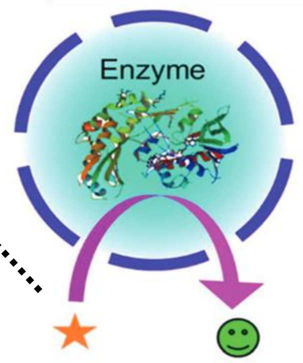


ACS applied materials & interfaces. **2020´,** 30;12(34):37862-72.
Small. **2024,** 20(33):2401344.
Advanced Functional Materials. **2024.** 34(19):2303601

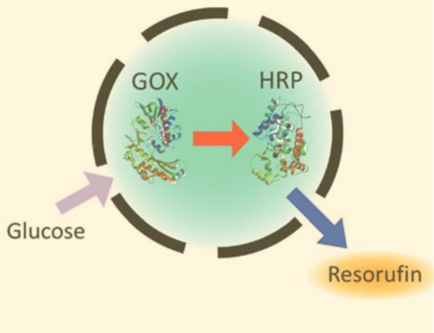
PRINTING OF FUNCTIONA ARTIFICIAL CELLS



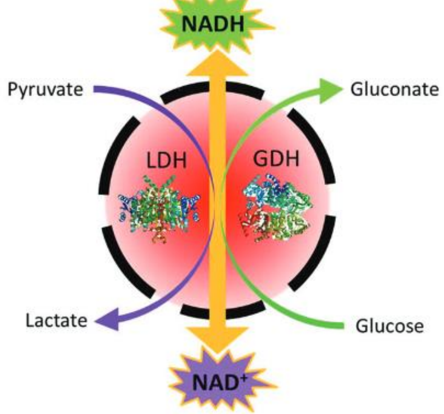
Cascade reactions



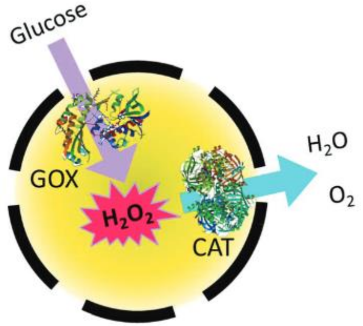
Glucose detection

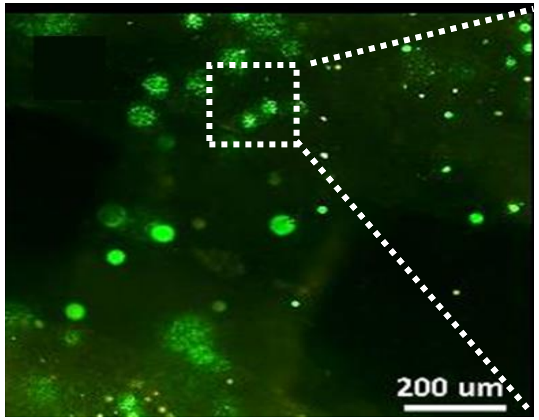


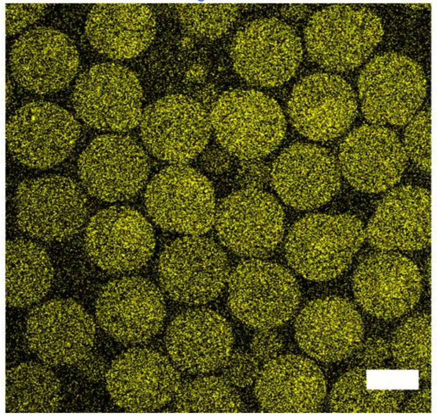
Lactate-Glucose metabolism

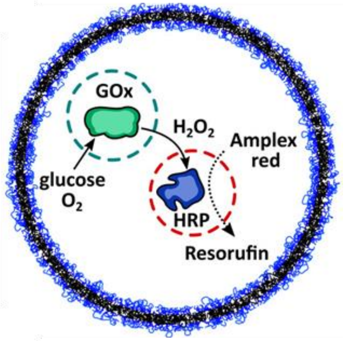


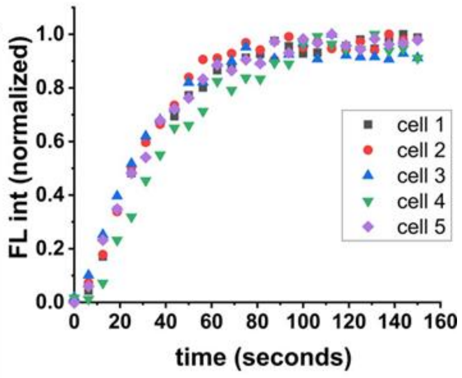
H_2O_2 degradation,











Dr. Tsvetomir Ivanov

Lukas Hein

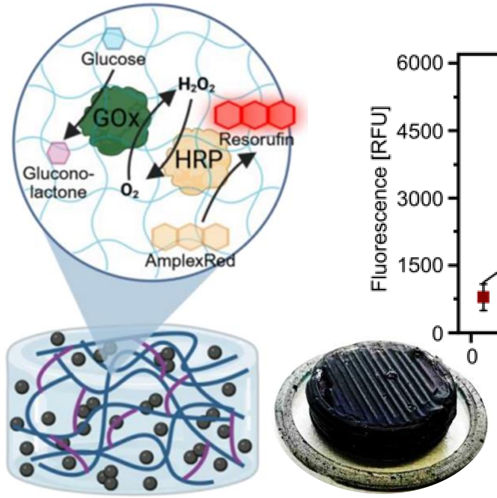
Angewandte Chemie, **2022**, 134(6), p.e202113784.

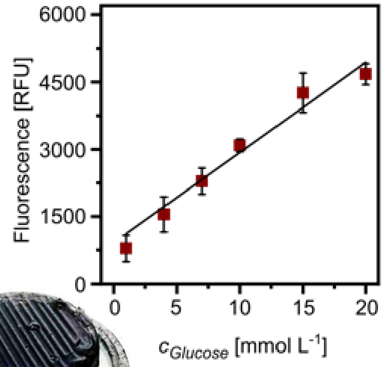
MULTICOMPONENT PRINTING: BIOSENSORS

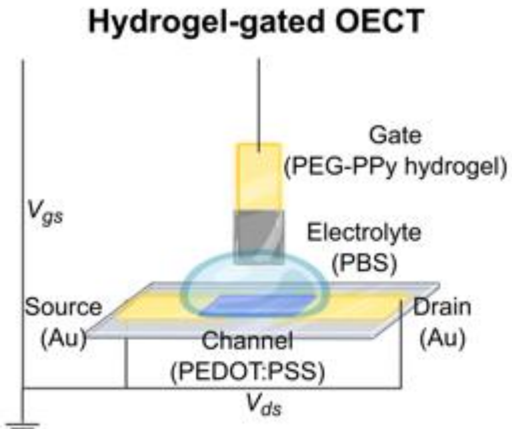
Daimler and Benz Foundation

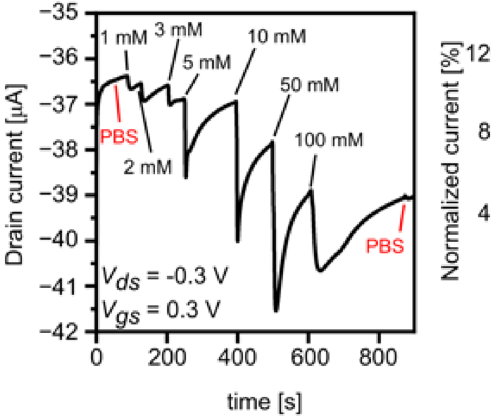
ARTCELL

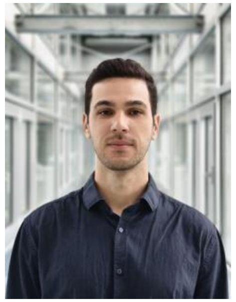
Glucose Biosensors





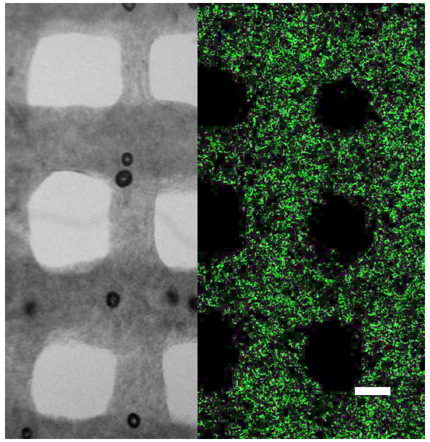


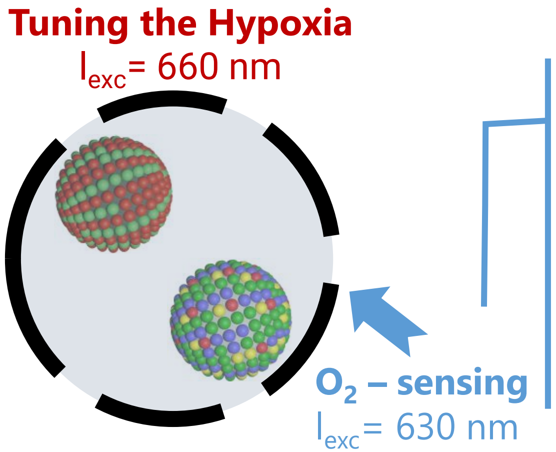


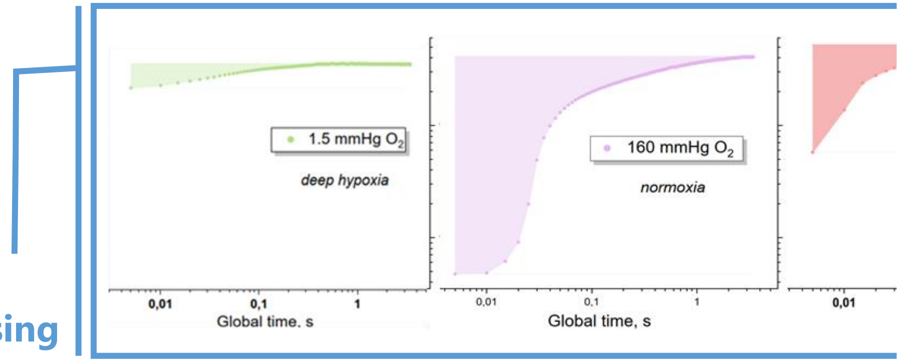



Lukas Hein Dr. Renan Colucci

O_2 Sensor for Cells

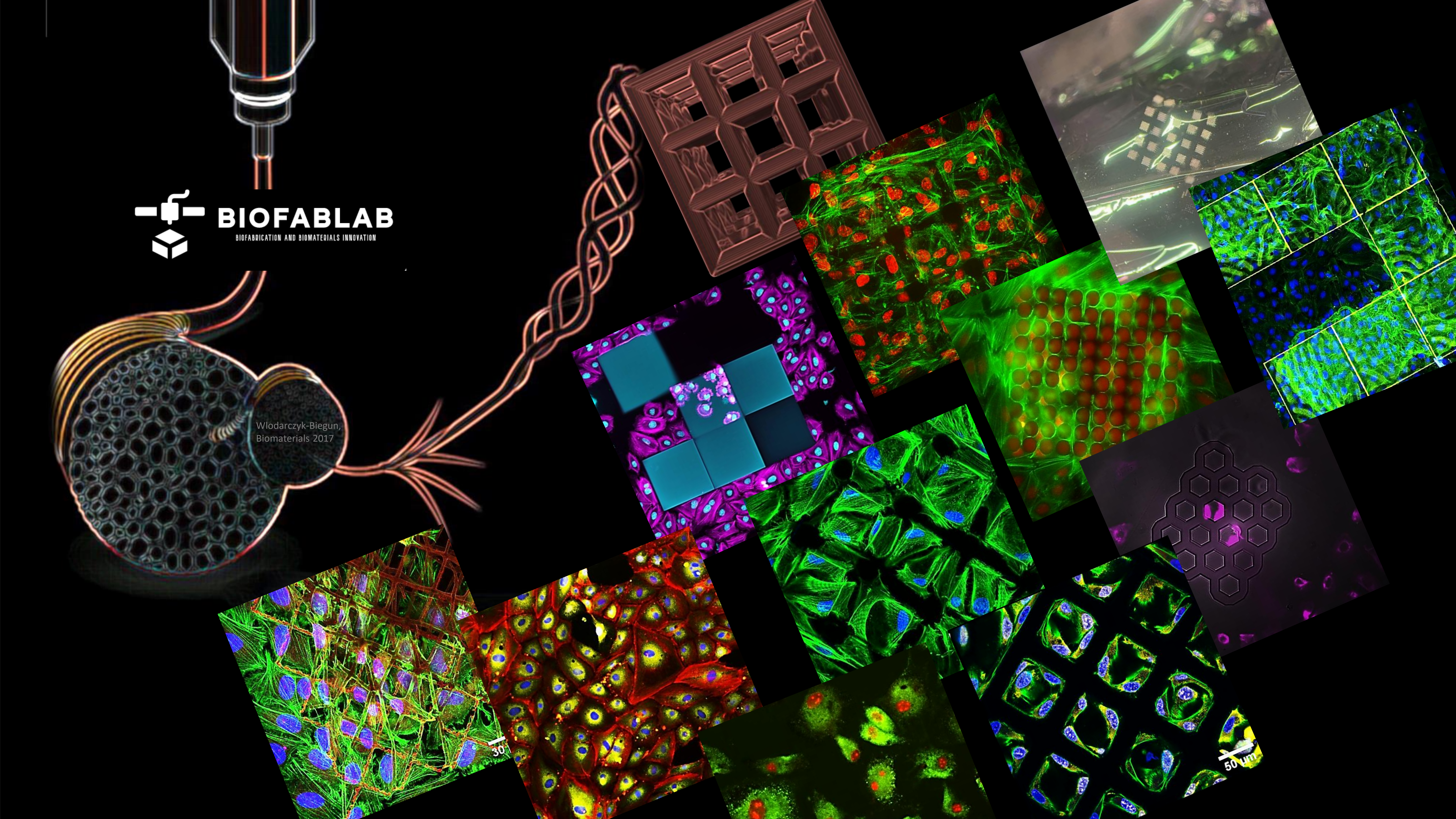






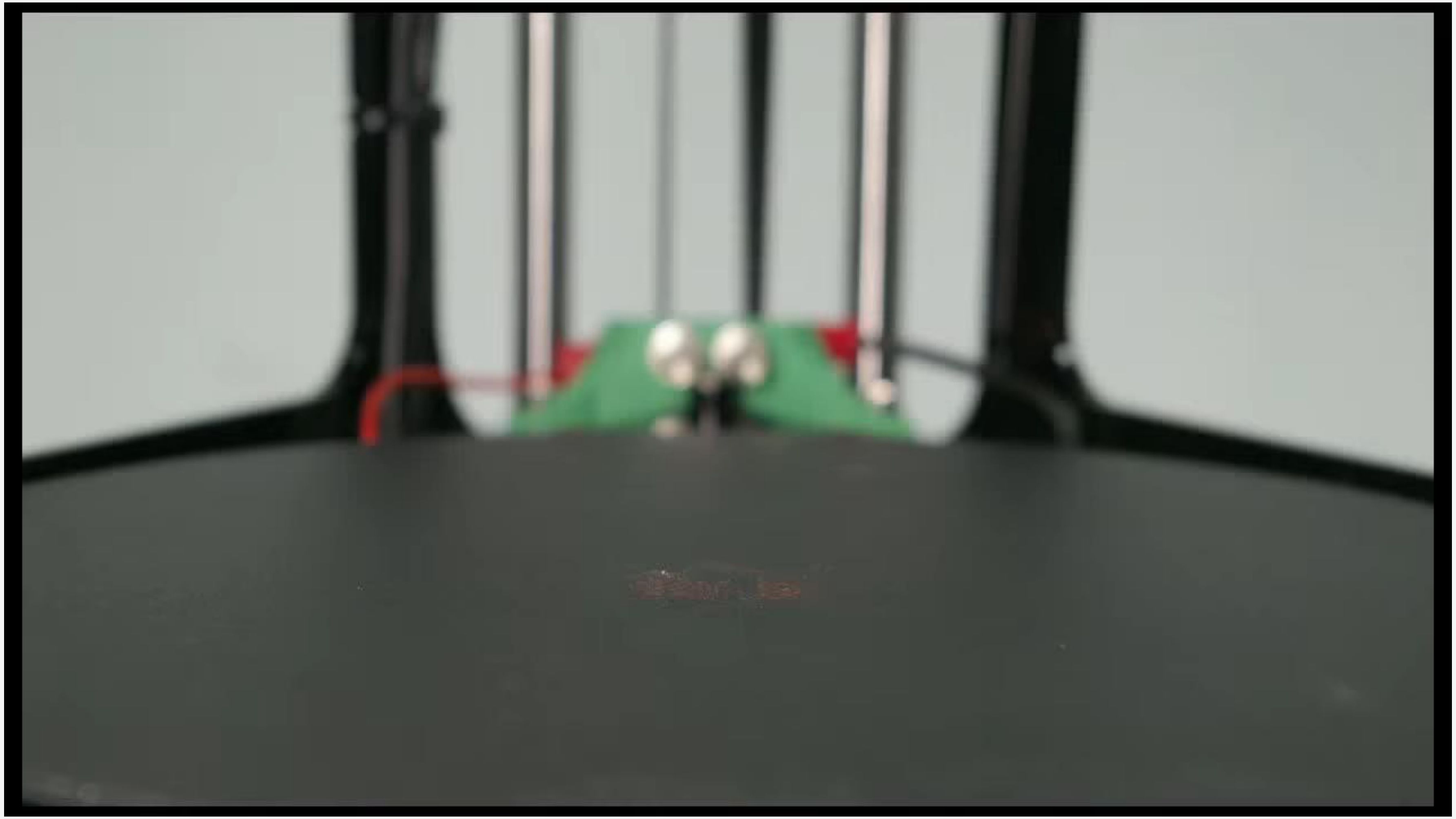

Maria Micheva Dr. Stanislav Balouchev

Hein; Colucci; Submitted in Advanced Science, **2025**


BIOFABLAB
BIOFABRICATION AND BIOMATERIALS INNOVATION
Wlodarczyk-Biegun,
Biomaterials 2017
30
50 µm

INTRODUCTION TO COMPUTER AIDED DESIGNING (CAD)

USE THE DESIGNS FOR 3D Printing



Problem?

Solution

Planning: What is the problem?

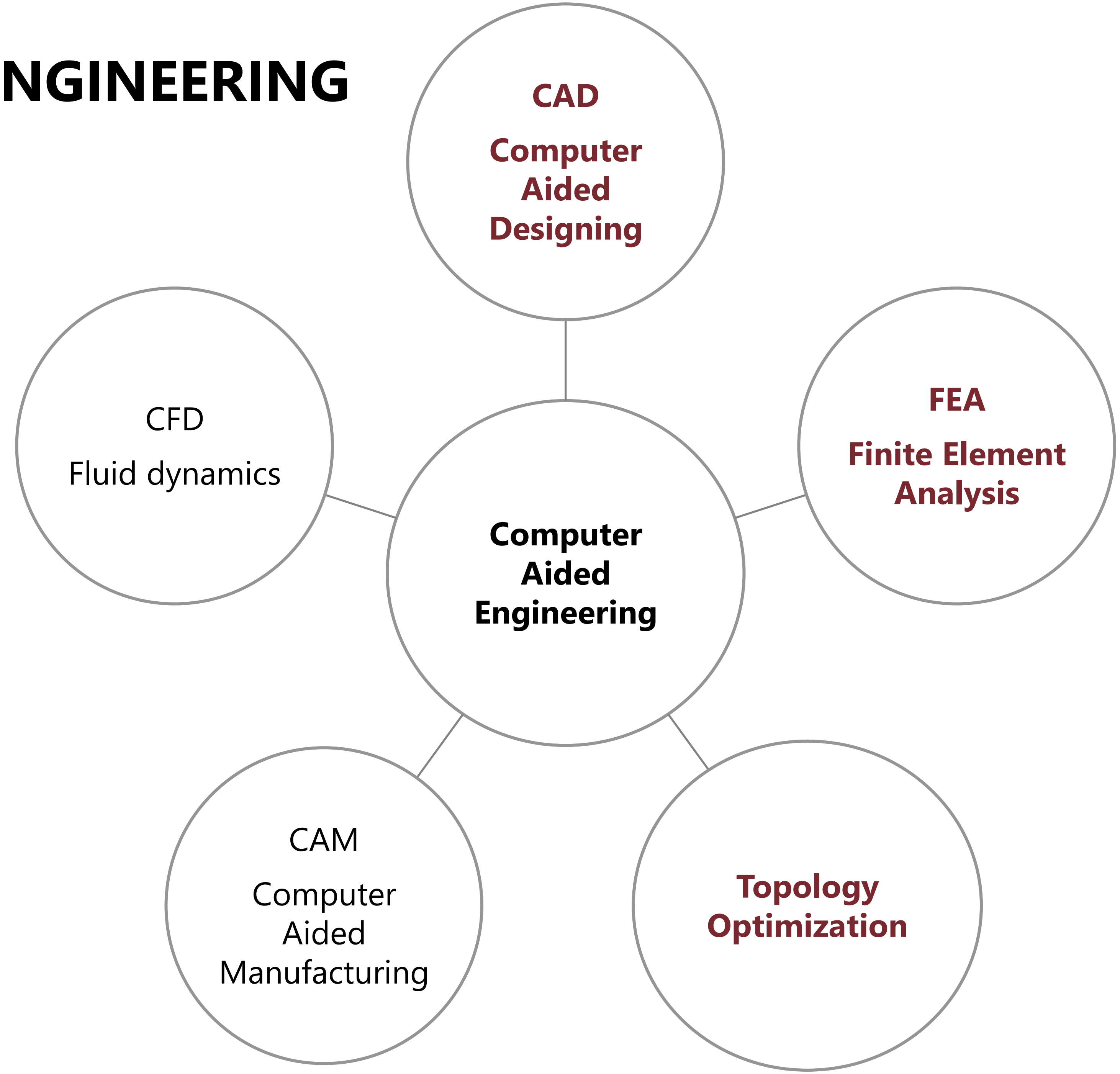
Concept: How can I solve the problem?

Drafting: What solutions are possible?

Design: What is the final product?

Computer-Aided Engineering Tools

COMPUTER EIDED ENGINEERING



COMPUTER AIDED DESIGN

- **Replaces traditional hand drafting**

Faster, more accurate, and easily editable compared to manual drawings.

- **Used to design, draft, and produce digital models**

Supports the entire workflow from concept sketches to detailed production drawings.

- **Applied across nearly all industries**

Architecture, construction, engineering, automotive, aerospace, manufacturing, product design, and more.

- **Creates precise 3D models**

Allows visualization of shapes, dimensions, assemblies, and internal components.

- **Enables realistic materials and lighting**

Produces photorealistic renderings for presentations, marketing, and client approvals.

- **Simulates real-world performance**

Includes stress, motion, heat, flow, and structural analysis to validate designs before physical prototyping.

- **Provides comprehensive design documentation**

Generates technical drawings, BOMs (Bill of Materials), reports, and files for patents, manufacturing, and communication.

STRESS SIMULATION IN CAD: USE FINITE ELEMENT ANALYSIS (FEA)

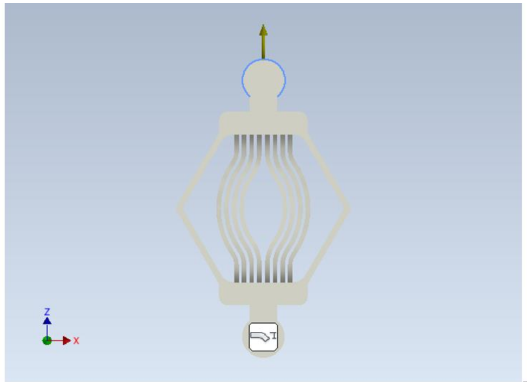
- **Non-destructive virtual testing**
Evaluates strength, durability, and failure points without damaging physical prototypes.

- **Simulates real usage and application conditions**
Models loads, pressure, vibration, impact, temperature, and other operational forces.

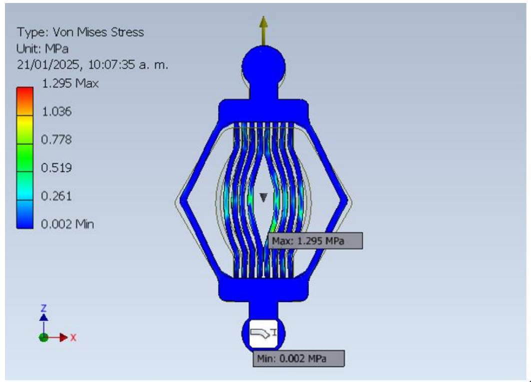
- **Identifies weaknesses early in the design stage**
Reveals stress concentrations, deformation, and potential failure zones before manufacturing.

- **Optimizes materials and geometry**
Helps reduce weight, increase strength, and improve overall performance and safety.

- **Reduces cost and development time**
Minimizes the need for multiple physical prototypes and shortens the design-validation cycle.



Fixed Constraint:1



1st Principal Stress

STRESS SIMULATION - FINITE ELEMENT ANALYSIS (FEA)

TOPOLOGY OPTIMISATION IN CAD

- Uses computational algorithms to automatically improve a model's mechanical performance.

- **Enhances strength-to-weight ratio**

Adjusts geometry to achieve maximum stiffness or strength with minimal material

- **Removes non-contributing material**

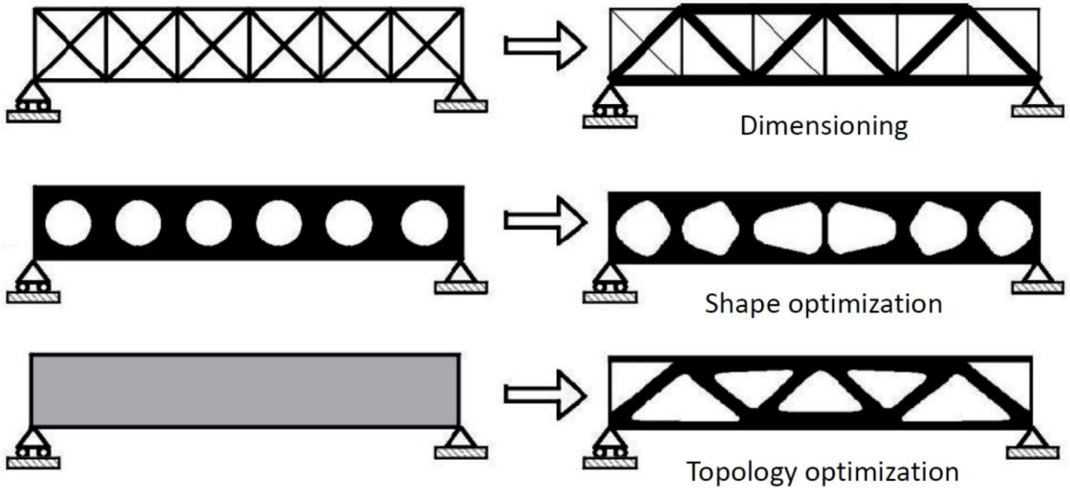
Identifies and eliminates excess areas that do not improve structural performance.

- **Generates efficient, lightweight structures**

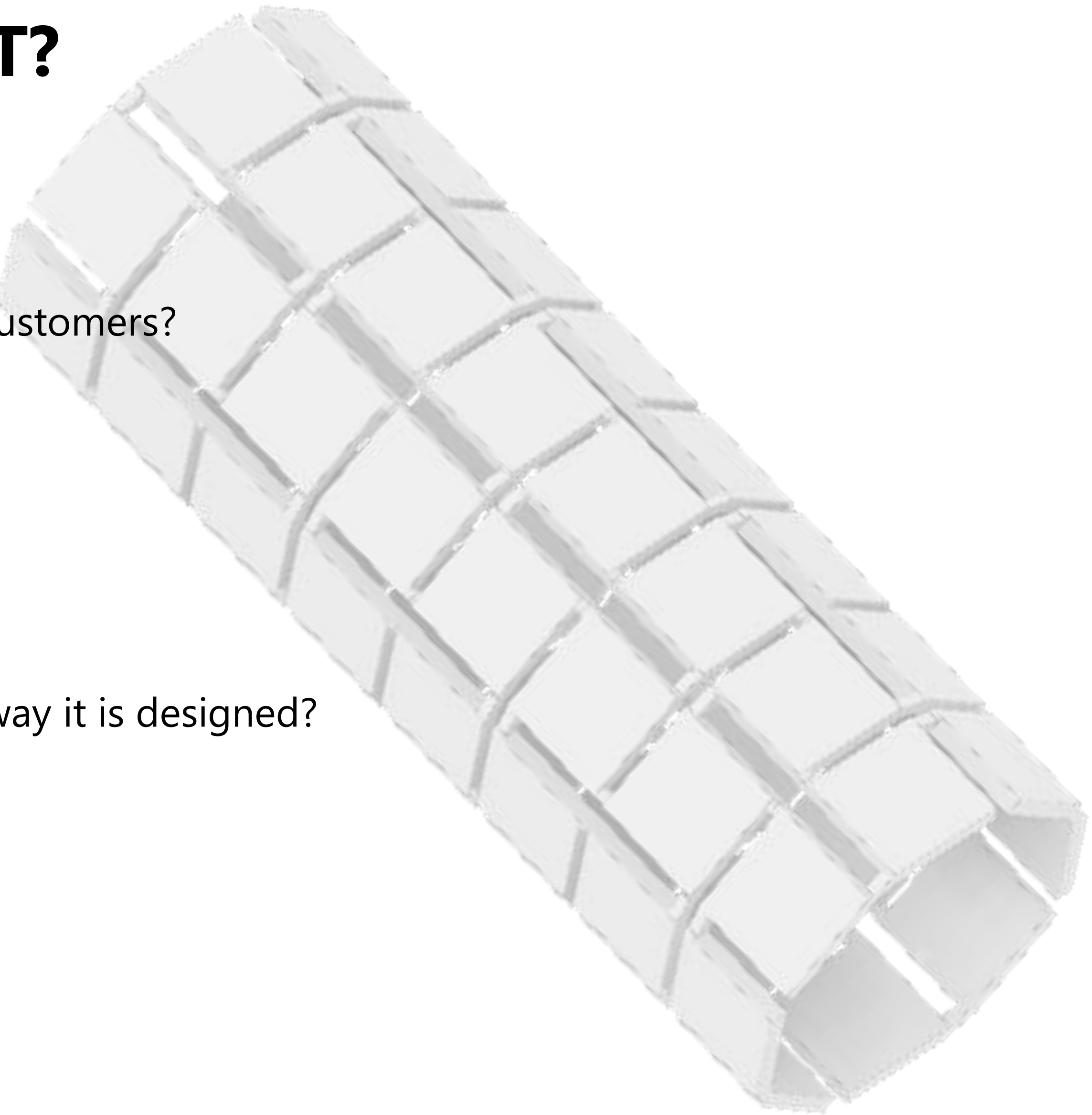
Produces organic, high-performance shapes ideal for aerospace, automotive, and additive manufacturing.

- **Supports rapid iteration and redesign**

Integrates directly into CAD workflows for quick evaluation and modification of optimized designs.



WHAT TO TAKE INTO ACCOUNT?



The design
- Does it look nice? Beautiful? Attractive for science/customers?

Costs
- Time of production
- Material: type and quantity

Technical specification
- Does it follow the rules, the size, materials, etc.
- How is it produced? Is it possible to produce it the way it is designed?

COMPUTER AIDED DESIGNING (CAD)

- Create **3D** or **2D models**
- **Supports multiple file formats**, examples: .ipt, .iam, .step, .dwg for design and sharing.
- Common CAD software: **Autodesk Inventor/ Fusion, Tinkercard, SolidWorks**….

CAD SOFTWARES

Commercial software [edit]

- AC3D
- Alibre Design
- ArchiCAD (Graphisoft)
- AutoCAD (Autodesk)
- Autodesk Inventor
- AxSTREAM
- BricsCAD
- CATIA (Dassault Systèmes)
- Cobalt
- CorelCAD
- Fusion 360 (Autodesk)
- IntelliCAD
- IRONCAD
- KeyCreator (Kubotek)
- Landscape Express
- MEDUSA
- MicroStation (Bentley Systems)
- Modelur (AgiliCity)
- Onshape
- Promine
- PTC Creo (successor to Pro/ENGINEER)
- PunchCAD
- Remo 3D
- Revit (Autodesk)
- Rhinoceros 3D
- Siemens NX
- SketchUp
- Solid Edge (Siemens)
- SolidWorks (Dassault Systèmes)
- SpaceClaim
- T-FLEX CAD
- TranslateCAD
- TurboCAD
- Vectorworks (Nemetschek)

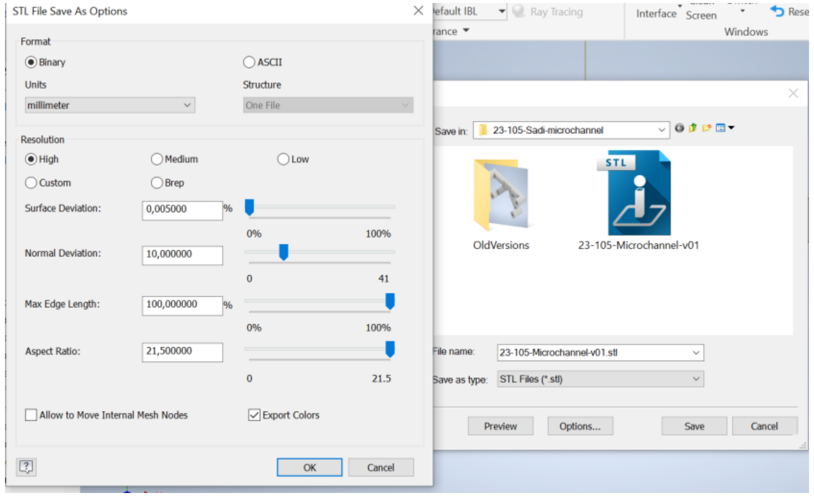
Not the best user interface but its ok

Open-source software

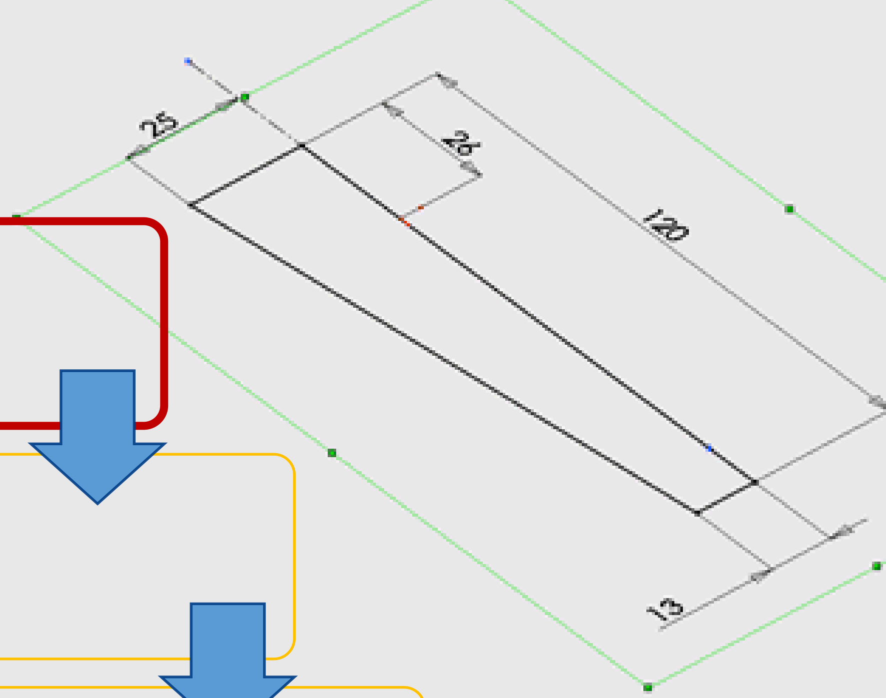
- BRL-CAD
- FreeCAD
- LibreCAD
- OpenSCAD
- QCAD
- Salome (software)
- SolveSpace
- CAD Sketcher

COMPUTER AIDED DESIGNING (CAD)

- Create **3D** or **2D models**
- **Supports multiple file formats**, examples: .ipt, .iam, .step, .dwg for design and sharing.
- Common CAD software: **Autodesk Inventor/ Fusion, Tinkercard, SolidWorks**….
- **Prepares models for 3D printing**: Always export as **STL-file** which converts geometry into a triangle mesh.
- **Control STL export quality:** Adjust resolution, deviation, and accuracy for smoother prints.
- **Speeds up prototyping and reduces errors:** Enables fast iteration before manufacturing.



3D PRINTING WORKFLOW: GENERAL STEPS



Designing your structure on the computer (CAD)
→ export your model commonly as **STL-file**

Choosing a **suitable type of 3D printer**
→ material restrictions? Size of final structure? Costs ? …?

Preparing a **print job file via the printers slicing software**
→ import the STL-file; set printing parameters (Temperature, …)

Start print job and **cross your fingers for it to succeed**

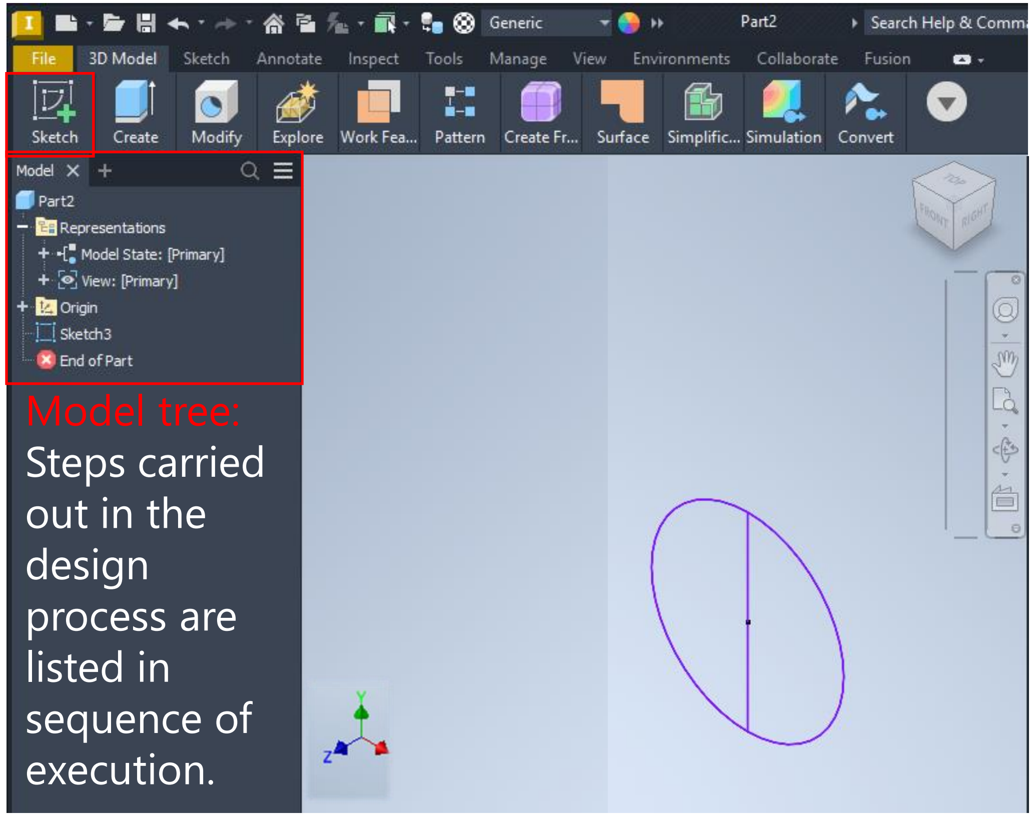
Take out your printed part
→sometimes post printing processes are required

AUTODESK INVENTOR GOLDEN RULES

- **Verify your starting planes and directions**
  Ensure visibility is correct; create additional reference planes when needed.

- **Always sketch in 2D first: Use ''Sketch"**
  Build clean sketches, then apply 3D operations like extrude, revolve, or sweep.

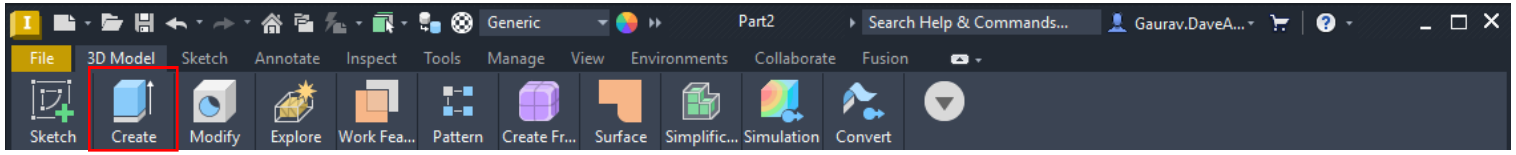
2D drawings



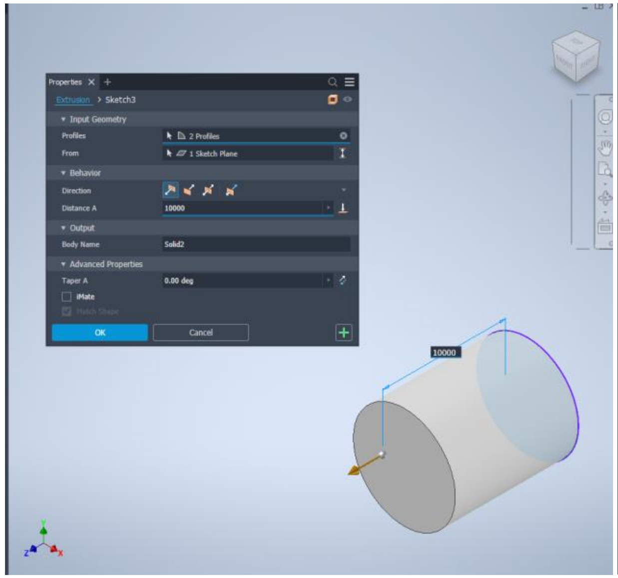
AUTODESK INVENTOR GOLDEN RULES

- **Verify your starting planes and directions**
  Ensure visibility is correct; create additional reference planes when needed.

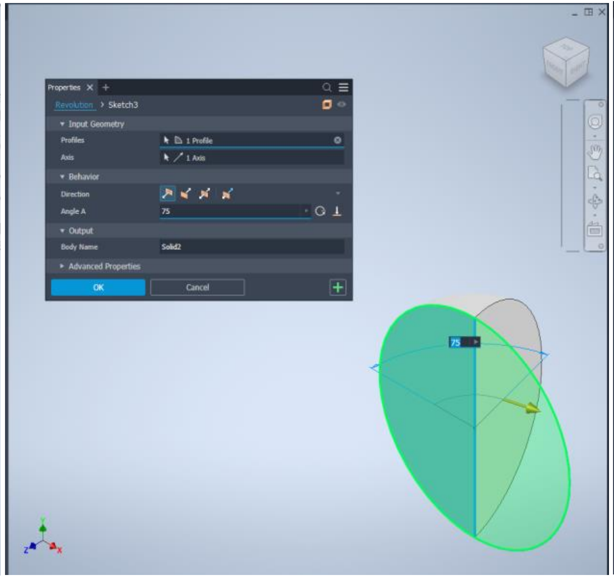
- **Always sketch in 2D first**
  Build clean sketches, then apply **3D operations like extrude, revolve, or sweep: Use ''Create''**



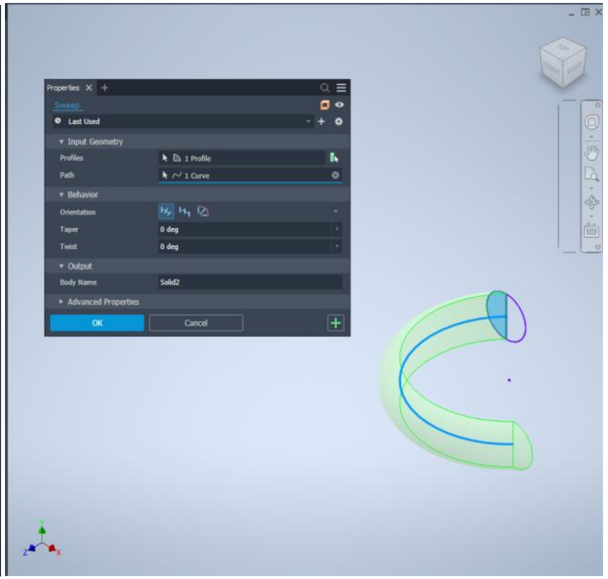
Extrude



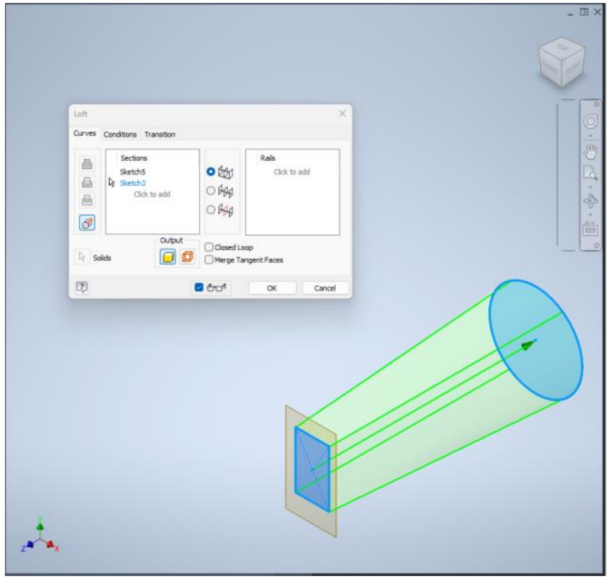
Revolve



Sweep



Loft



AUTODESK INVENTOR GOLDEN RULES

- **Fully define every sketch**
  Use dimensions and constraints to avoid errors and make later modifications easier.

- **Maintain proper sketch origin placement**
  Size and position your geometry relative to the origin; center sketches whenever possible.

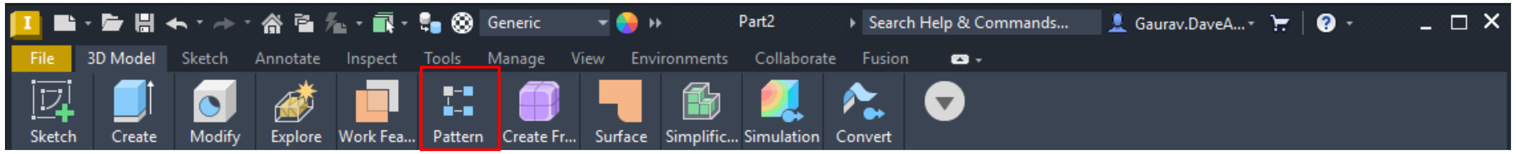
- **Use construction lines for alignment**
  Improve accuracy, symmetry, and constraint management.

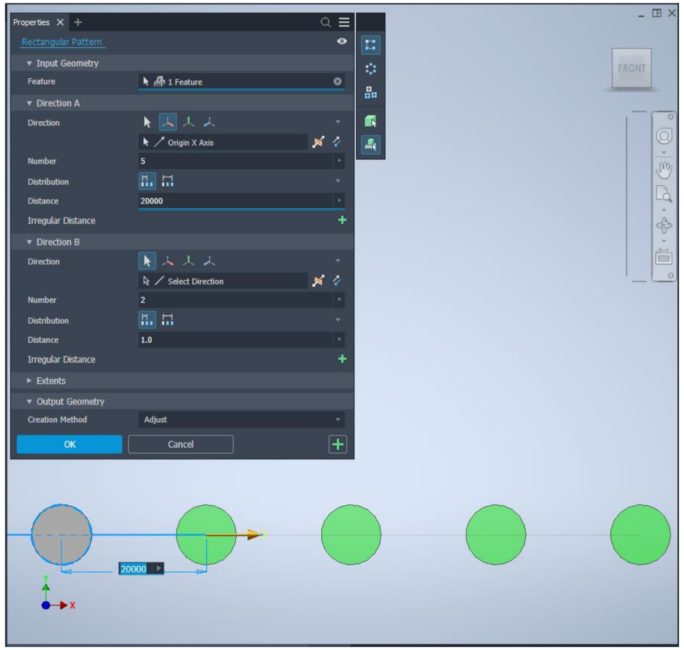
- **Reuse sketches when appropriate**
  Share sketches to avoid redundant work and maintain design consistency.

- **Use quick tools efficiently**
  The “M” key helps with measurement and verification.

AUTODESK INVENTOR GOLDEN RULES

- **Leverage pattern and mirror features: Use ''Pattern''**
  Speed up repetitive geometry creation and ensure perfect symmetry.



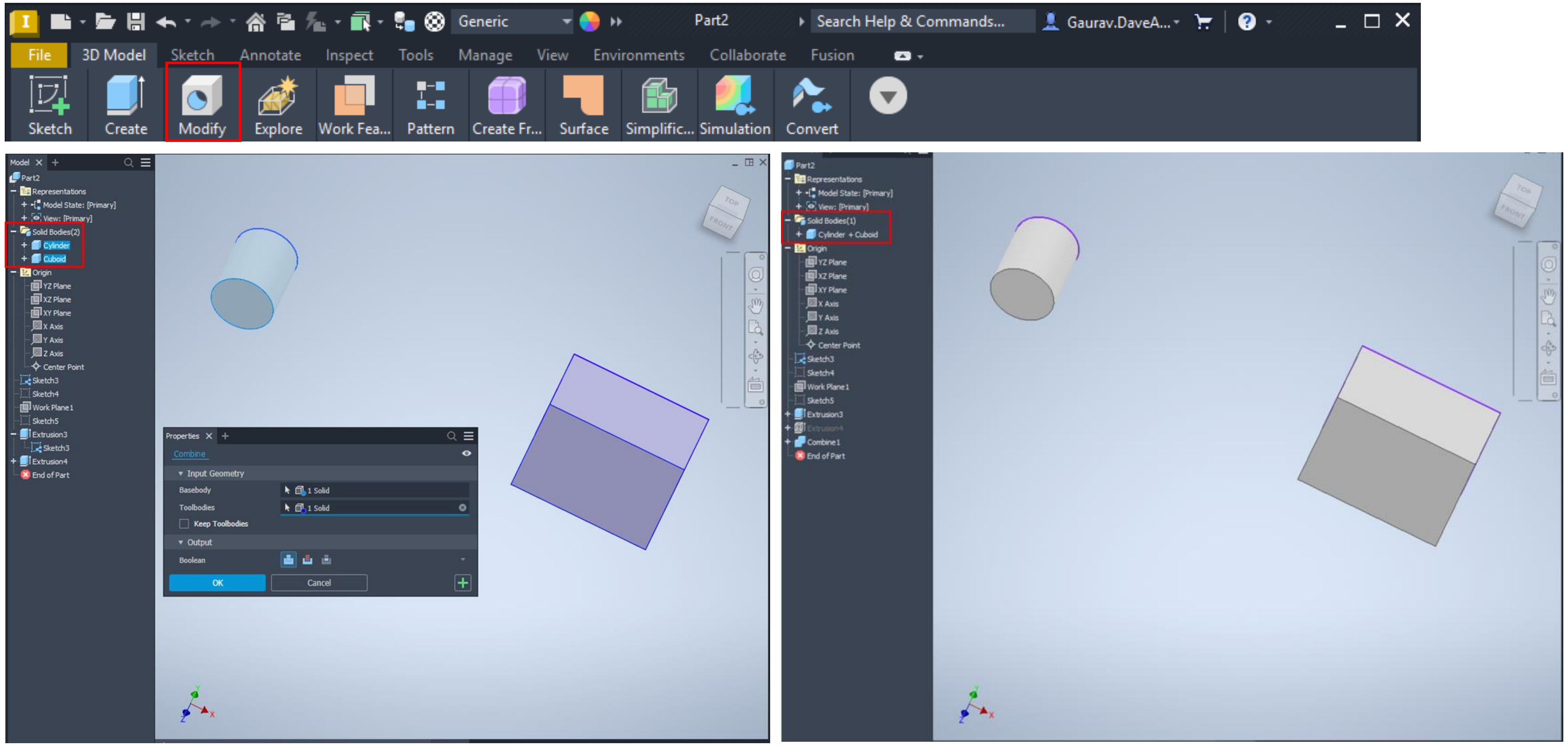


Mirroring

AUTODESK INVENTOR GOLDEN RULES

- **Leverage pattern and mirror features**
  Speed up repetitive geometry creation and ensure perfect symmetry.

- **Combine multiple solids when needed: Use ''Modify''**
  Final part should contain **one single solid body** unless intentionally modeling multi-body parts.



Move, Fillet

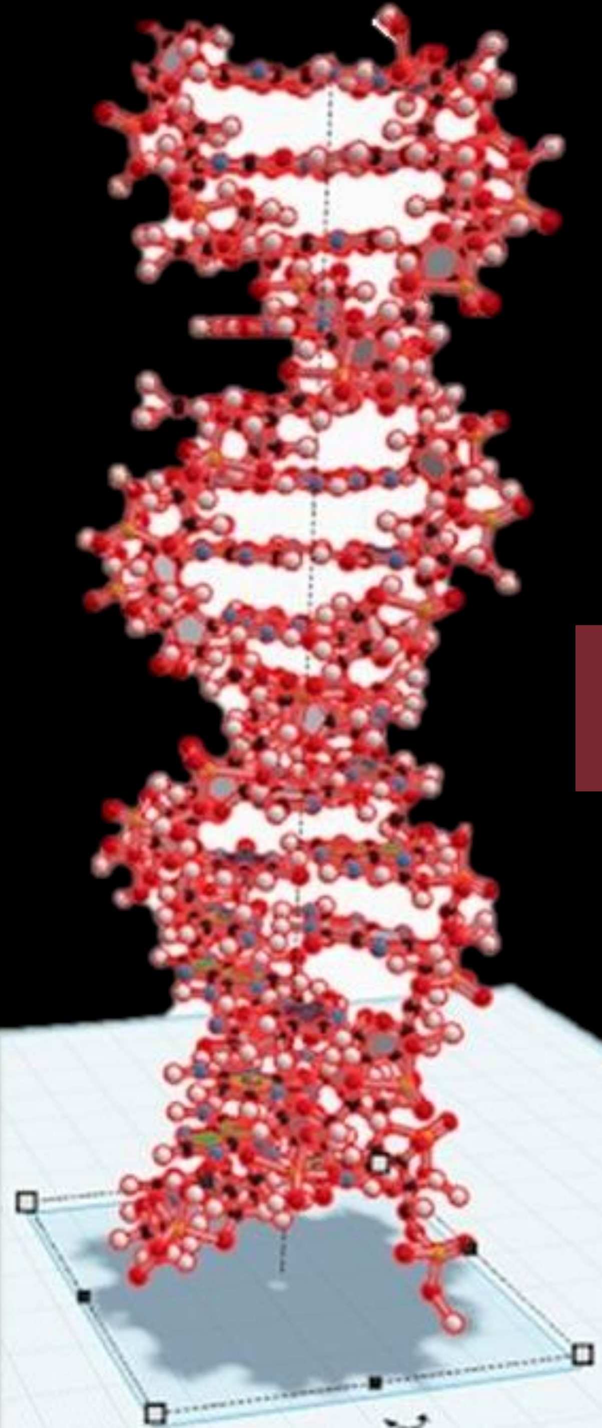
AUTODESK INVENTOR GOLDEN RULES

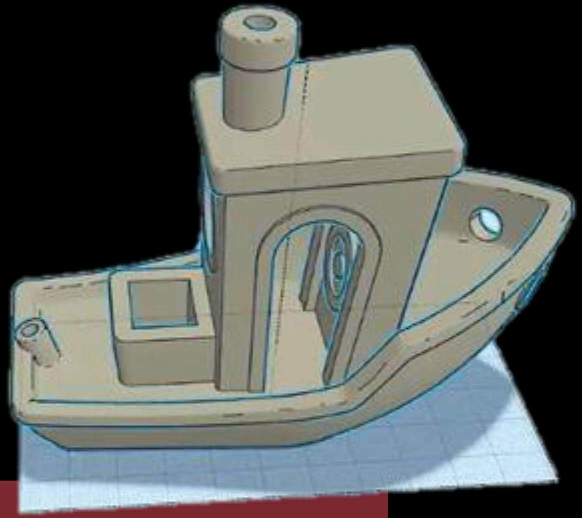
- **Adjust visual style**
  Shaded, wireframe, or hidden-line views can help detect issues.

- **Use section views**
  Half-section or full-section views help inspect internal geometry.

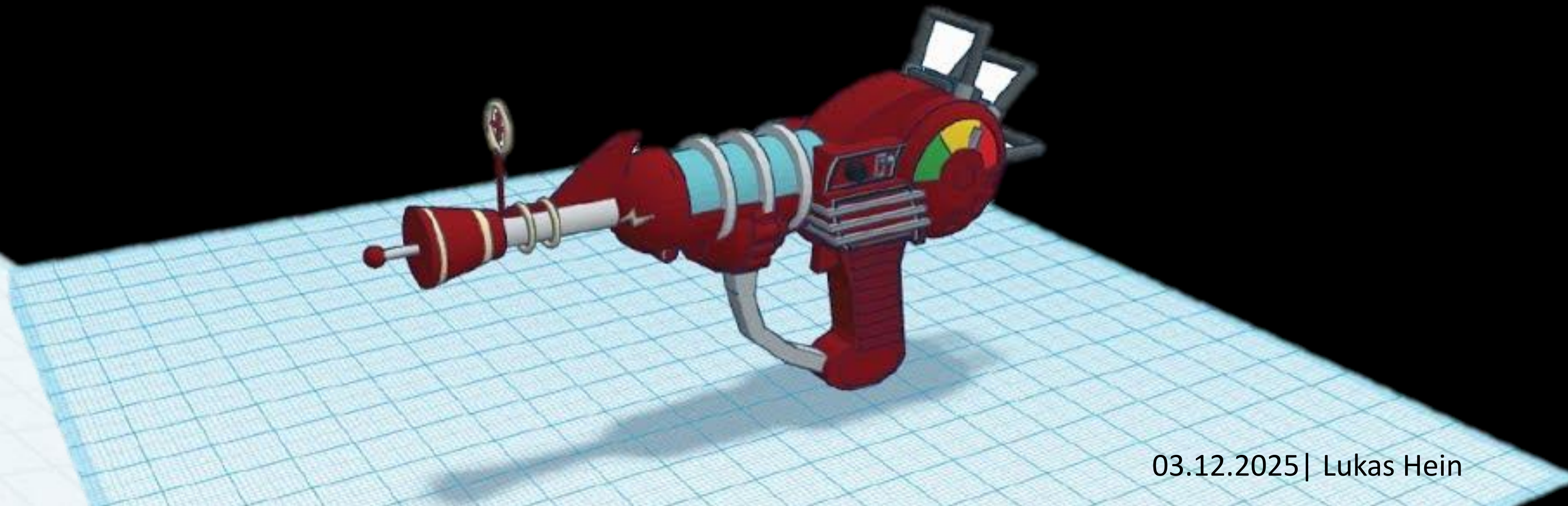
- **Export images when documenting your work**
  Useful for reports, presentations, or reviews.

- **Use ESC key frequently**
  Quickly cancel unwanted commands or actions.
  Prevent accidental operations or sketch edits.
  Helps you reset the cursor and navigate faster in the CAD environment.





AN INTRODUCTION TO TINKERCARD



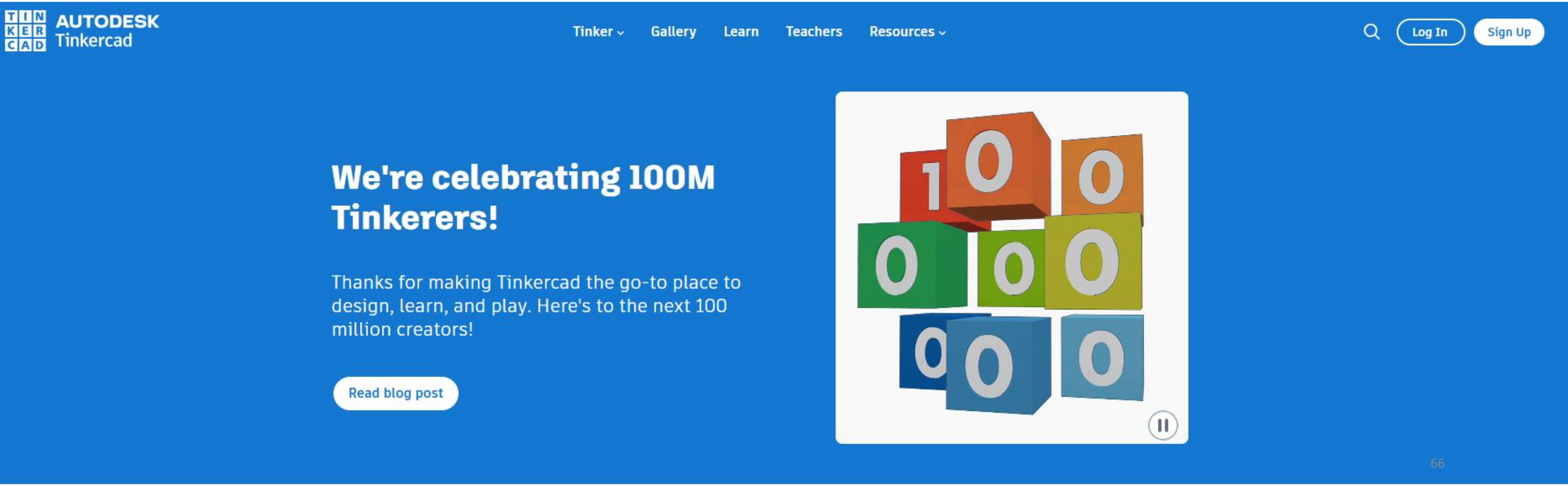
03.12.2025| Lukas Hein

WHAT IS TINKERCAD?

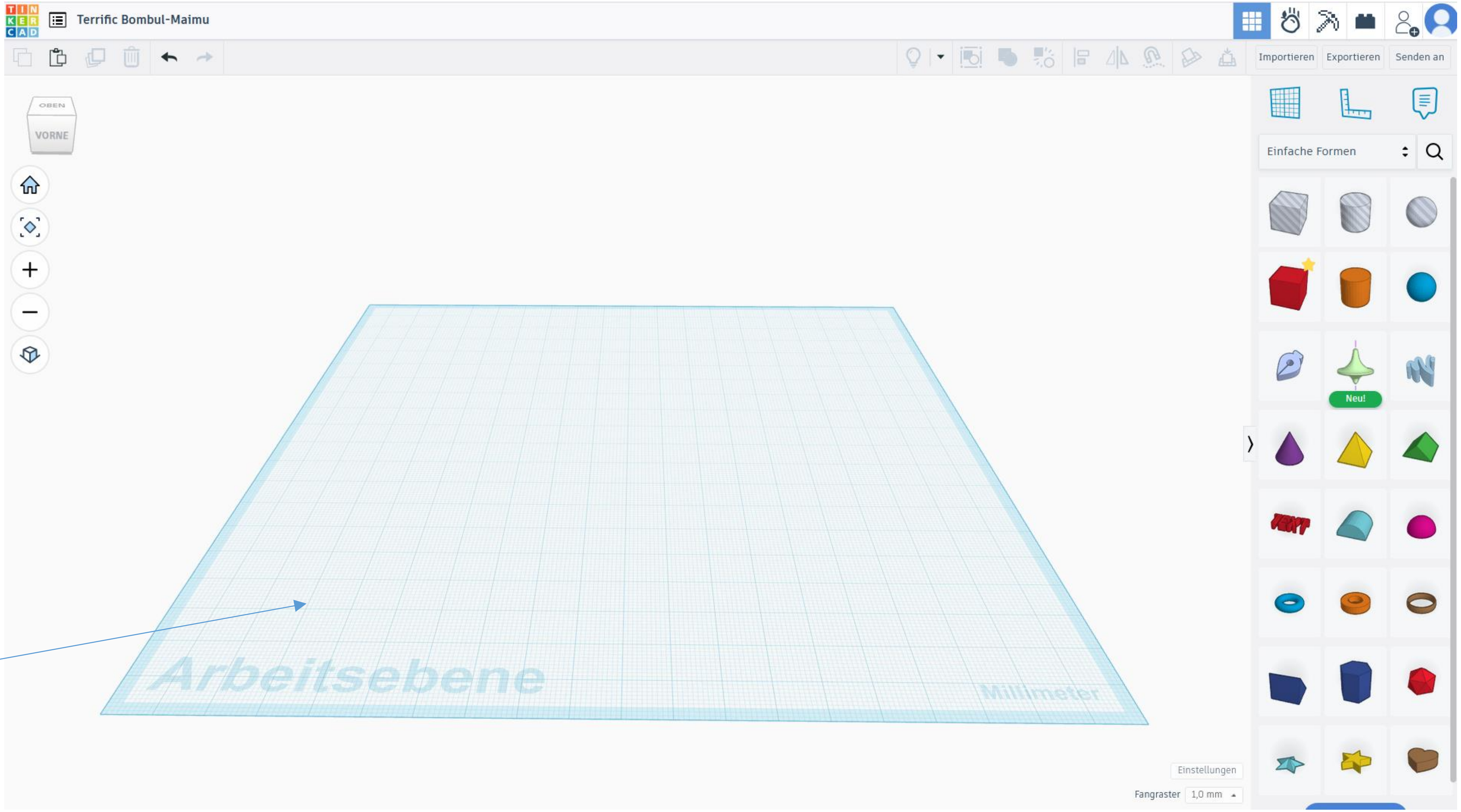
- Free, browser.based 3D-design tool
- Log in by visiting tinkercad.com
- Sign in using Google or Apple
- Create a new design and get creative!

TINKERCAD…THE EASIEST OPTION!!

Join now: https://www.tinkercad.com/

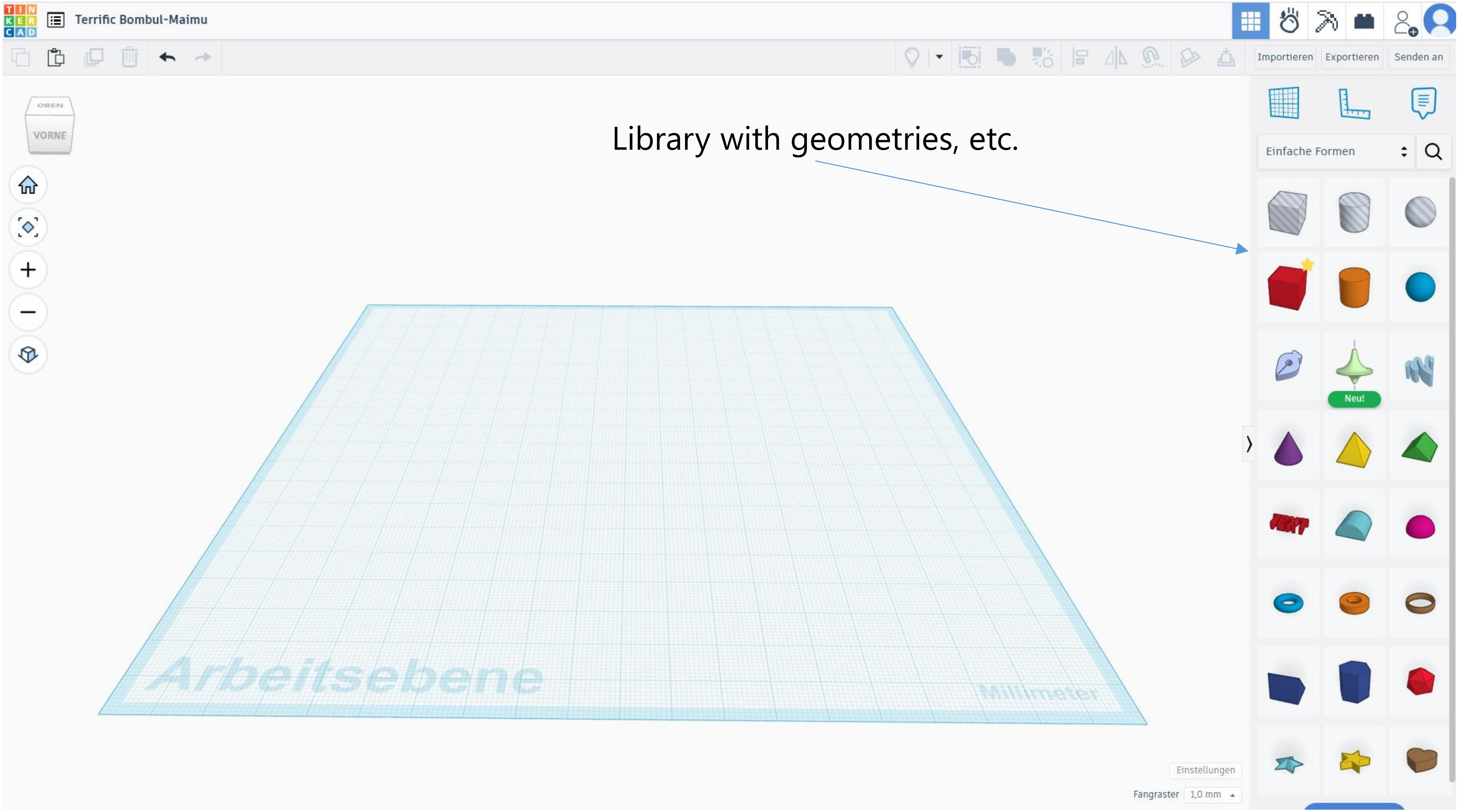


THE HUD



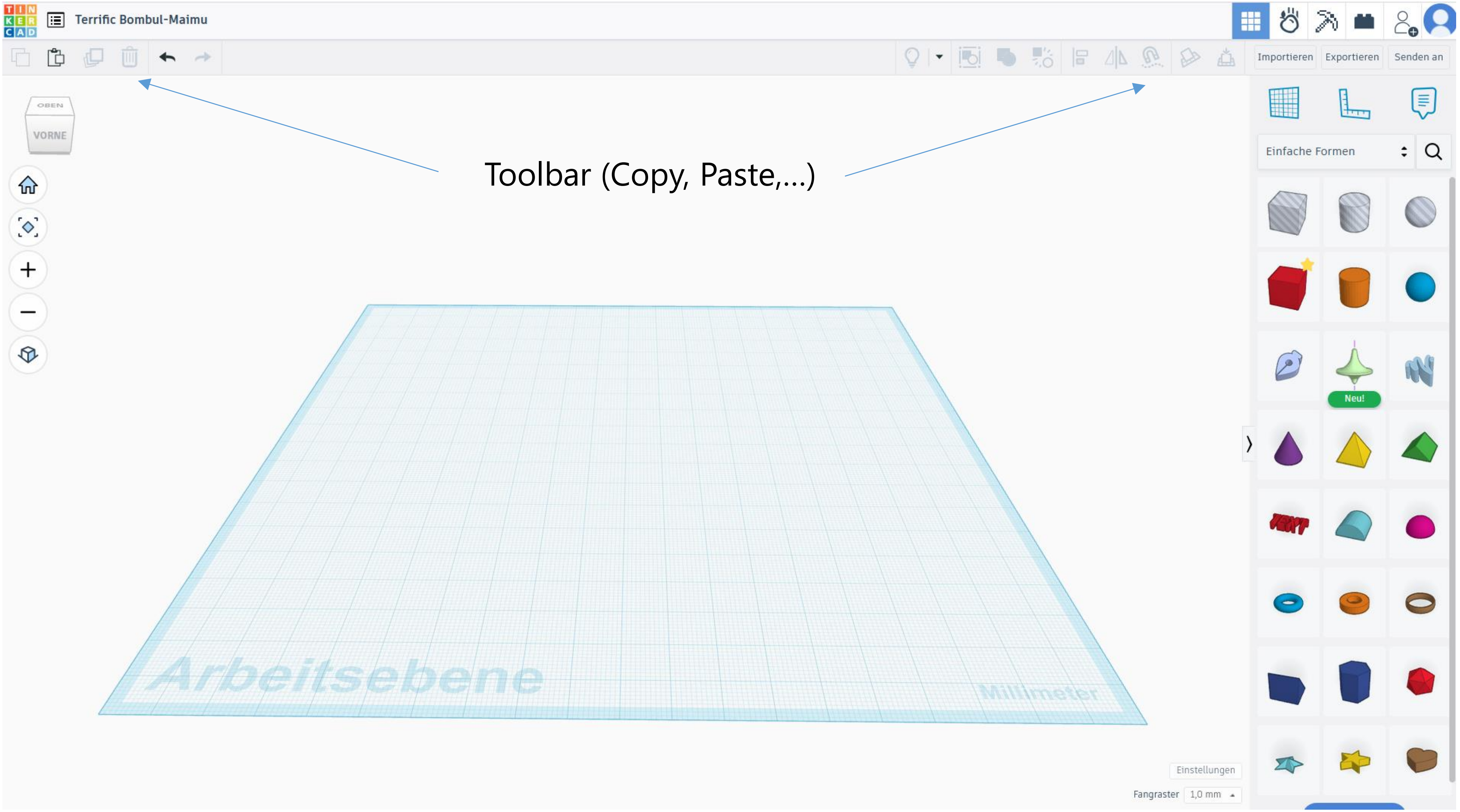
Workplane

THE HUD

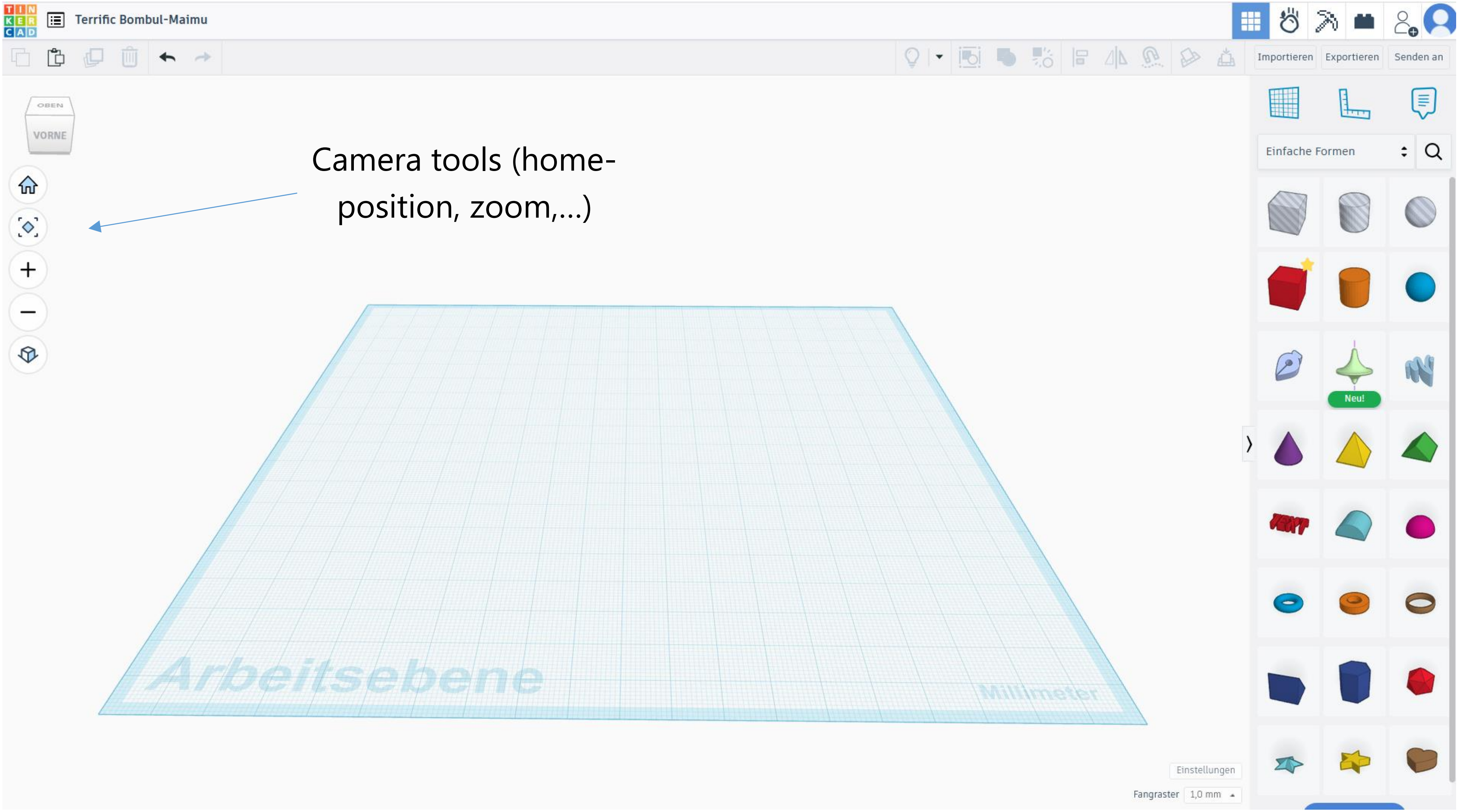


Library with geometries, etc.

THE HUD

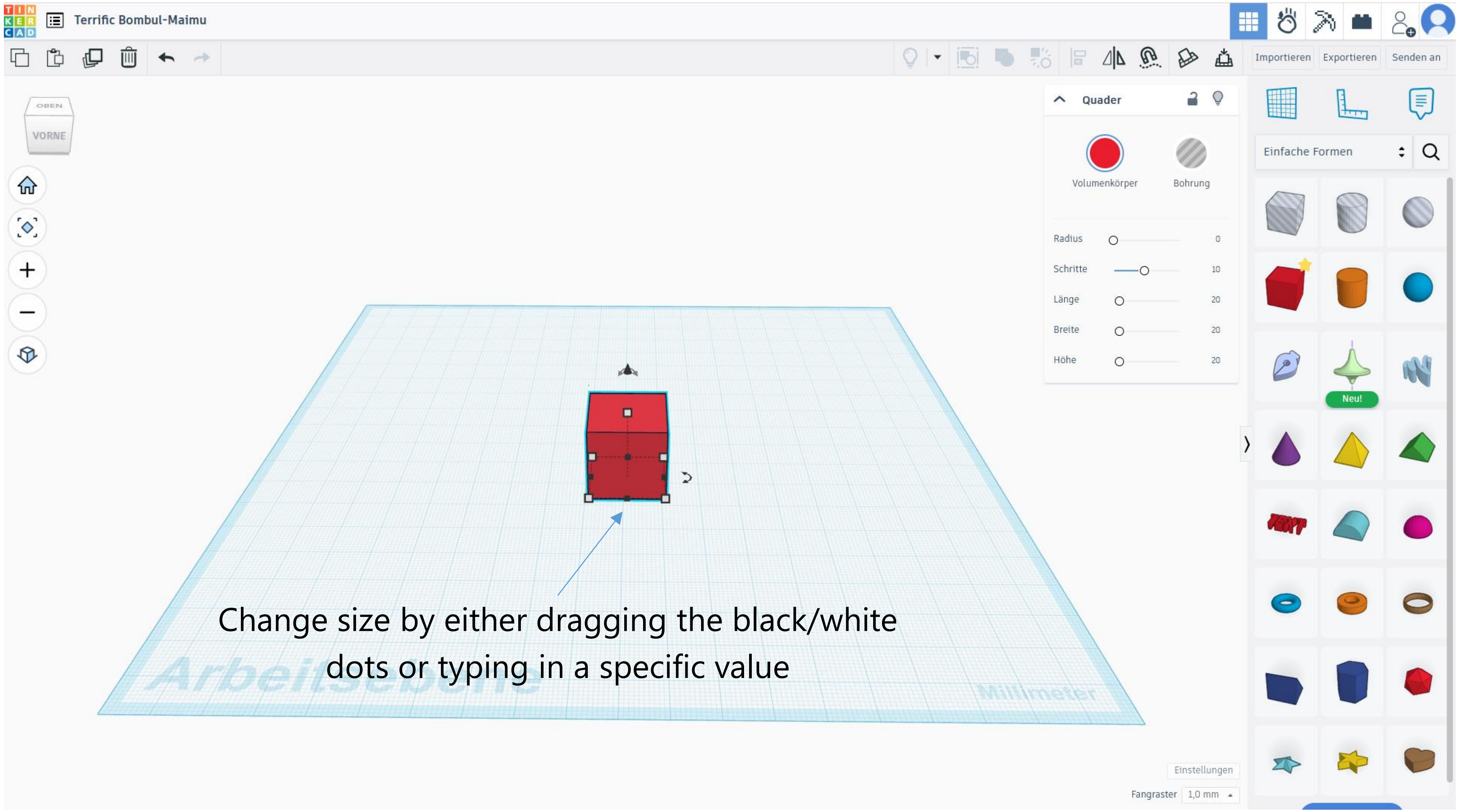

Terrific Bombul-Maimu
Importieren
Exportieren
Senden an
OBEN
VORNE
Toolbar (Copy, Paste,...)
Einfache Formen
Neu!
Arbeitsebene
Millimeter
Einstellungen
Fangraster
1,0 mm

THE HUD

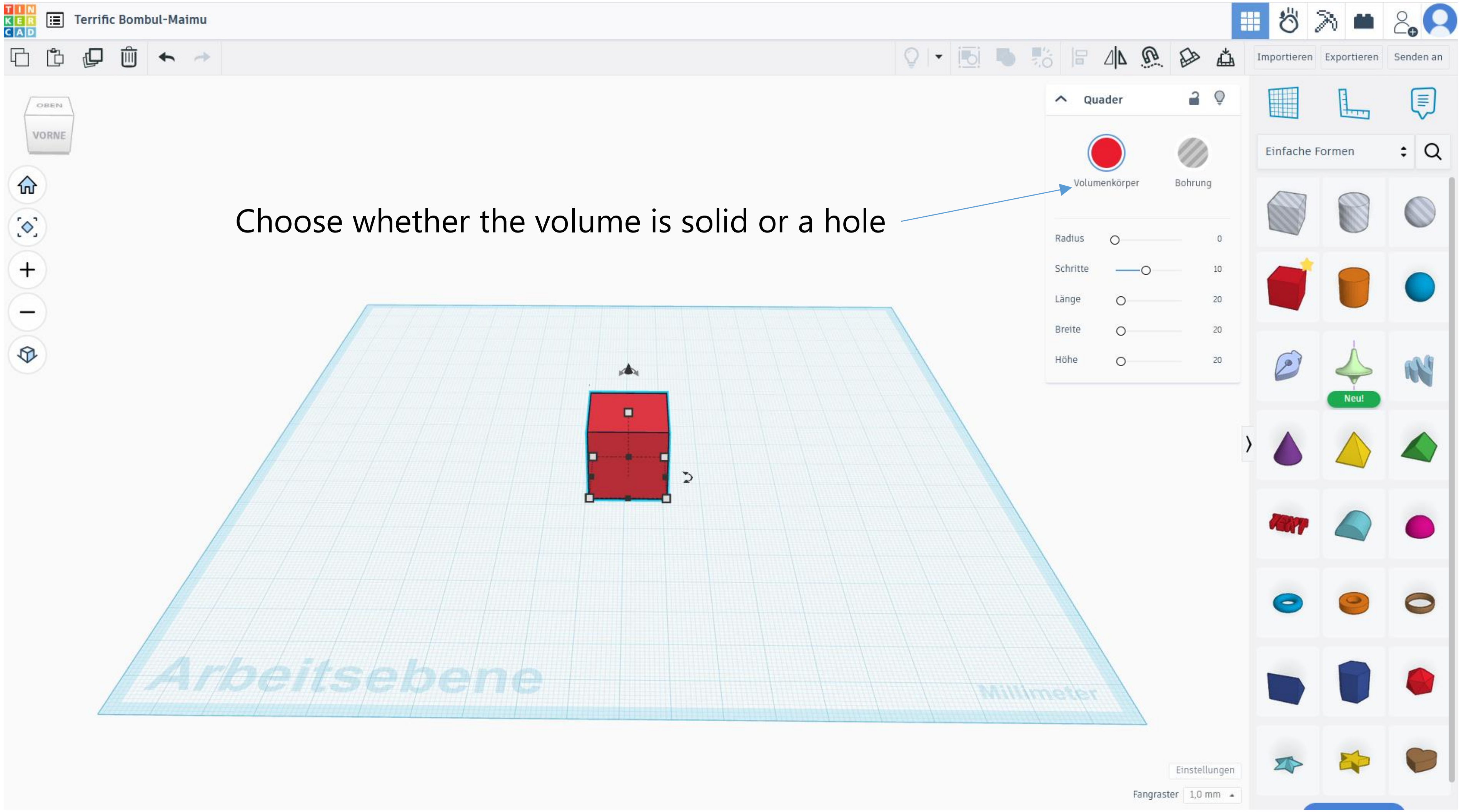


Camera tools (home-position, zoom,…)

CREATING YOUR 3D-DESIGN



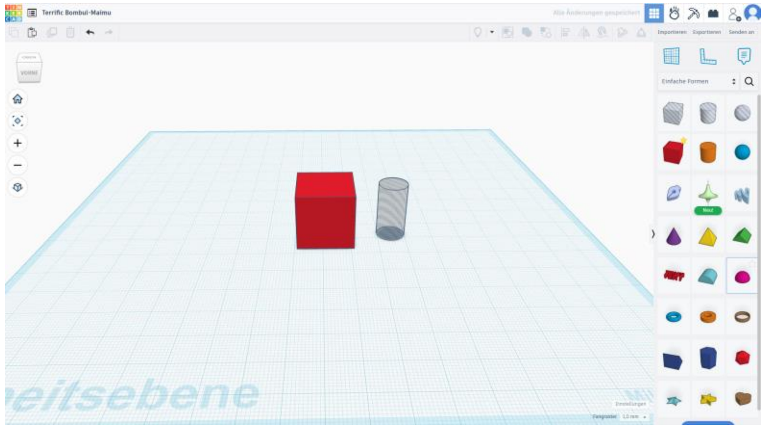
CREATING YOUR 3D-DESIGN

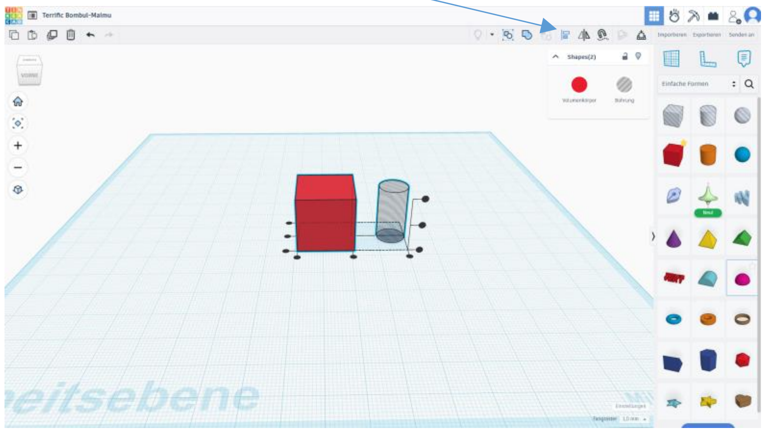


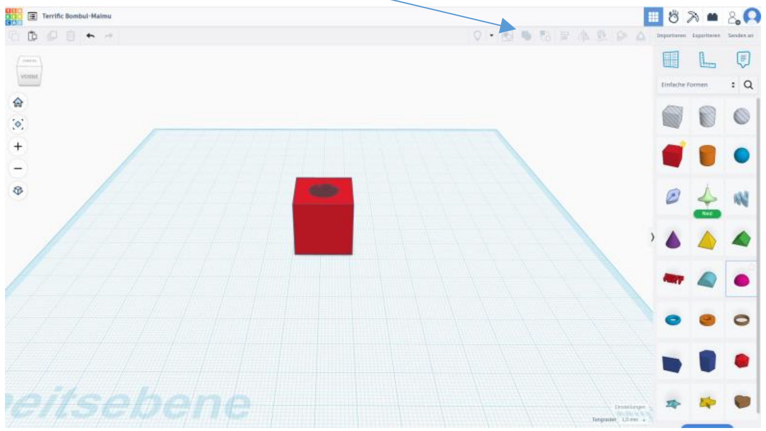
CREATING YOUR 3D-DESIGN

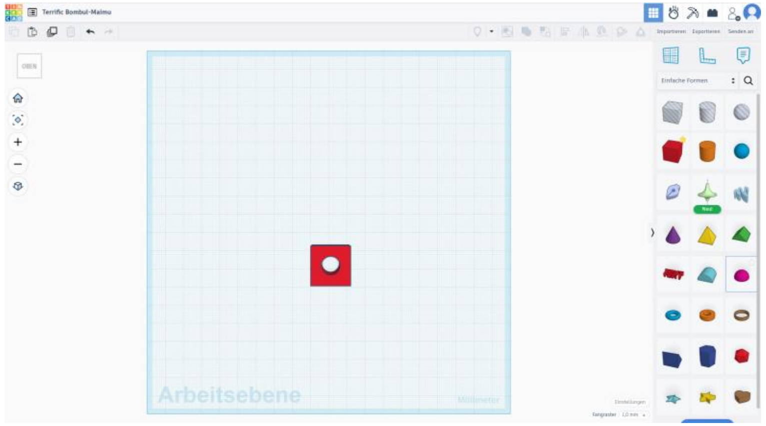
Align the geometries

Group the geometries









EXPORT YOUR DESIGN... as an STL file!