



BioRobotics and Materiomics: tools and approaches for scientific and technologic advancements

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LAMM, Massachusetts Institute of Technology, USA***

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Where I work



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Scuola Superiore Sant'Anna The BioRobotics Institute



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What we do:

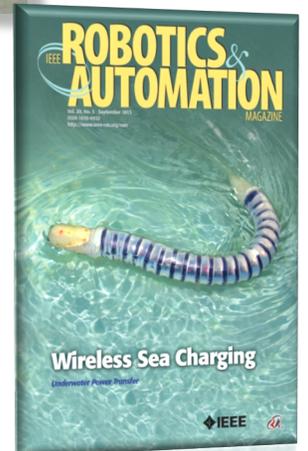
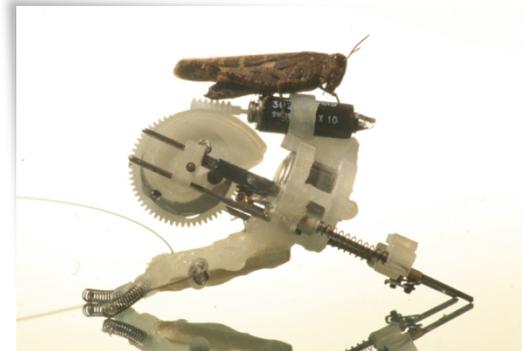
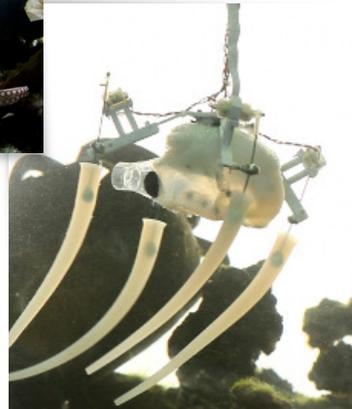
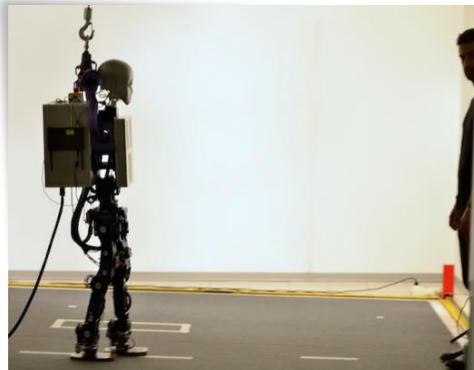
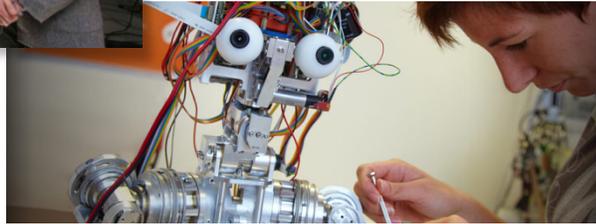
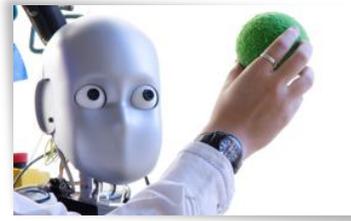
Use robotics to mimic life and unveil its principles



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What we do:

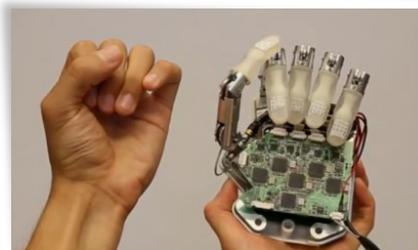
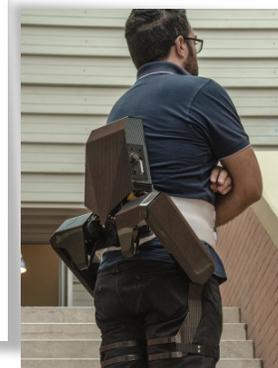
Use robotics to rehab, assist and treat human beings



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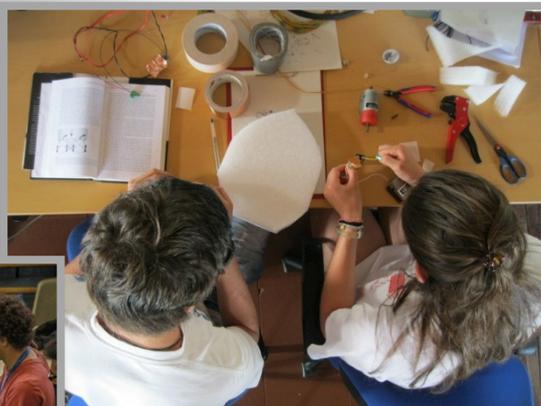
What we do: Use robotics to educate and change society



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What we do: collaborate with companies



ERIC BIGAGLI DESIGN



How to innovate with companies: Competence Centre for Industry 4.0



Industry 4.0 Competence Center on
**Advanced Robotics and
enabling digital Technologies
& Systems 4.0**

**Centro di Competenza ad alta
specializzazione ARTES 4.0:
Advanced Robotics and enabling digital
Technologies & Systems 4.0**

Capofila: Scuola Superiore Sant'Anna

13 Organismi di Ricerca, 138 Imprese, 9 altri enti e organismi
(DIH Toscana, INAIL, 3 Fondazioni e 4 ITS), 7 Regioni e
Comune di Pontedera

Formal support from:

- 6 Regions (Toscana, Marche, Umbria, Sardegna, Lazio e Sicilia) e Comune di Pontedera
- 6 DIH + draft agreement with DIH EDI ConfCommercio
- CCIAA (Camera di Commercio Firenze)
- Istituto Superiore per le Industrie Artistiche (ISIA), Firenze (Design Industriale)

Consortium:

- 13 Research Centres
- 138 Companies
- 1 DIH (Digital Innovation Hub Toscana)
- INAIL
- 3 Foundations (R&I, Toscana Life Sciences, Don Gnocchi)
- 4 ITS partner





CENTAURO Project: aims and goals

Humans and **environment** are the two main pillars at the core of the CENTAURO Project which aims at assuring high efficiency, competitiveness and risk prevention in industrial environments.

Main goals:

- **Reduction** of the working loads for workers involved in manipulating components and materials
 - To **increase** efficiency and competitiveness by optimizing the duty cycles in selected manufacturing processes.
 - To **reduce** the environmental impacts of the manufacturing processes
-



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CENTAURO Project: consortium



•Piaggio & Co. S.p.a. (Pontedera, PI)



The BioRobotics Institute of Scuola Superiore Sant'Anna
(Pontedera, PI)



Robot System Automation s.r.l. (Perignano, PI)



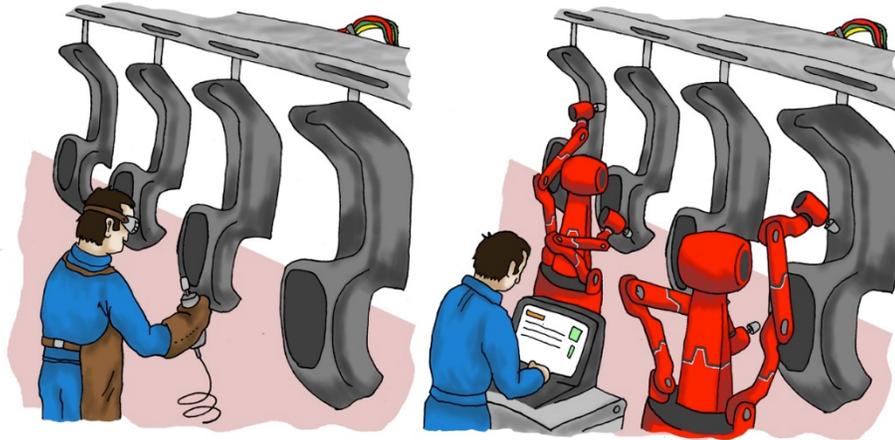
Roggi s.r.l. (Cinigiano, GR)



Robotech s.r.l. (Pisa, PI)



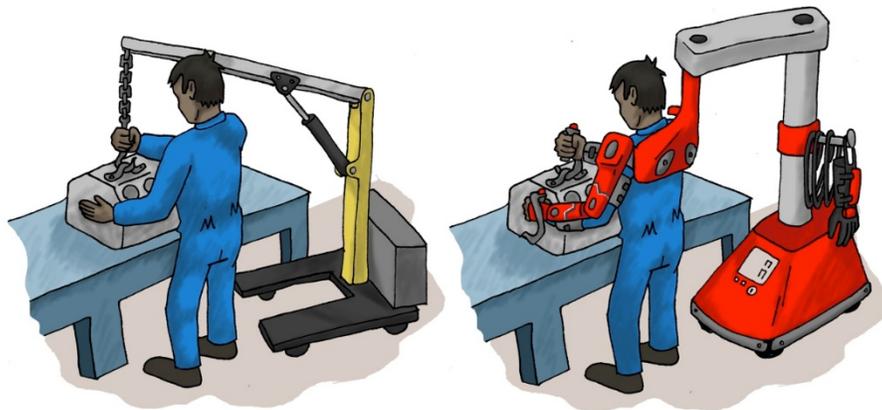
CENTAURO Project: developing 4 innovative platforms



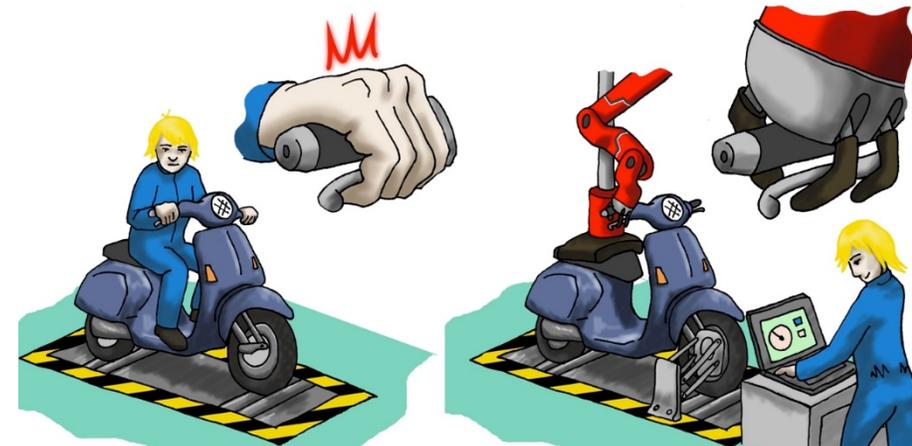
iGrind – Robotic Platform to identify, evaluate and to intervene on defects on the frames.



iSort – Autonomous system to collect and manage litter recycling.

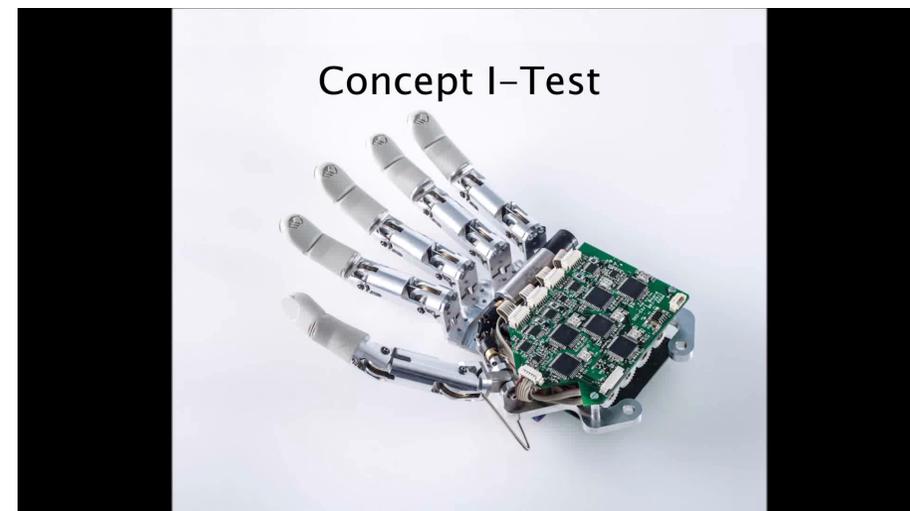
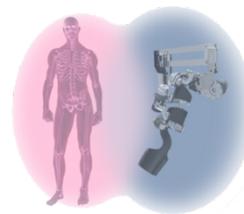
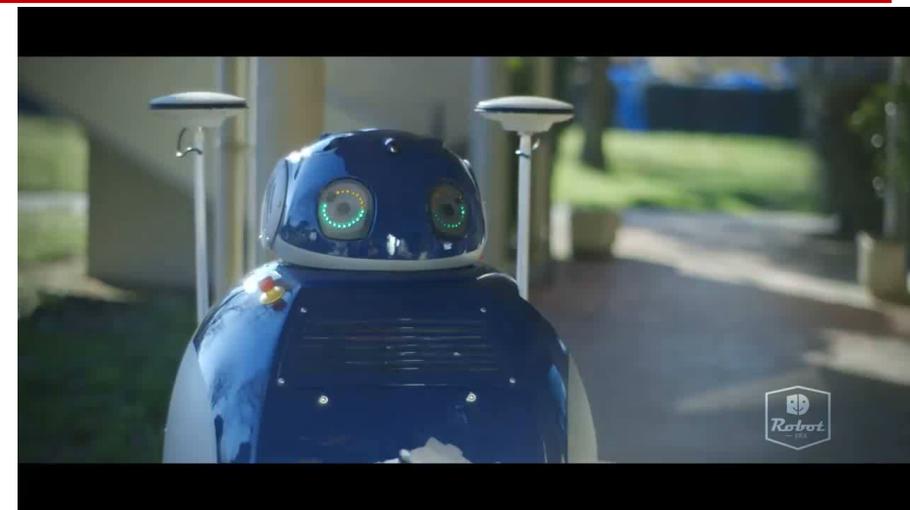
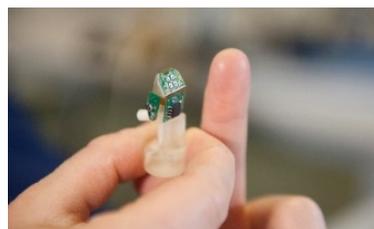


iWear – Wearable device to help workers in manipulating heavy loads.

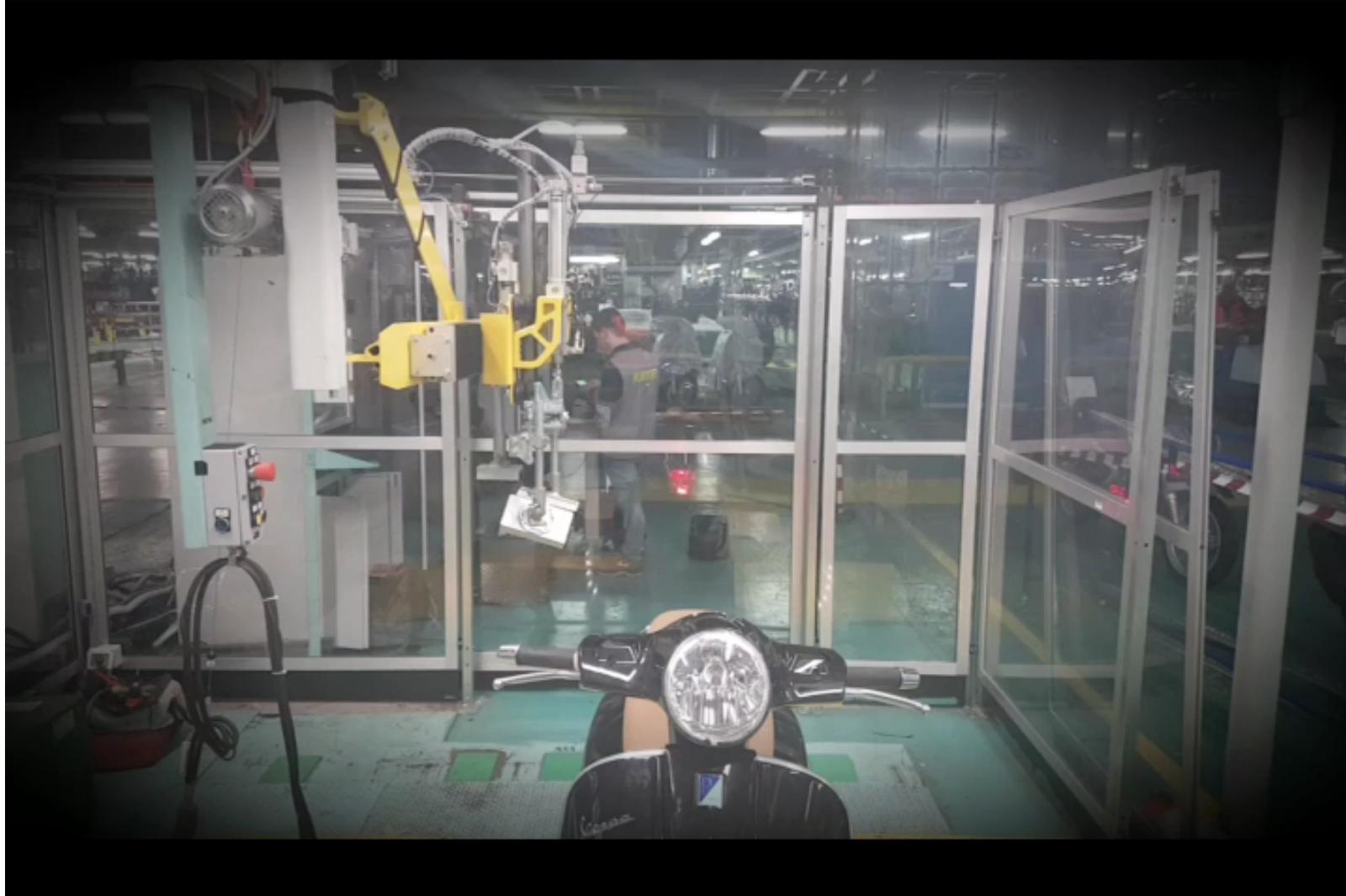


iTest – Automatic system to test the breaking systems of the motorcycles.

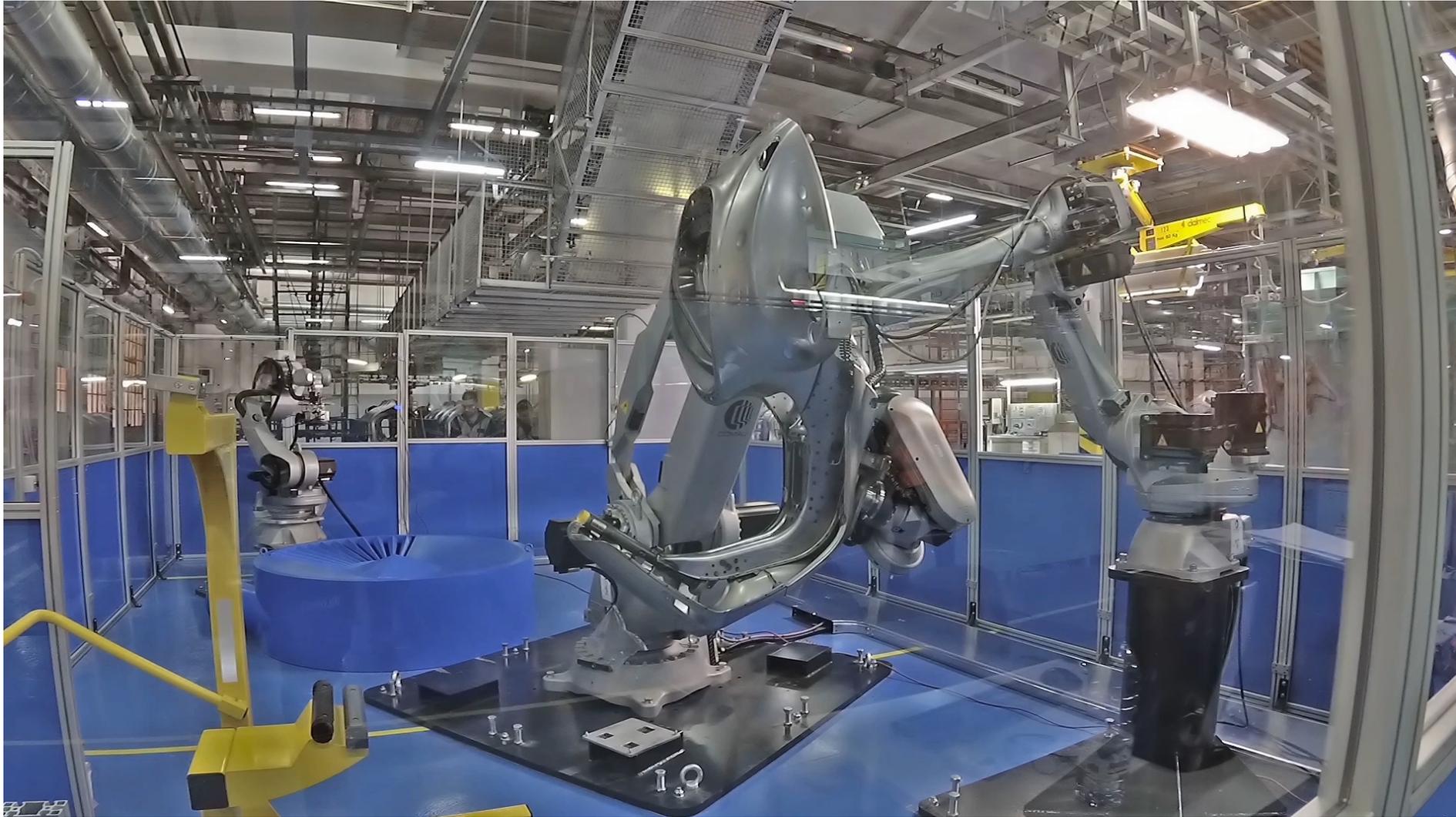
CENTAURO Project: preliminary results



CENTAURO Project: the iTest Platform



CENTAURO Project: the iGrind Platform



Galileo Weeding Machine:

an mechatronic solution for applications in serigraphy

WORLD PREMIERE

A BREAKTHROUGH
FOR SCRAP
REMOVAL



Galileo scrapper is the result of a collaborative research project between **Esanastri S.r.l.** and **BioRobotics Institute of Scuola Superiore Sant'Anna** (Pisa, Italy).

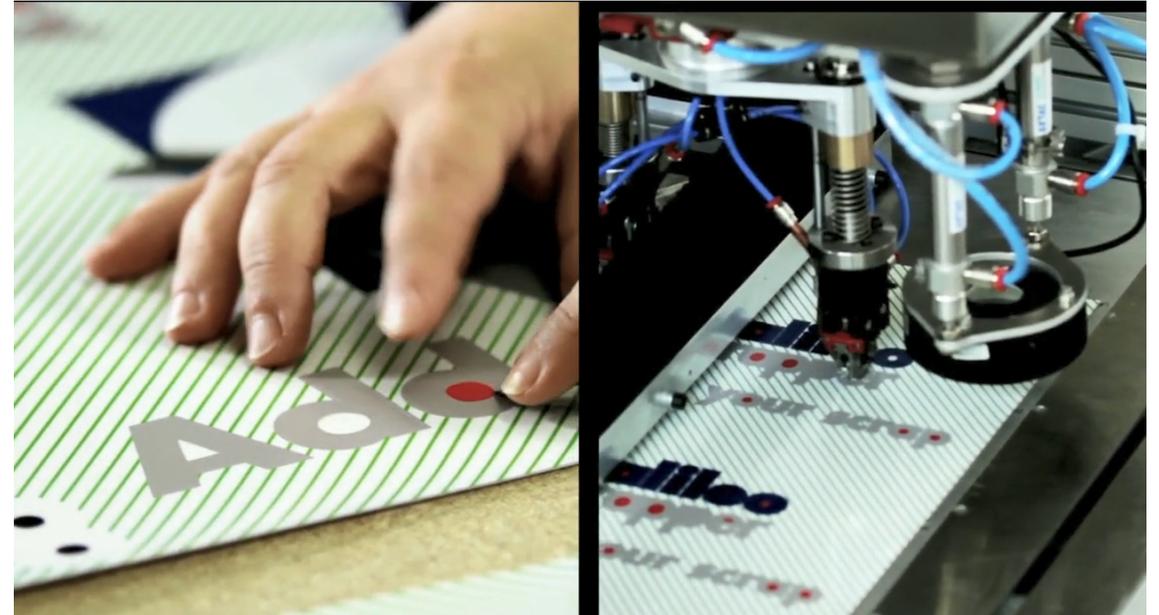
It is the first system in the world for smart automation **SCRAP REMOVAL** for **multilayered self-adhesive materials**.

Its revolutionary and proprietary technology represents a game changer in the elaboration of self-adhesive media for visual communication, enabling fast, accurate and cost effective production.

Our set of three proprietary enabling technologies permits the processing of a wide range of sheet sizes (up to 100 cm x 140 cm) with minimal waste of raw materials and with low operational costs, guaranteeing at the same time high reliability and repeatability, in addition to compacting waste material.



Project funded by Regione Toscana under the program **Bando Unico R&D**



An inspiring success story

Topic: innovative approaches for robotic welding & manufacturing

Joint Lab

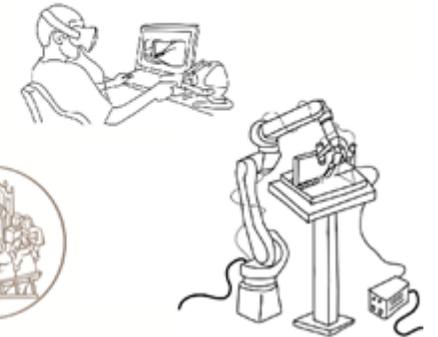
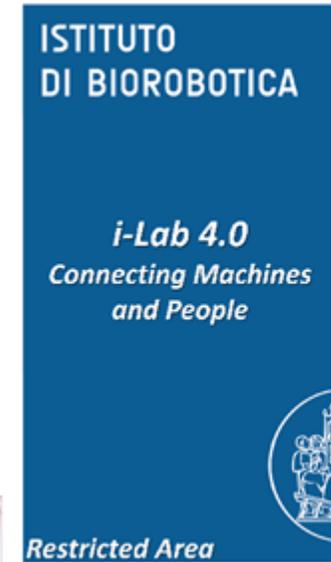
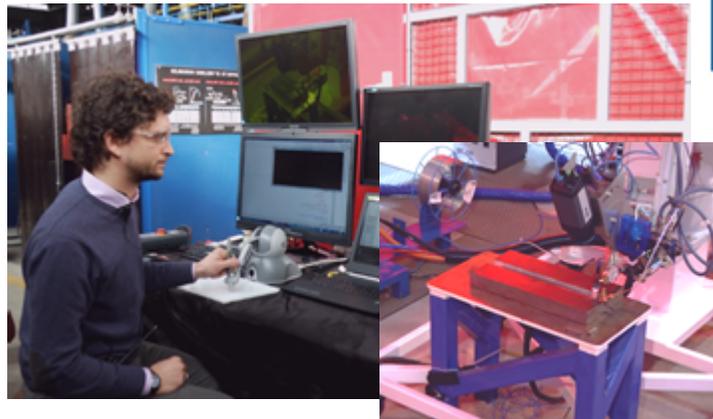
«i-Lab Connecting Machines and People»



2014
48 k€

2015
130 k€

2016
209 k€

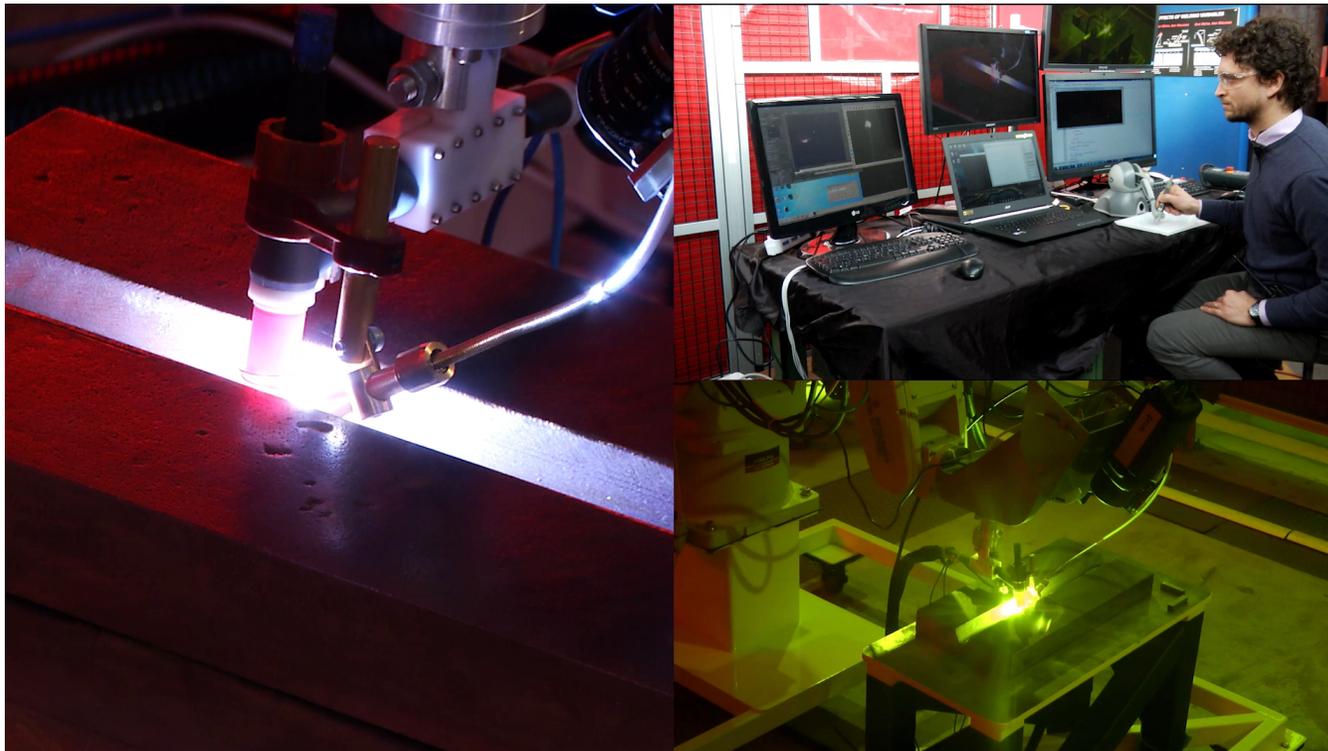


Funding for 2017 – 2020
1.2 M€



New generation «human in loop» robotic technologies

REMOTE WELDING: a collaborative control system which connects the fine movement capability of a robotic arm with the experience of the welder.



ADVANTAGES:

- *an increase of comfort and ergonomics, thanks to the distance from the hot environment of the welding;*
- *an increase of productivity thanks to the better working conditions;*
- *a reduction of injuries due to the possible contact with hot and electrified components.*



Massachusetts Institute of Technology Lab. for Atomistic and Molecular Mechanics



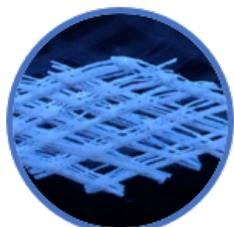
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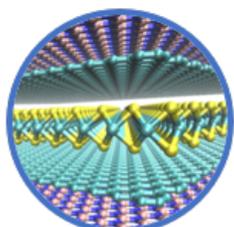
What we do



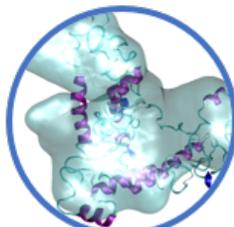
Bio-inspired
materials



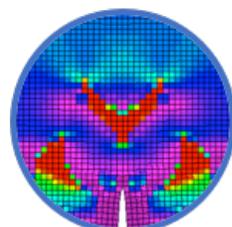
Silk-based
materials



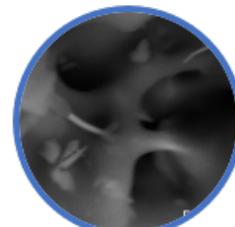
Nano-
materials



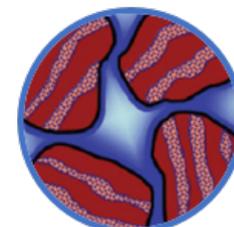
Protein
design



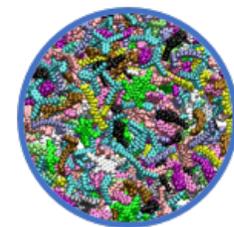
Composite
design



Biomass
processing

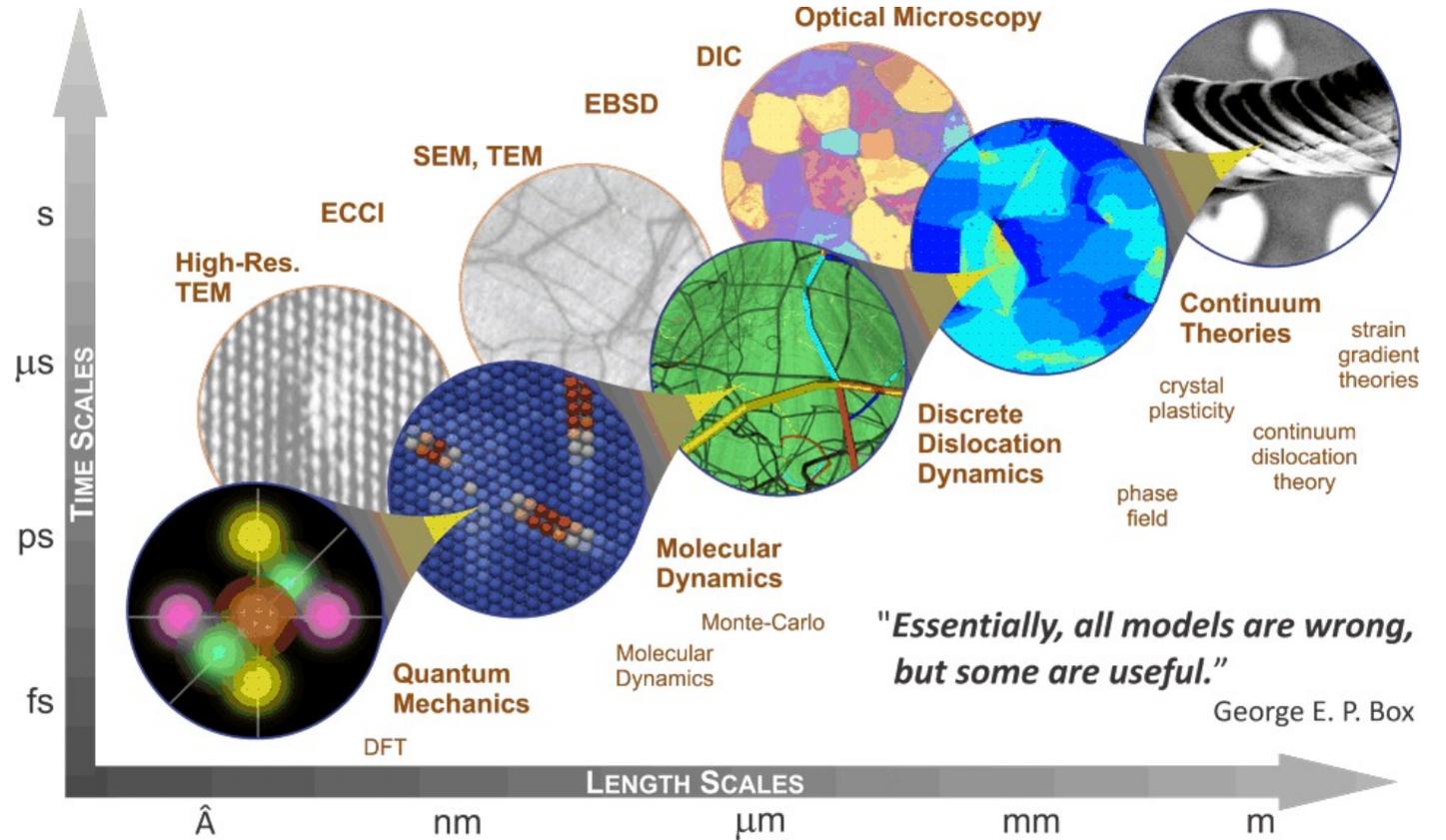


Concrete
modeling



Asphalt
modeling

Materiomics
The study of the
properties of materials
at all scales



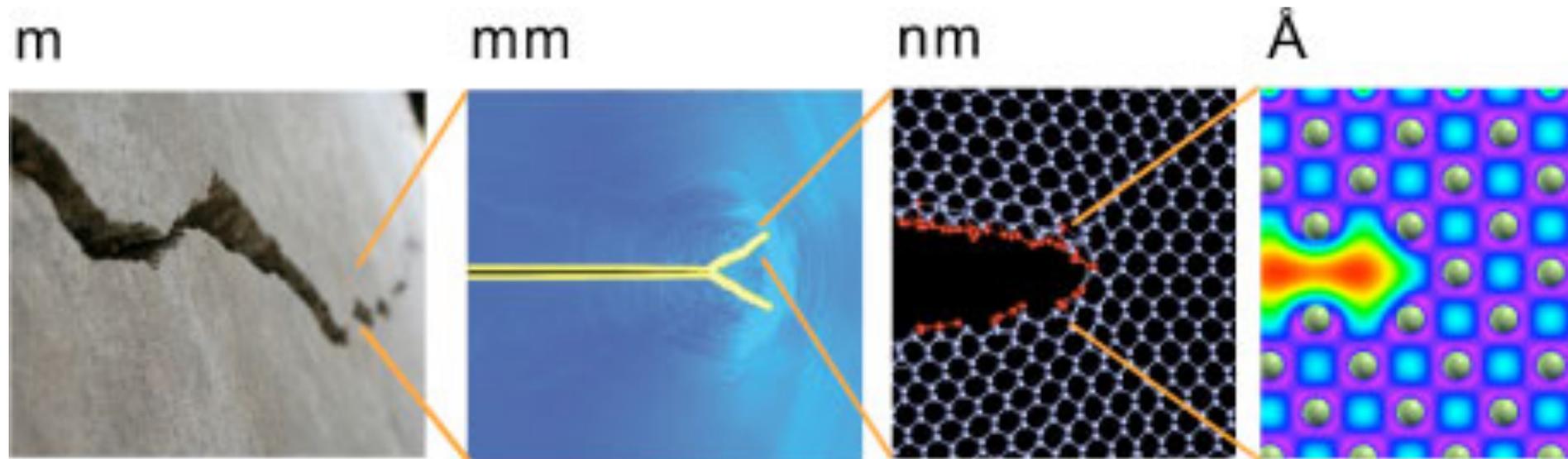
**Macroscale fracture
(glass, bridge,
airplane) begins at
the nanoscale**



Aloha Airlines Flight 243



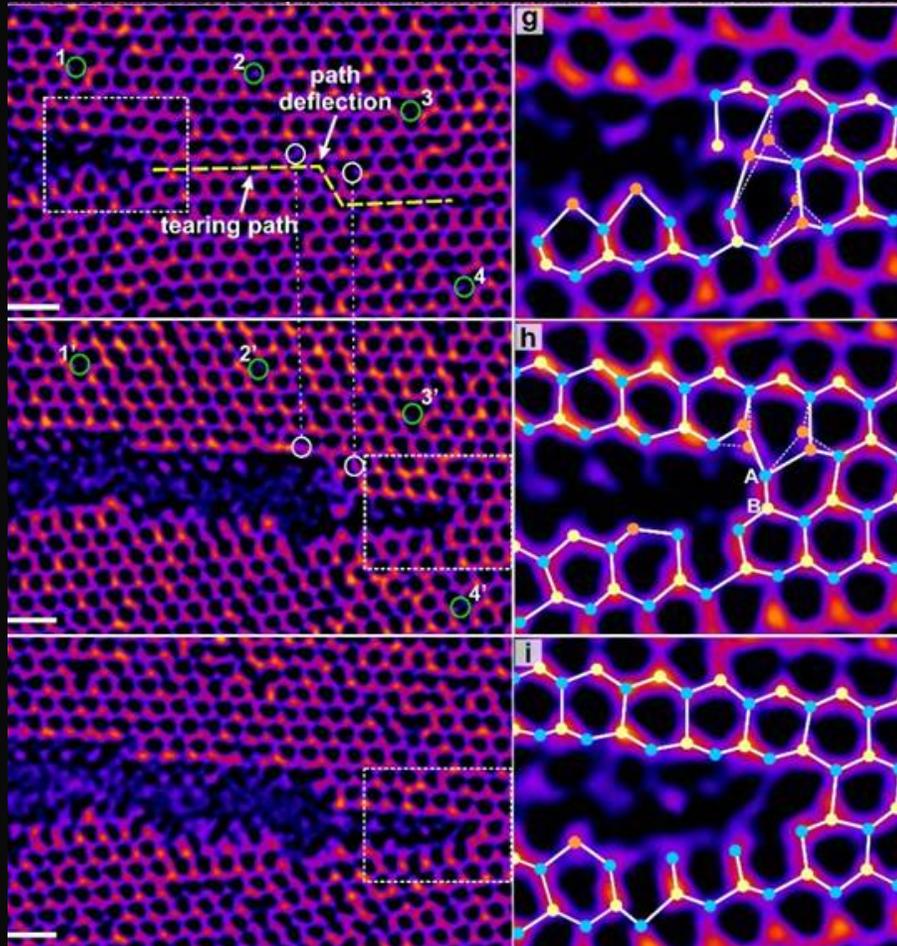
Multiscale nature of fracture – from nano to macro (and back)



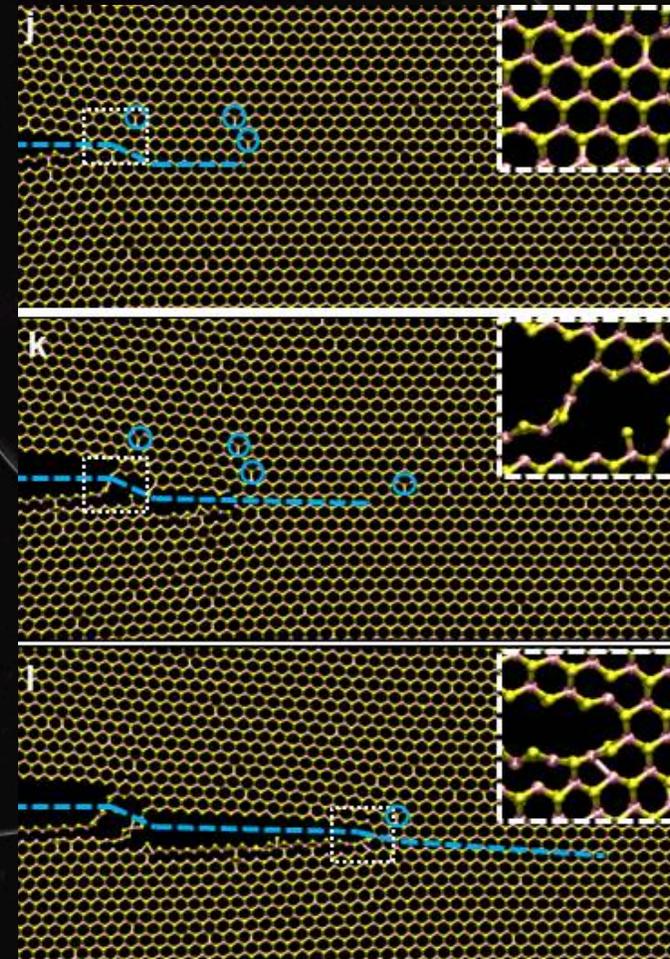
Advanced imaging

Collaboration: J. Warner (Oxford)

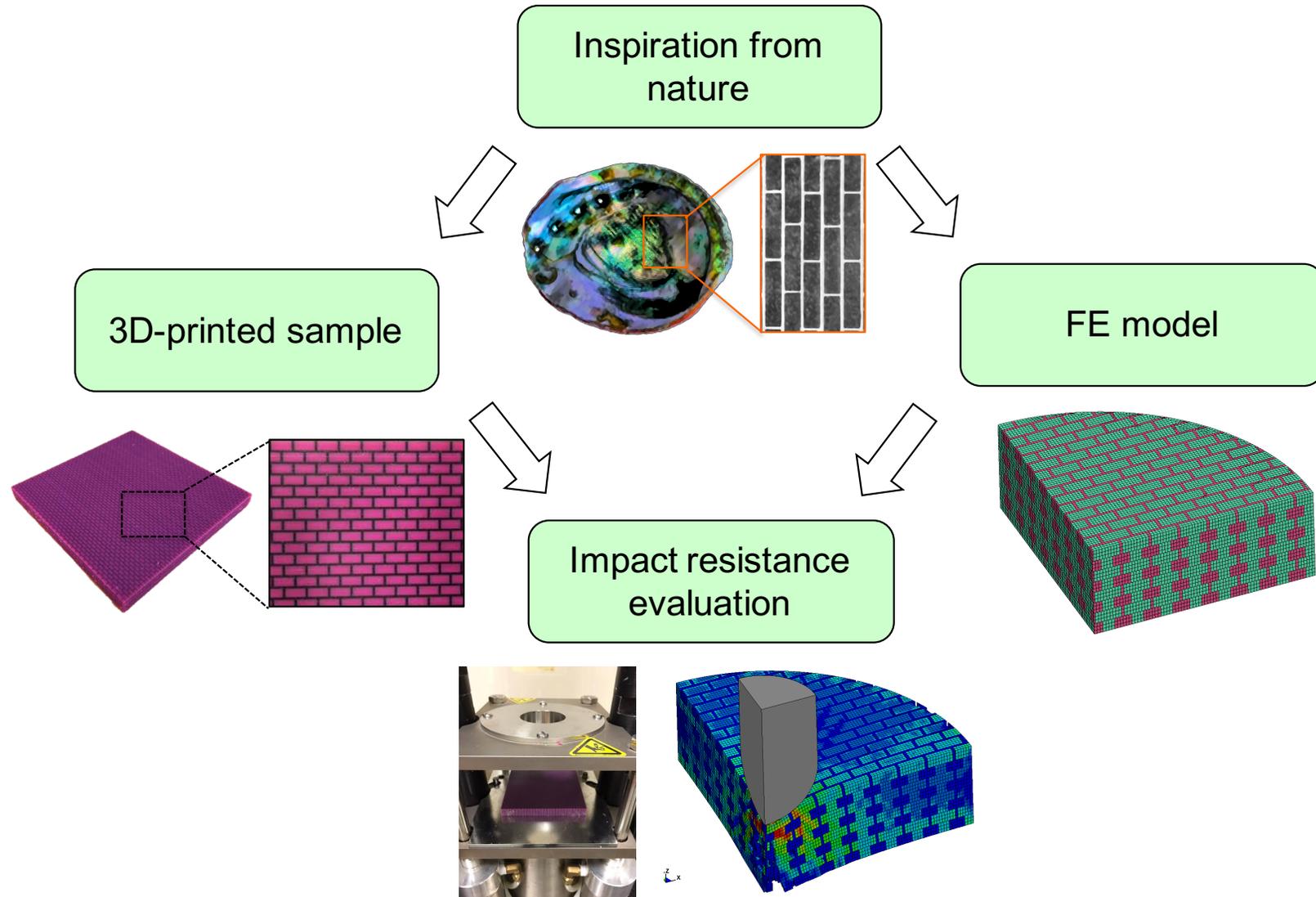
Experiment



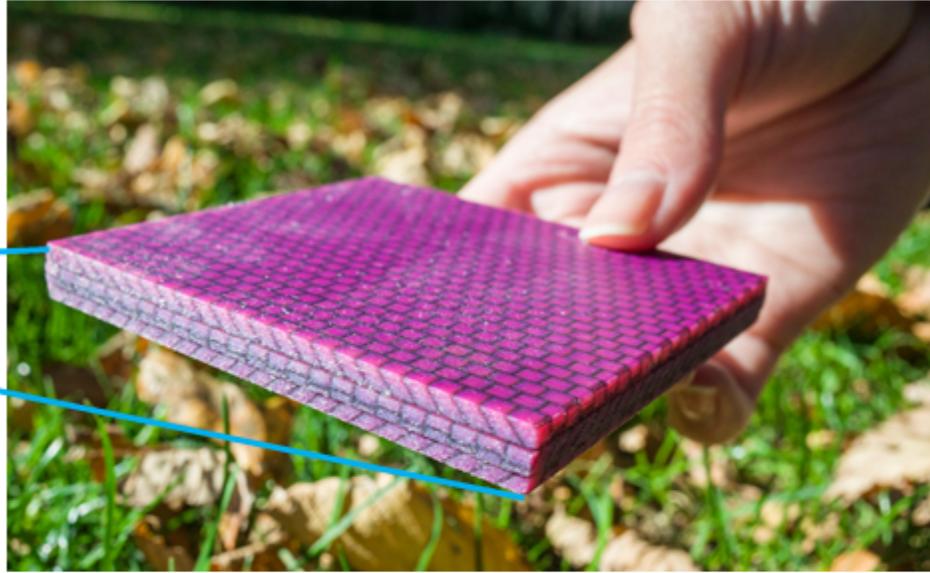
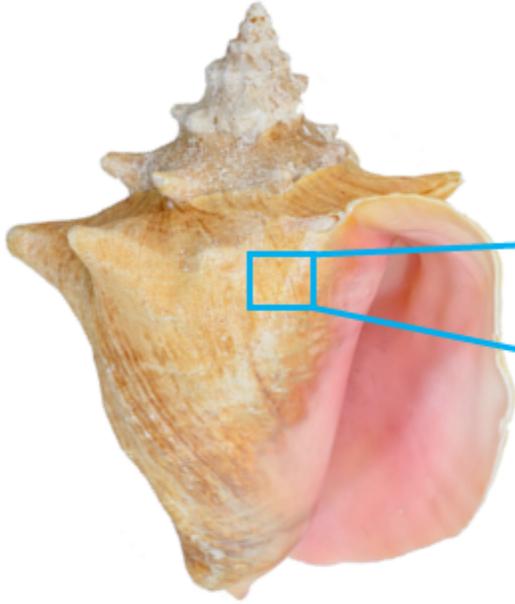
Simulation



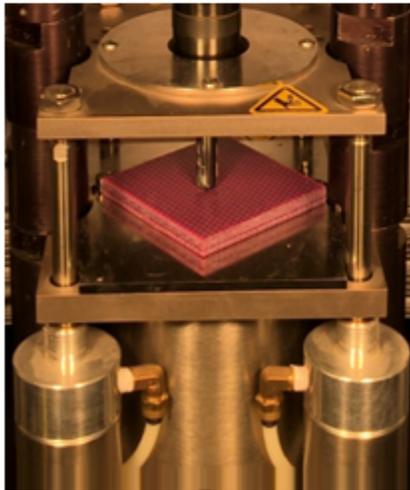
Design of impact resistant smart composites



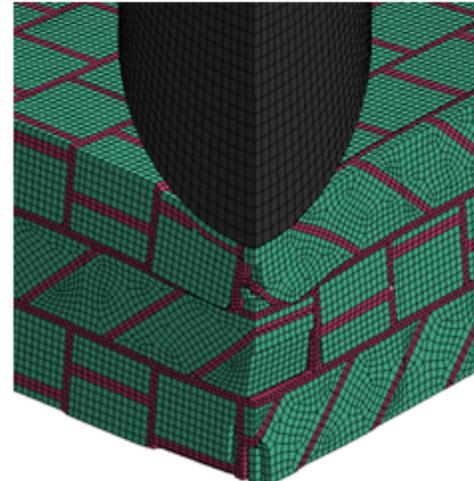
Bioinspired design

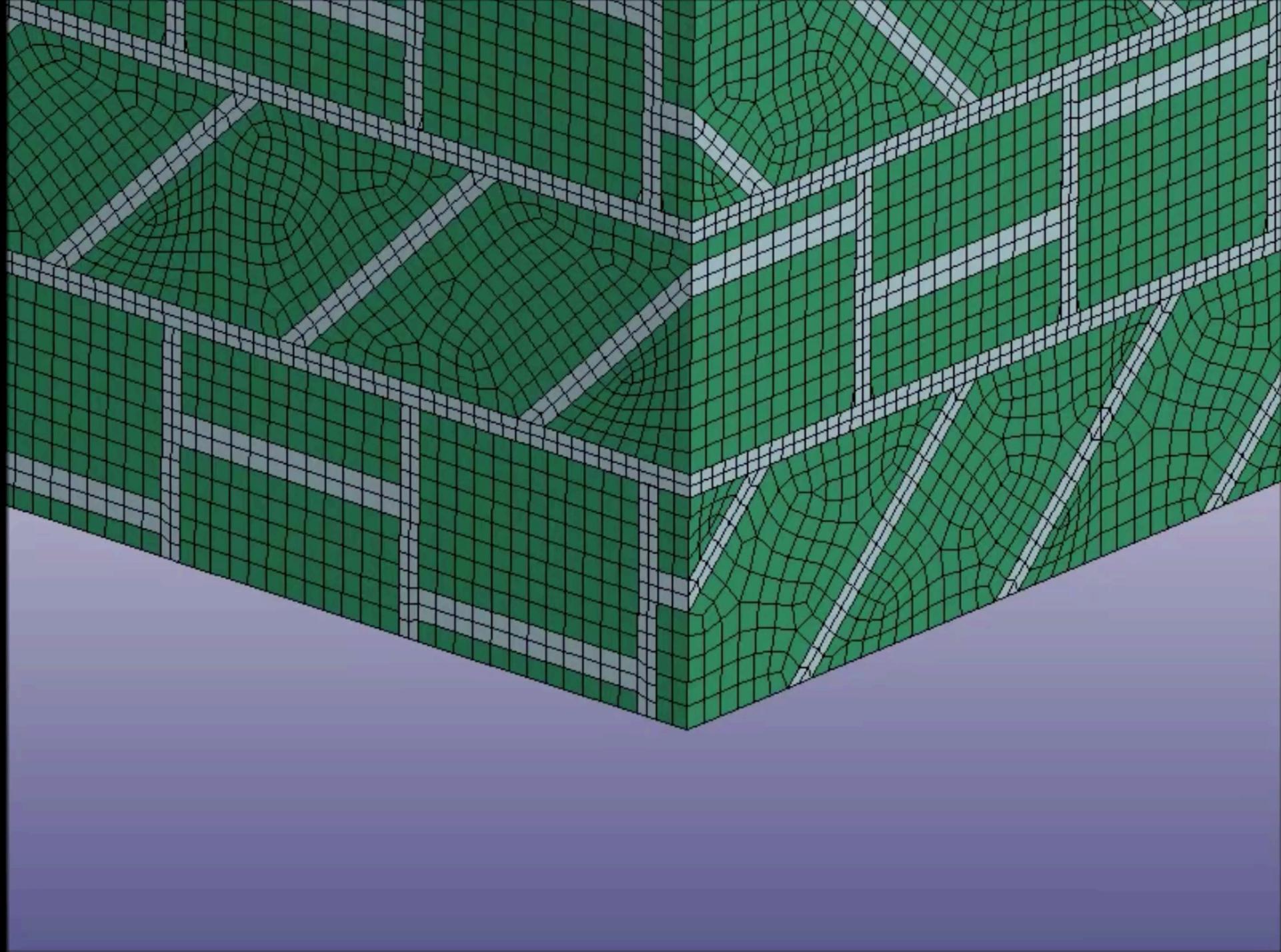


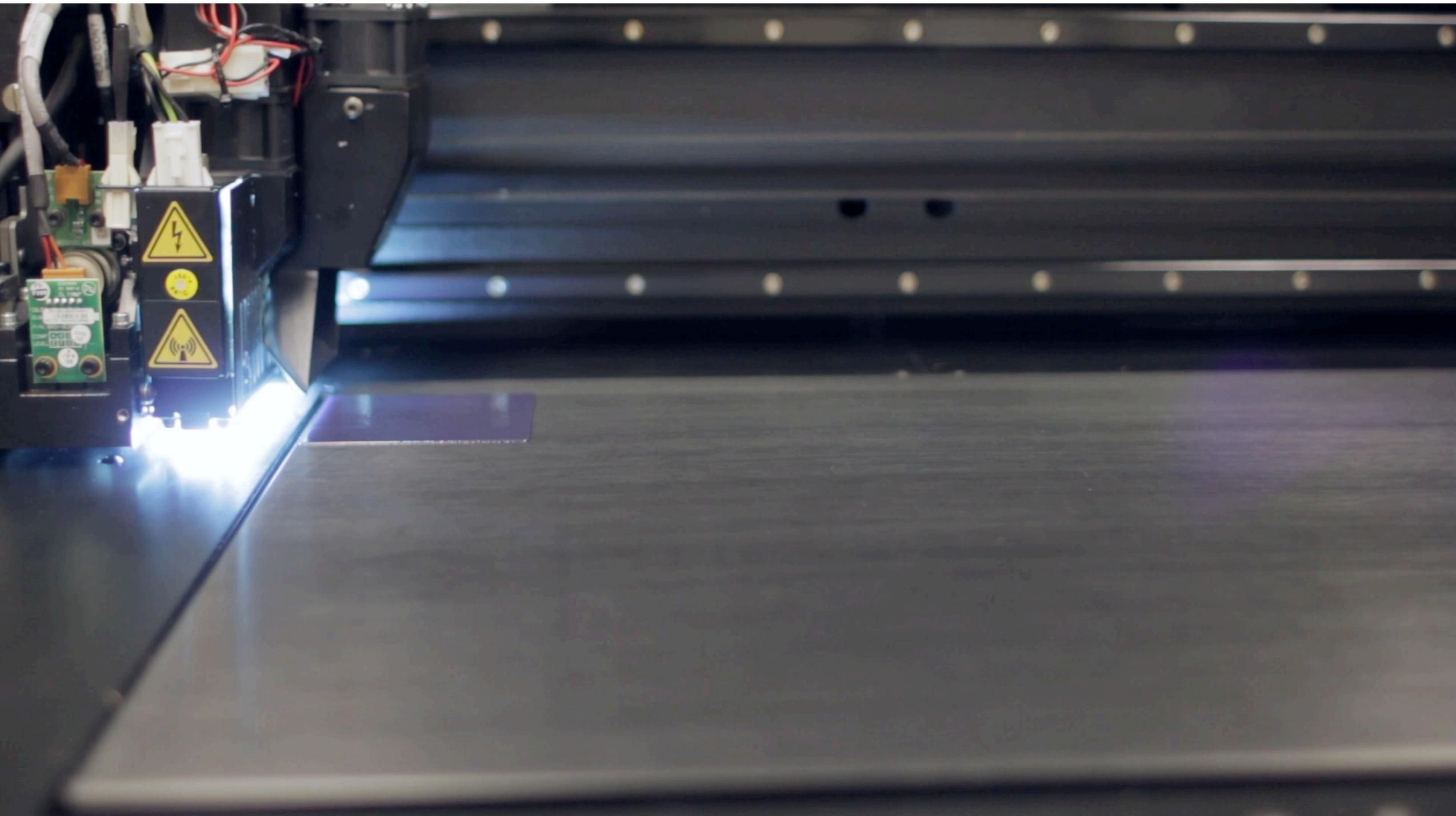
Testing

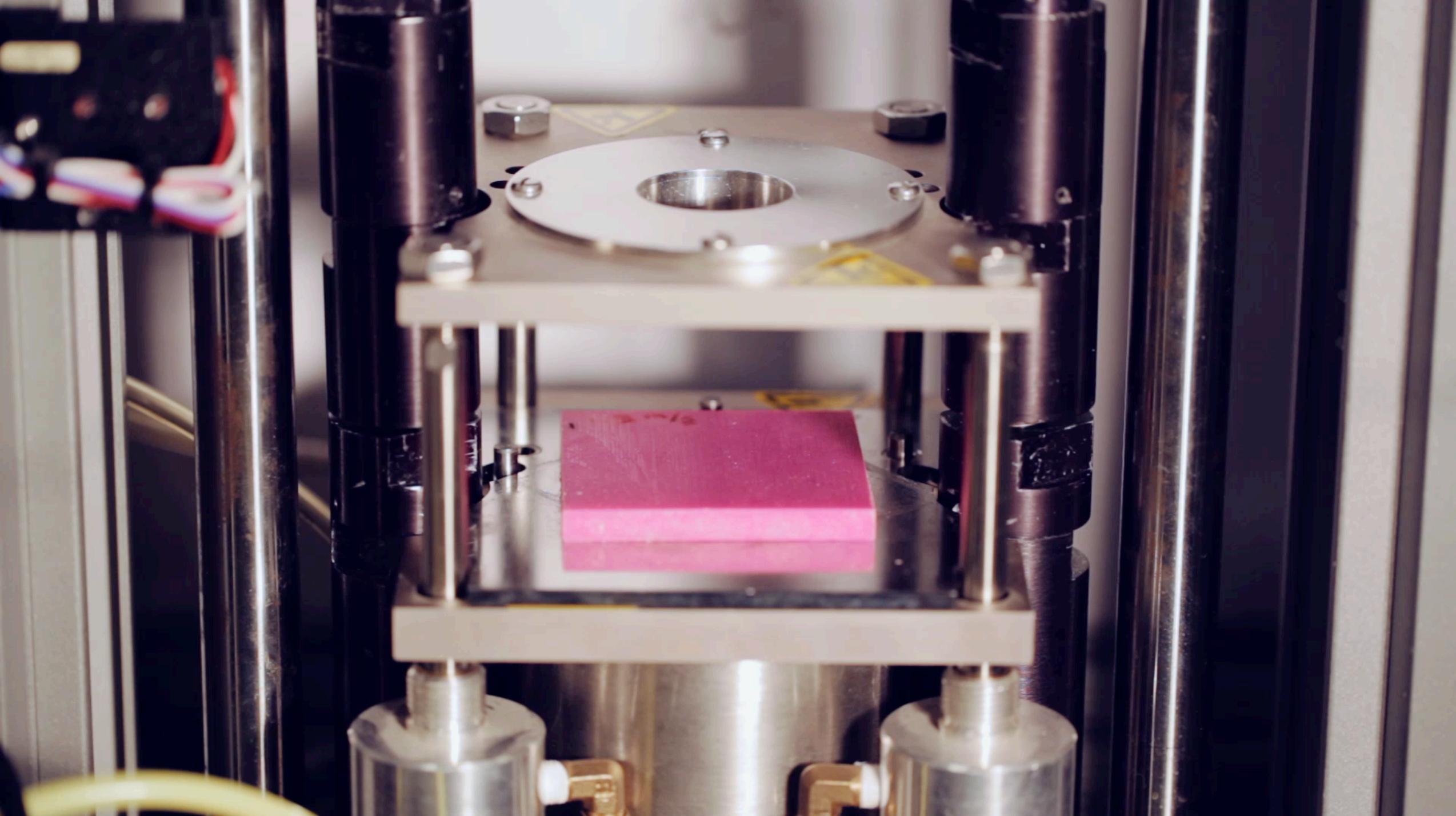


Analysis

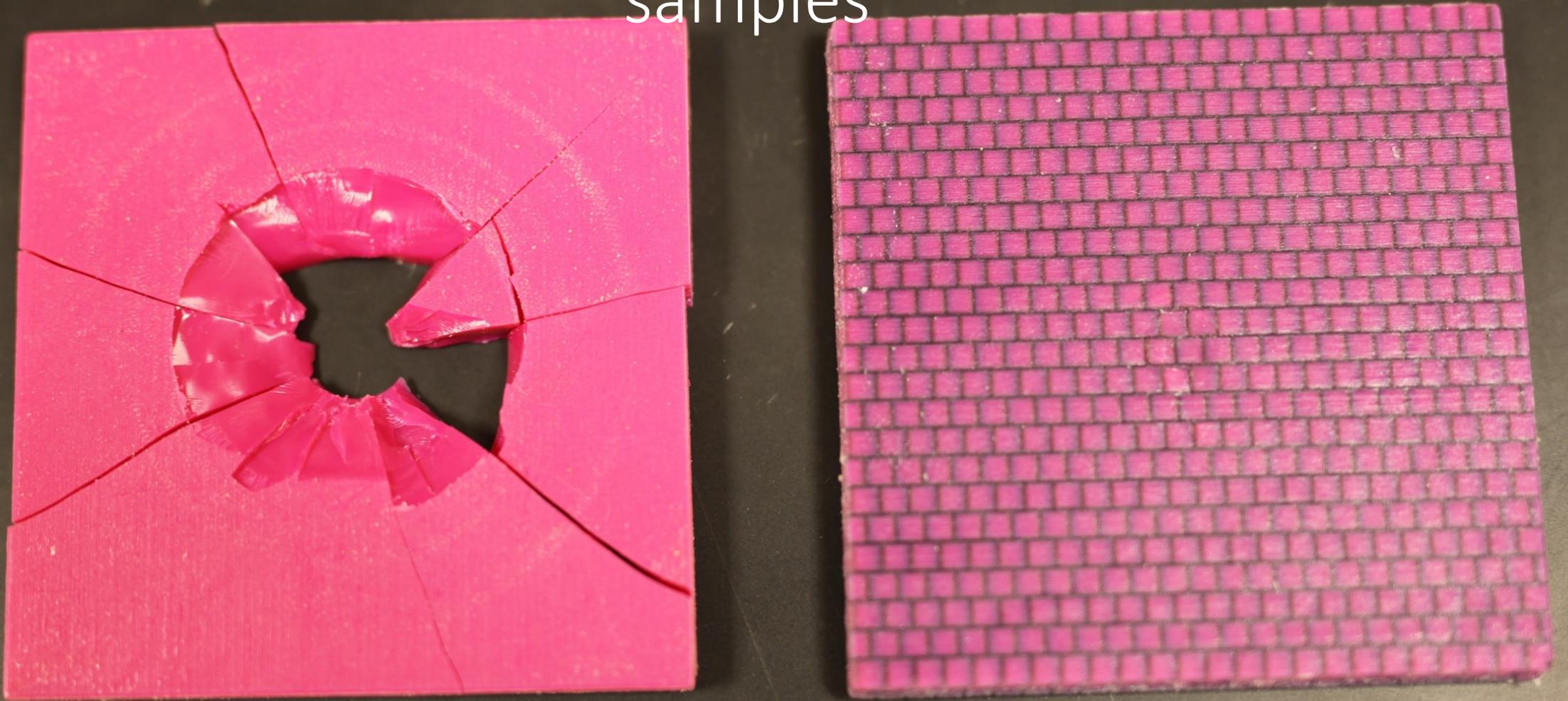








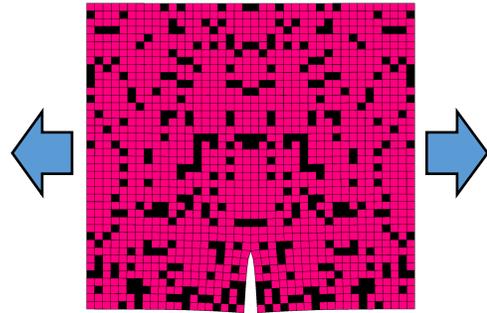
Tested samples



- Performed better than nacre-inspired sample, fiber-matrix configuration, stiff-soft-stiff layer configuration, among others

Machine learning applied to composite design

Finite element method



- Four node elements, Linear model
- Linear elastic materials with stiffness ratio of one magnitude difference
- Materials have same toughness
- Sample fails with first element failure
- Toughness defined as area under stress-strain curve

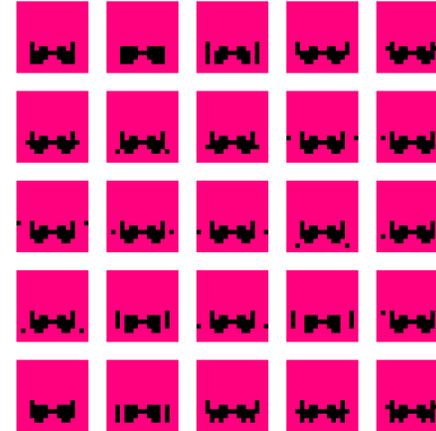
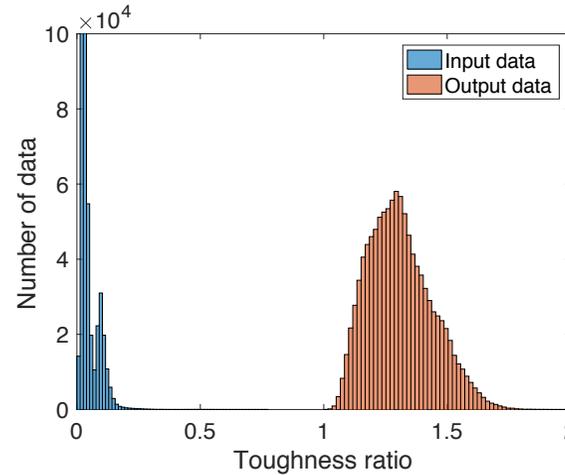
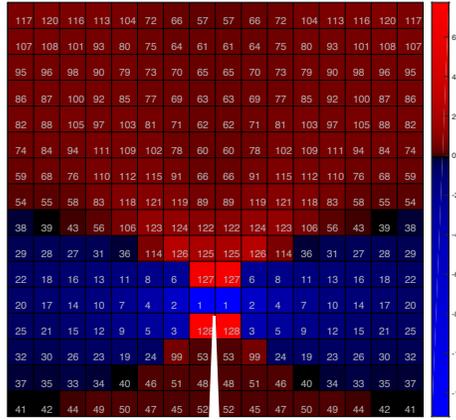
Machine learning



[0 1 1 0 1 1 0 ...]

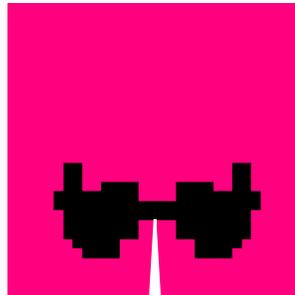
- Tensorflow (Google)
- Classification model
- Does not see crack, boundary conditions, etc.
- Training data from FEM as input (geometries with score)
- Testing data to obtain accuracy
- Parameters: batch density, batch size, number of loops

Application of machine learning to composite design

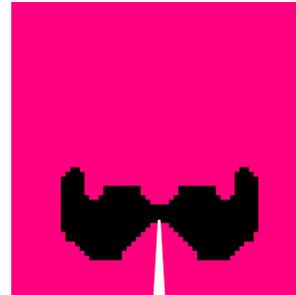


- Weights outputted from ML model show how much each element contributes to toughness
- Output data from ML model superior to input data
- Top 25 geometries obtained from model

32 x 32 system



64 x 64 system

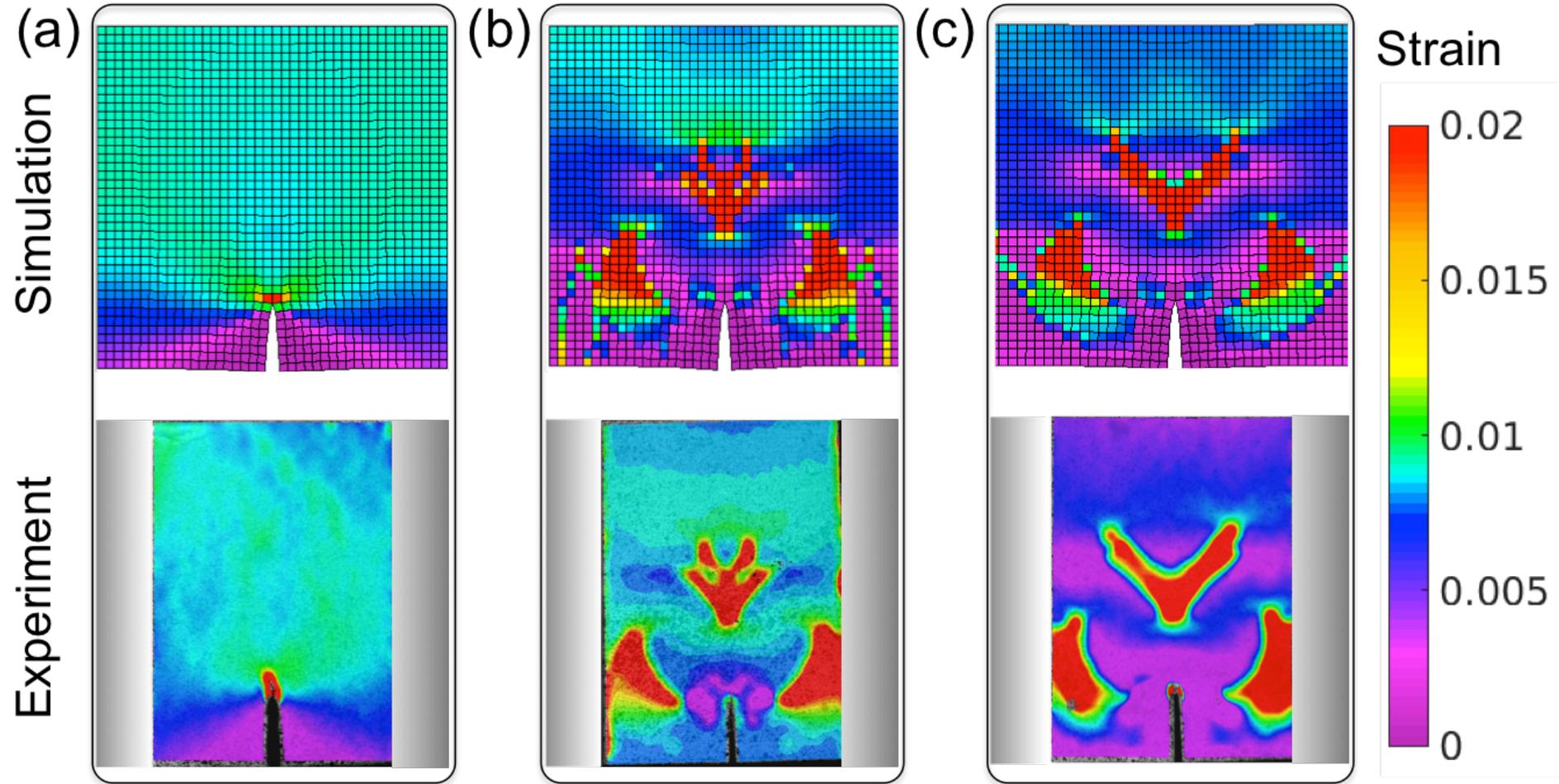


128 x 128 system

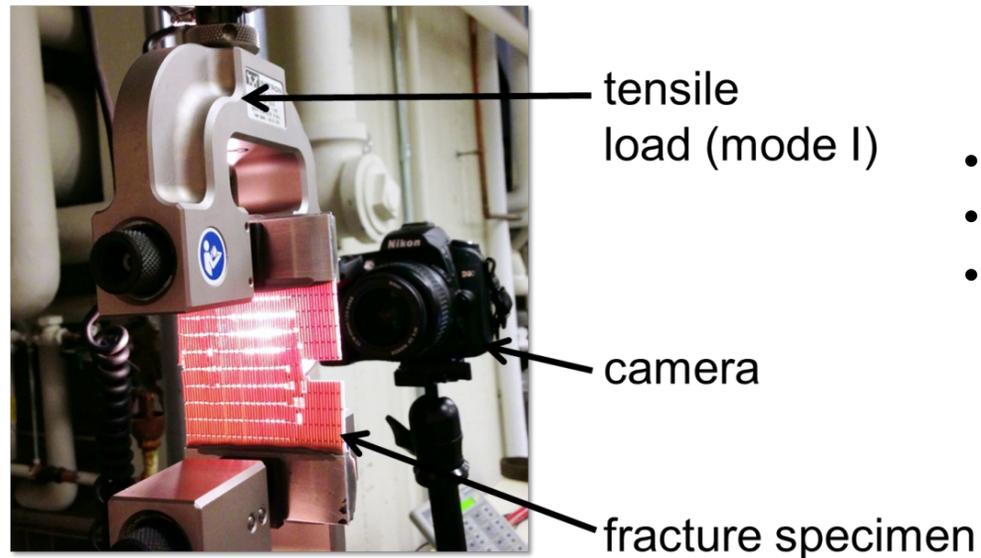
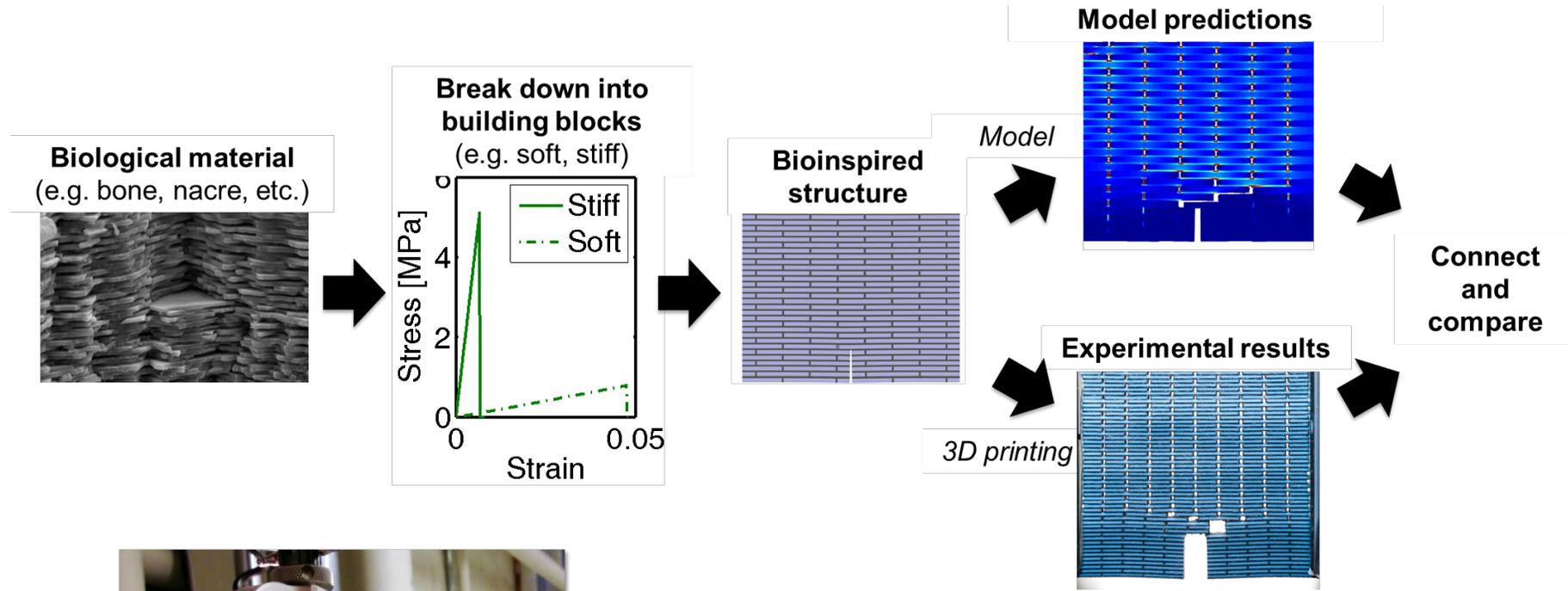


Learn patterns from smaller systems to generate refined shapes

Comparison between simulations and experiments (cont'd)



From optimization to manufacturing



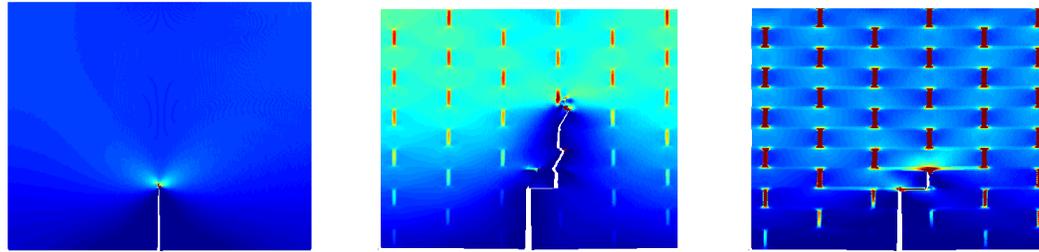
- Samples tested in tension
- Measure force-displacement
- Image deformation/failure mechanisms

Tuning Interactions with Constitutive Laws

Longitudinal Strain-fields

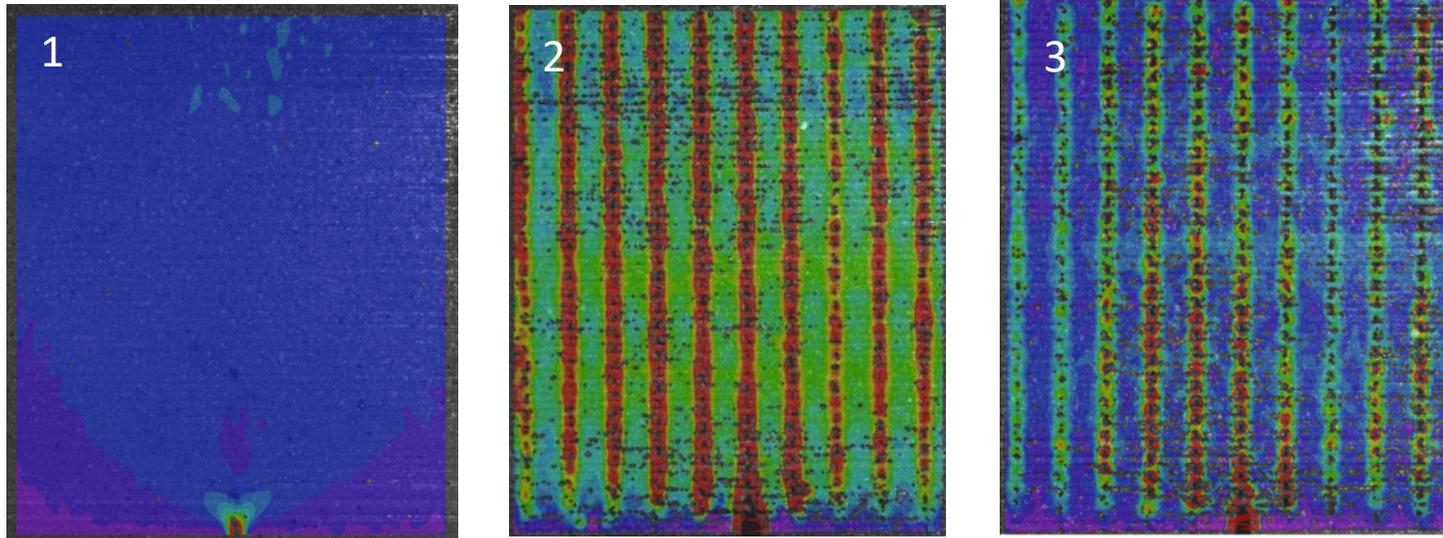
As matrix becomes more compliant deformation mechanisms change – delocalized loading at the cost of stiffness loss – optimum in the middle

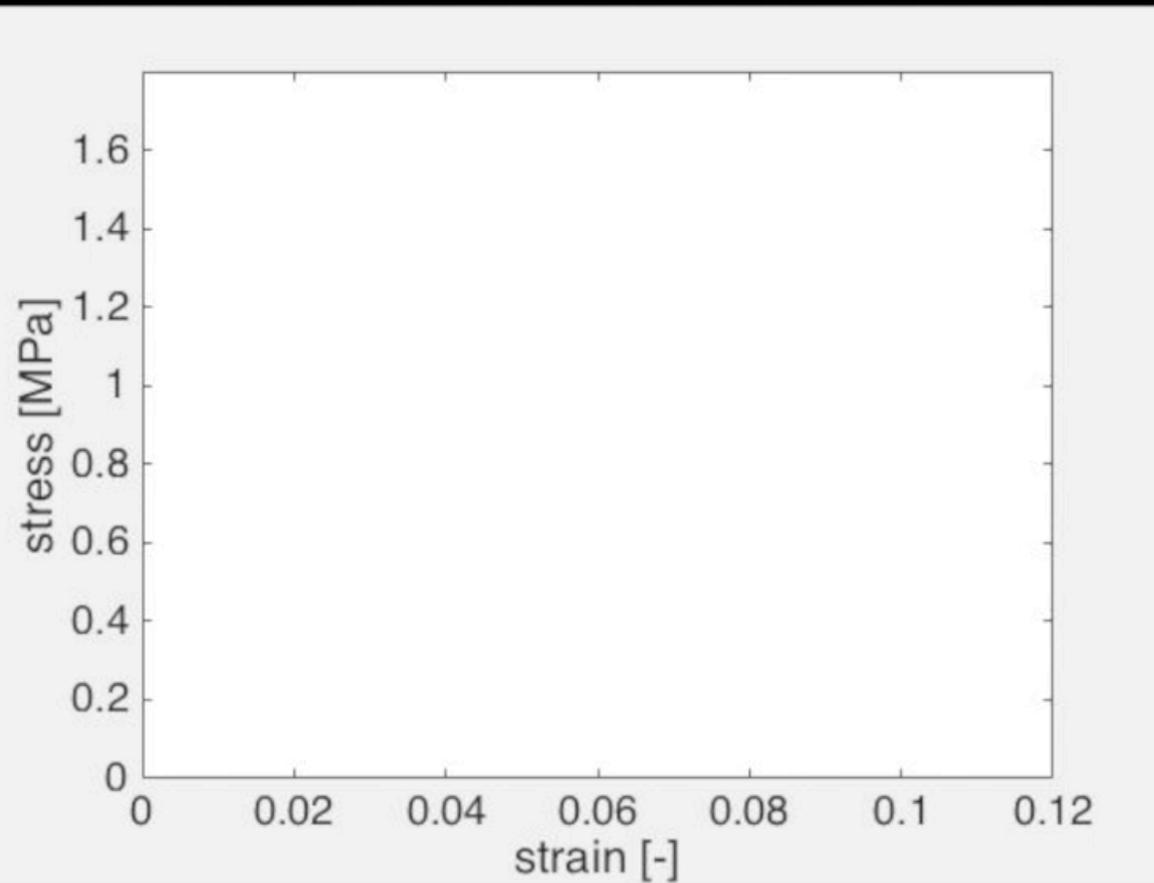
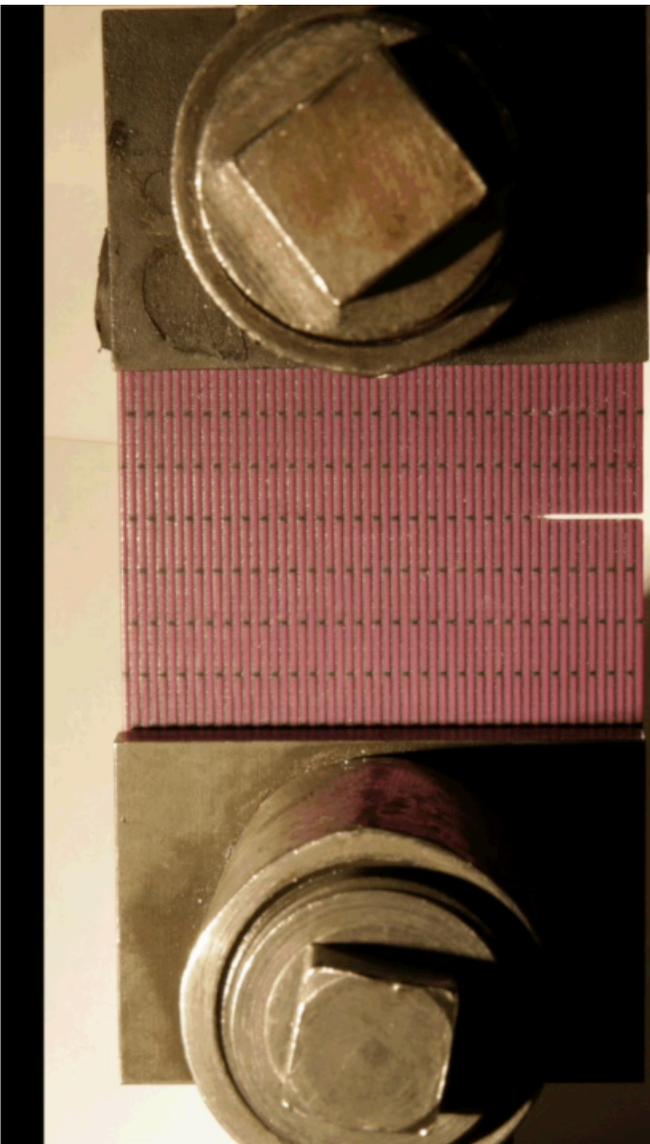
Simulation



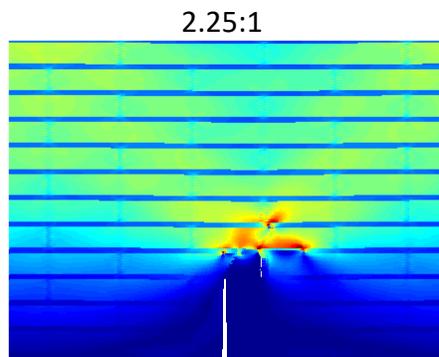
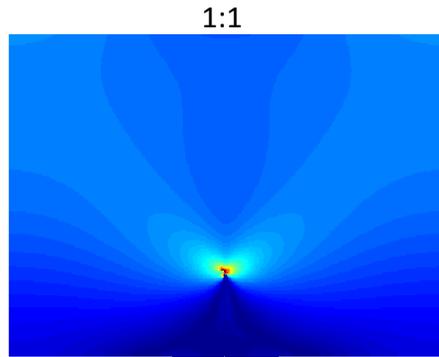
Increasing compliance of matrix phase

Experiment

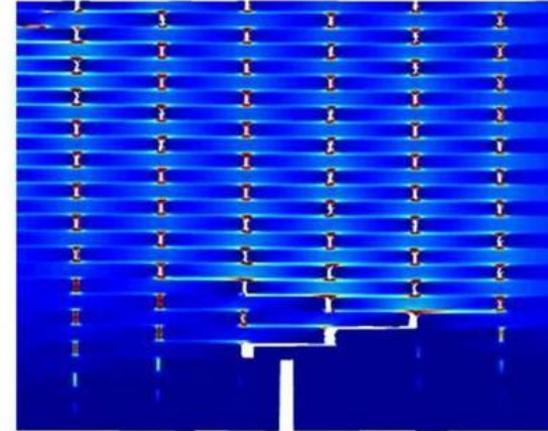




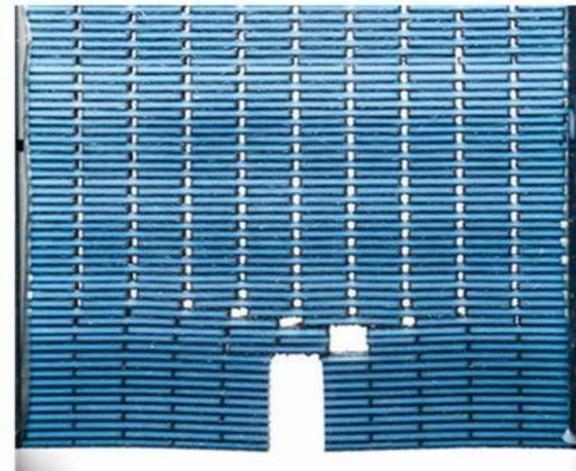
Defects make materials tough!



Model predictions

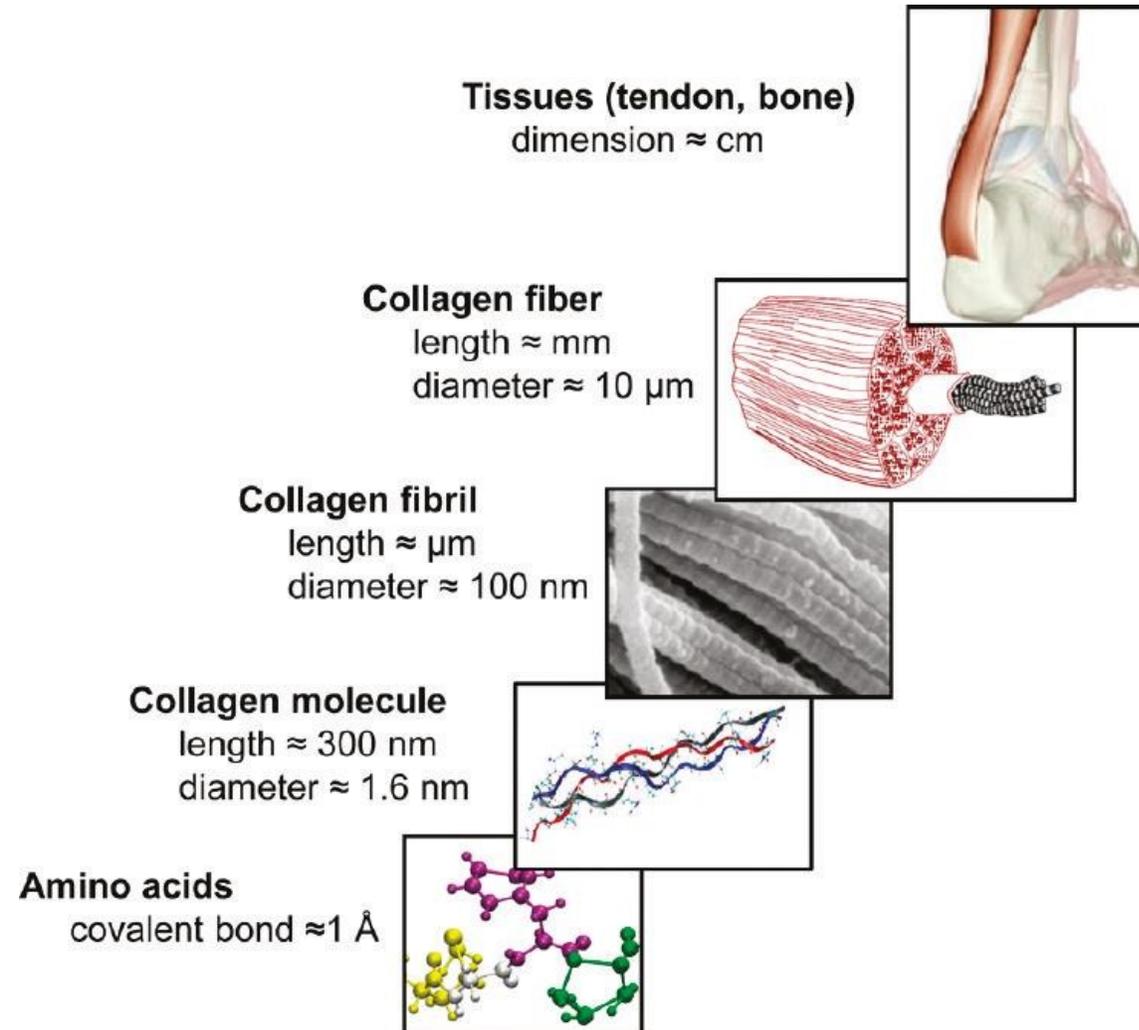


Experimental results

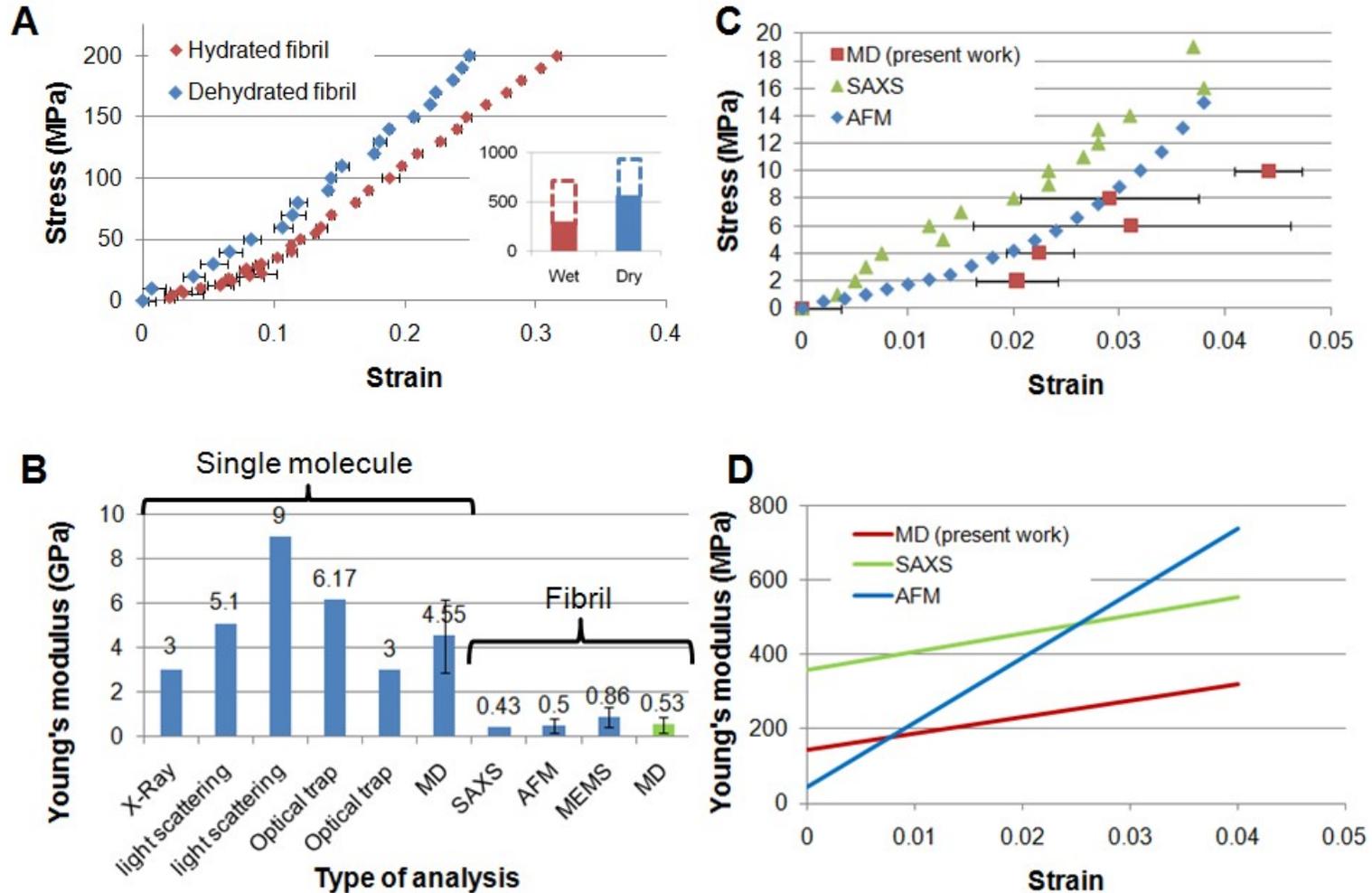


3D printed

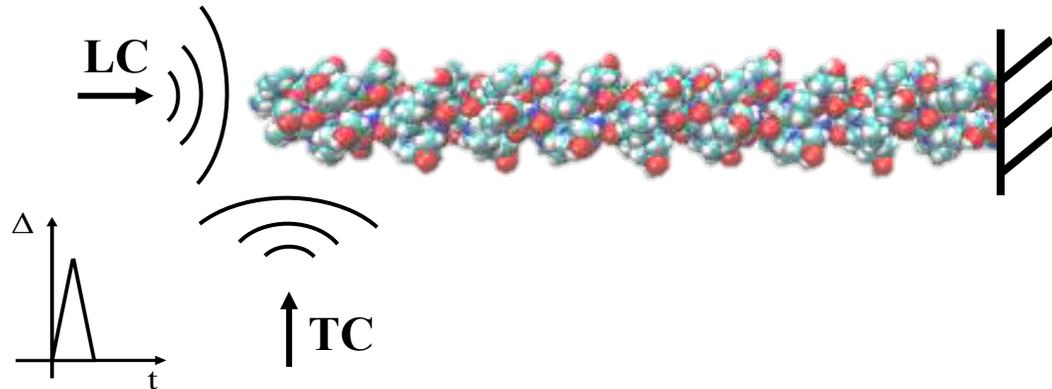
Case Study: non mineralized collagen



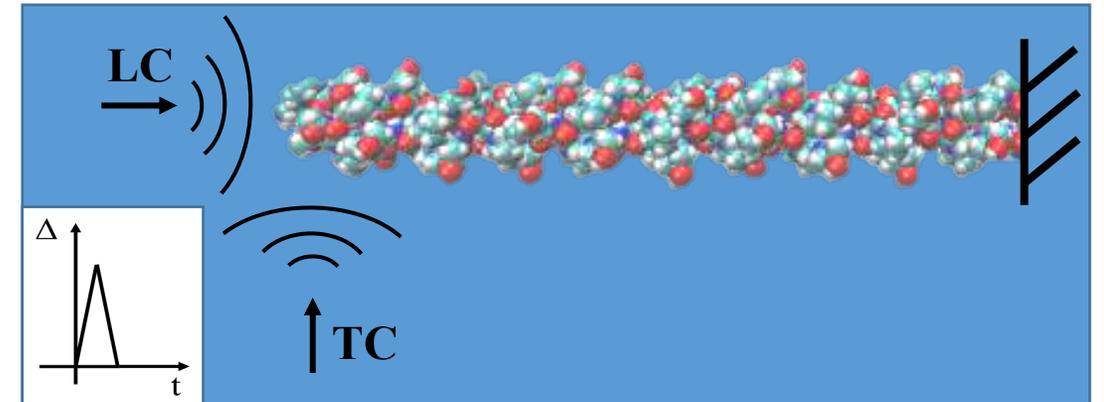
Case Study: Collagen fibril mechanics



Dry Structure

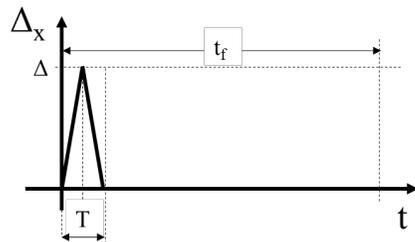
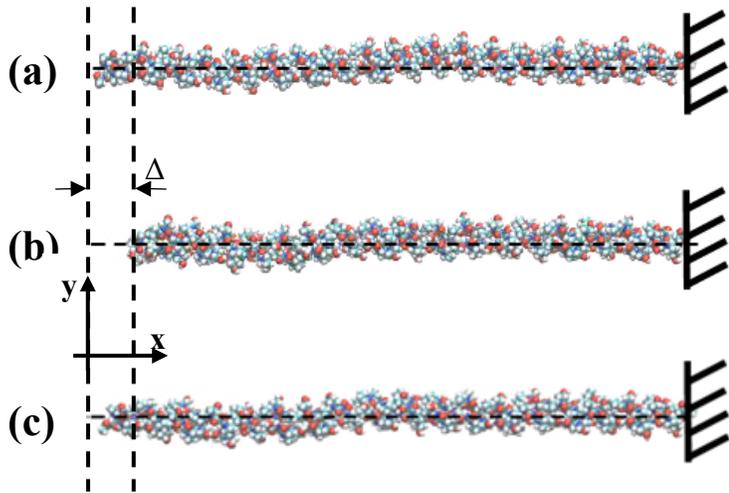


Hydrated Structure

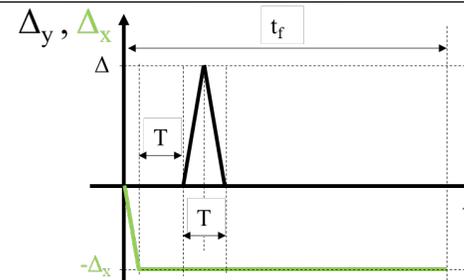
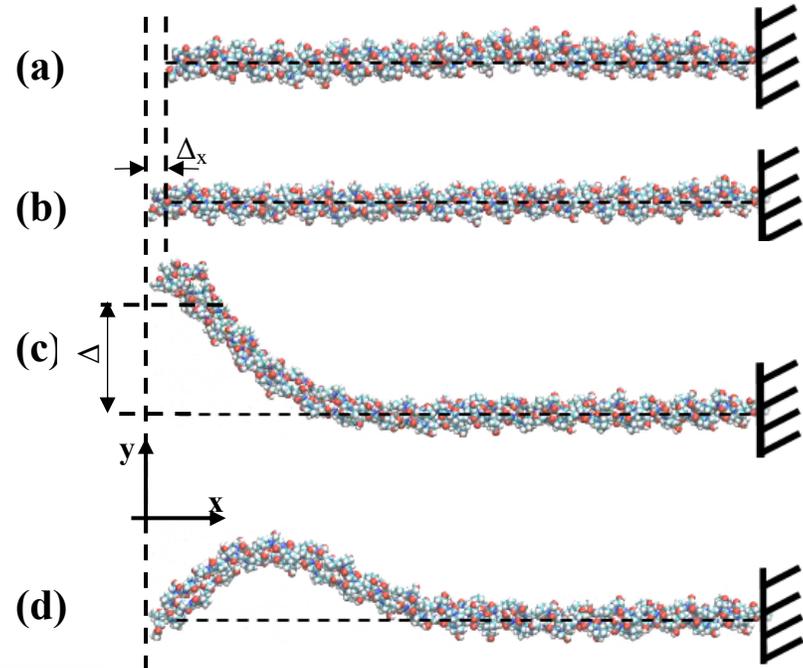


- Collagen peptides: $(GPO)_{20}$ triplets
- Length: 180 Å

Longitudinal Case



Transversal Case



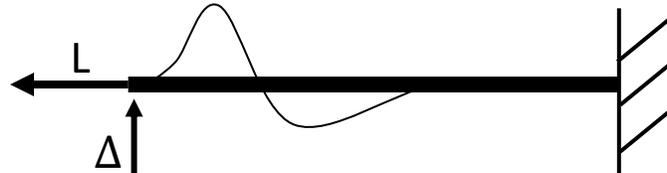
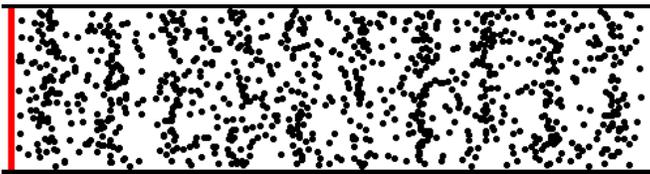
Wave propagation

Longitudinal waves

$$v = \sqrt{\frac{E}{\rho}} \rightarrow E = v^2 \rho$$

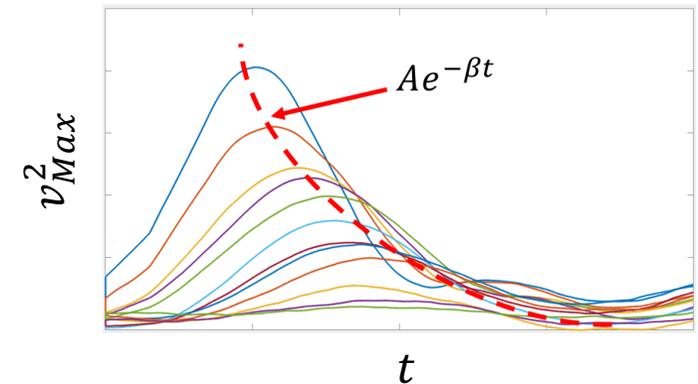
Transversal waves

$$v = \sqrt{\frac{T}{\mu}} \rightarrow E = \frac{v^2 \mu}{A \varepsilon}$$



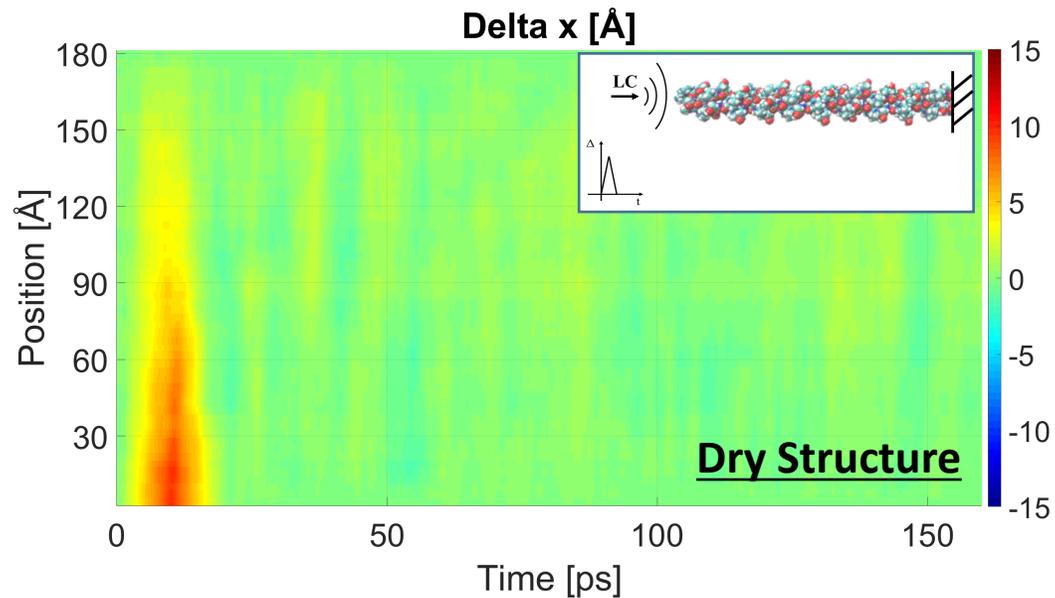
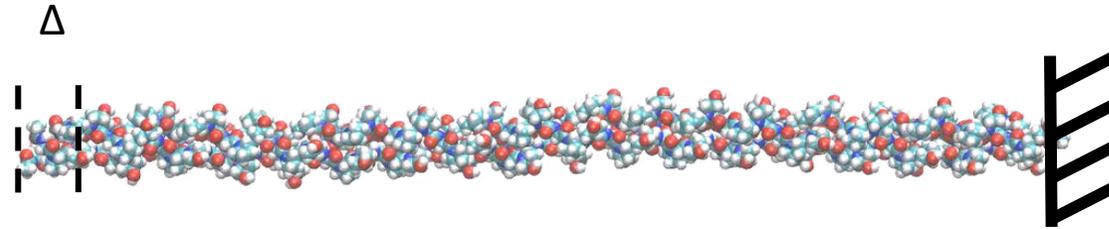
Dissipation

$$v_{Max}^2 = A e^{-\beta t} \rightarrow \tau = \frac{1}{\beta}$$

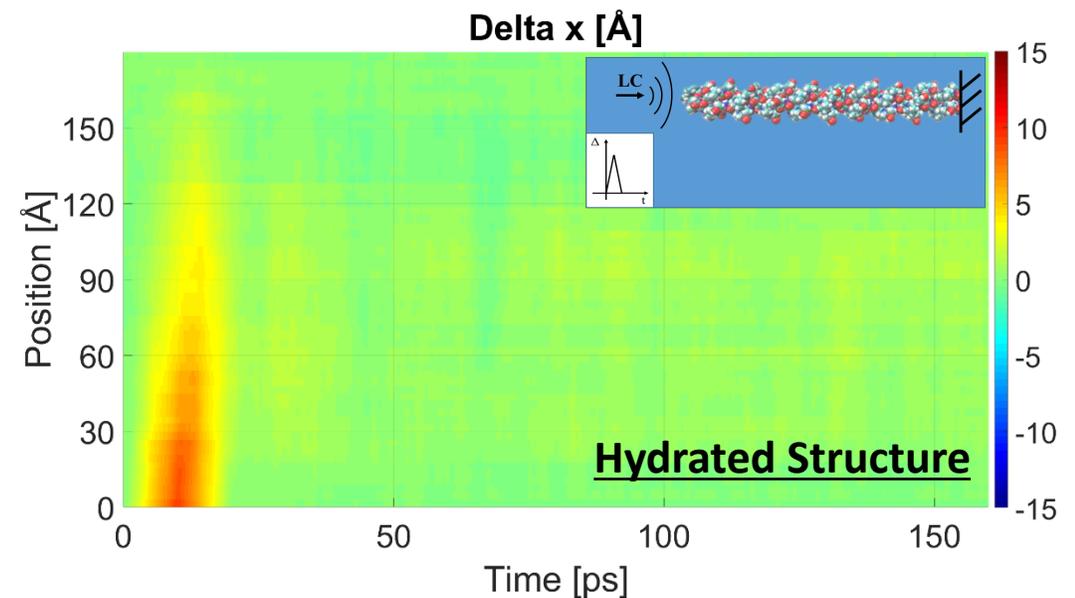


Case study: Wave transmission in collagen segments

Longitudinal Case



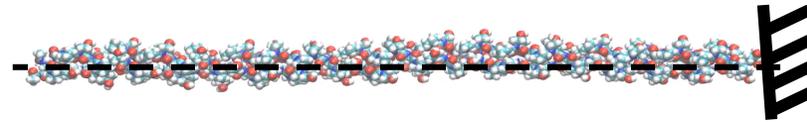
$$v = 3082 \text{ m/s}$$



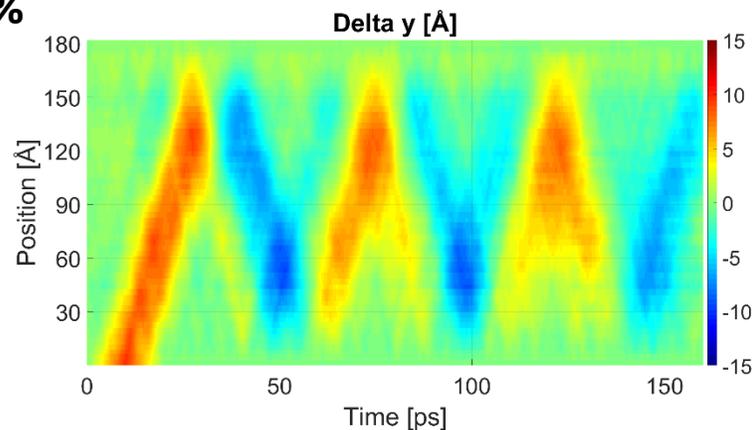
$$v = 2190 \text{ m/s}$$

Case study: Wave transmission in collagen segments

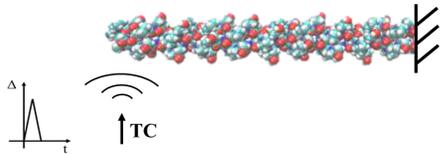
Transversal Case



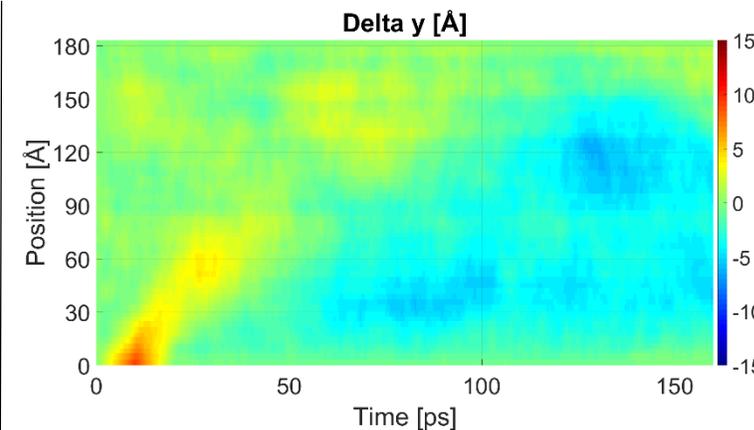
$\epsilon = 1\%$



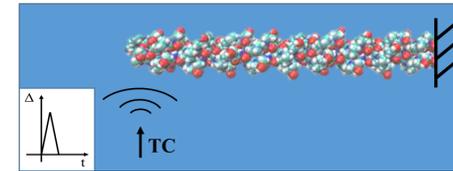
Dry Structure



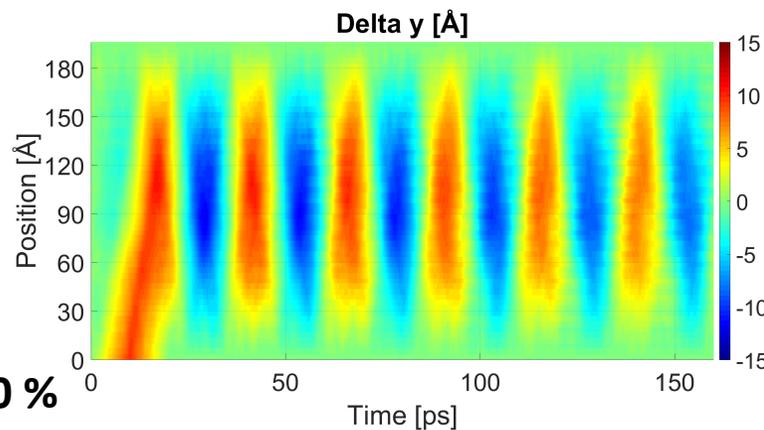
$\epsilon = 1\%$



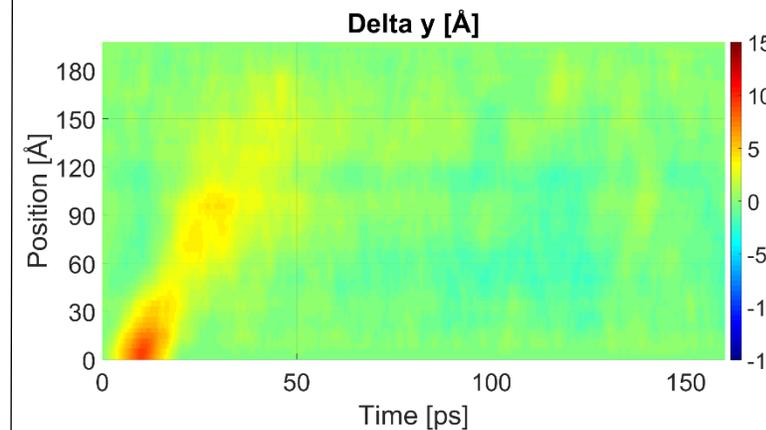
Hydrated Structure



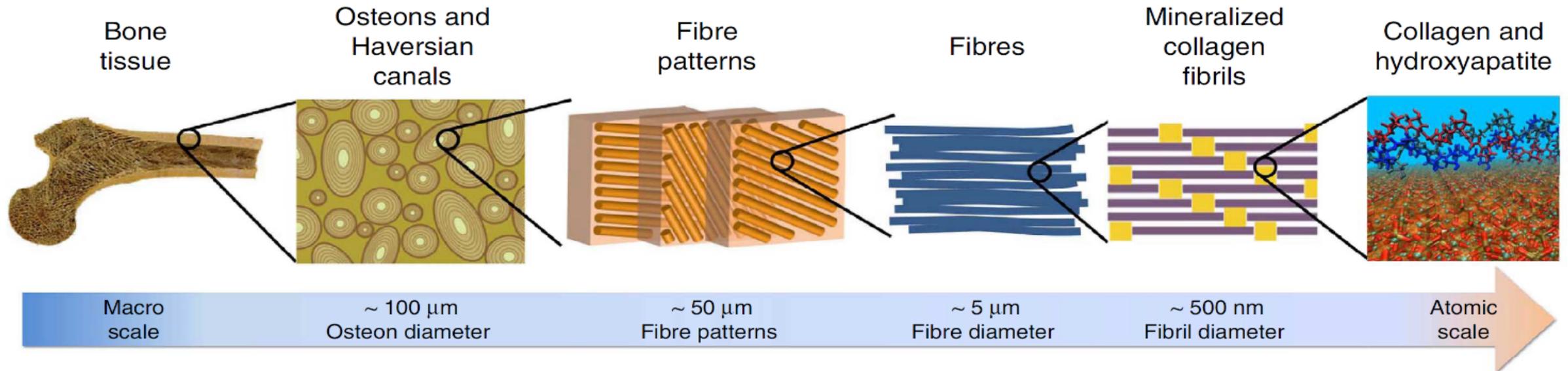
$\epsilon = 10\%$



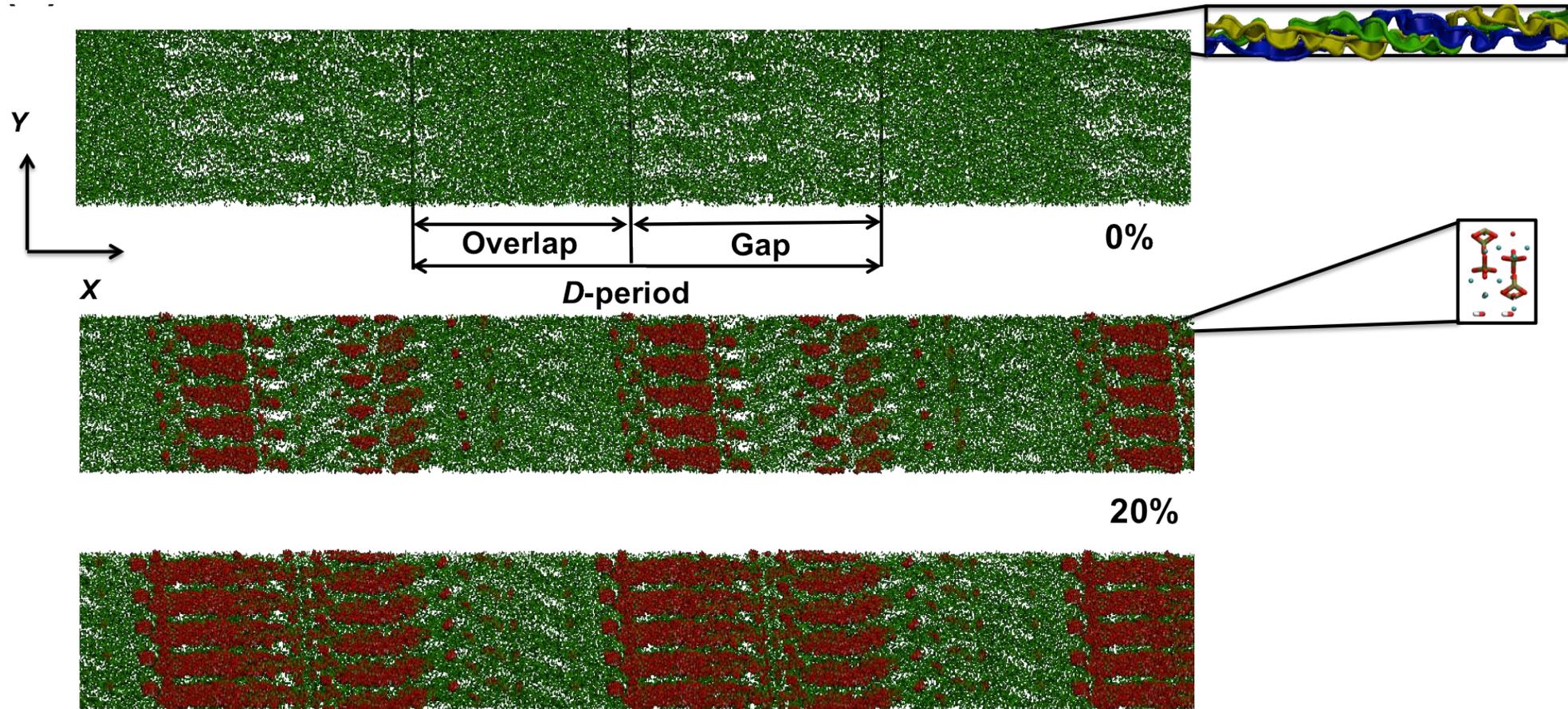
$\epsilon = 10\%$



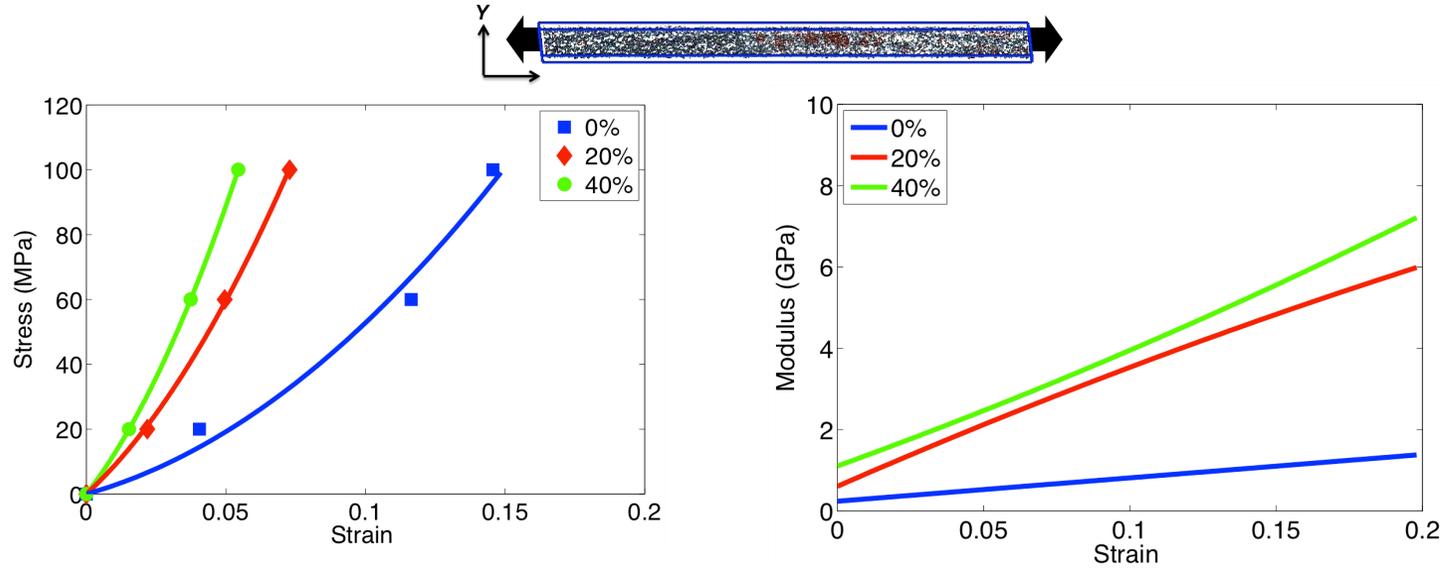
Case Study: bone



Case Study: mechanics of mineralized collagen



Case Study: mechanics of mineralized collagen



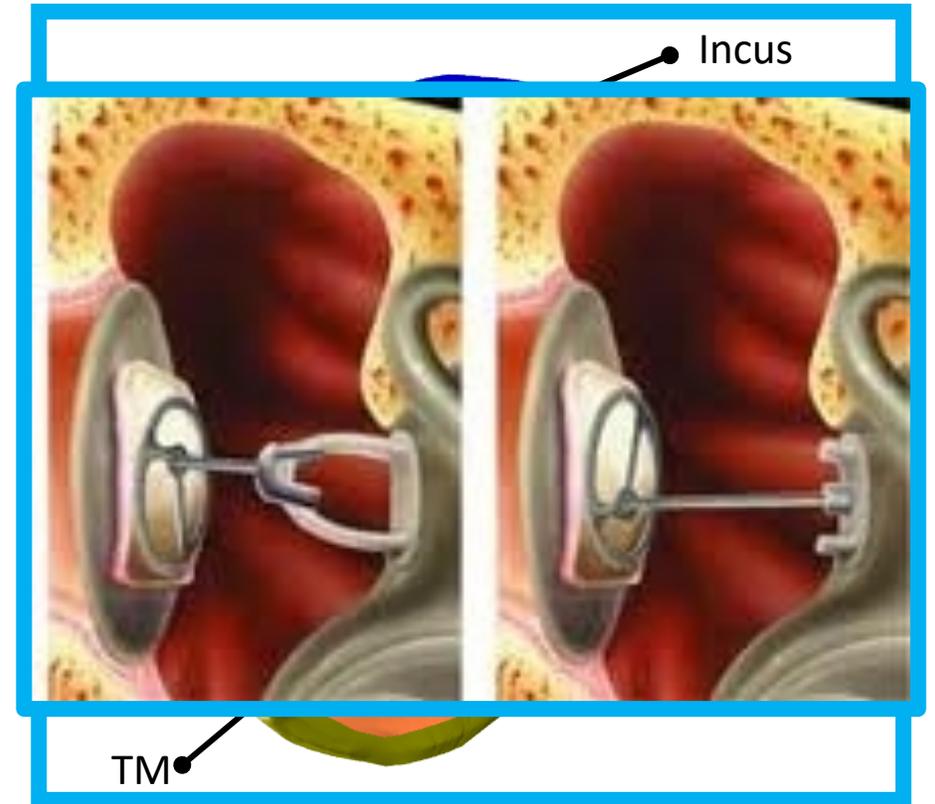
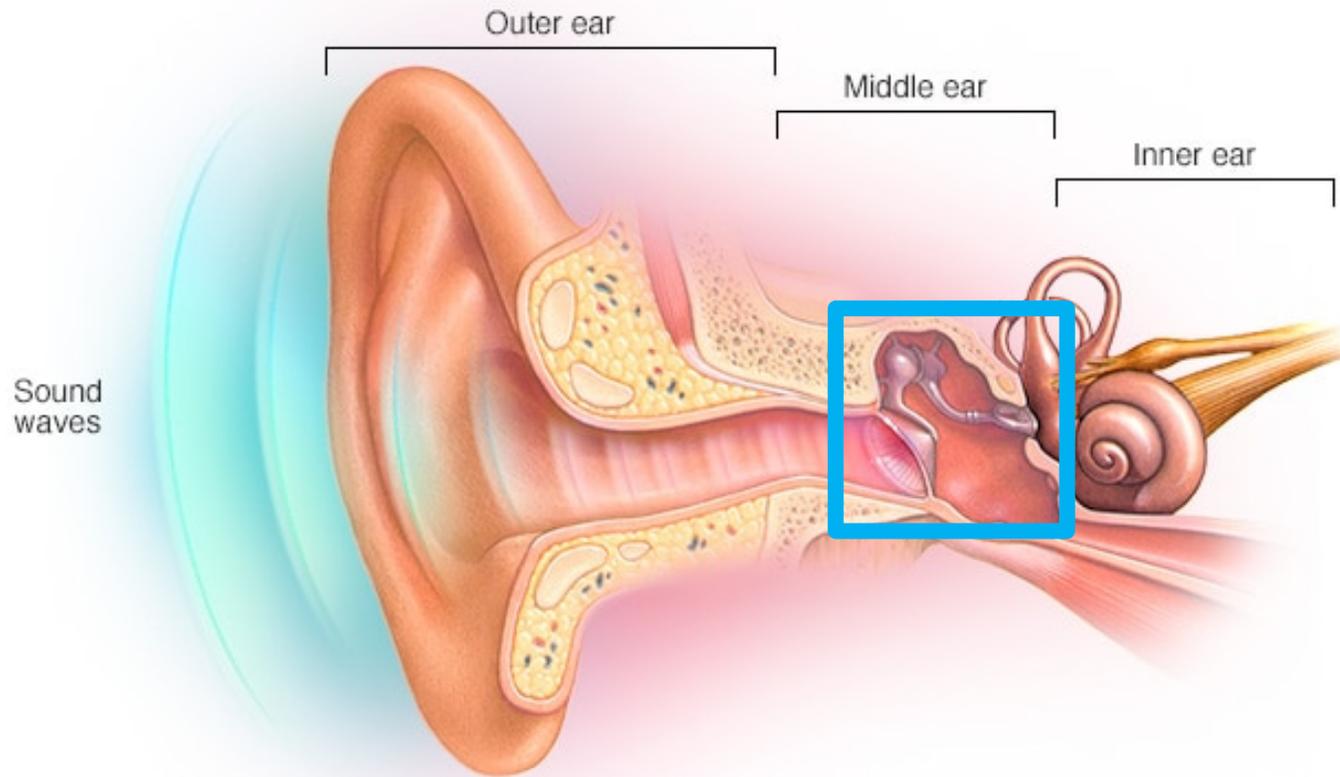
Young's Modulus

0% case 1.1 GPa at 100 MPa
 40% case 2.8 GPa at 100 MPa \curvearrowright 150% increase

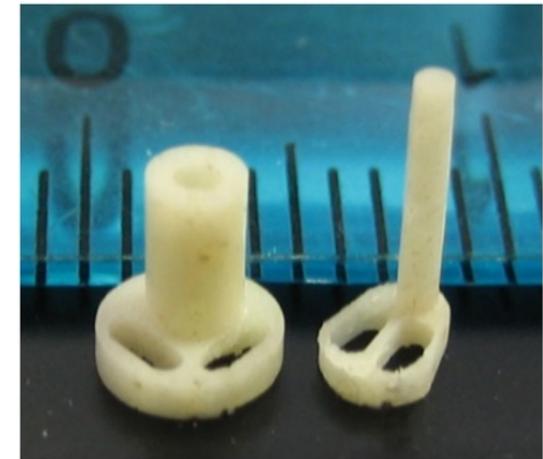
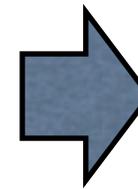
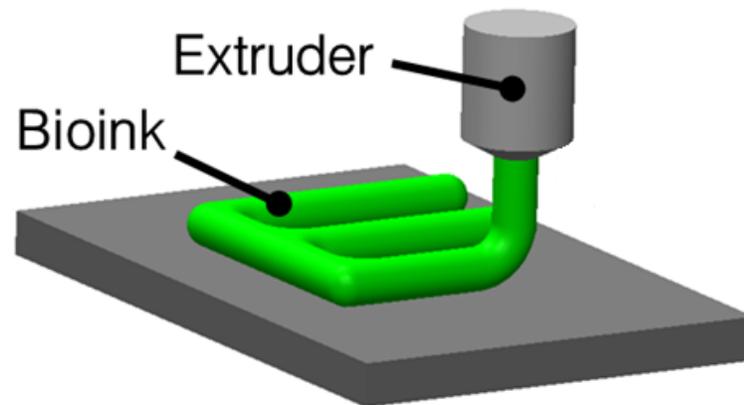
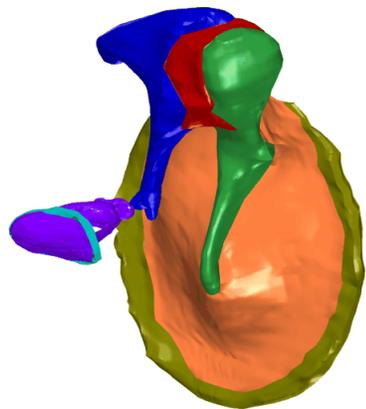
Experiment: 2-3 GPa
 Hang and Barber *et al.*, *J. R. Soc. Interface*, 2011

COLLHEAR:

“3D printed COLLagen type I-Hydroxyapatite prostheses for the middle EAR”

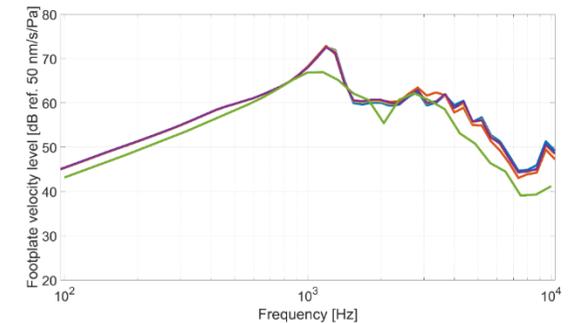
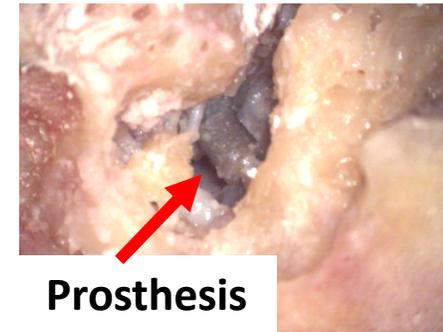
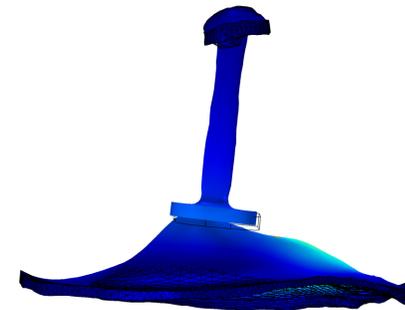
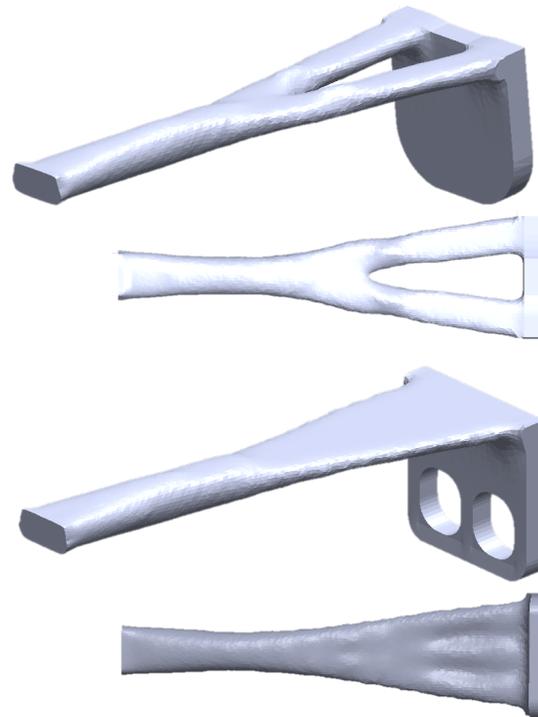
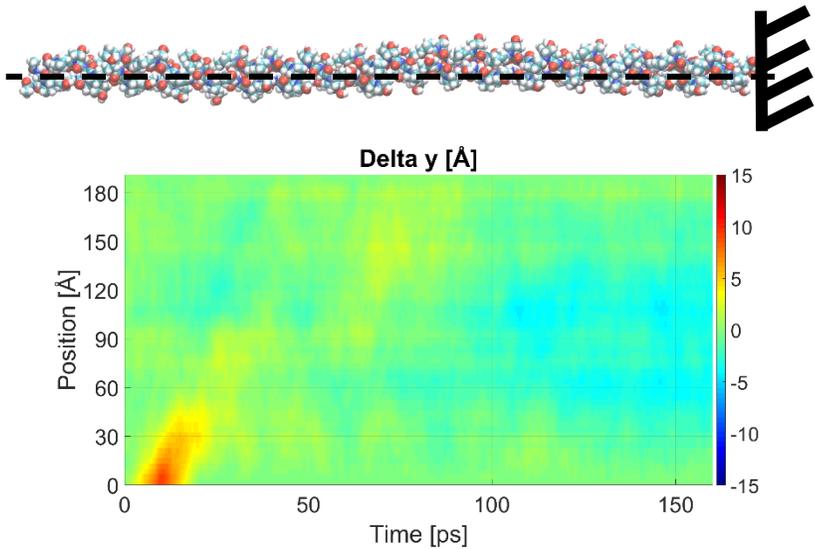


“3D printed COLLagen type I-Hydroxyapatite prostheses for the middle EAR”



COLLHEAR:

“3D printed COLLagen type I-Hydroxyapatite prostheses for the middle EAR”



Simulations at the molecular scale

Topology optimization

Development of a new product



**Thank you
for your attention!**

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milazzo@mit.edu



Note: Selected pictures were taken or modified from Literature and Web.