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CARBON3D.COM

TRUE POLYMER-BASED ADDITIVE MANUFACTURE: CARBON'S TECHNOLOGY AT 5 YEARS

USPTO
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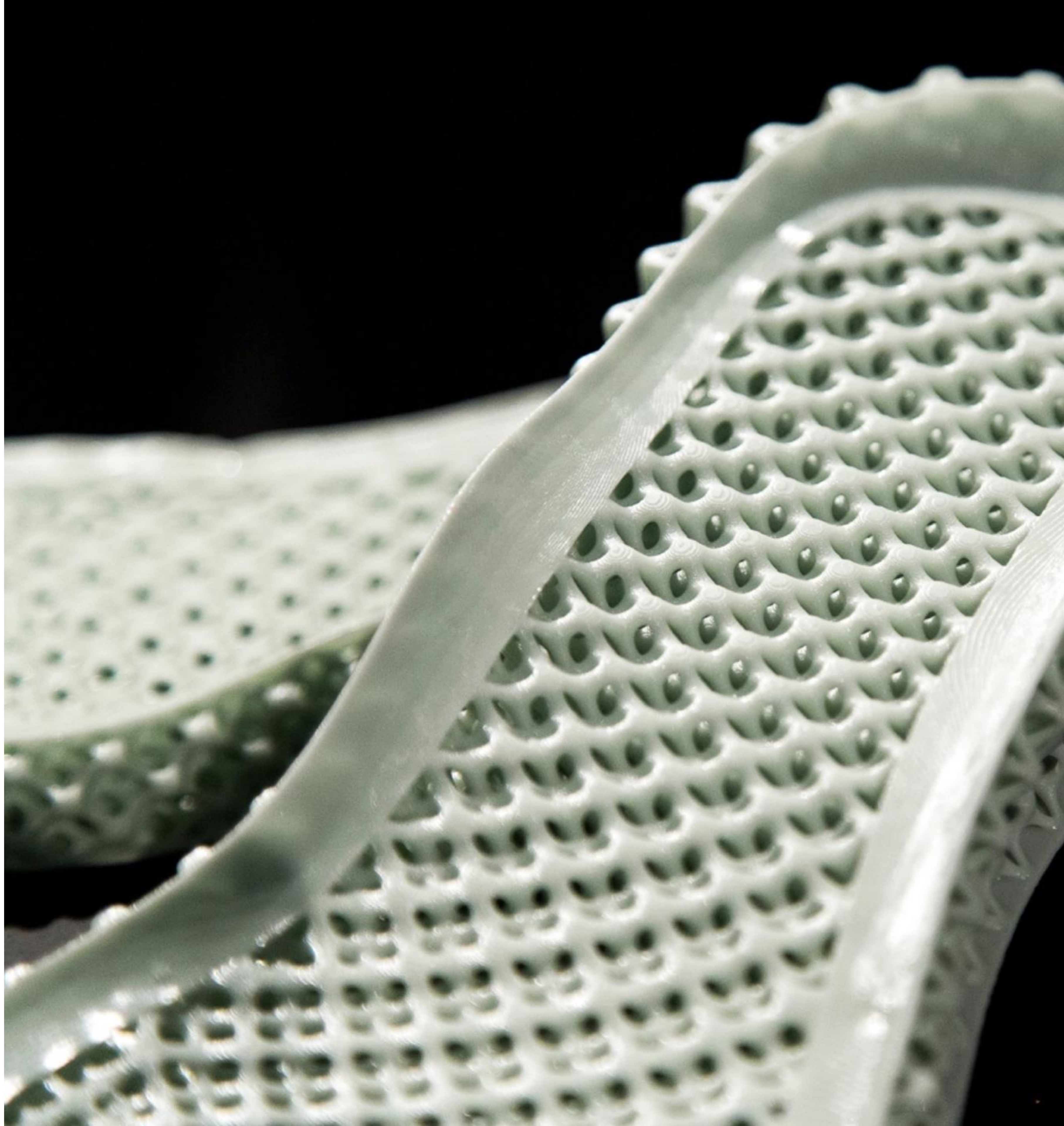
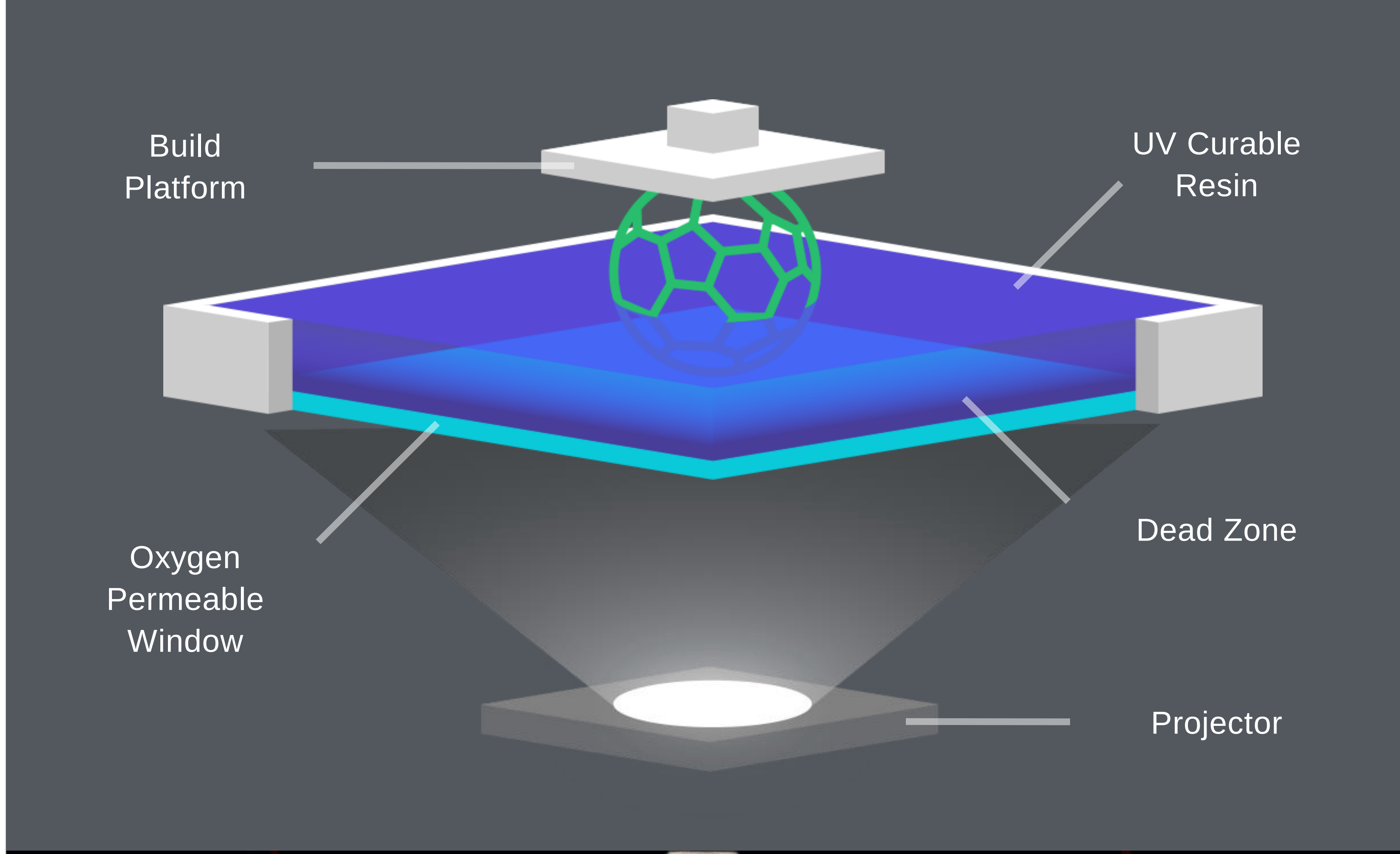
CARBON is transforming the ways things are designed, to engineered & manufactured

- Design tools have been limited because manufacturing technology hasn’t been able to execute on amazing designs.
- Now that we have the technology, we are elevating the opportunities with design.
- Hardware, software, materials and **design.**



TED
Ideas worth spreading



THREE FUNDAMENTAL BREAKTHROUGHS: Our Technology

1

Continuous Printing (CLIP): New 3D Printing Process

- Layerless
- Injection molded qualities
- Best-in-class printer uptime
- US Patent 9,498,920
- US Patent 9,360,757
- US Patent 9,211,678
- US Patent 9,205,601

2

Dual-Cure Materials: New 3D Materials

- Wide range of proprietary materials
- Unmatched mechanical properties
- US Patent 9,676,963
- US Patent 9,598,606
- US Patent 9,453,142

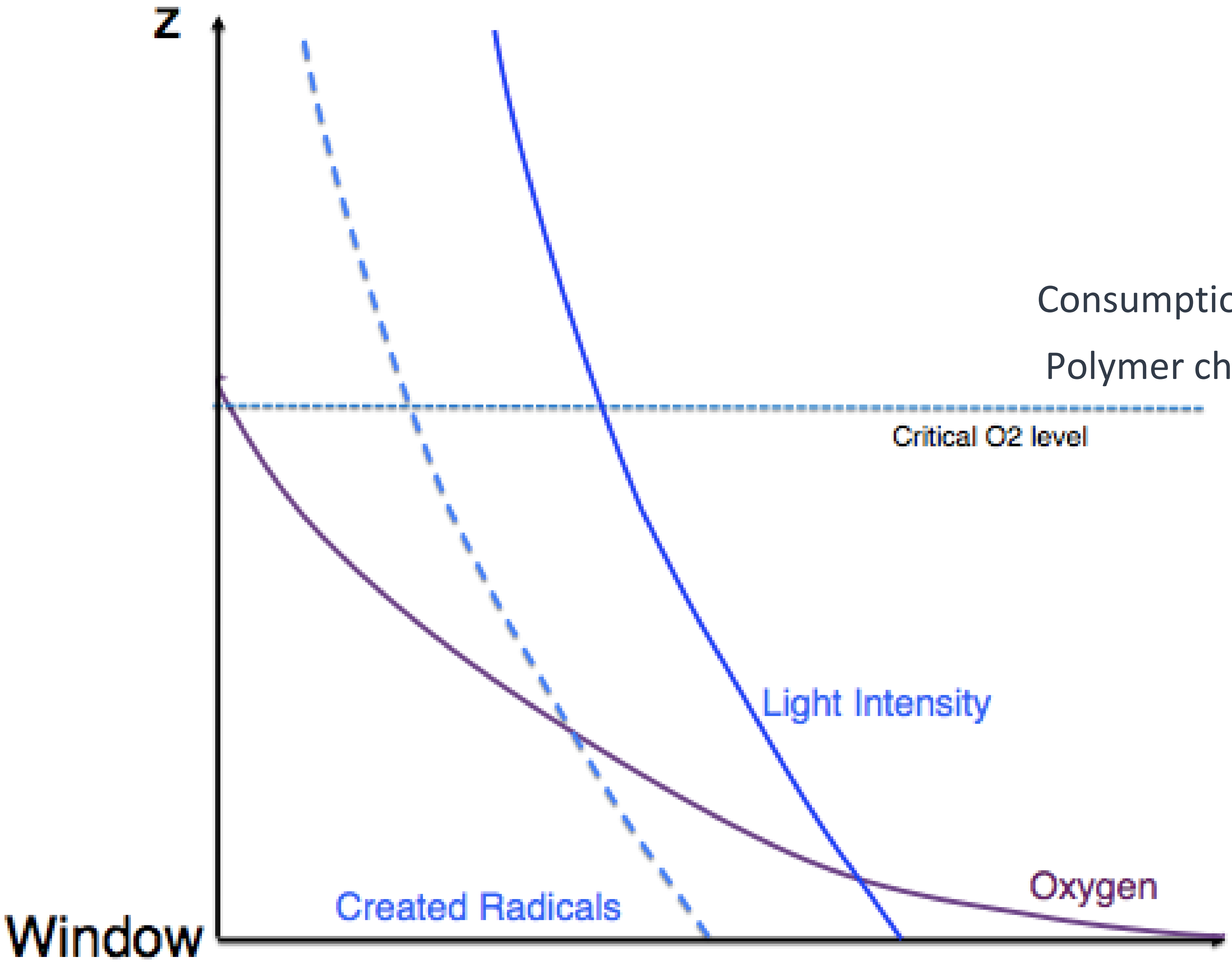
3

Modern Software: Securely Connected Architecture

- Cloud-based
- Regular upgrades until production
- Traceability of digital process
- New design tools (lattices, textures)

At the Interface

$$\Phi = \Phi_0 e^{-\alpha z}$$



Radical formation $PI \xrightarrow{hv} PI\cdot \xrightarrow{k_d} 2R\cdot$

Chain initiation $R\cdot + M \xrightarrow{k_i} RM\cdot$

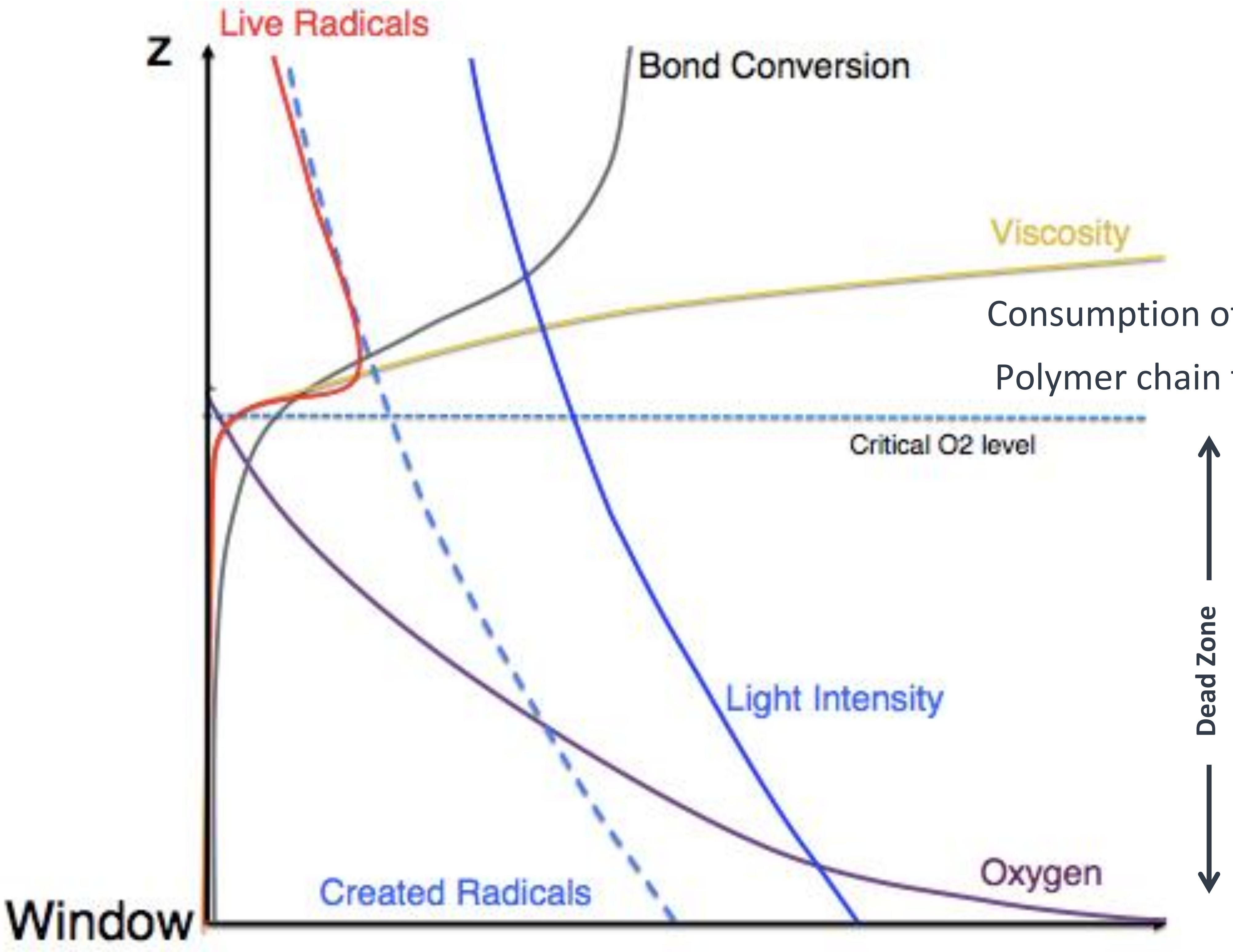
Chain propagation $RM_n\cdot + M \xrightarrow{k_p} RM_{n+1}\cdot$

Consumption of photoinitiator by O_2 $PI \longrightarrow PI\cdot + O_2 \longrightarrow Quenching$

Polymer chain termination by O_2 $RM_n\cdot + O_2 \longrightarrow RM_nOO\cdot$

At the Interface

$$\Phi = \Phi_0 e^{-\alpha z}$$



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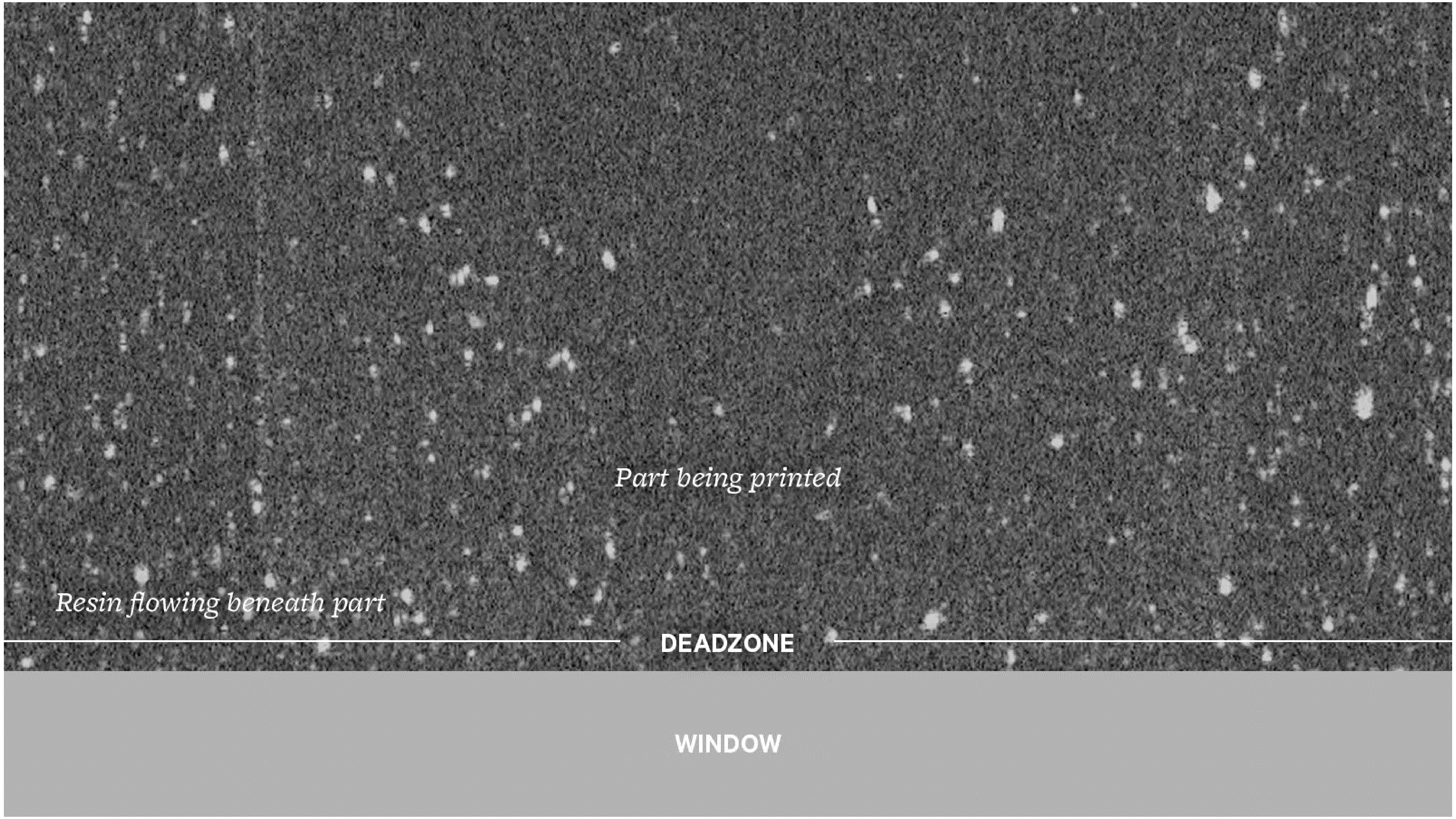
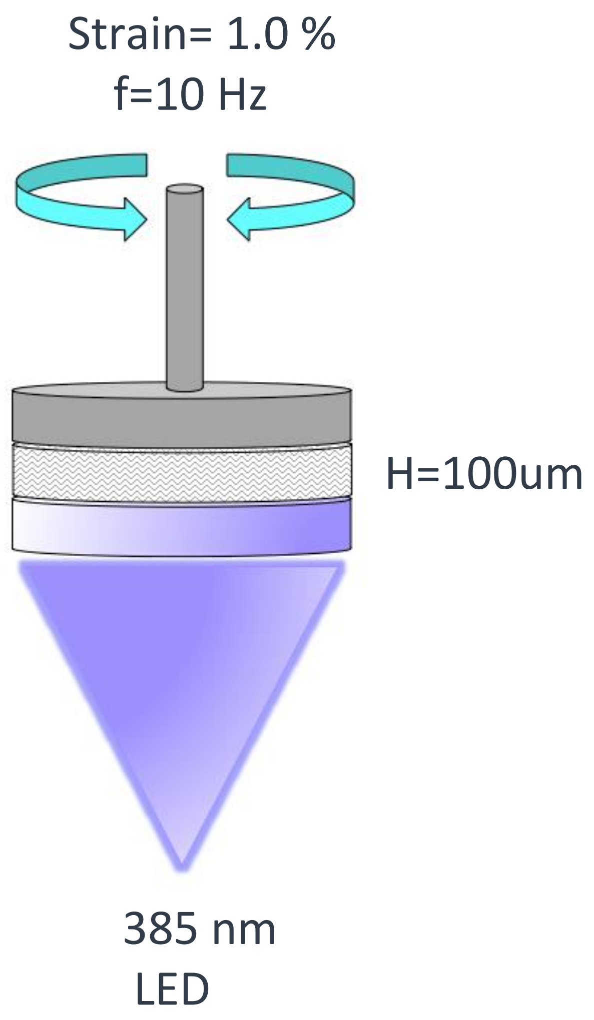
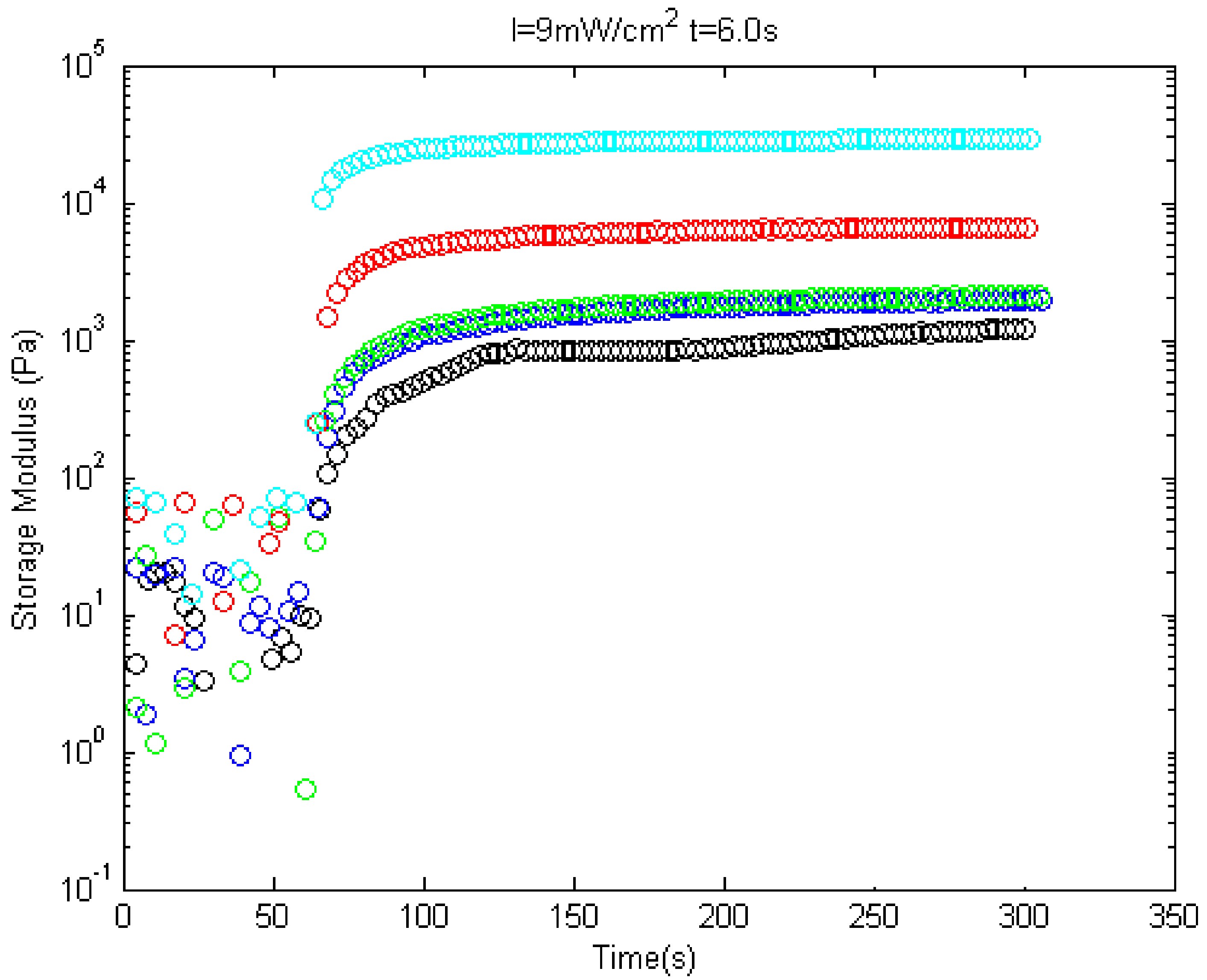


Part being printed
Resin flowing beneath part
DEADZONE
WINDOW

Photo-Rheology

Experimental Set-Up:

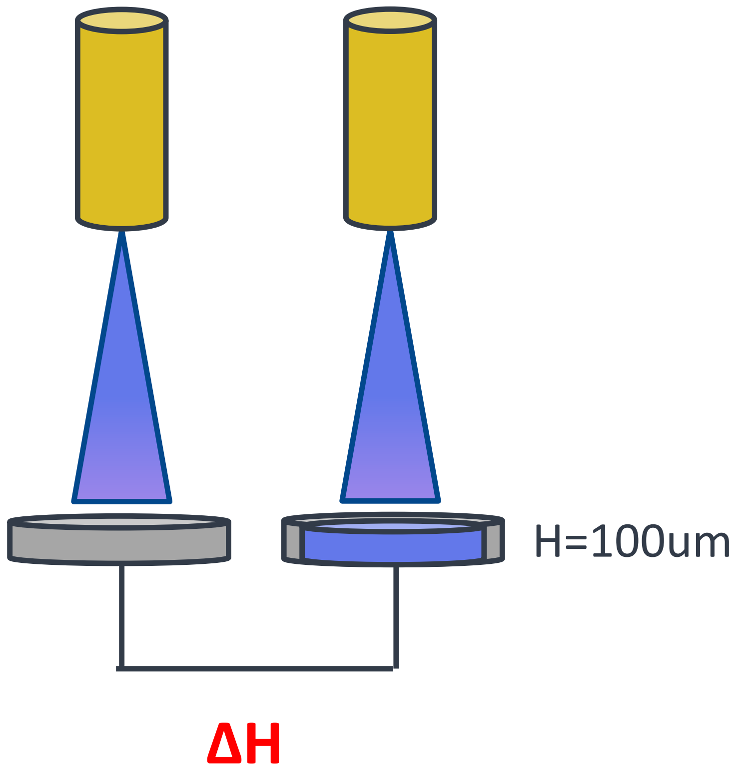


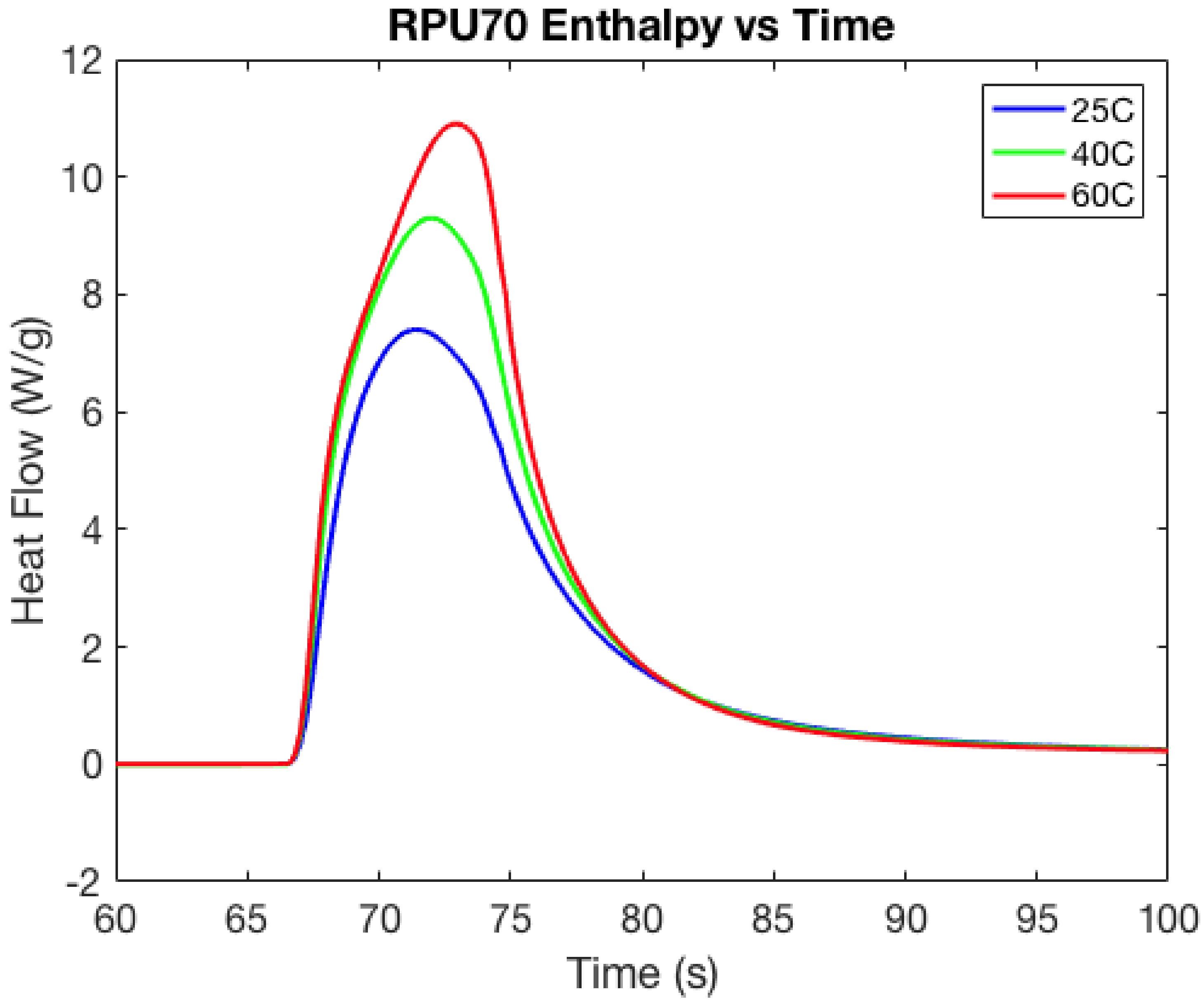


- Our customized photo-rheometer is integrated into our 1st generation printer and sheds light into the time scales of curing for various formulations.

Photo-DSC

Experimental Set-Up:

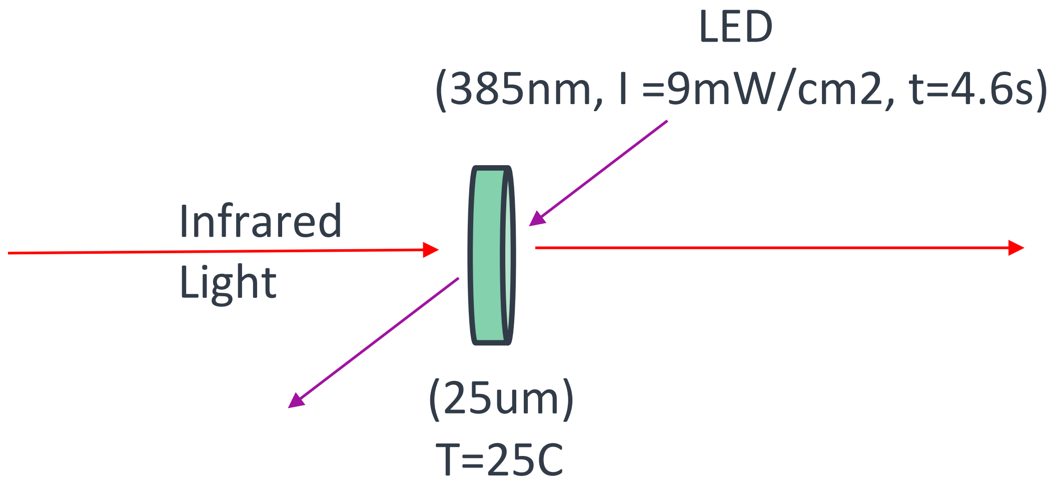


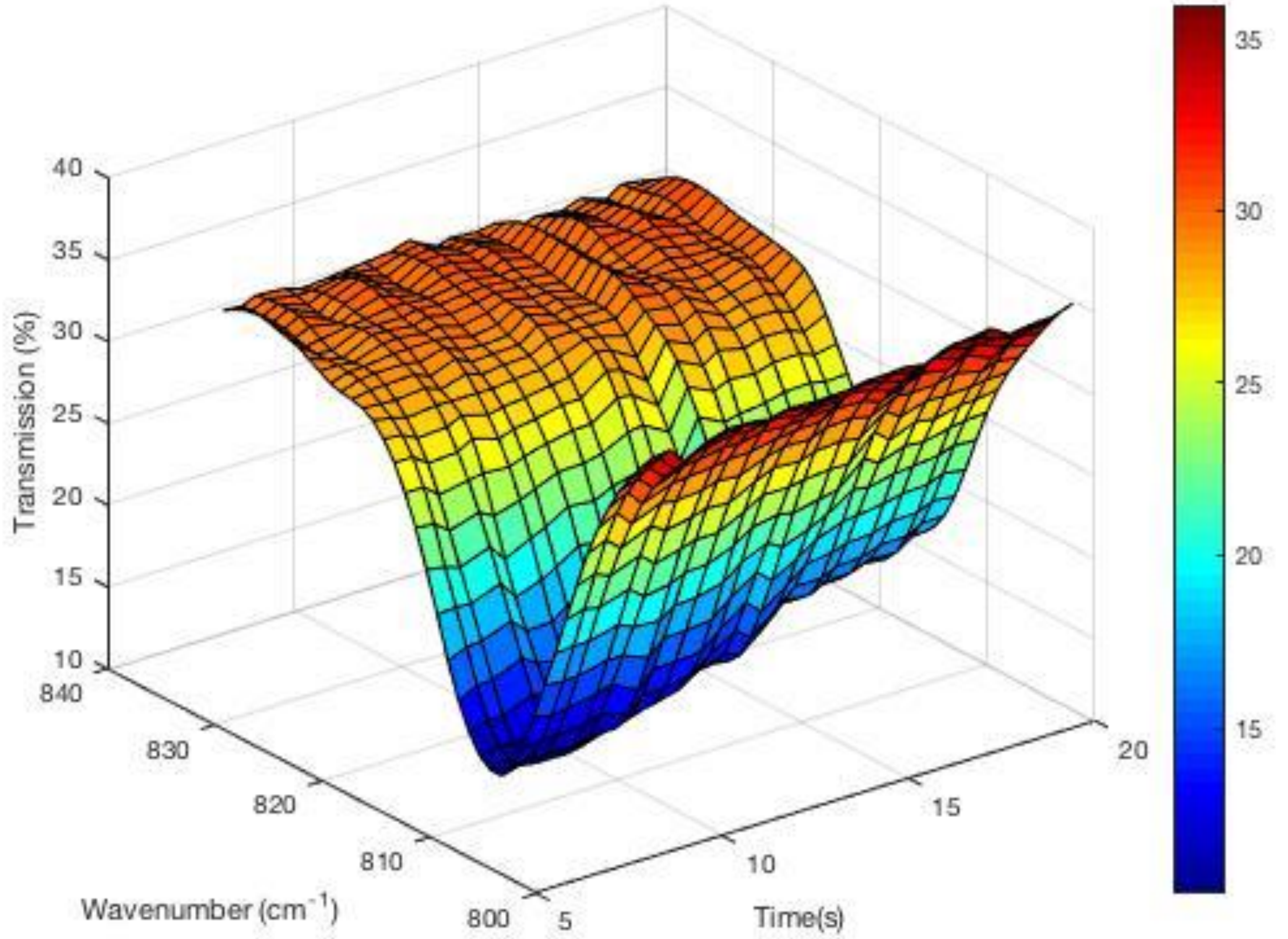


- Photo-DSC can be used to quantify conversion but also sheds light into the reaction enthalpy at various temperatures. Here we see signs of an auto-acceleration at elevated temperatures. Chemical bond resolution is needed.

Photo-FTIR

Experimental Set-Up:





- This technique measures conversion and kinetics by directly measuring the IR transmission through the acrylate double bond (810 cm^{-1}). Photo-FTIR and Photo-DSC agree when considering conversion but give complimentary information that tell the story behind what is happening during printing.

Print planner: A dynamic process controlled by software

Resin properties

- Dose-to-cure
- Molar absorptivity
- Viscosity
- “Green” mechanical properties

Machine configuration

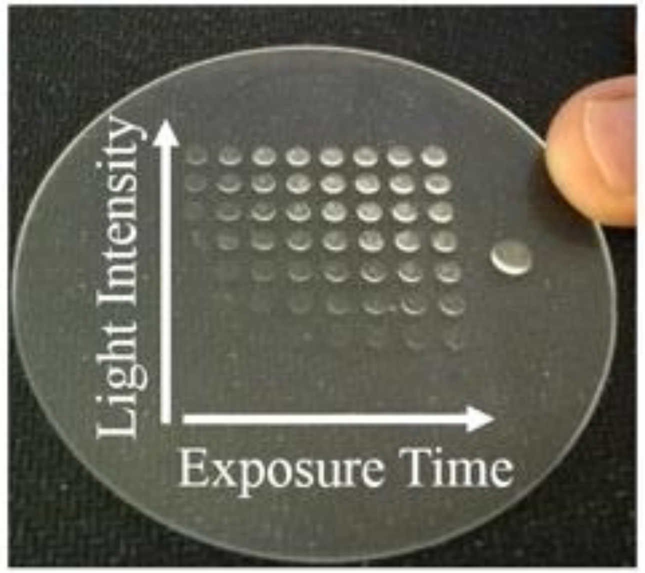
- Light intensity
- Oxygen flux
- Pixel size

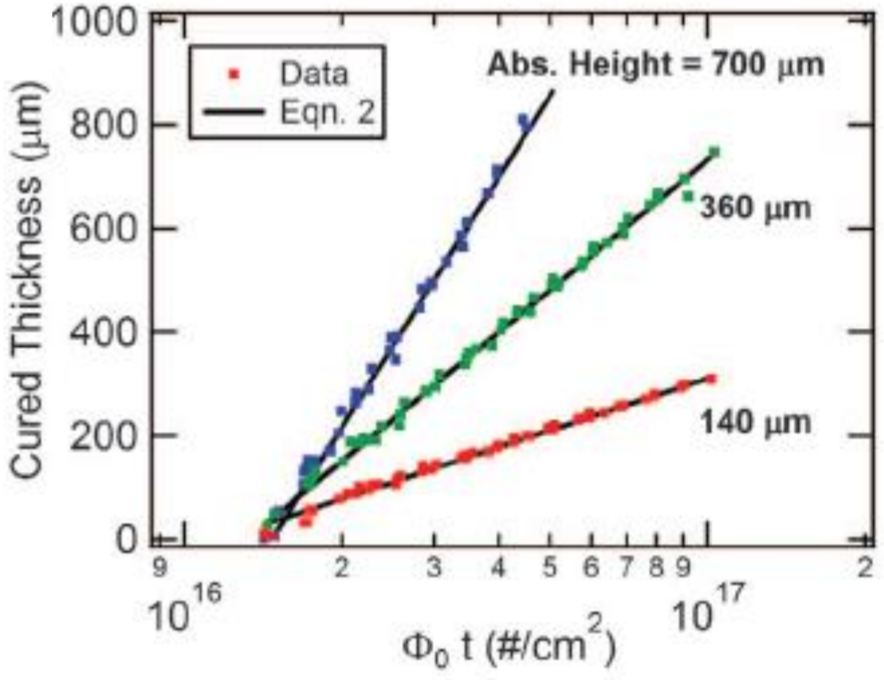
Part geometry

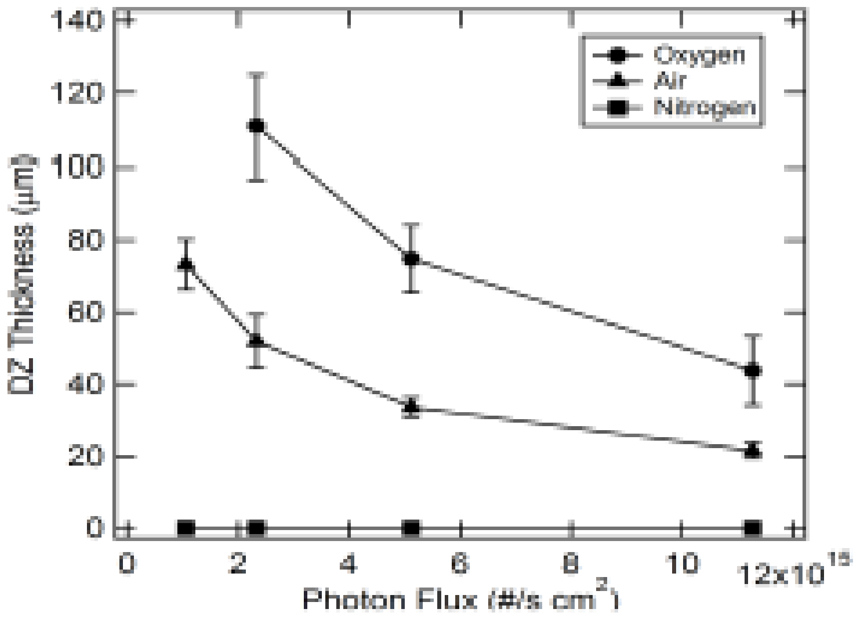
- Cross-sectional area
- Cavities and trapped volumes
- Orientation

Desired operating conditions

- Accuracy
- Trade-off between resolution and speed
- Use of latent heat
- General Purpose Printer mode vs Manufacturing mode







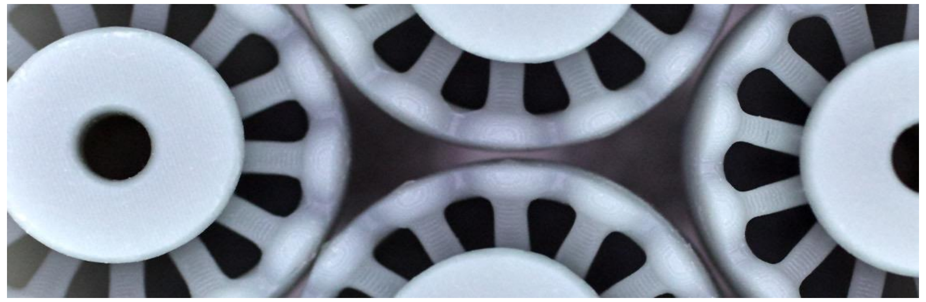
CARBON'S EXPANDING FAMILY OF RESINS

UMA Urethane Methacrylate

Rigid, fast prints

CE Cyanate Ester

High temperature resistance, strength, stiffness

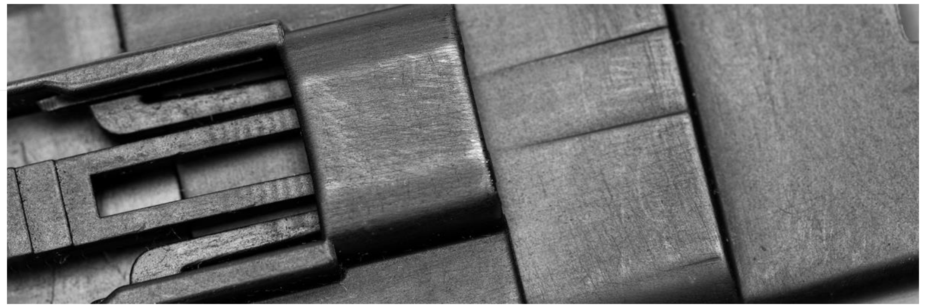


SIL Silicone-Urethane

Soft touch, biocompatible, and tear resistant

RPU Rigid Polyurethane

Tough + abrasion resistant, stiff

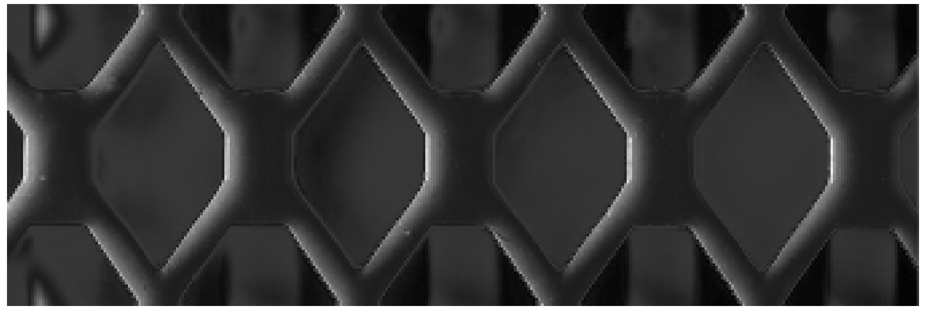


EPX Epoxy

Temperature resistant, strong, accurate

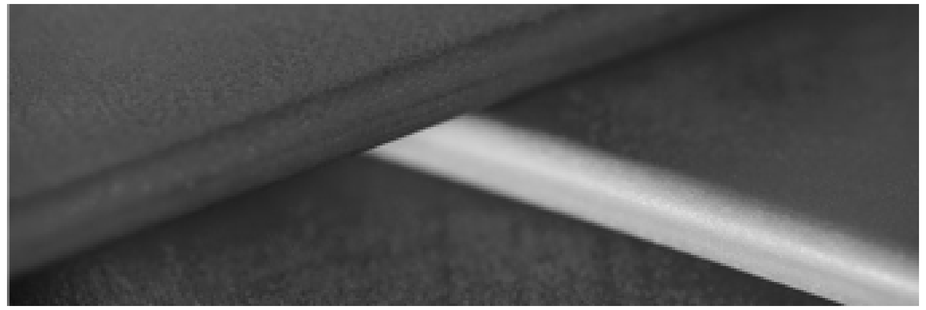
Dental Production

Prints fast and accurately



EPU Elastomeric Polyurethane

Highly elastic, resilient



FPU Flexible Polyurethane

Tough, impact + abrasion resistant, moderate stiffness

Third-party Materials

Clear, biocompatible, and print fast and accurately

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Programmable Dual-Cure Resins

1 **Dual-cure Resin**

US Patent 9,676,963

Programmable Dual-Cure Resins

1 Dual-cure Resin

2 UV Light Cured Green Part

CLIP

Continuous Liquid Interface Production sets the shape

Green Young's Modulus
250- 280 MPa

US Patent 9,676,963

Programmable Dual-Cure Resins

1 Dual-cure Resin

2 UV Light Cured Green Part

3 Thermally Cured Final Part

CLIP

Continuous Liquid Interface Production sets the shape

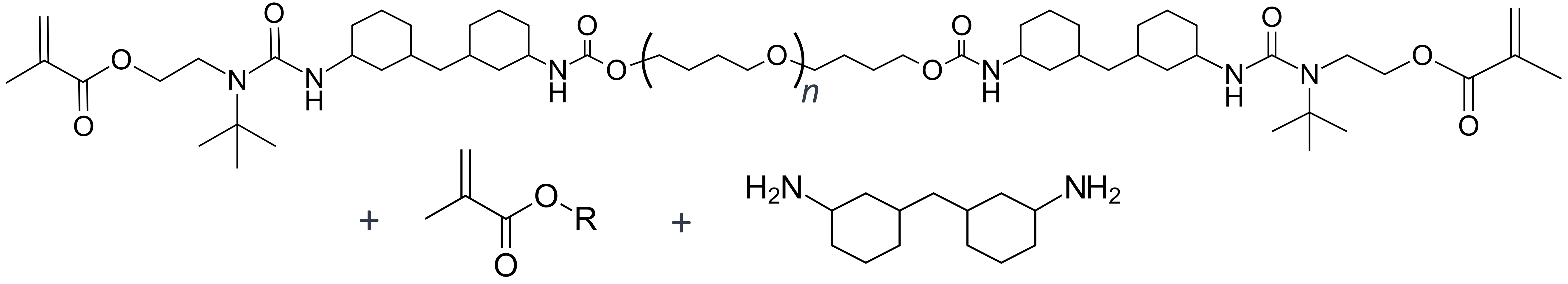
Green Young's Modulus
250- 280 MPa

Thermal baking provides ultimate mechanical properties

Cured Young's modulus
3800 – 4000 MPa

US Patent 9,676,963

Acrylate blocked polyurethanes (ABPUs) as a platform for high performance 3d-printed materials



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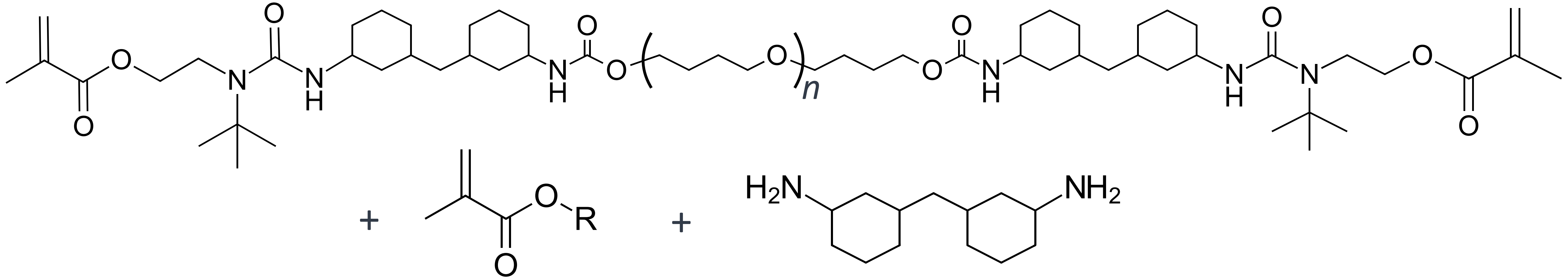
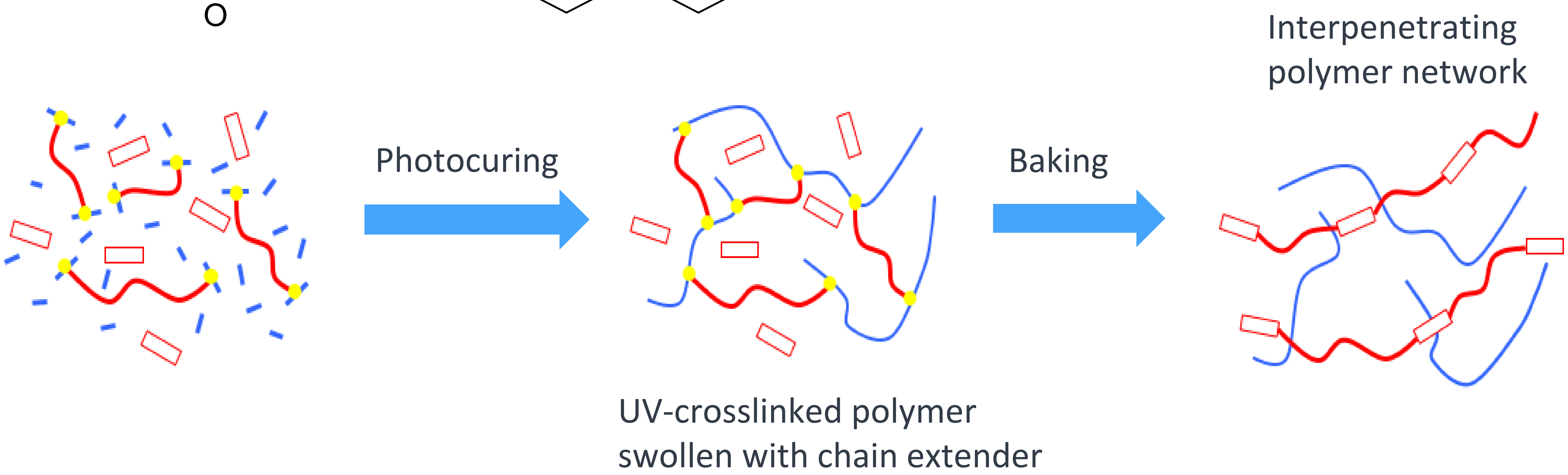


- ABPU
- Reactive diluent
- UV absorber
- Pigment
- Photoinitiator



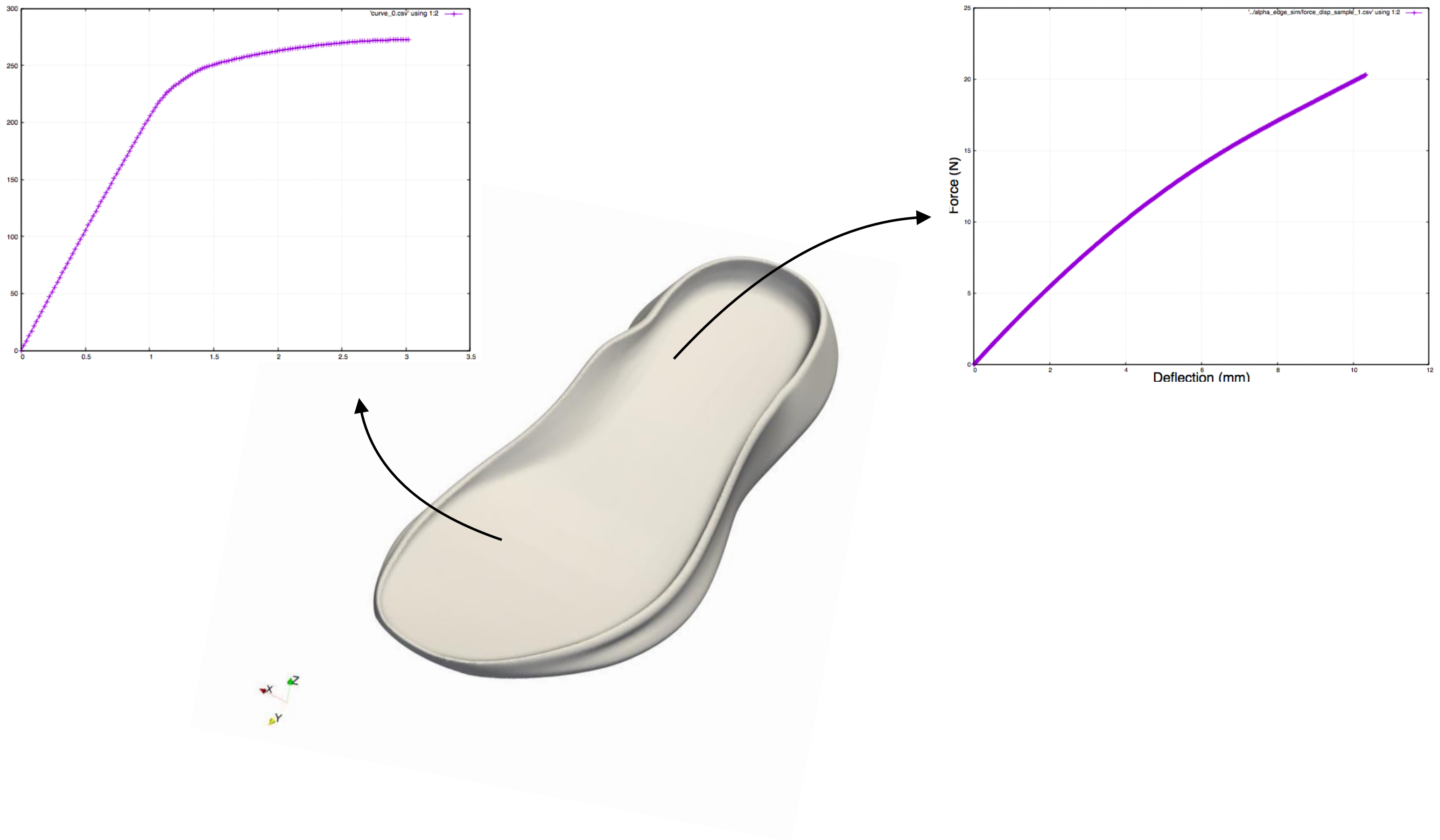
COMPUTER AIDED LATTICE DESIGN

INPUT

CAD of primitive, the loading conditions and expected mechanical responses, the cost function (optimize for weight, speed …)

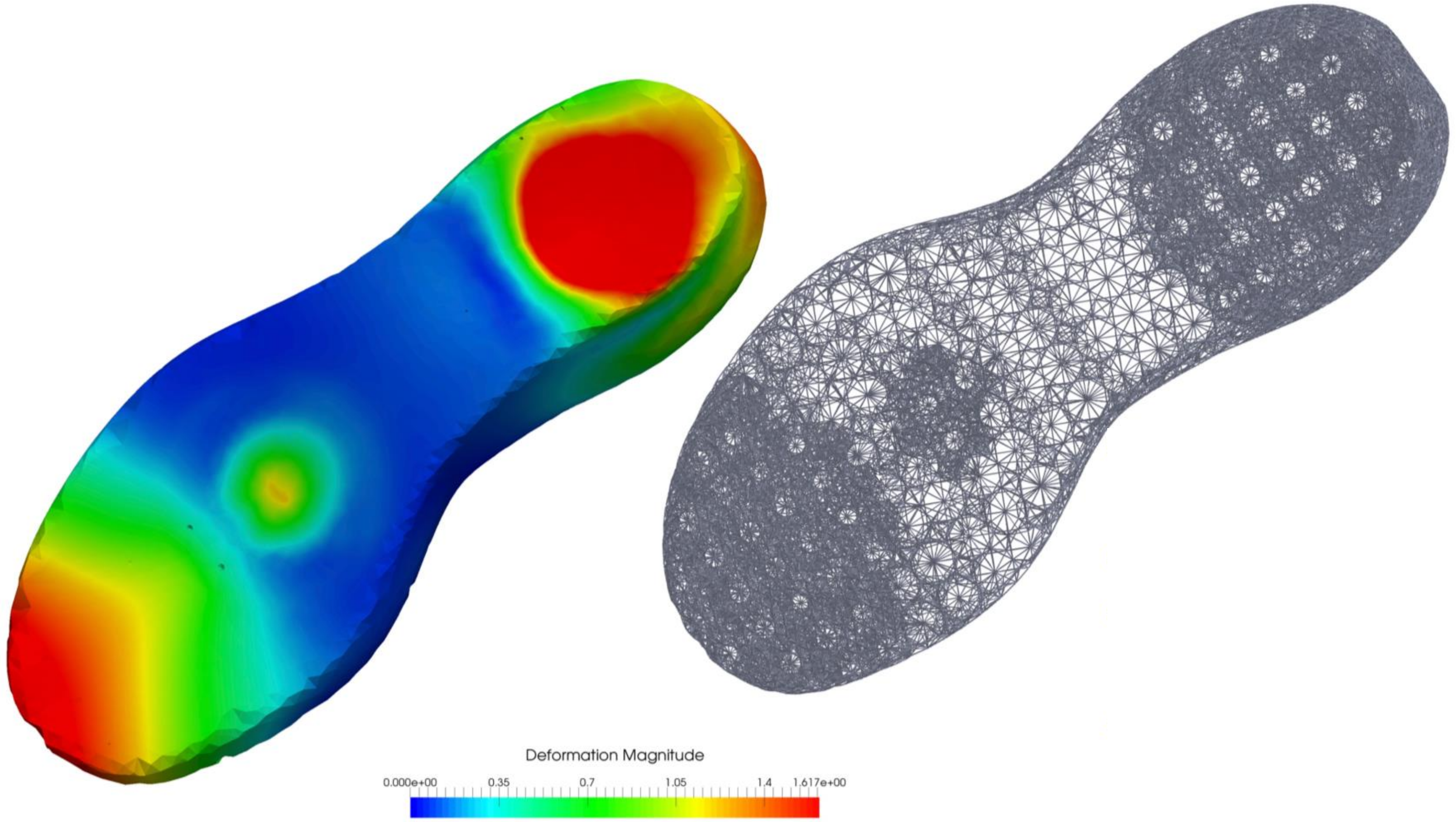
OUTPUT

DLS manufacturable latticed design(s) with different materials



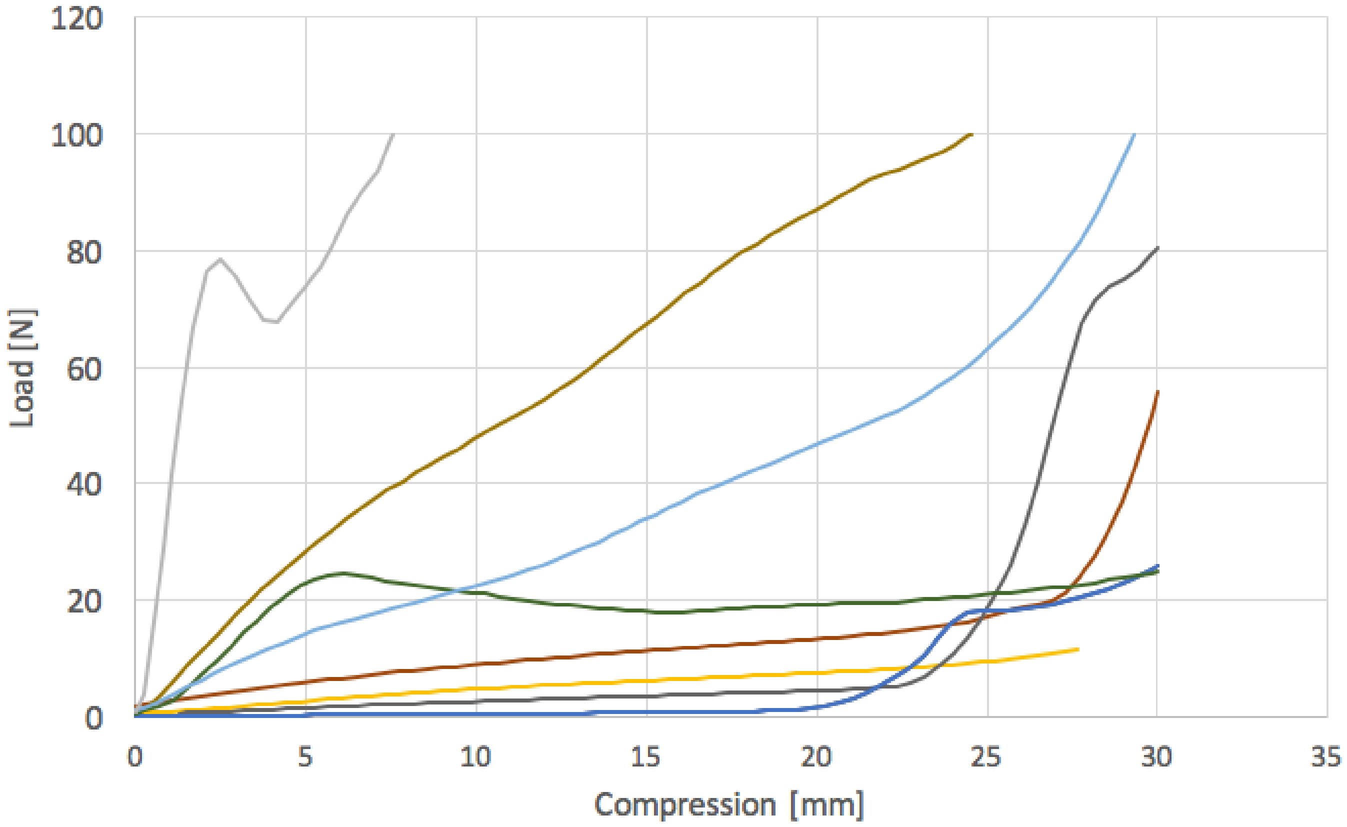
COMPUTER AIDED LATTICE DESIGN

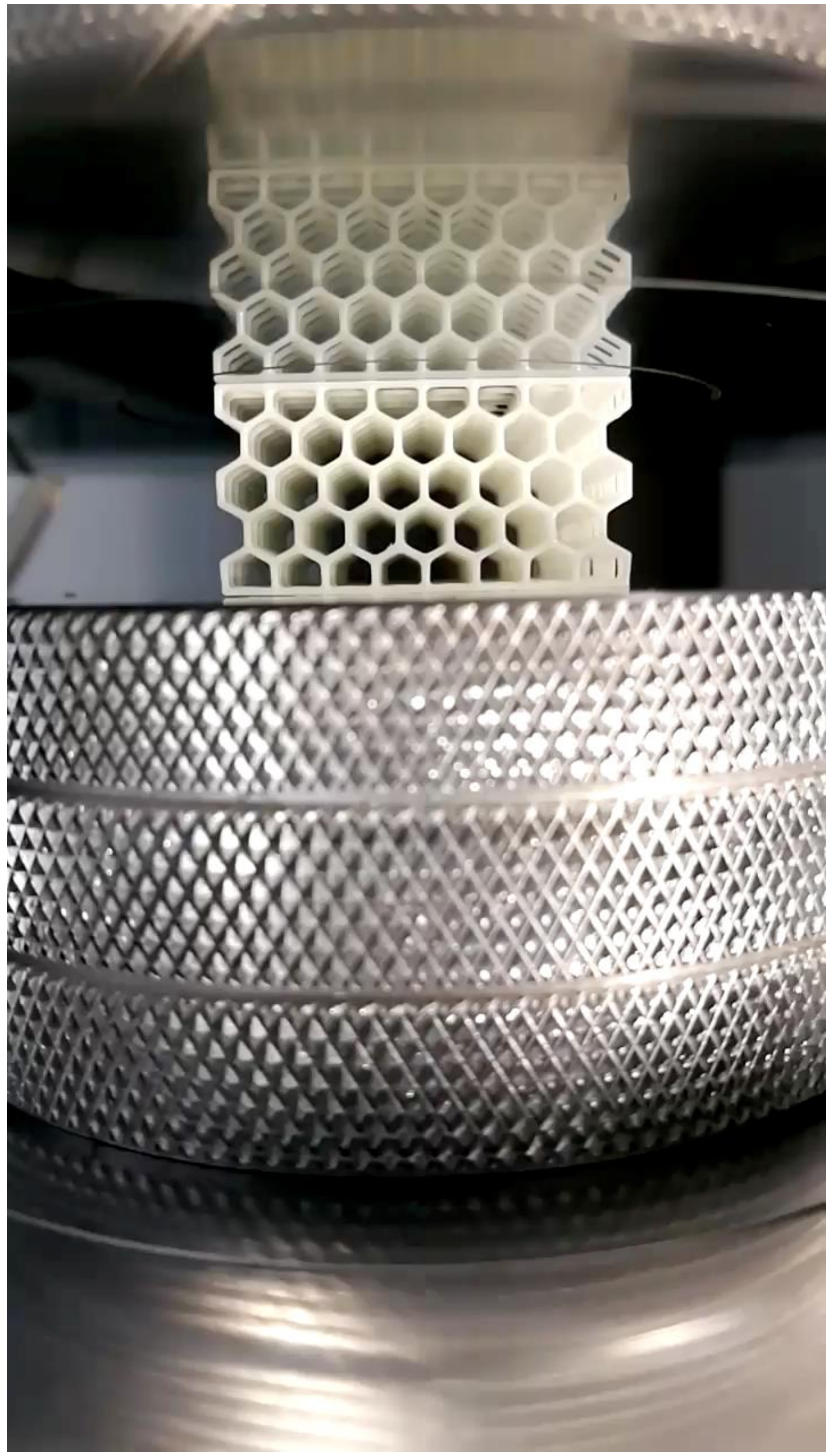
- Output lattice designs can have more than a mechanical response based on different geometric structures.
- An algorithm smooths the two different mechanical responses in the single CAD.



WIDE VARIETY OF MECHANICAL RESPONSES

- Difficult to know how best to choose lattice parameters
  - Unit cell, min/max size of cell, cell gradients, strut thickness, printability
- Preferable to describe the performance and response needed across the part—maximum mass allowed—and software should do the rest





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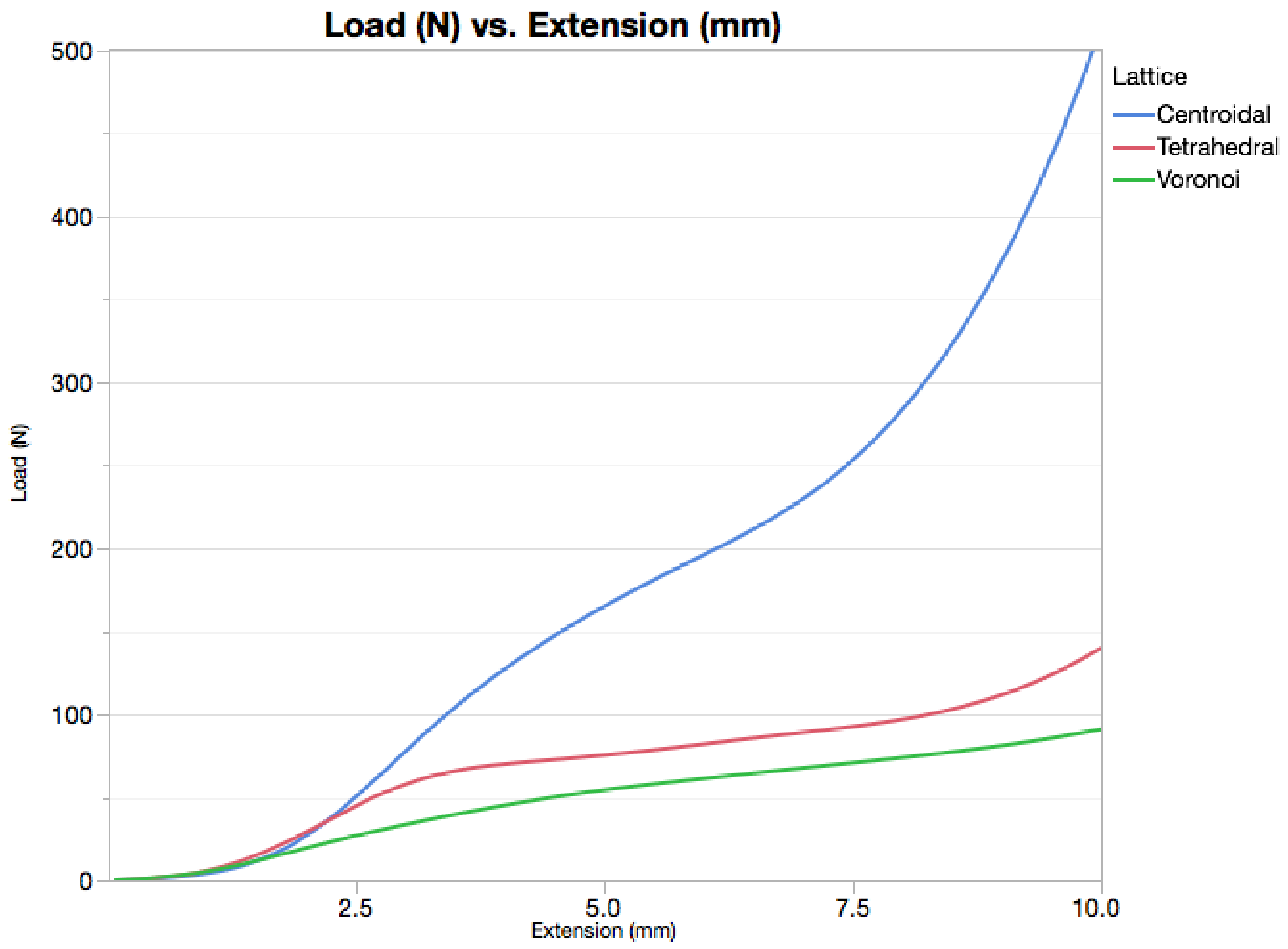
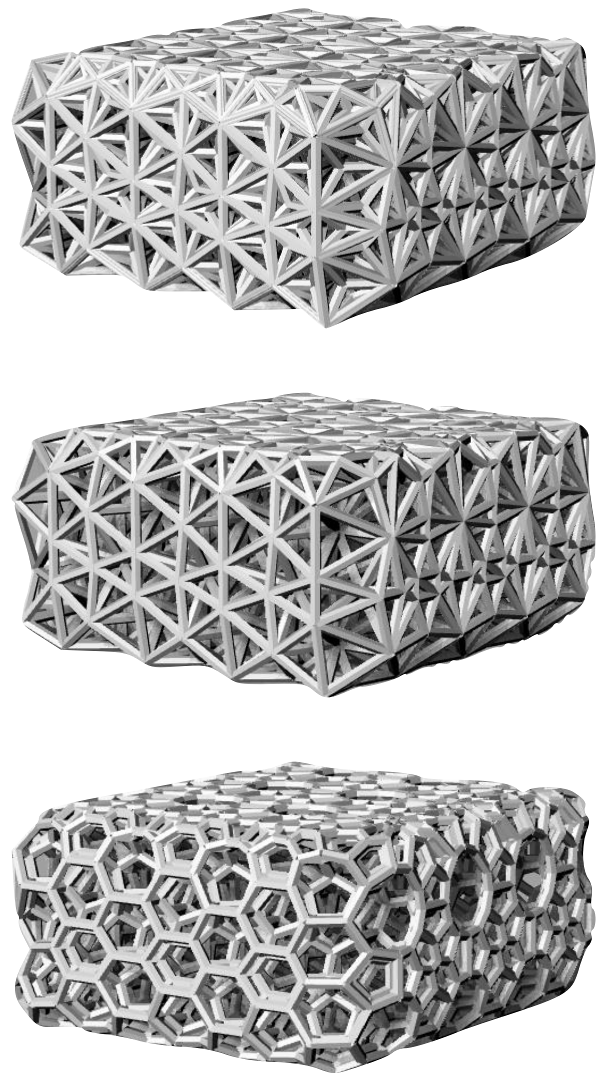
LIBRARY OF META MATERIALS

- We can generate a variety of mechanical responses from the same material and bulk volume.
- **Assembled 100+ data points**: mapping geometry structure, strut thickness, and other lattice parameters to mechanical responses.





Mechanical response measured on Instron

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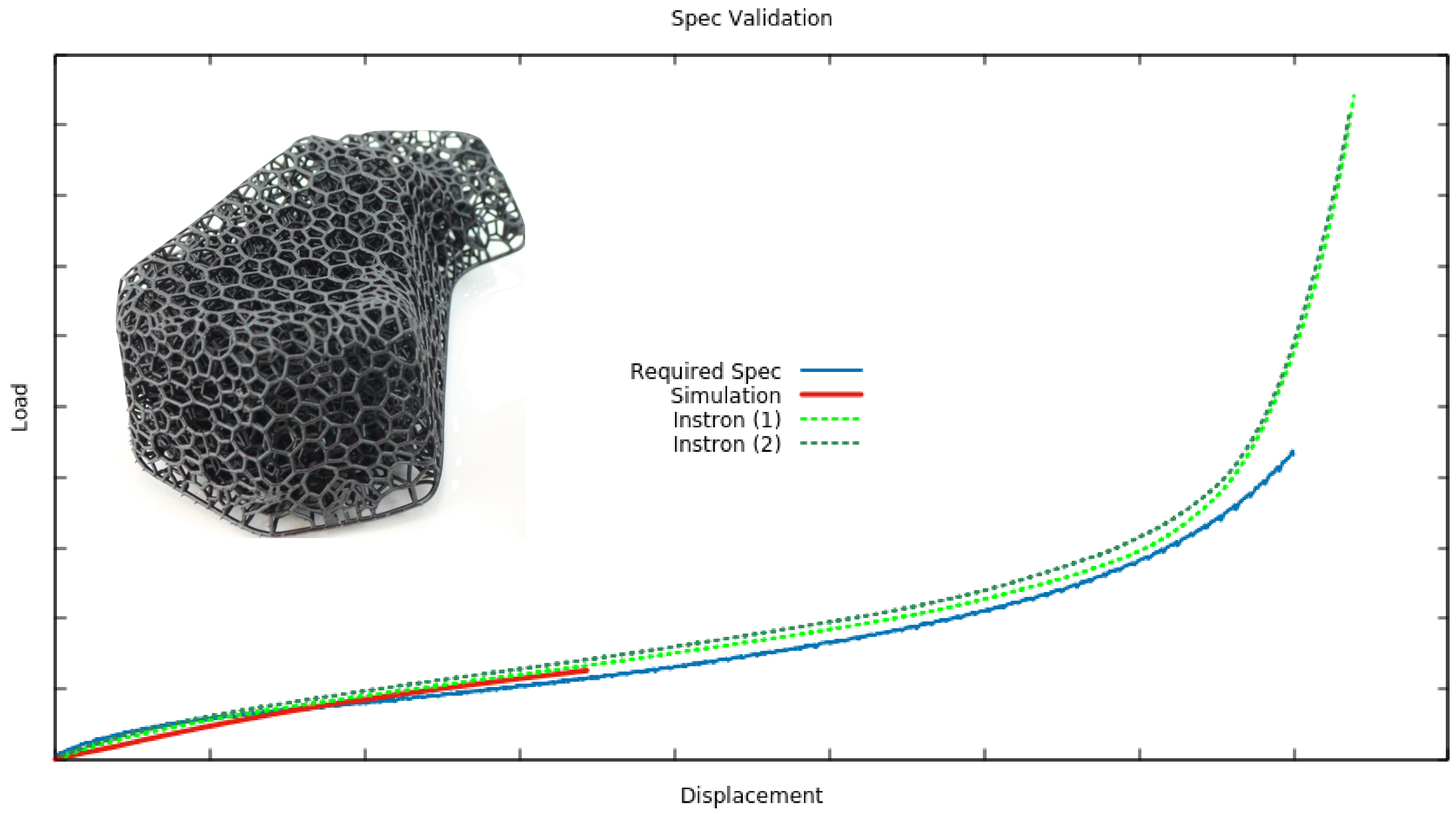
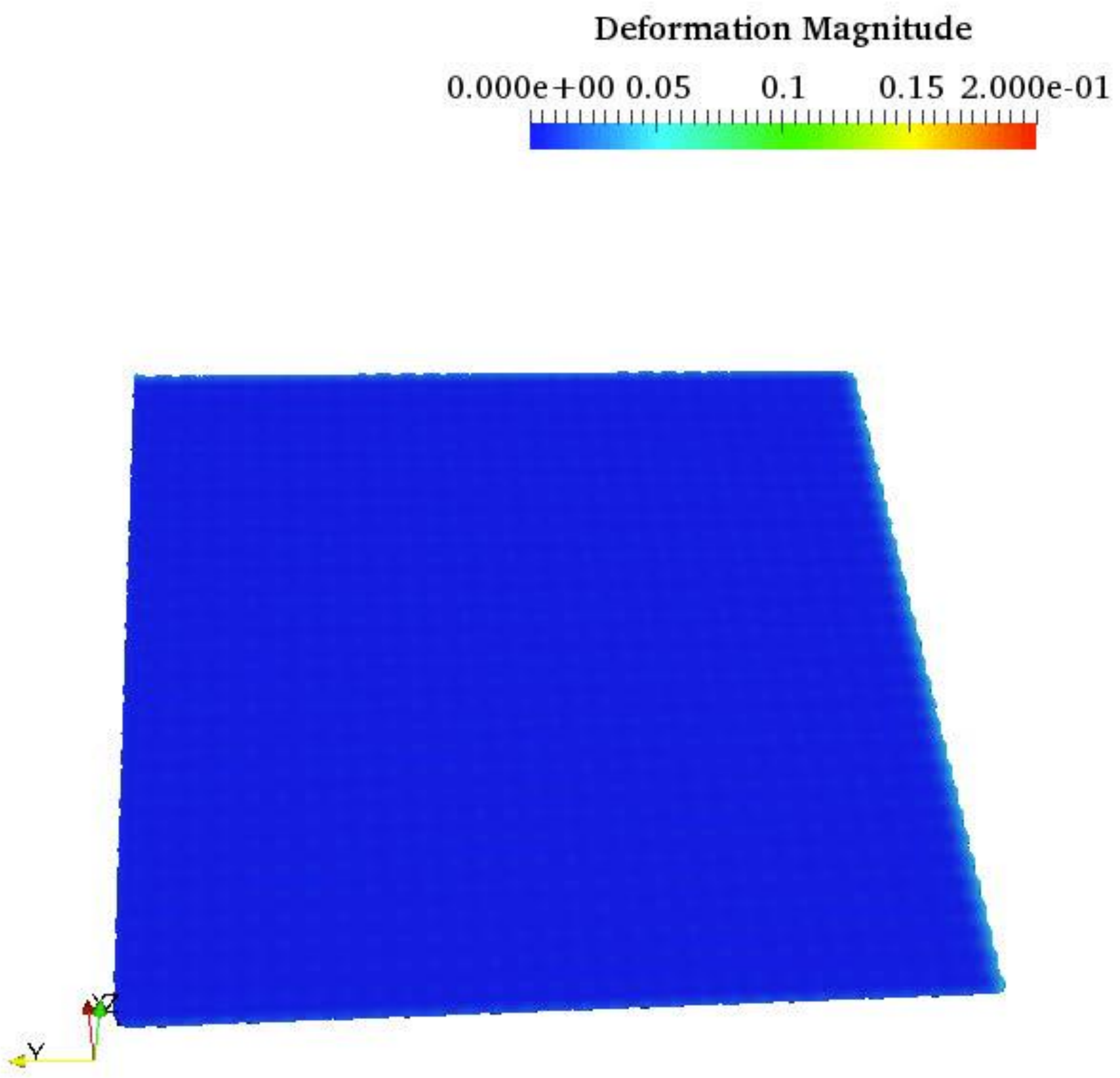
EXAMPLE: SIMULATION BASED DESIGN

- Customers provide us with the expected mechanical response of the part: stress-vs-strain curve measured on their test setup.
- The software module runs a number of optimization simulations to find the set of lattice parameters and resin that can achieve the spec.



DESIGNING FOR DLS USING SIMULATIONS

- We simulate the DLS process for any given part to guide the design optimization.
- **A completely autonomous** FEA module, for closed loop optimization.
- Used to validate the design at **each optimization iteration** and give it it a score to choose the best design in terms of manufacturability.
- The **simulations imitate the DLS process** slice by slice and predict deformation of the geometry during the print process.
- FEA based simulation software runs on AWS.



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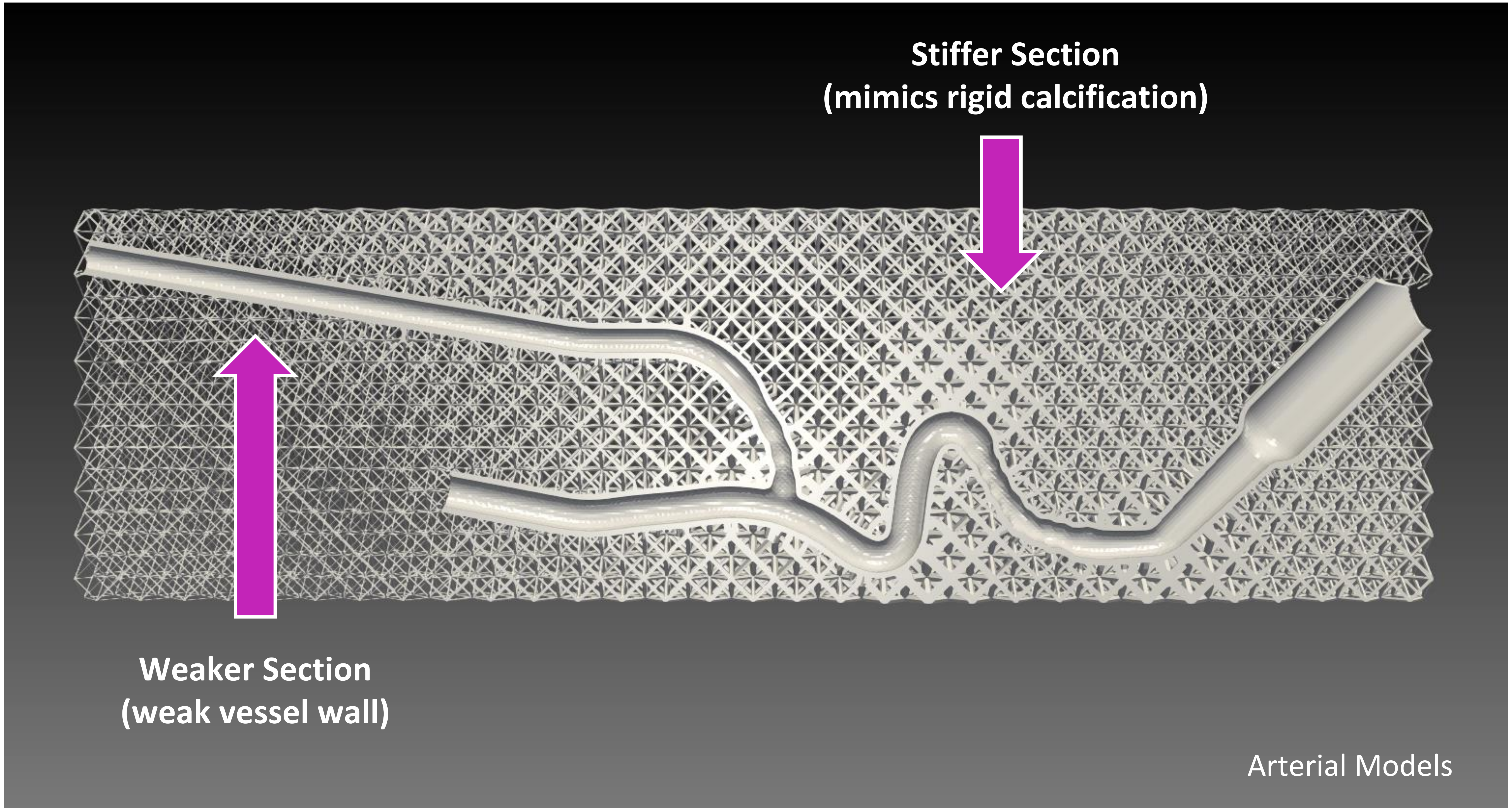
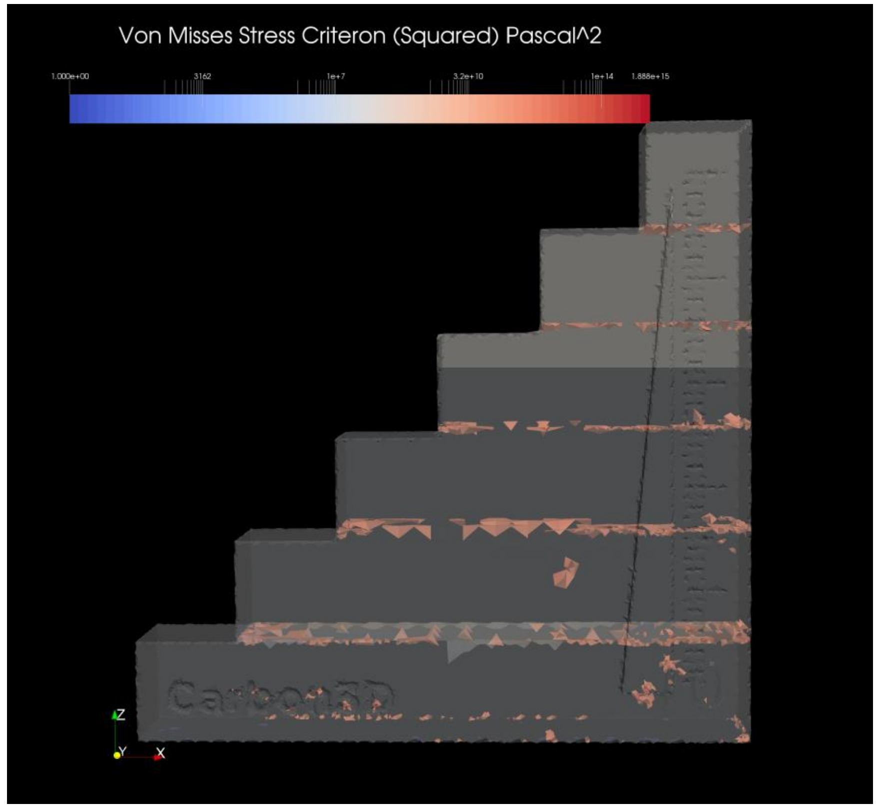
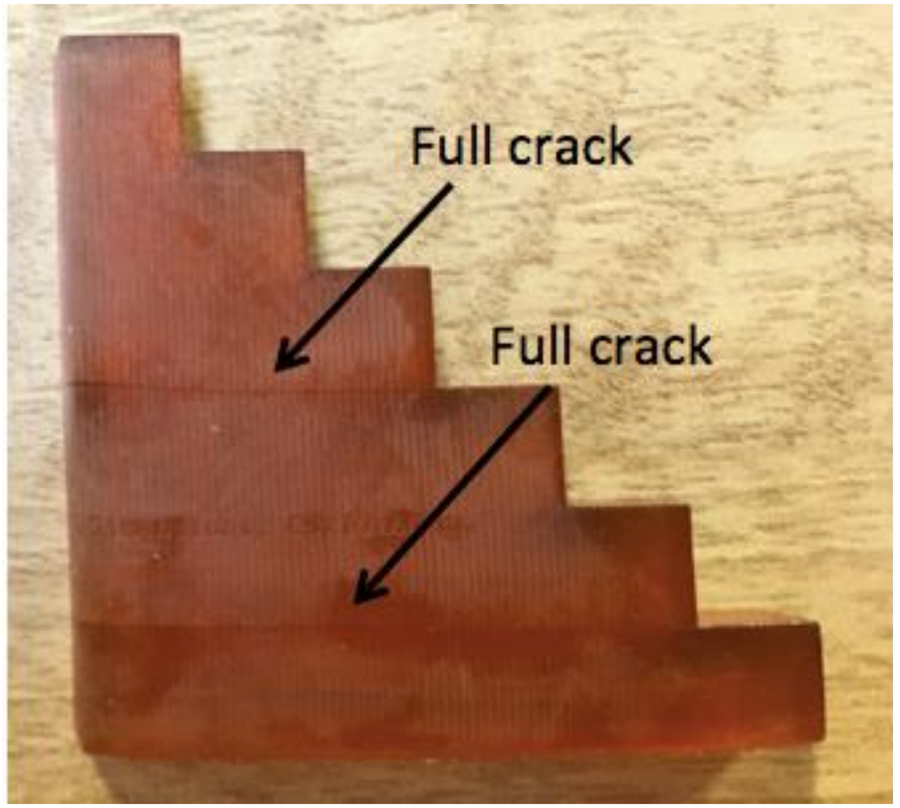
VARYING LATTICE DENSITY TO MIMIC RADIAL COMPLIANCE OF THE VESSEL



DESIGNING FOR DLS USING SIMULATIONS

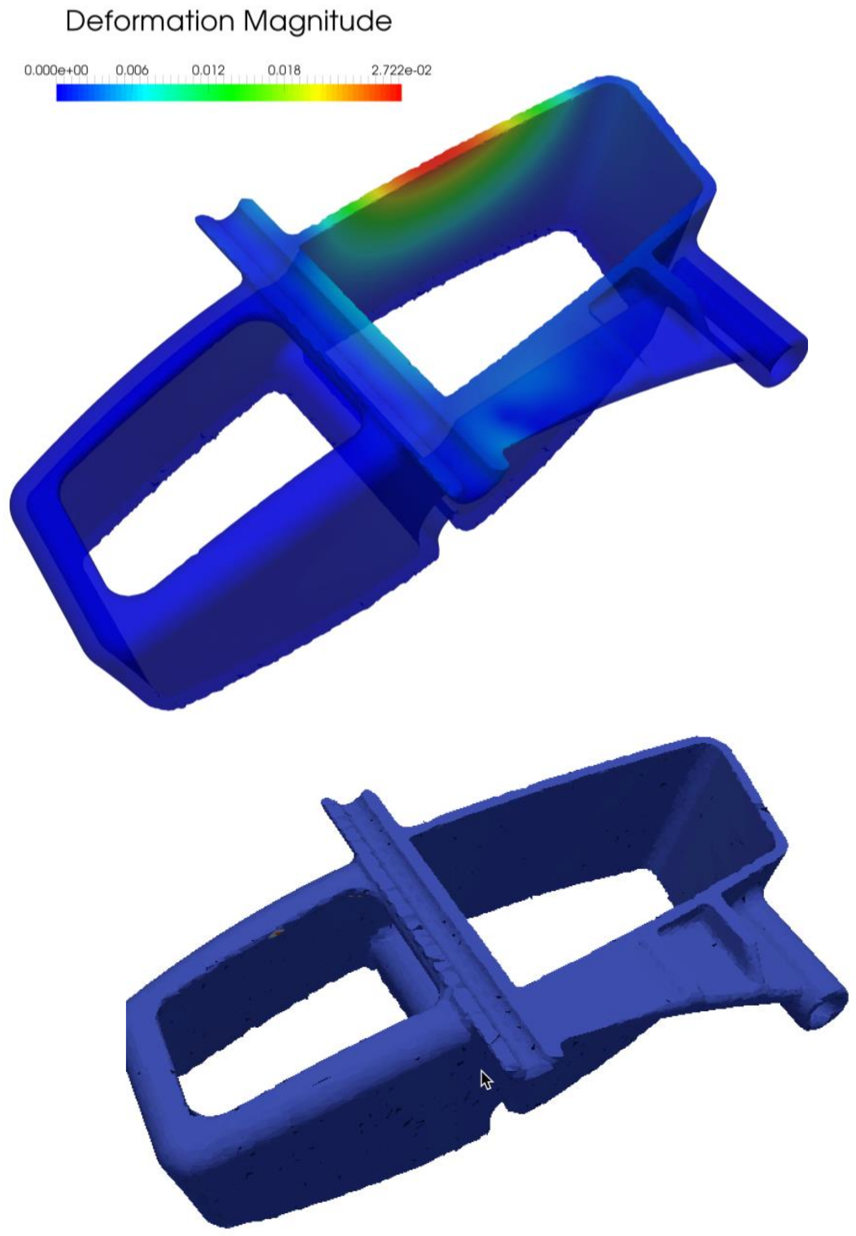
- Simulations produce an elastic (deformation) response of the material based on the part geometry and material parameters.
- This enables us to compute stress inside, compare that against green yield strength, and guide the design to be robust for manufacturing with DLS.





SIMULATION BASED SUPPORT GENERATION

- Simulations are used to automatically generate supports **for any given part.**
- We perform elasticity simulations **to predict how the part will deform under the effect of suction force** applied by the fluid.
- We run an optimization problem at each slice to figure out the minimal supports we need to put **to print a geometrically accurate part.**



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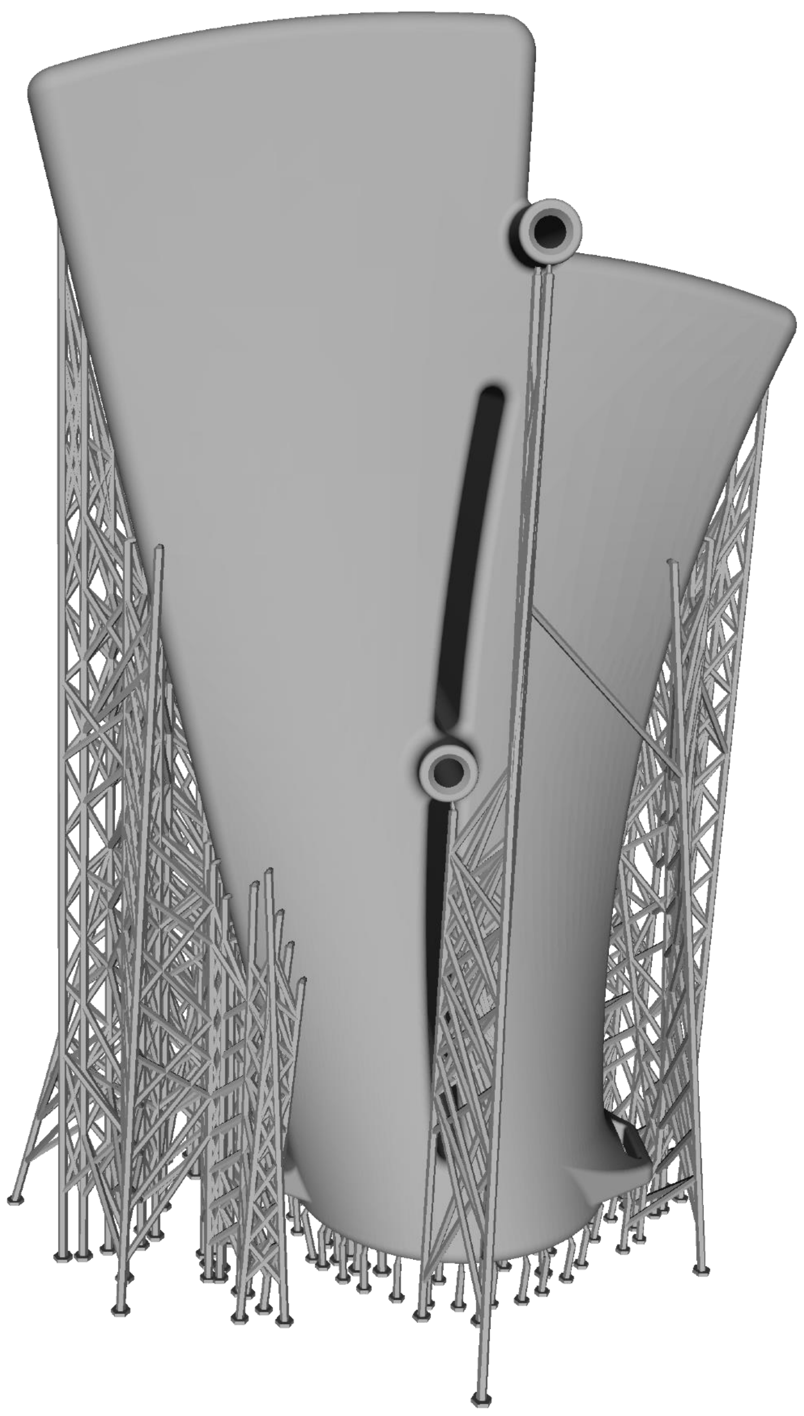
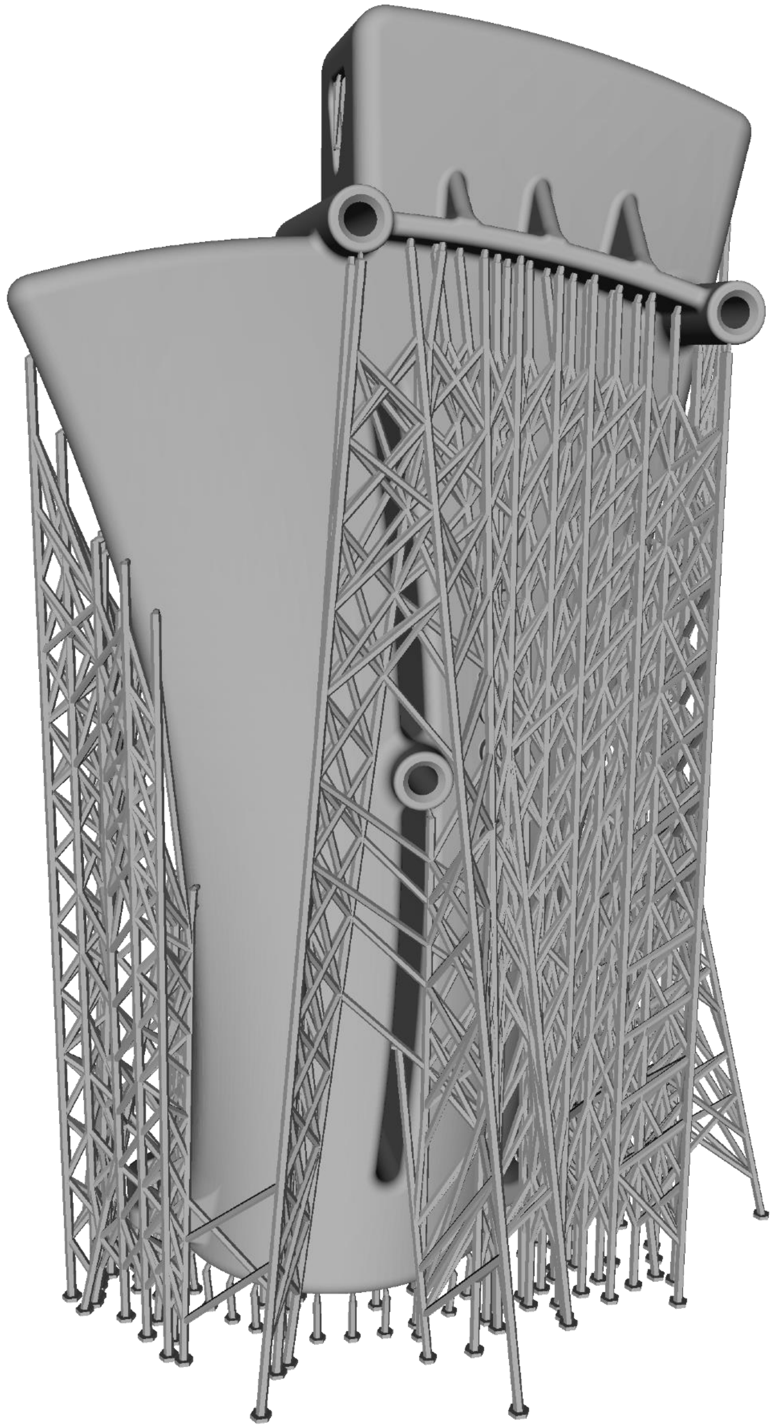
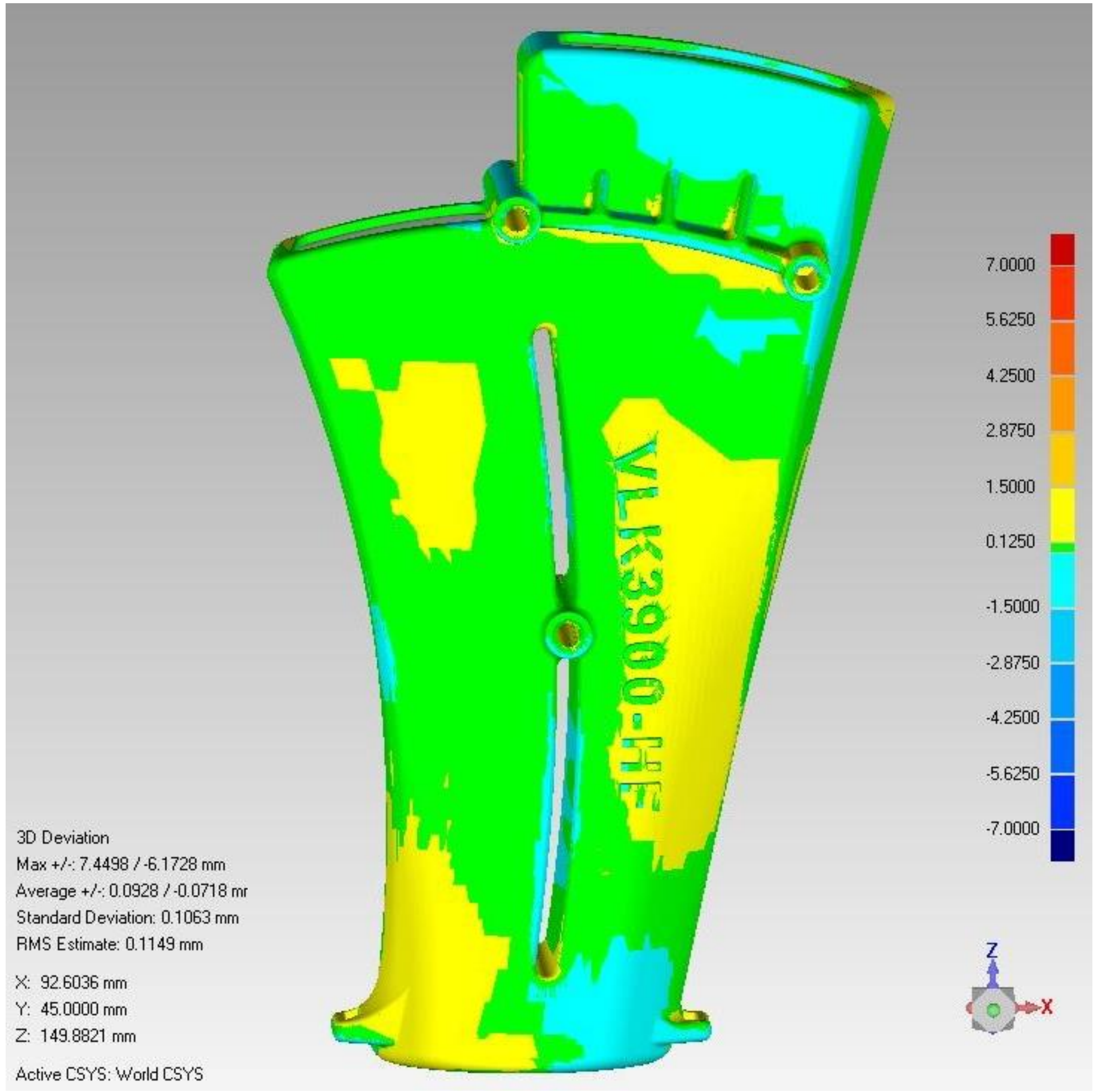
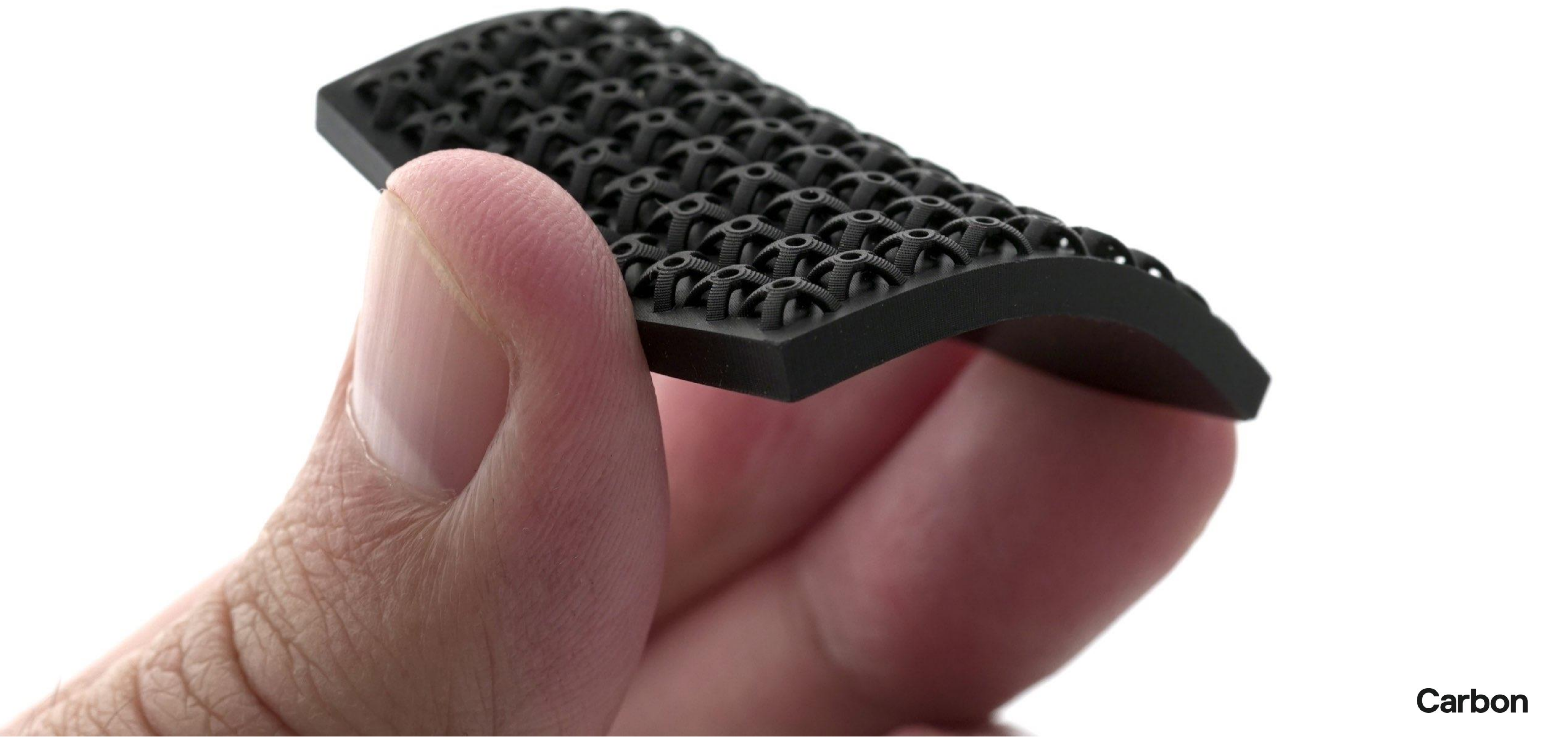






UNIQUE TO DLS: TEXTURE PRODUCTION PARTS



Biomimicry

Friction control

Hydrophobicity

Tunable mechanical properties

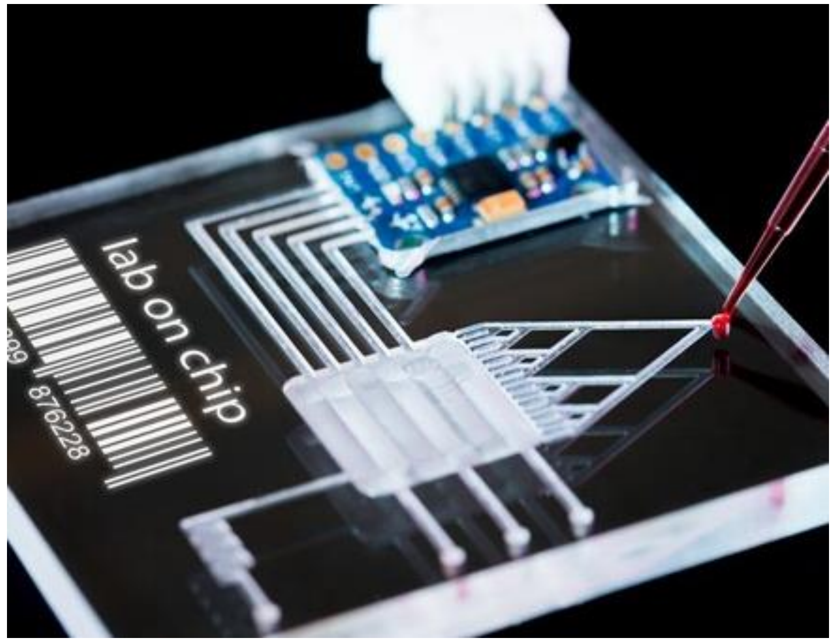
Flow control

Micro-needles

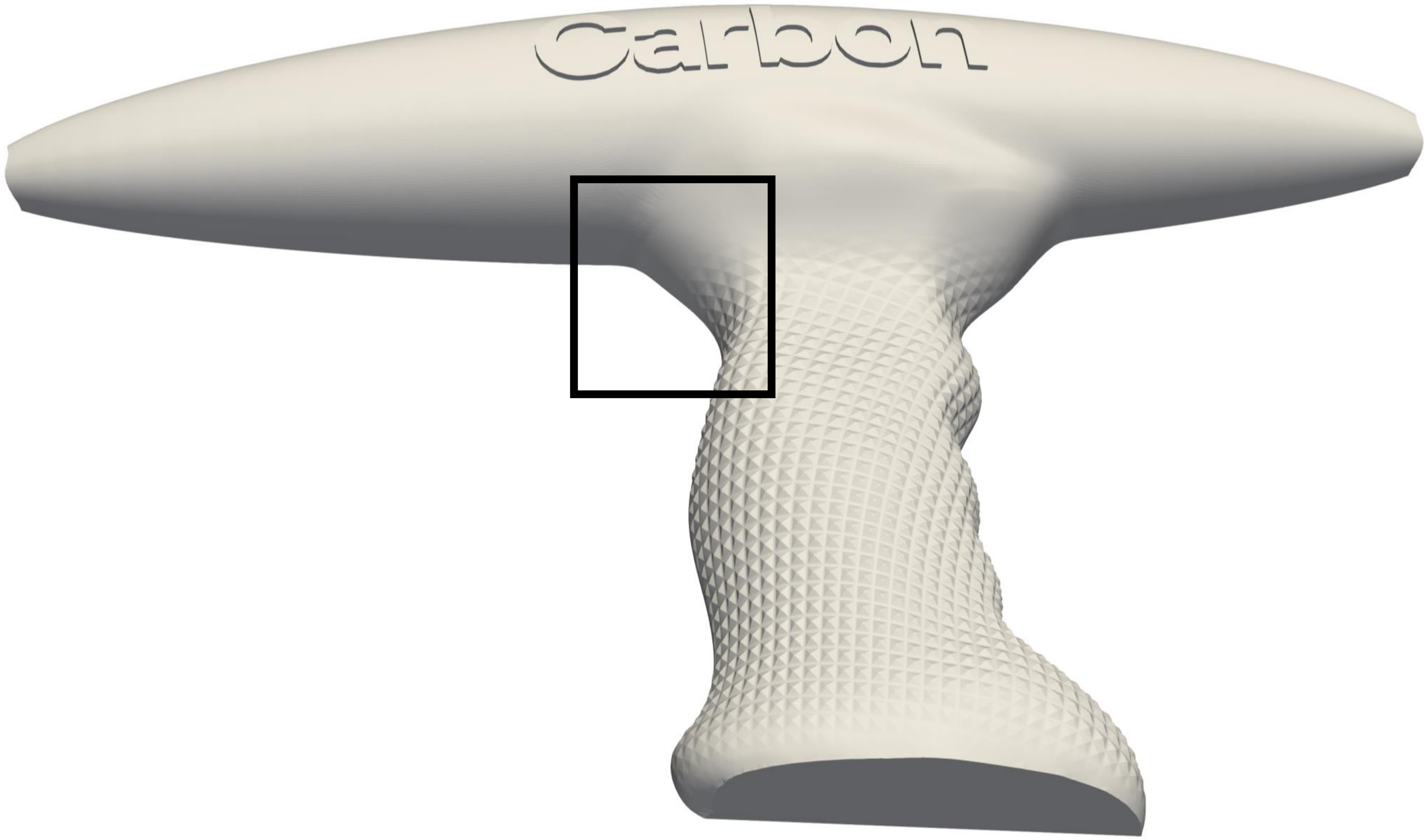
Sound and vibration dampening

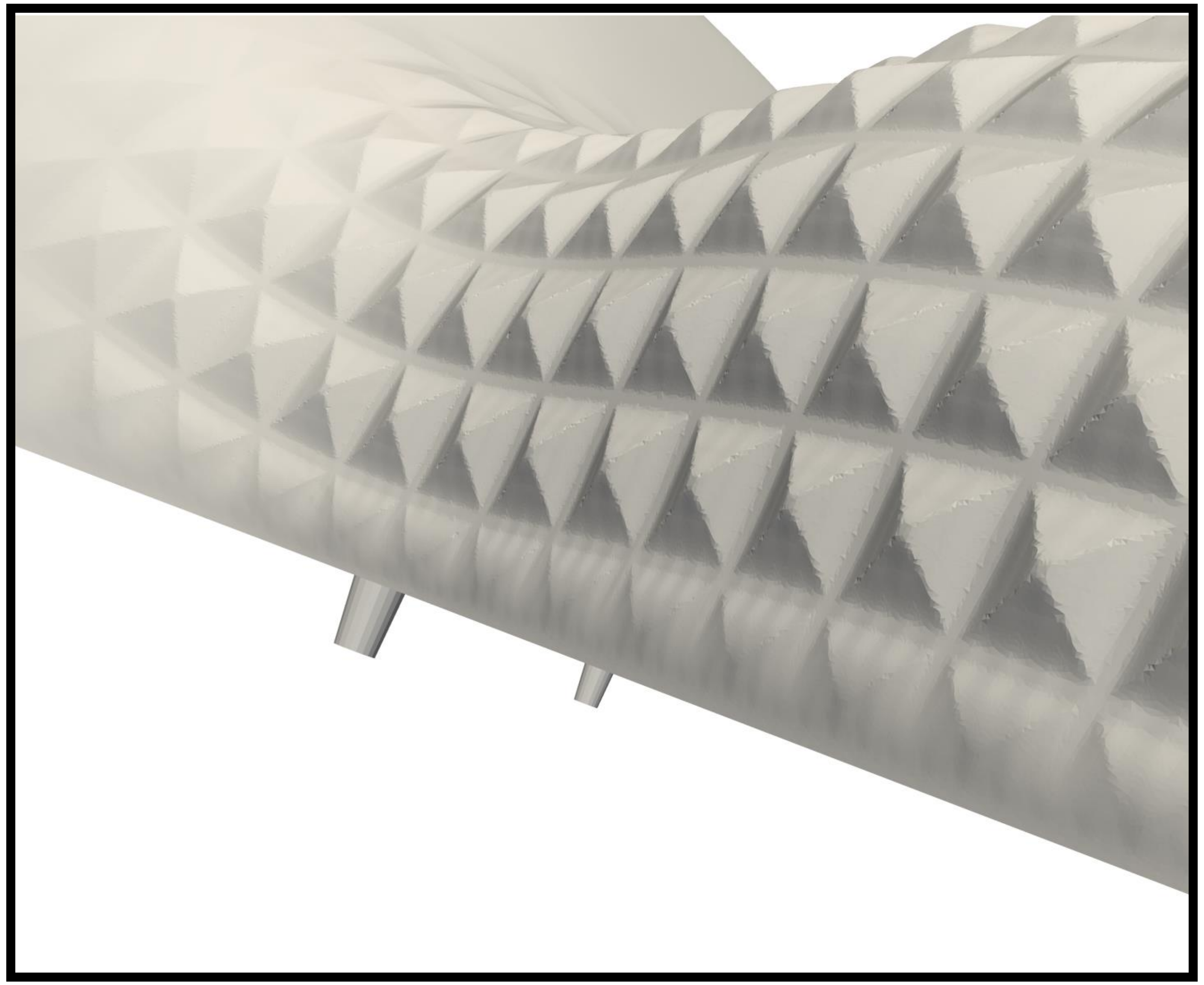
Ventilation

…



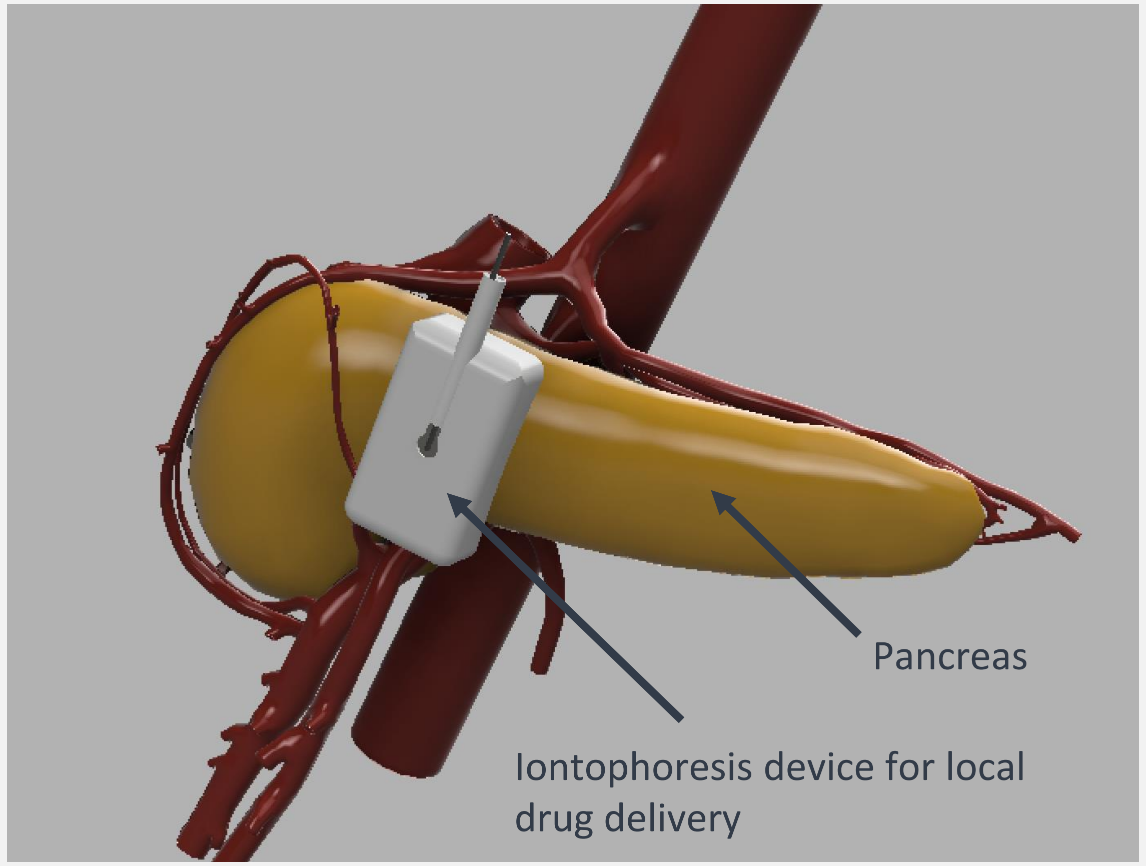
AUTOMATED TEXTURE APPLICATION

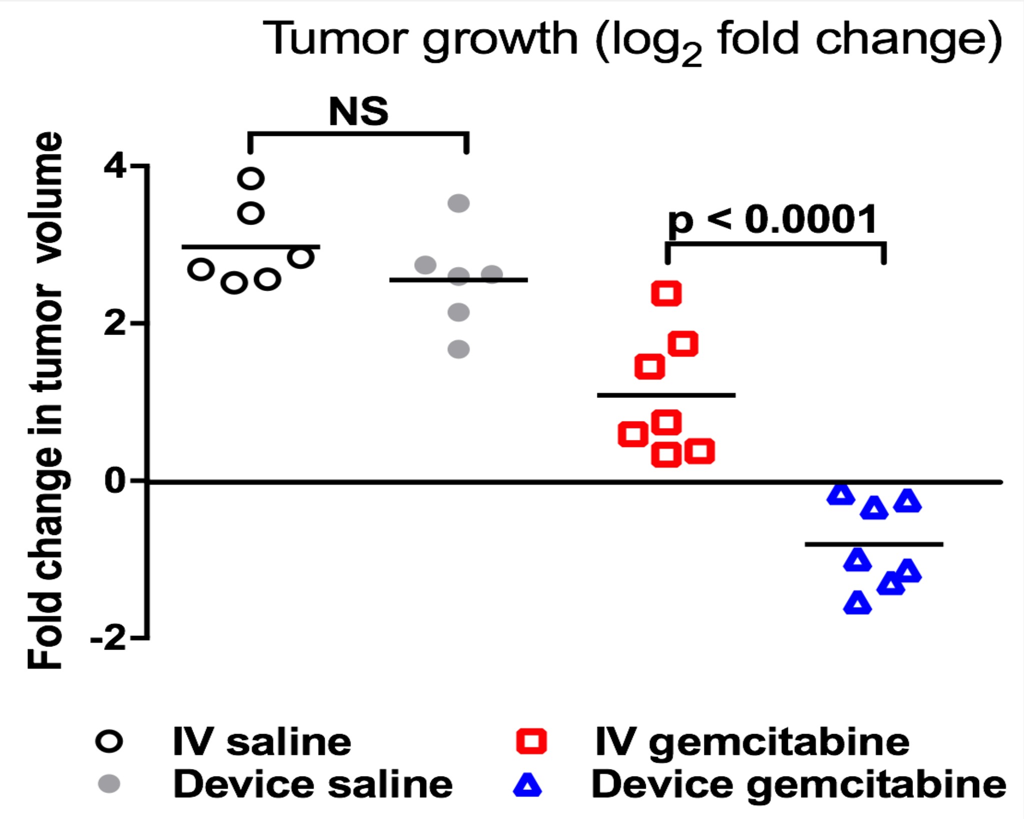


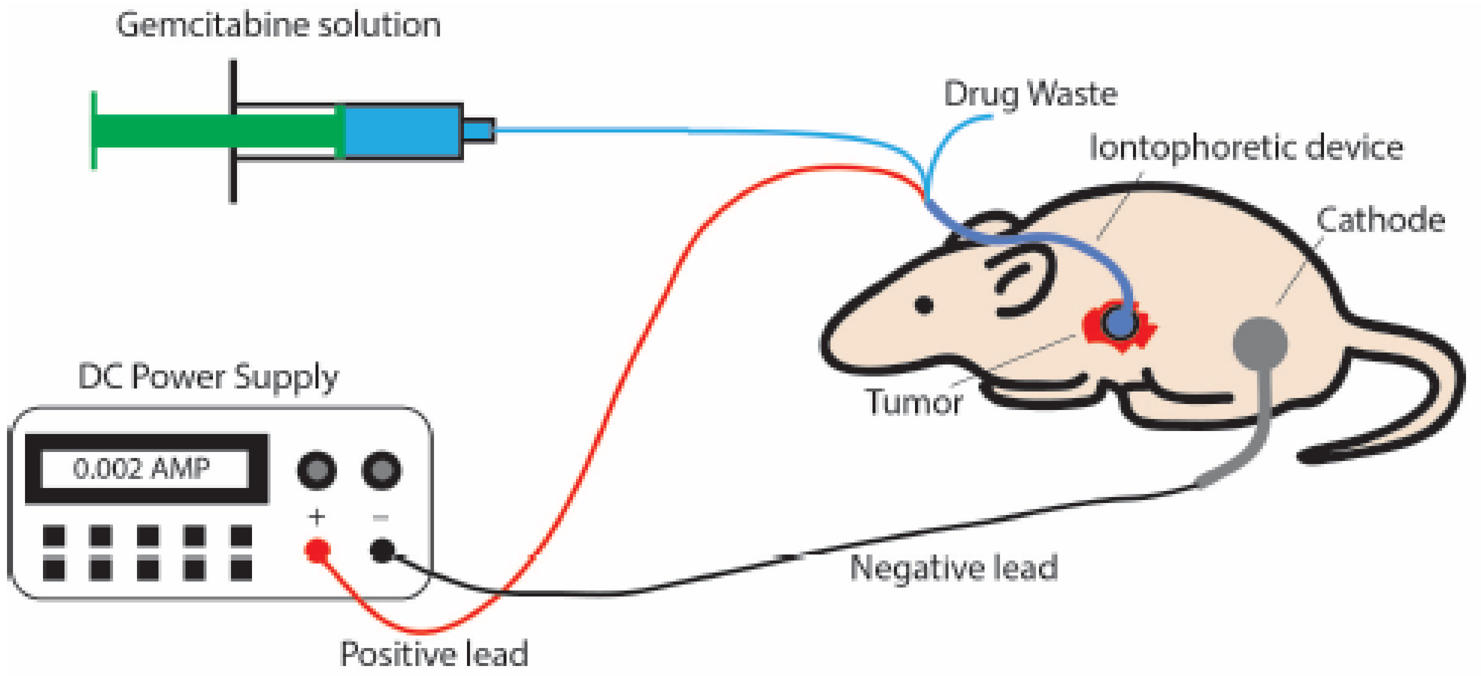


Local Drug Delivery: Pancreatic Cancer

- 53K new pancreatic cancer cases each year
- 5-year survival rate < 7%
- Only 15% of patients eligible for surgery
- Iontophoresis drug delivery shrinks tumors by 40%







[2] "Local iontophoretic administration of cytotoxic therapies to solid tumors", Byrne JD et al. *Sci Transl Med*. 2015 Feb 4;7(273).

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Anelle

IVR for Infertility Treatment

AnelleO PRO: Anello is a UNC-CH startup founded by Rahima Benhabbour.

DESCRIPTION

- Intravaginal ring for sustained release of progesterone

UNMET DEVELOPMENT NEEDS

- 1.7 million women treated annually for infertility in the US
- Current treatments: daily gels, inserts, or IM injections
- Total market $1.5B

SOLUTION

- Design controls mechanical properties, release kinetics
- Sustained release of progesterone for 30–90 days
- 100% release vs. 15–20% release with conventional IVRs
- *In vivo* local and systemic safety data in rodents

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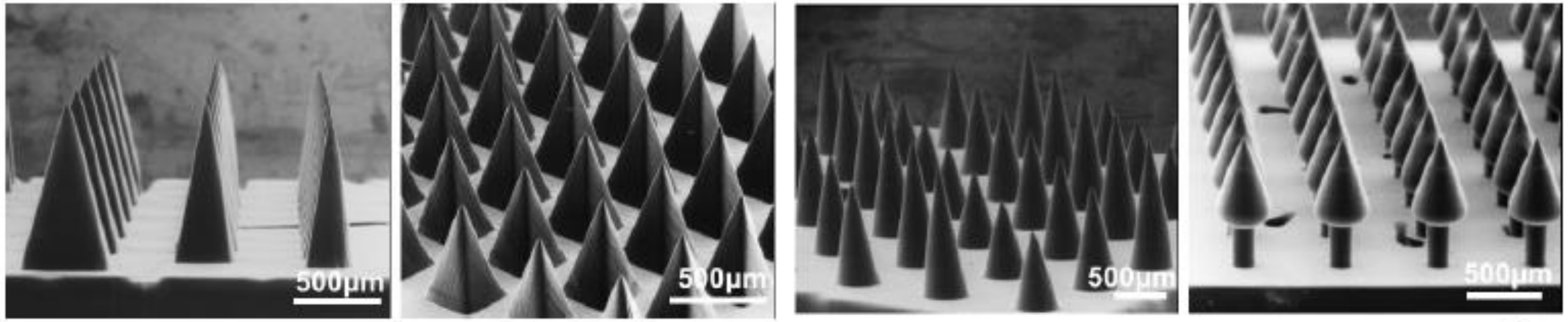
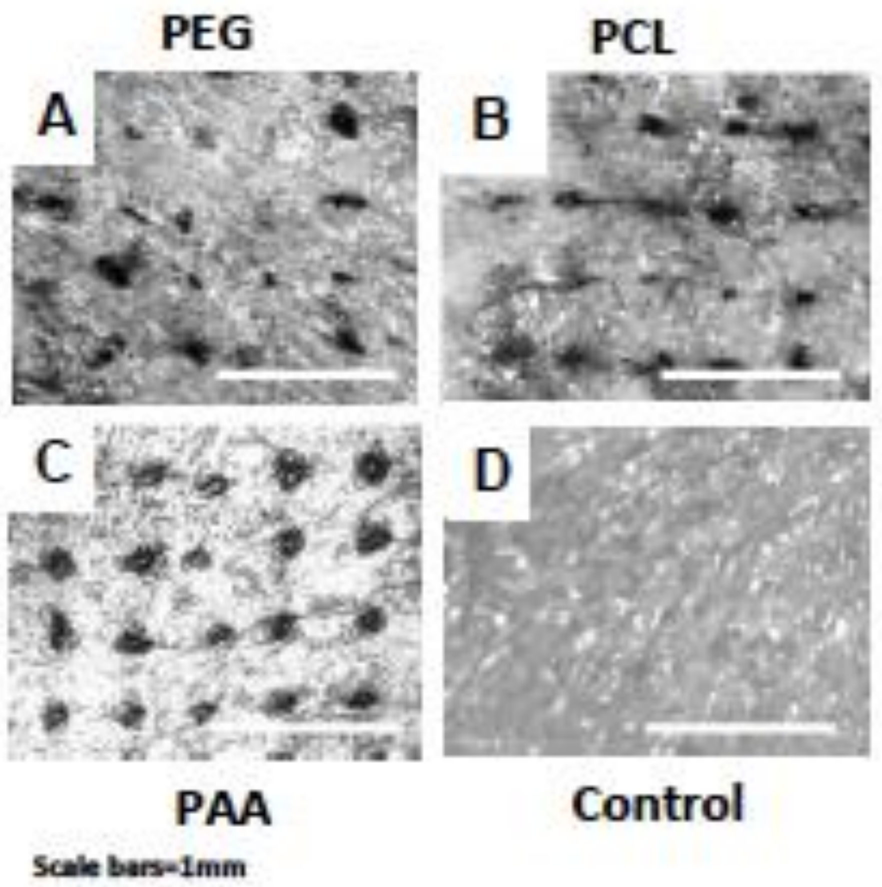
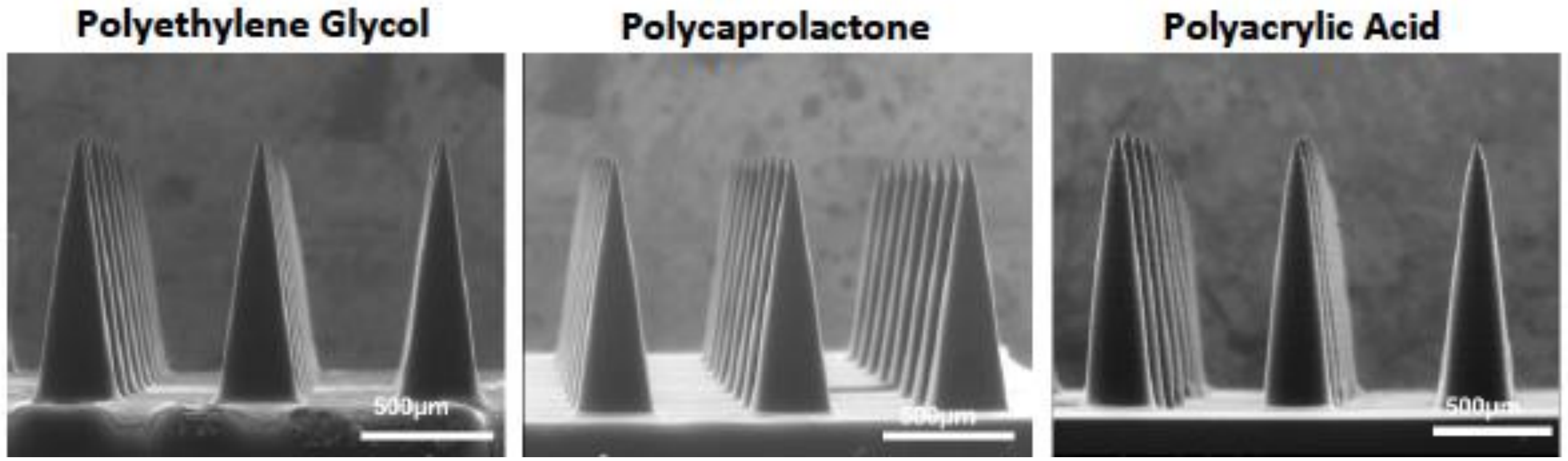
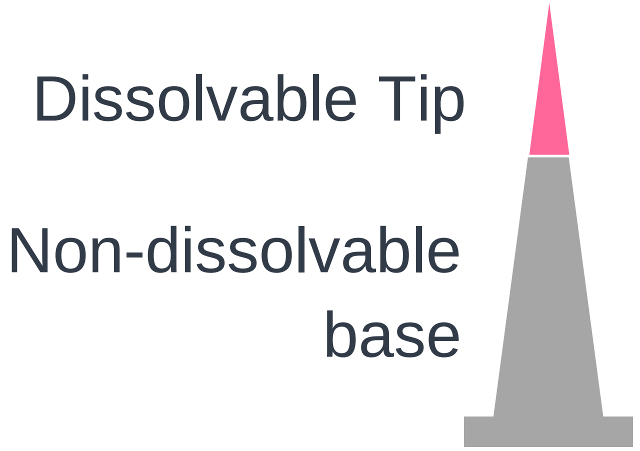
TRANSDERMAL DRUG DELIVERY VIA MICRO-NEEDLES

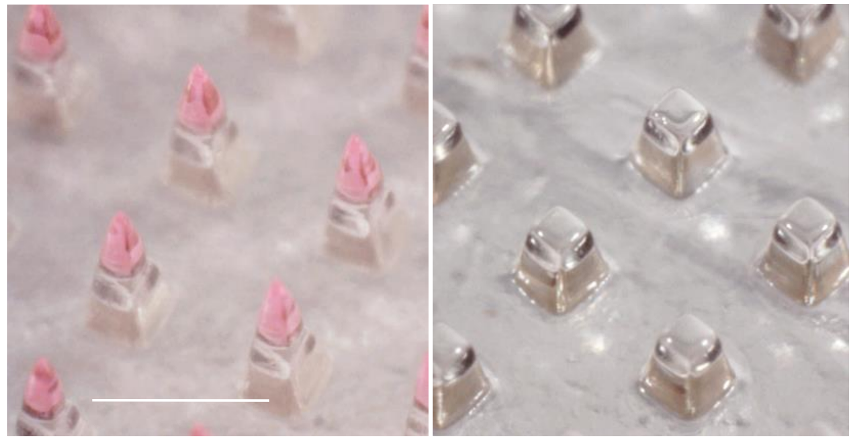


Tumbleston et. al (2015), *Science* ; Johnson et. al (2016), PLOS One.









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A future fabricated with light

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