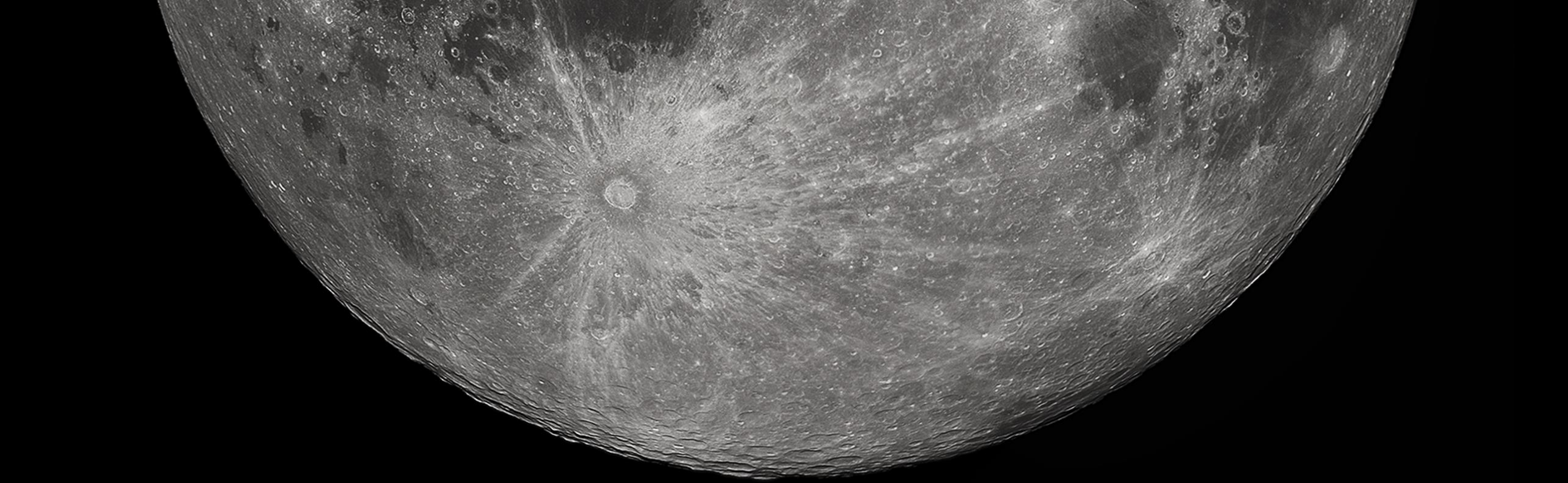


POLYTECHNIQUE MONTRÉAL
UNIVERSITÉ D'INGÉNIERIE

3D PRINTING OF A GEOMETRY OPTIMIZED SANDWICH PANEL FOR A LUNAR ROVER'S FRAME

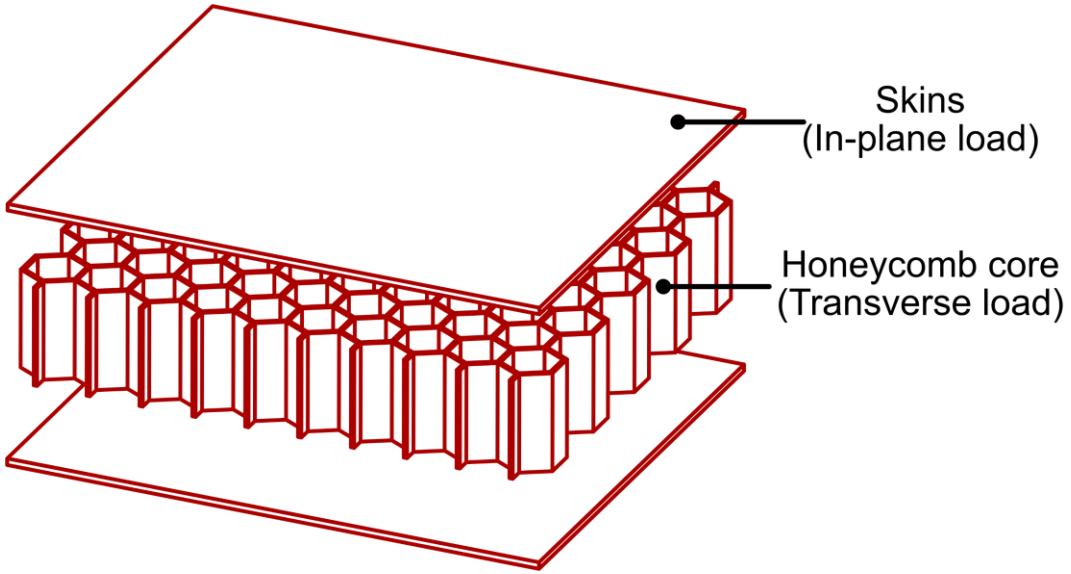
LM²
Olivier Duchesne, PhD student.
Laboratory for multiscale mechanics
Supervised by Pr. Daniel Therriault & Pr. Frédérick P. Gosselin

May 31st, 2023

CSA ASC
arianeGROUP
nanoXplore Performance Through Carbon Chemistry
DYZE DESIGN
Mëkanic
CRSNG NSERC
PRIMA Les matériaux pour avancer
crepec Research Center for High Perfomance Polymer and Composite Systems

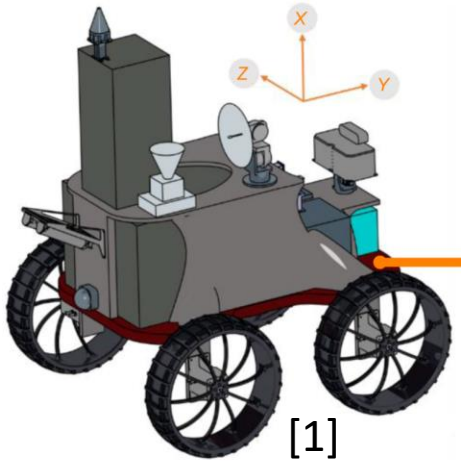
(NASA)

MOTIVATION



- Core's mass dispersion is homogeneous
- Could we make stiffer, lighter structures thanks to **3D printing** by redistributing the cell size ?

- Light
- High flexural modulus
- Low out of plane thermal conductivity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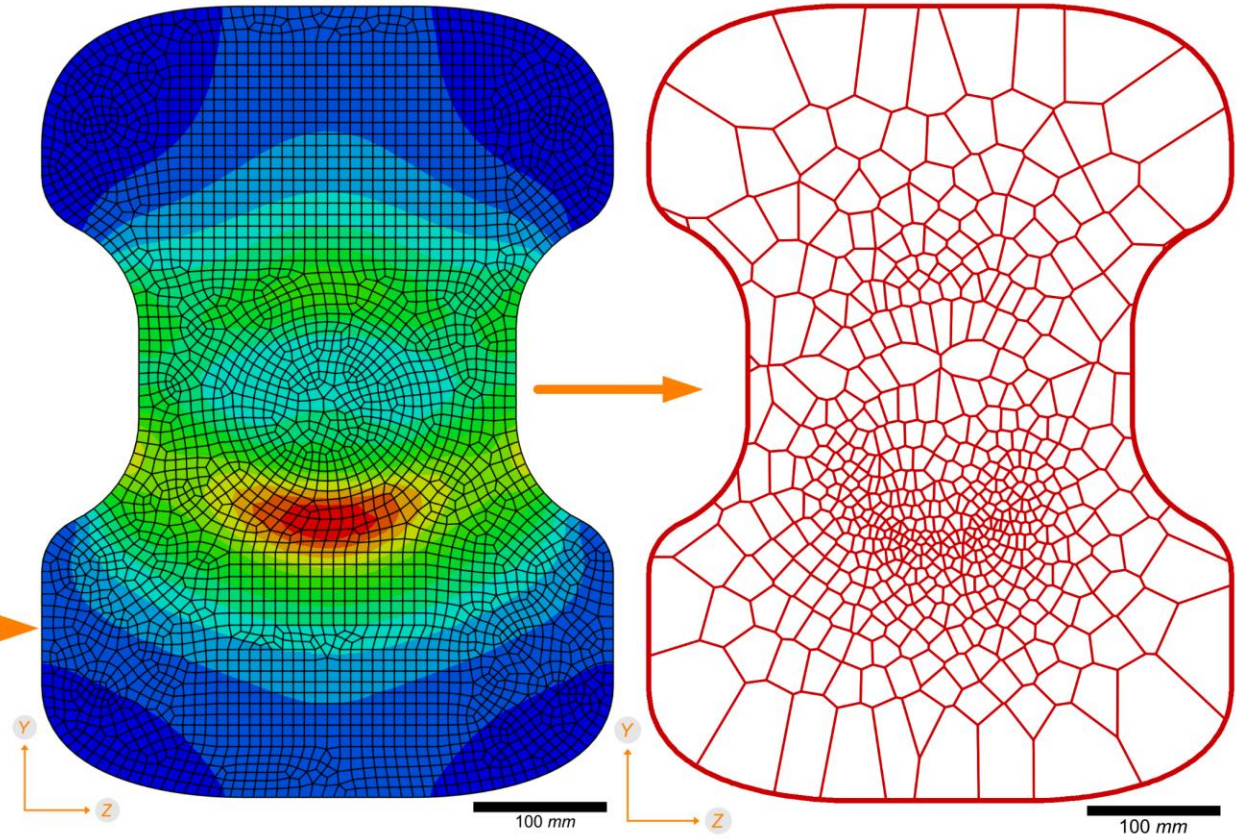


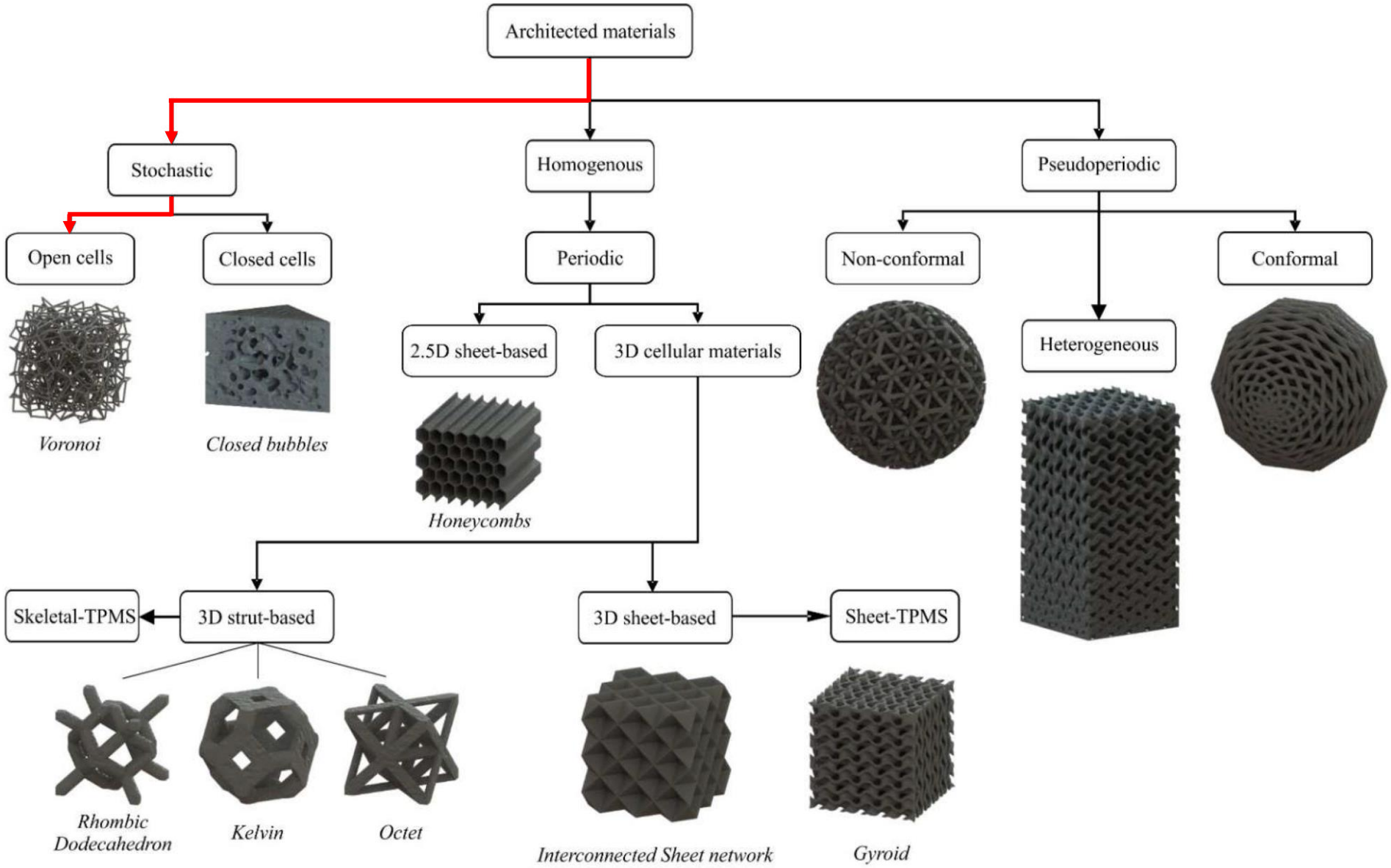
1. Broggi, « Conception et fabrication additive d'une structure bio-inspirée pour un rover lunaire en composites thermoplastiques ».

CELLULAR MATERIAL OPTIMIZATION OVERVIEW

- For sandwich panels
  - Light
  - Stiff

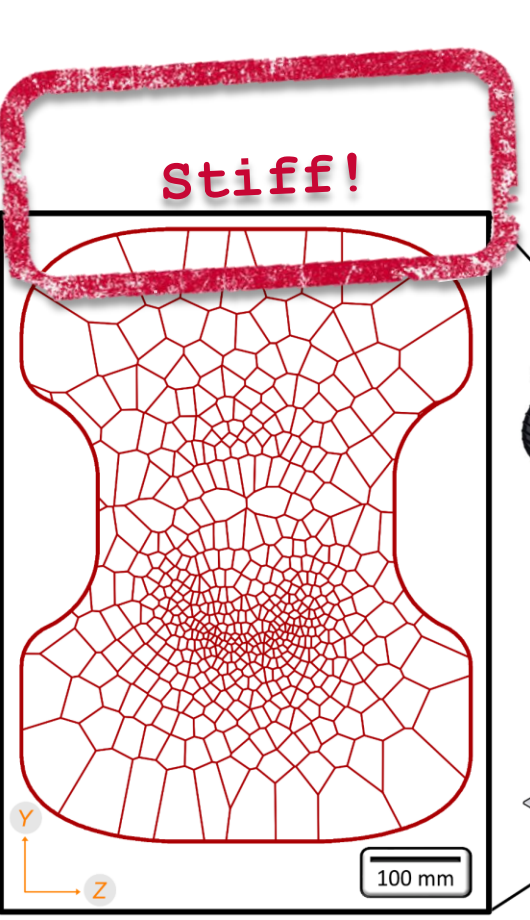
- **2D Cellular Material Optimization**
  - Honeycomb-like structure
  - Improve local stiffness
    - Mass distribution

- Challenge is to **smoothly distribute cells over a domain**

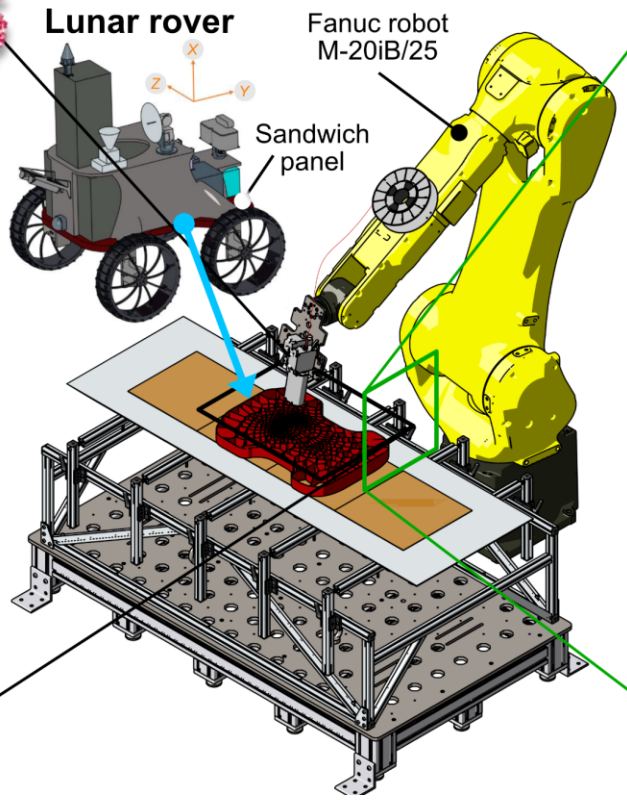


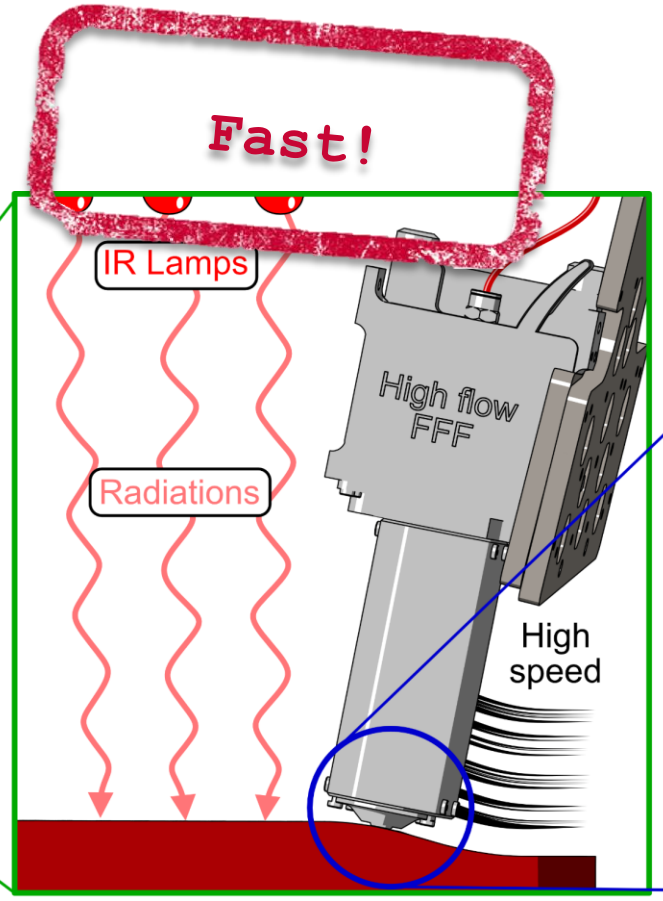
Classification of architected materials based on the geometry (*Kladovasilakis et al.*)

FFF FOR MOON EXPLORATION

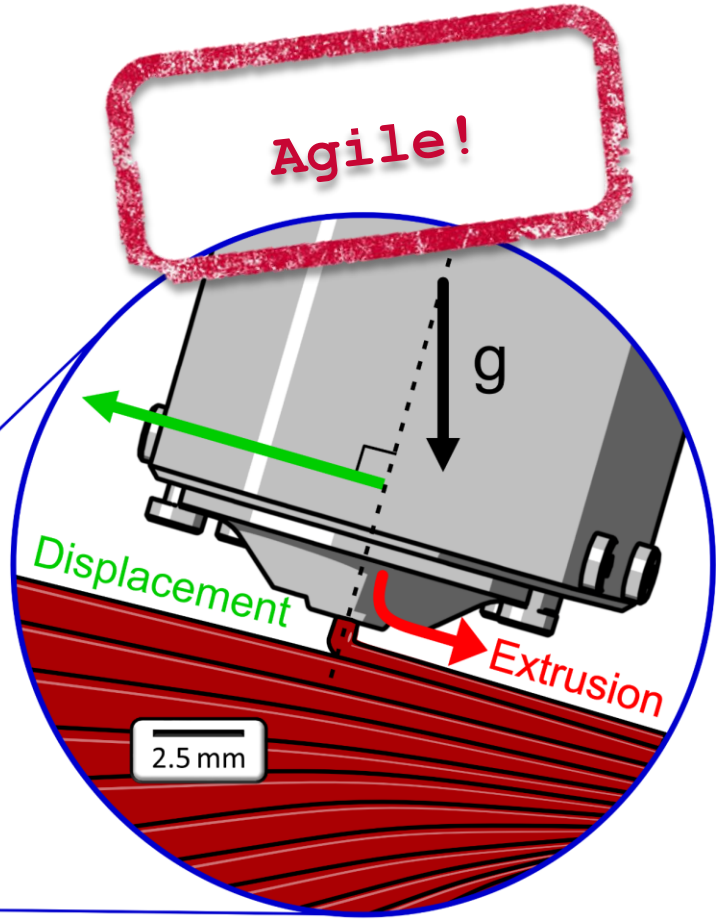


Optimization of sandwich panel's core



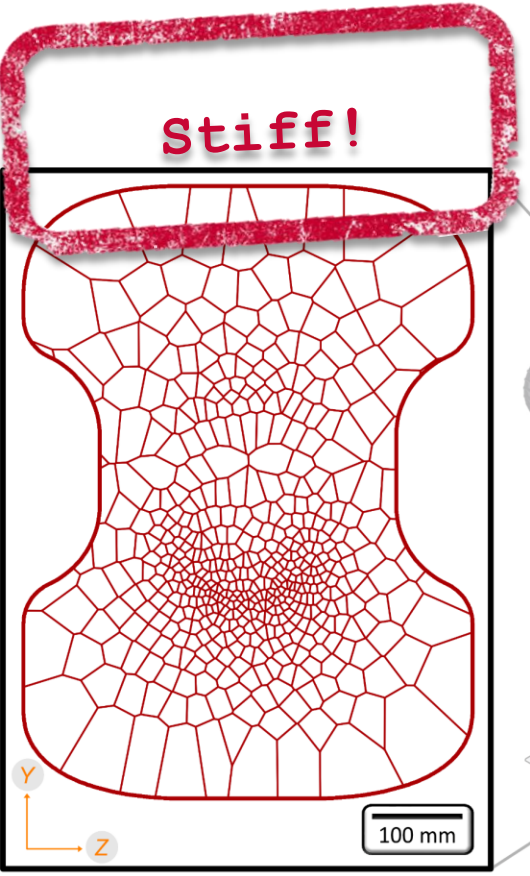


FFF of big parts with high temperature composites at high volumetric flow



Non-planar adaptive FFF with nozzle orientation control

MAXIMIZED STIFFNESS



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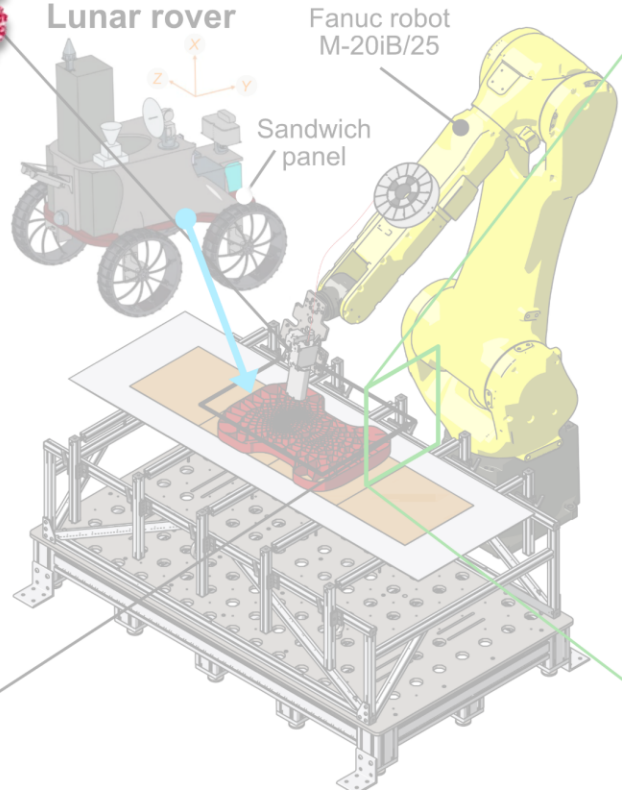

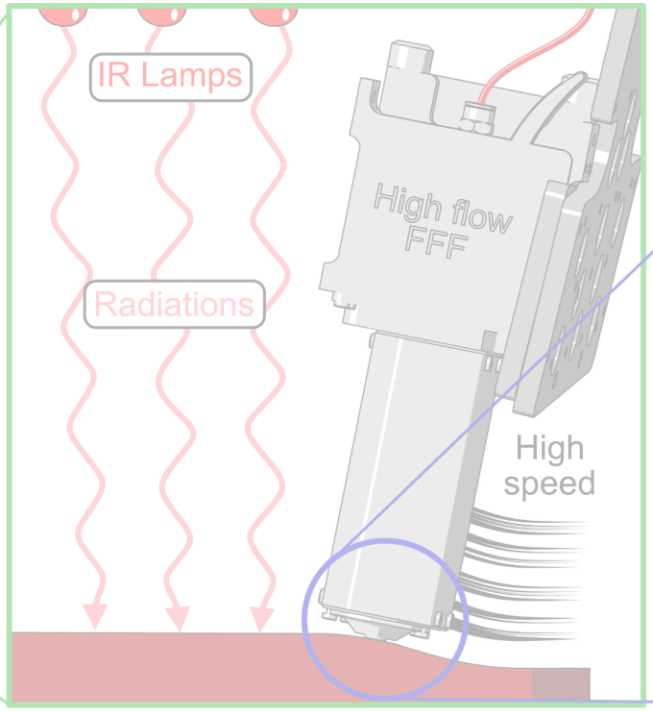

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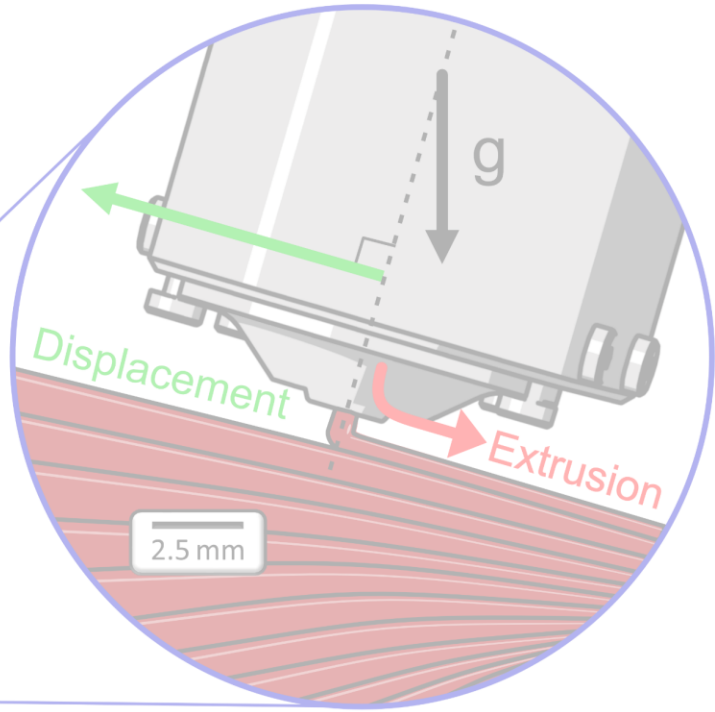
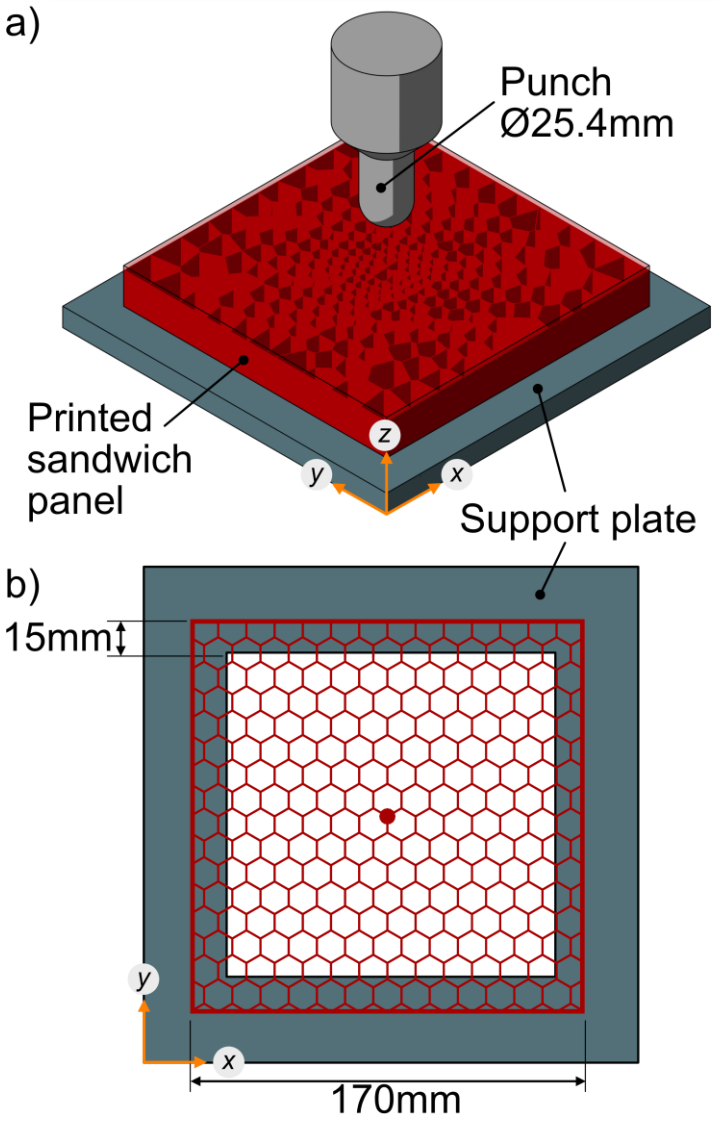


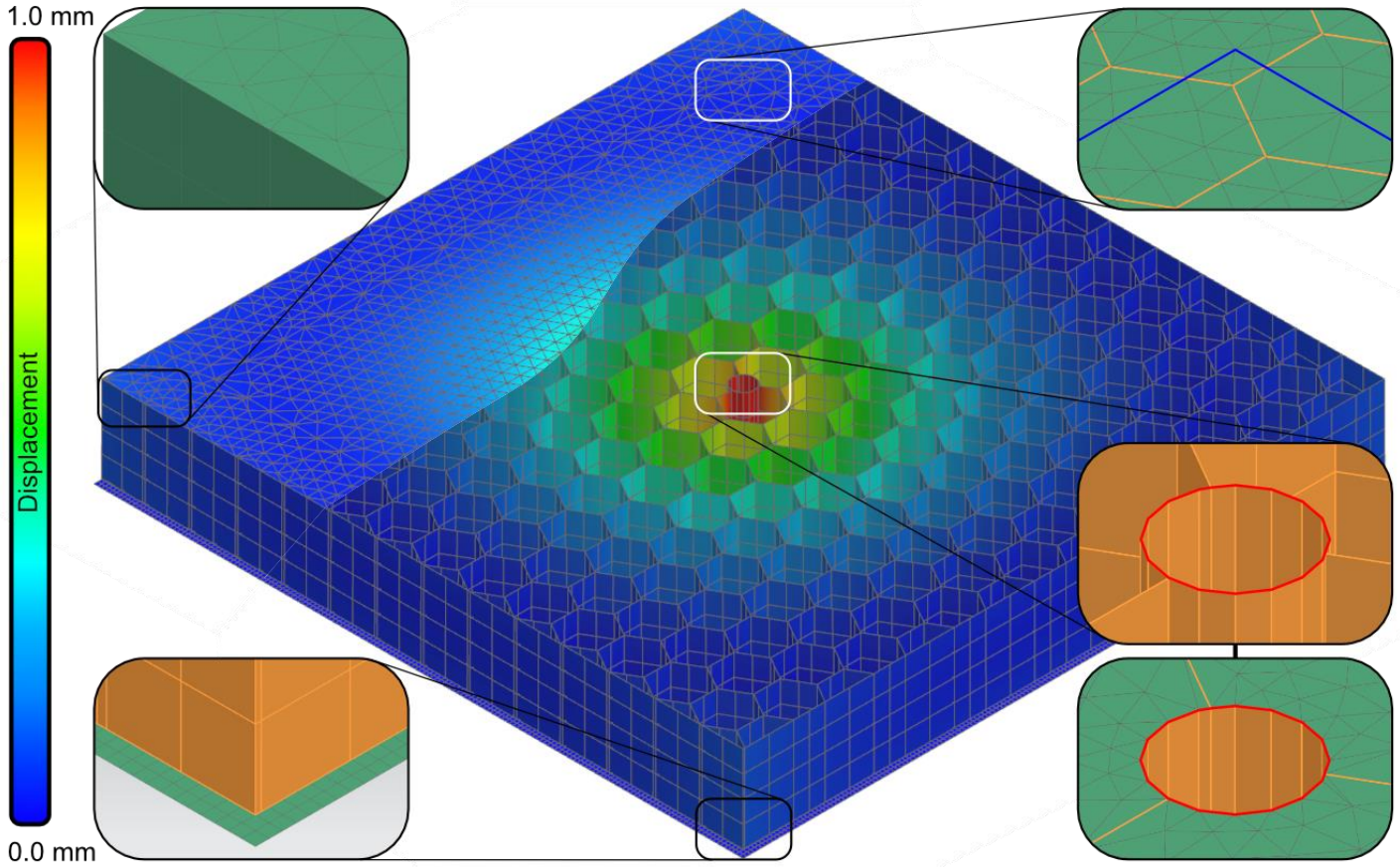
Non-planar adaptive FFF with nozzle orientation control

METHODOLOGY



Representation of the experimental setup a) showing the punch applying a central load on the panel b) simply supported on its edges.

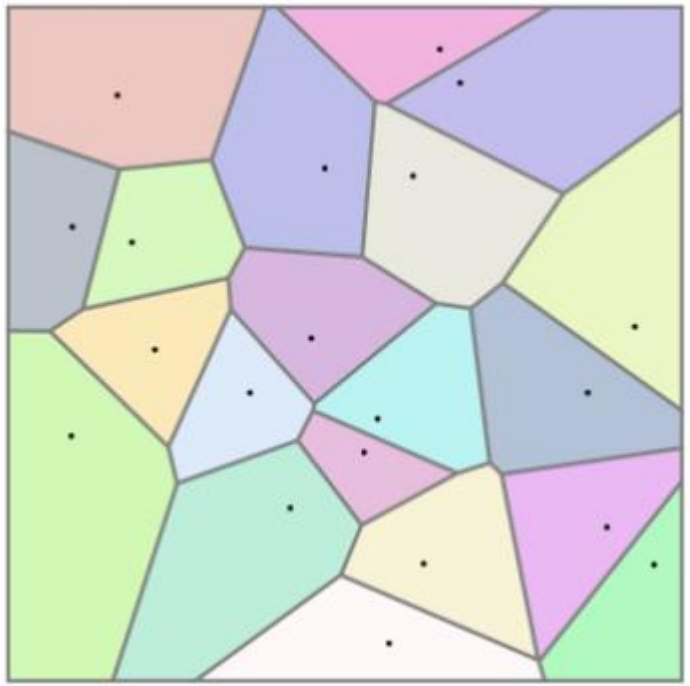
- Meshing with Gmsh, Solving with MSC Nastran
  - PSHELL: CQUAD8, CTRIA6
  - Bottom contact with edges
  - Imposed displacement on central nodes



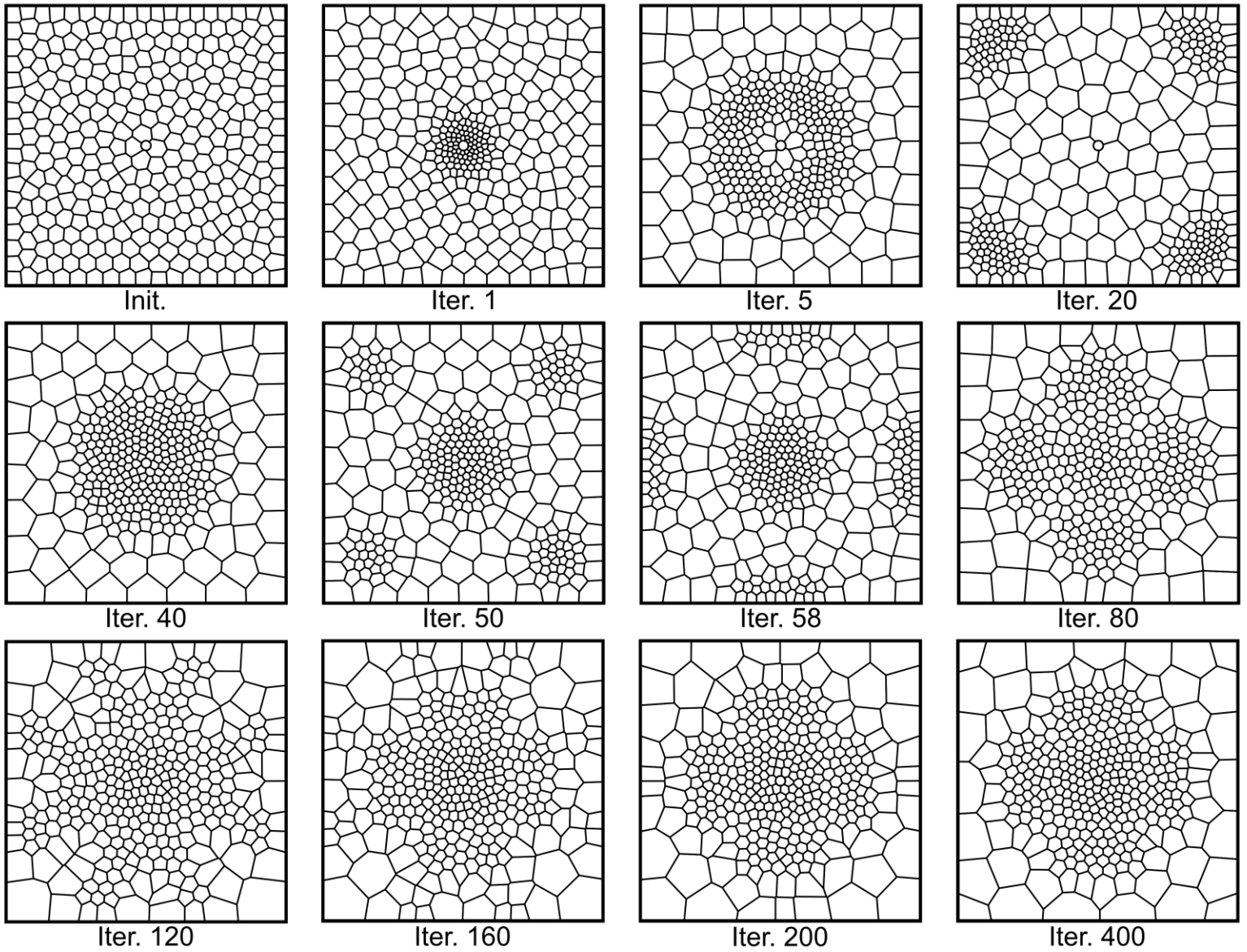
Finite element model evaluation by Nastran showing the displacement field of an imposed displacement in the center of the panel.

CELLULAR REDISTRIBUTION

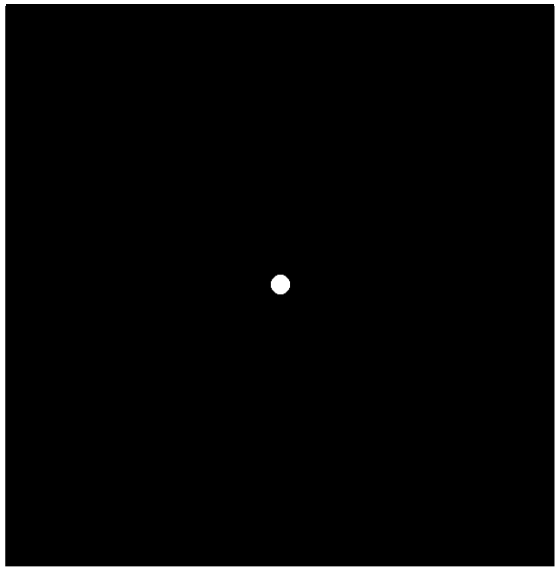
- Cost function: Compliance
  - Amount of cells: constant
  - Mass: slightly drops
  - Stiffness: increases



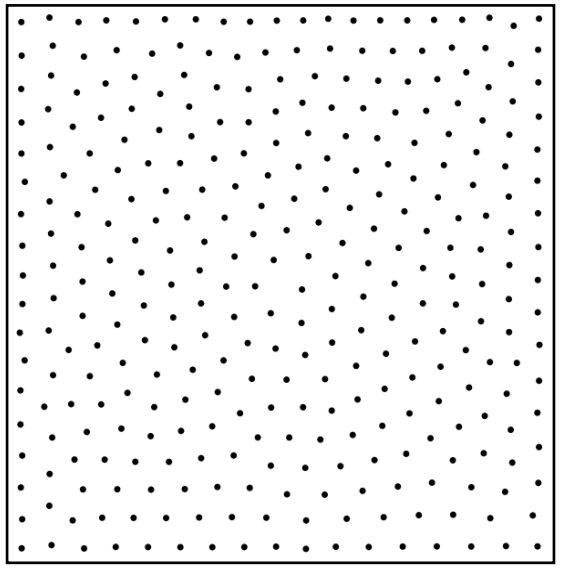
Visualisation of how a voronoi diagram is generated (*Wolfram*)



OPTIMIZATION PROCESS



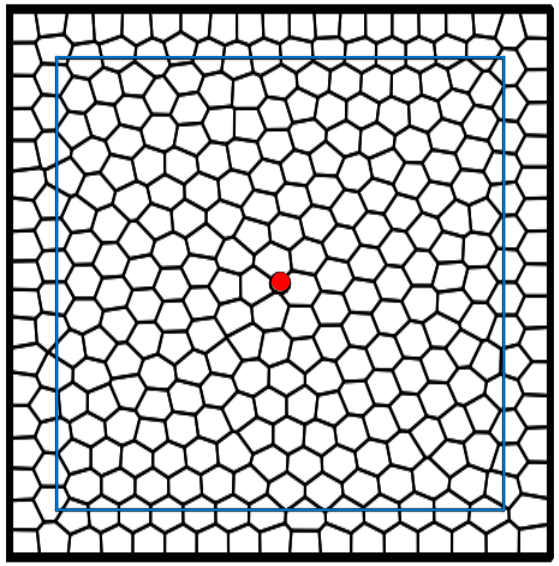
Density



Constant amount of cells (320)

15×15 grid

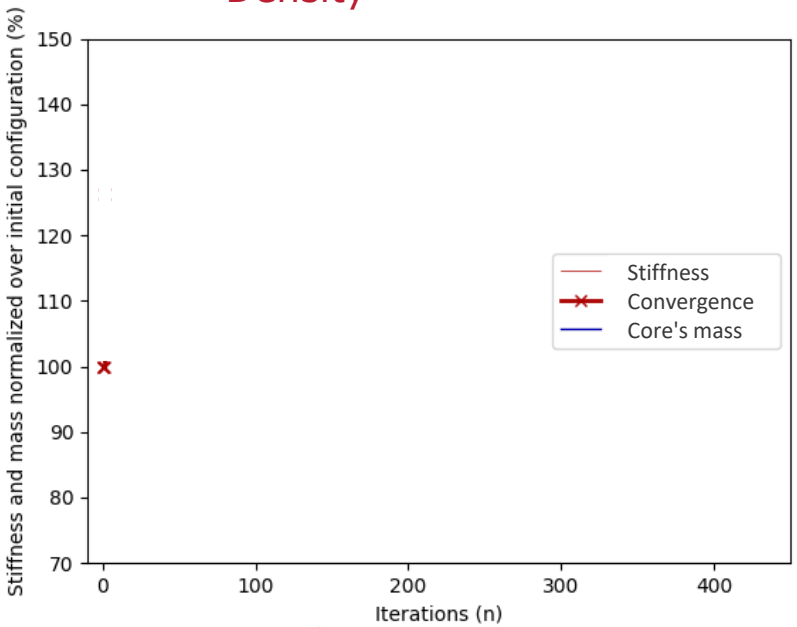
Seed distribution



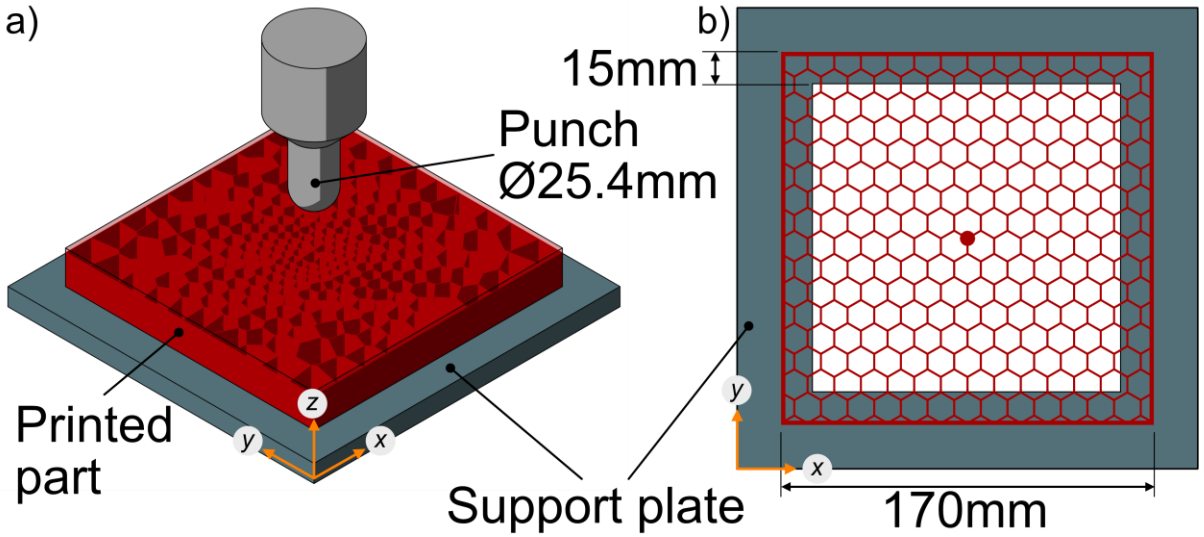
Edge supported area

Imposed displacement

Cell distribution



Convergence



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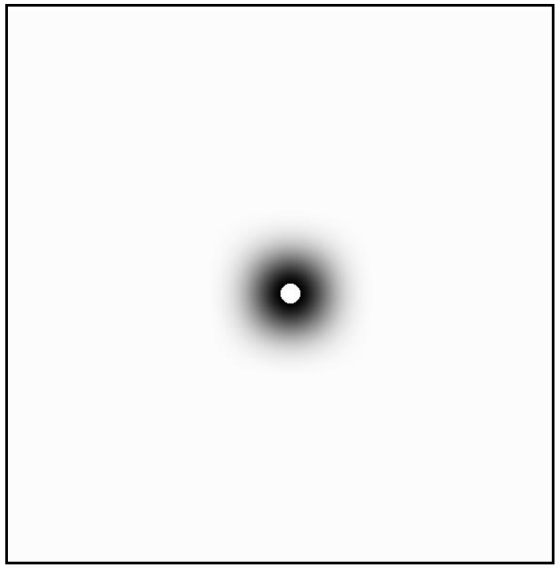
OPTIMIZATION PROCESS



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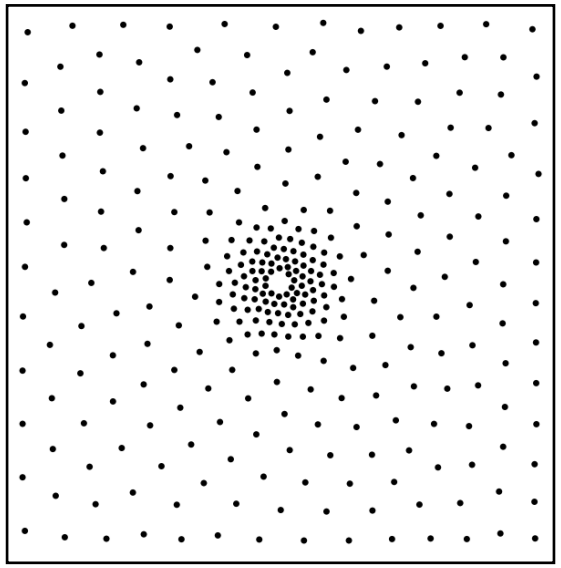

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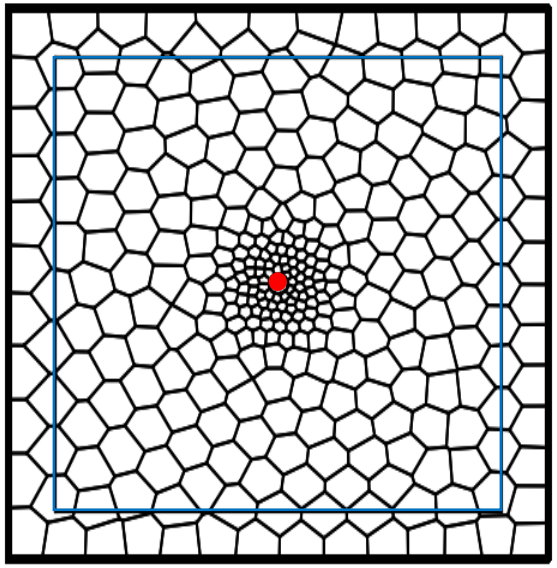
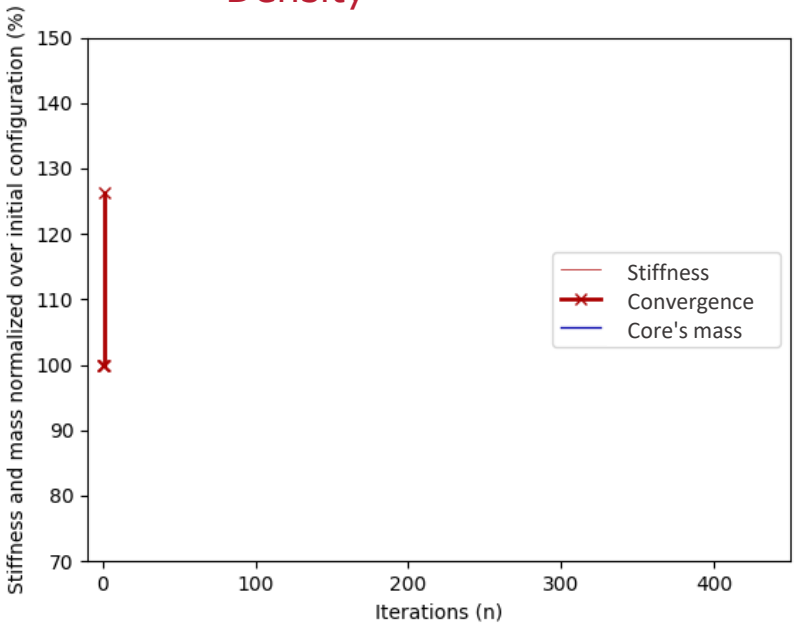


Edge supported area

Imposed displacement

Cell distribution



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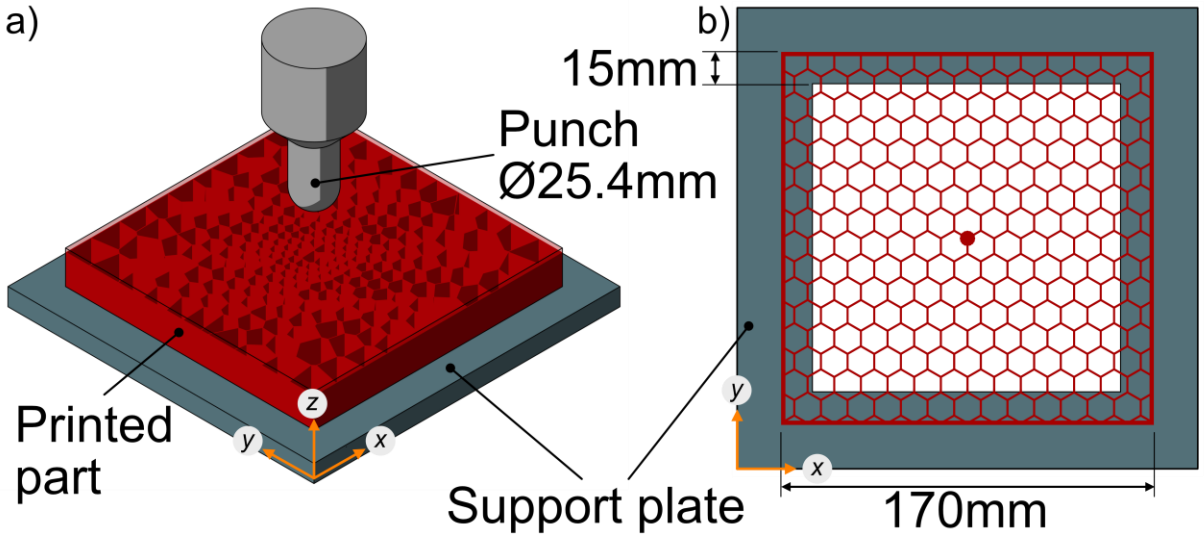

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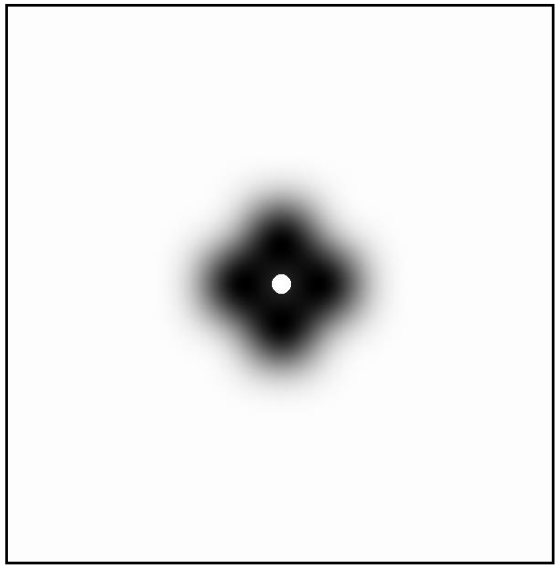
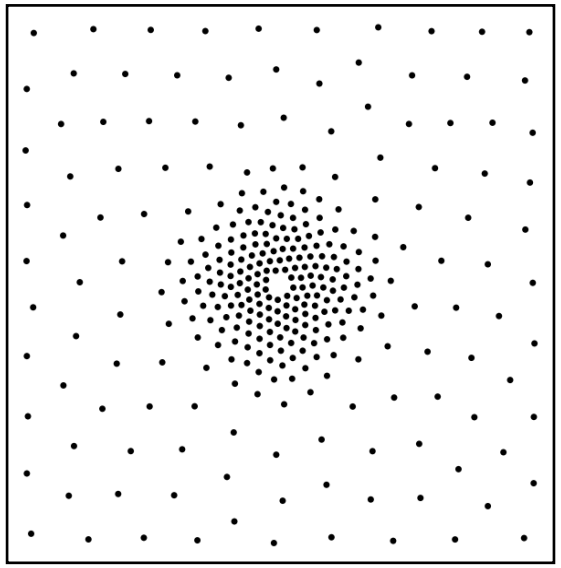


Density



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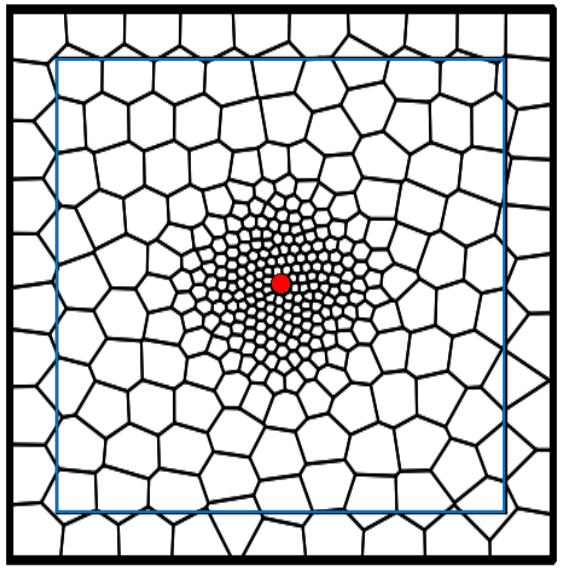

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Imposed displacement

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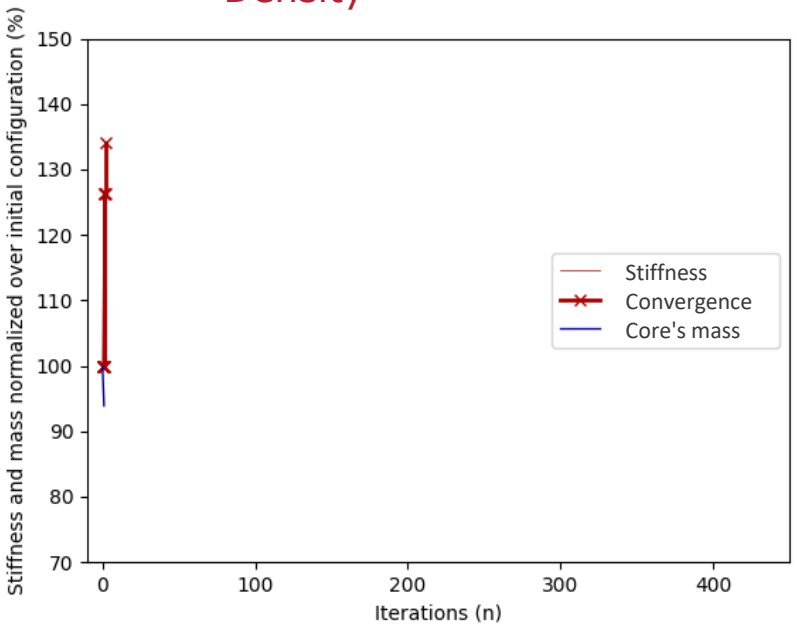

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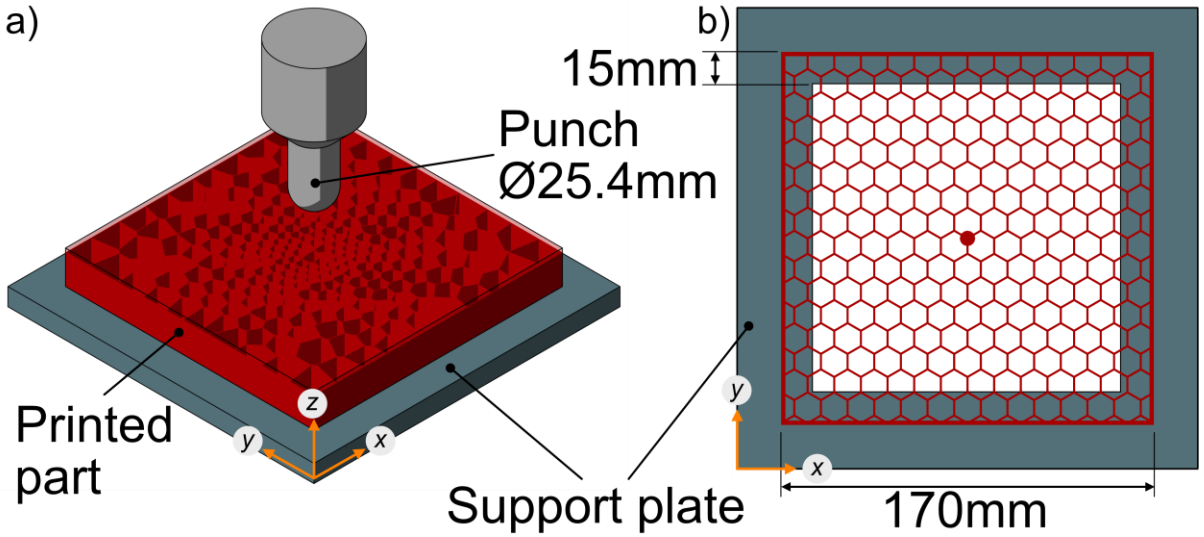

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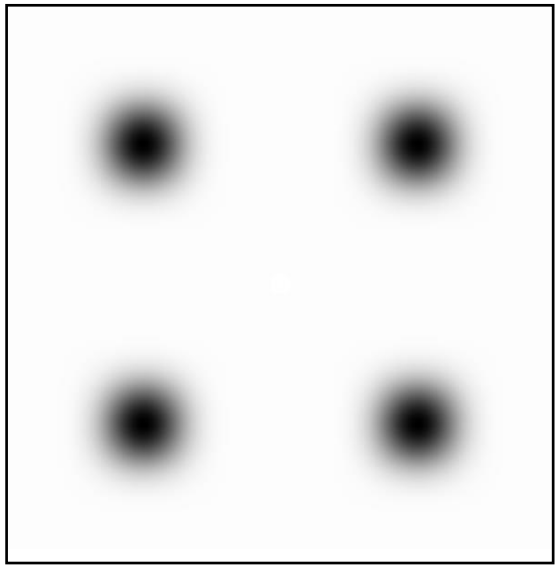

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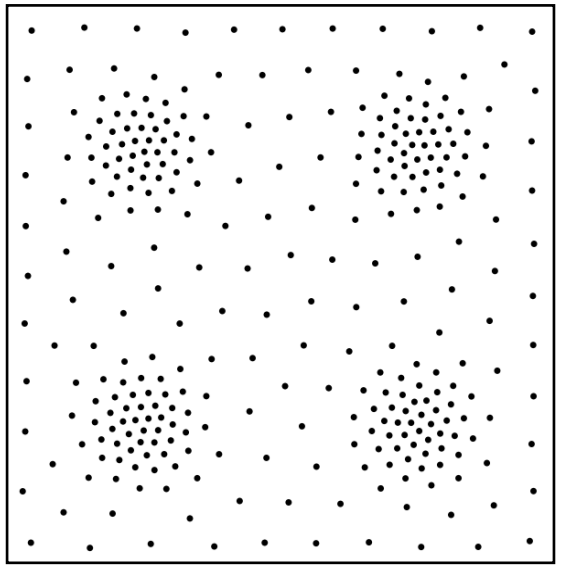

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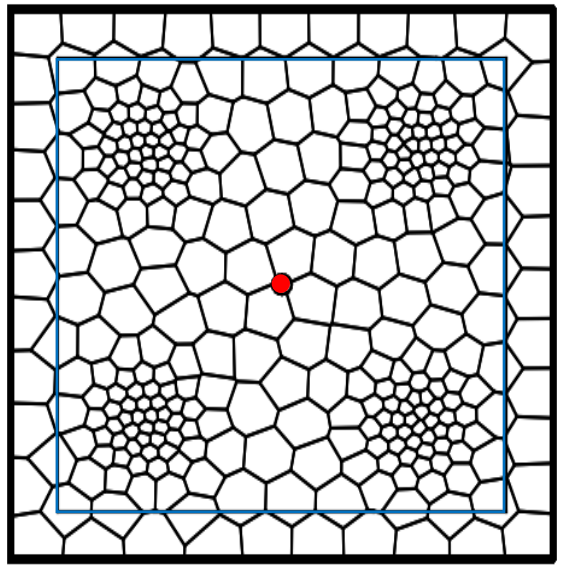

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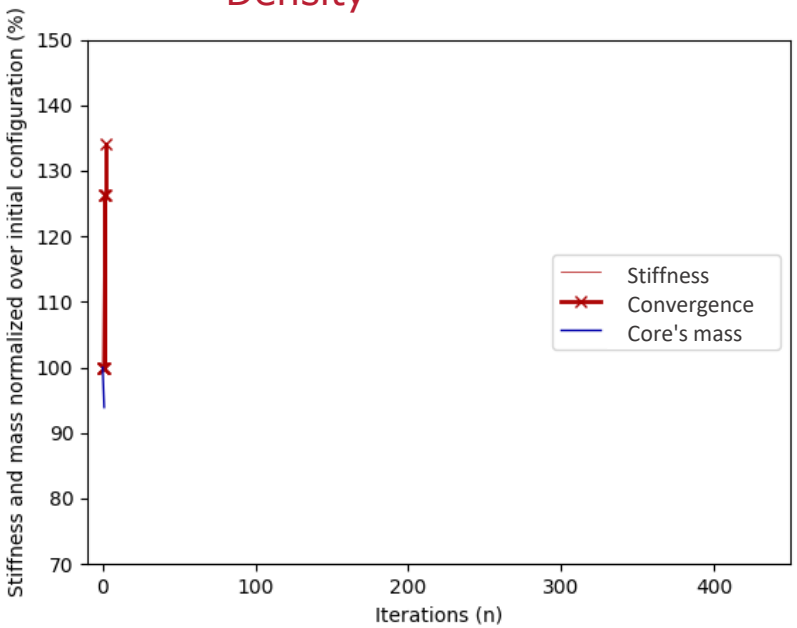
Imposed displacement

Cell distribution



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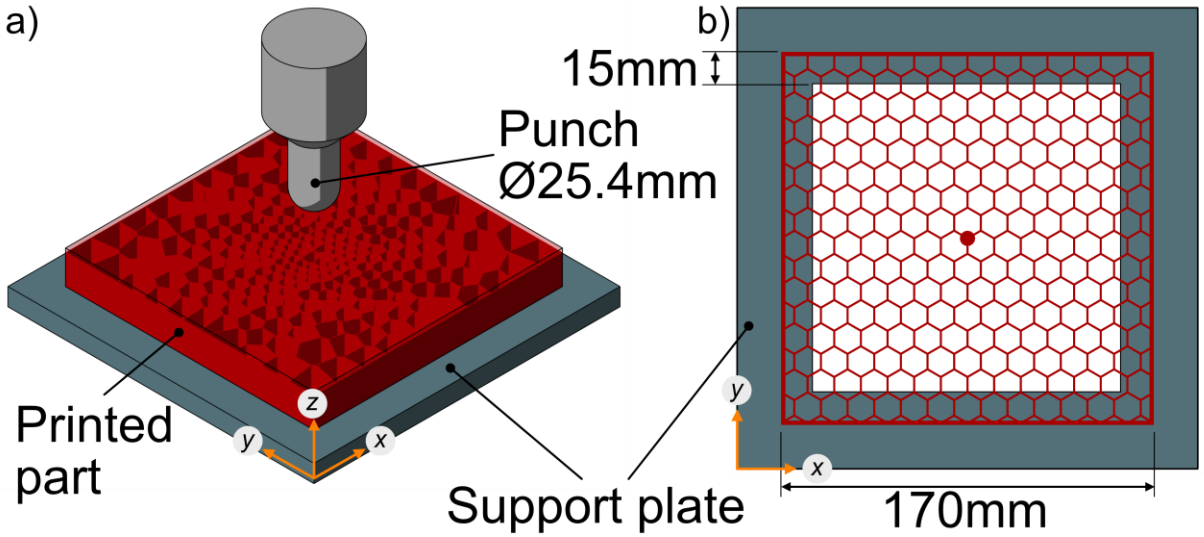

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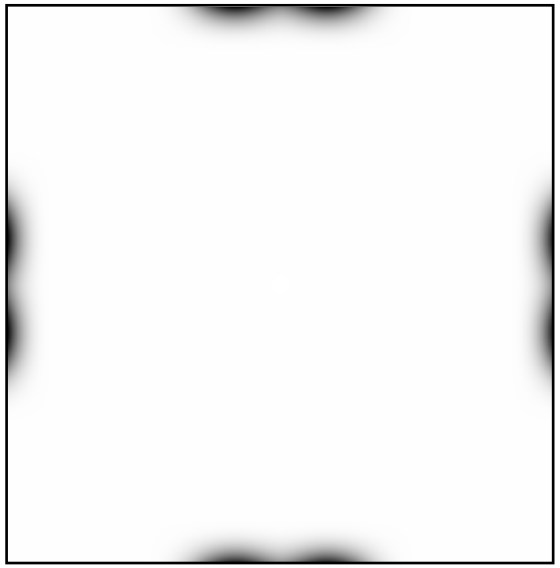

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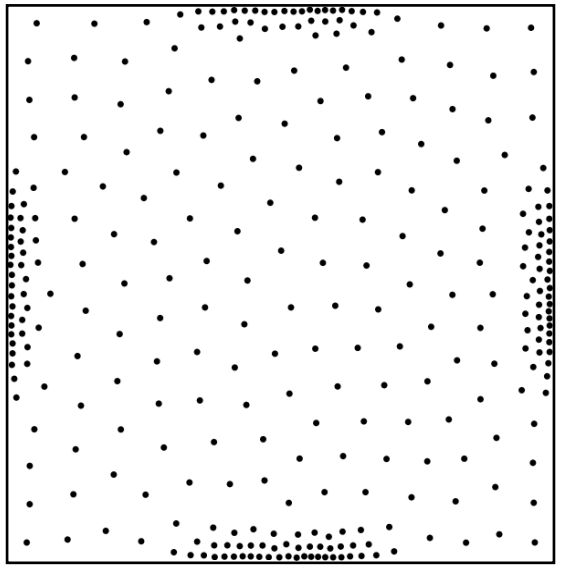

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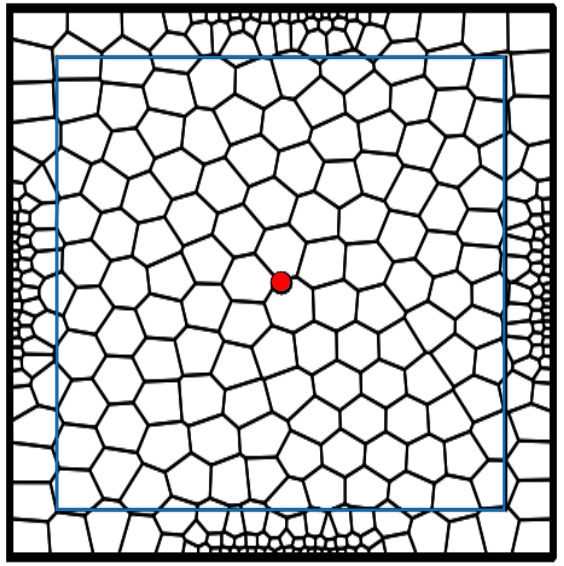

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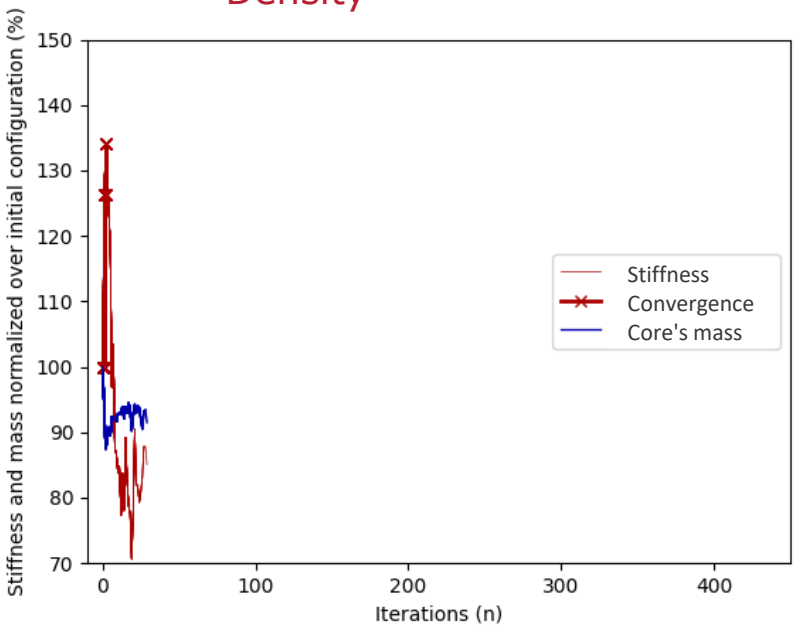

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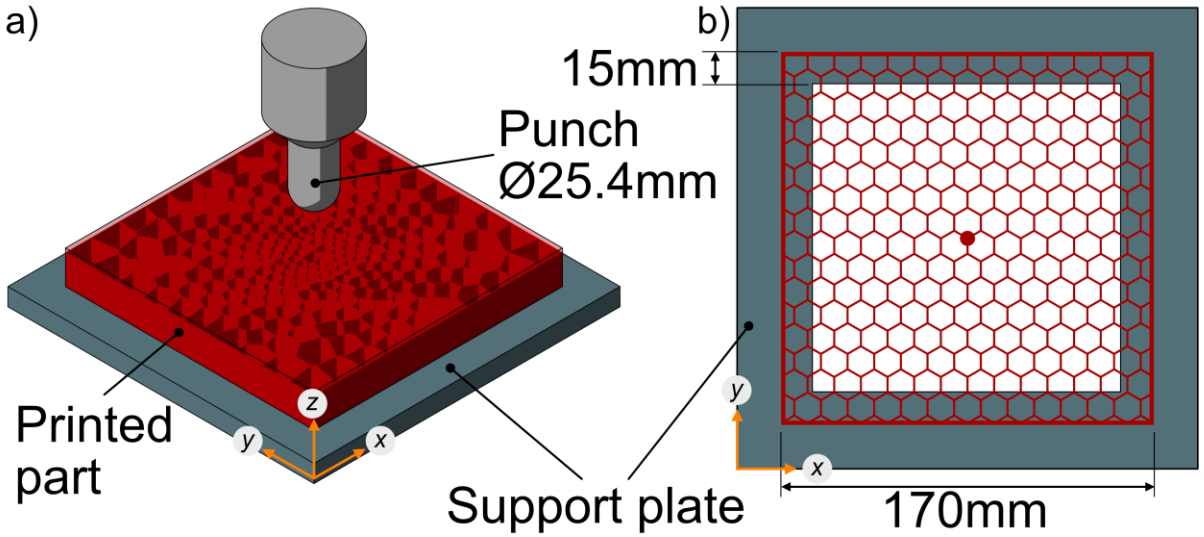

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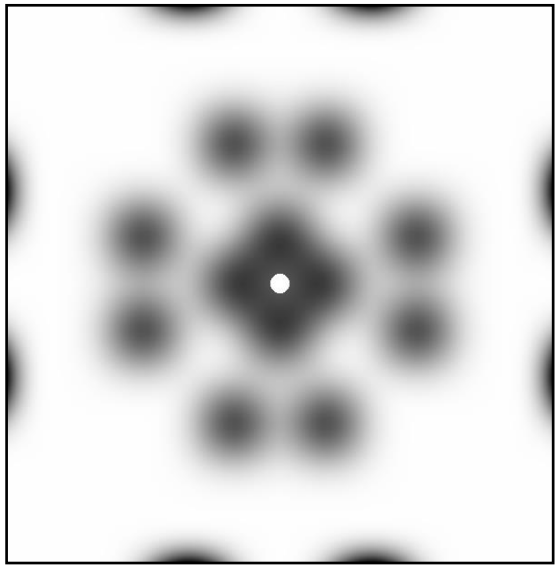

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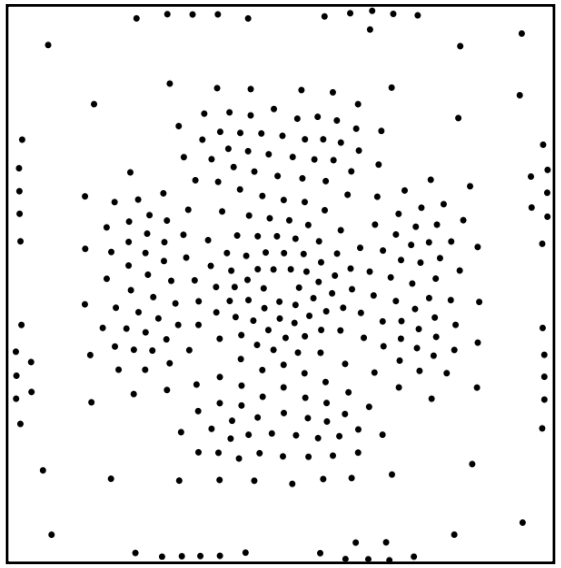

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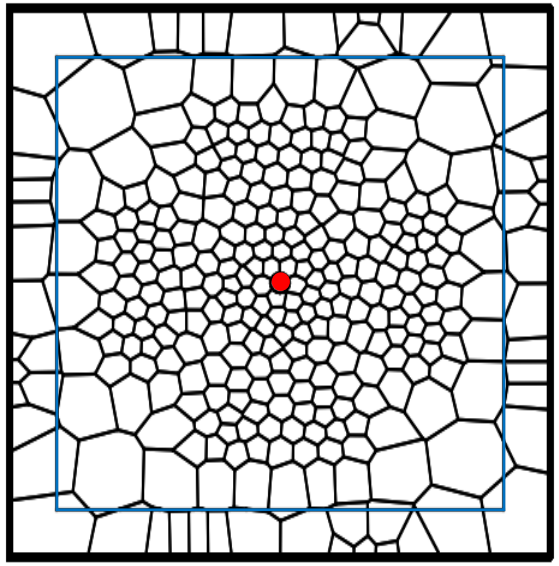

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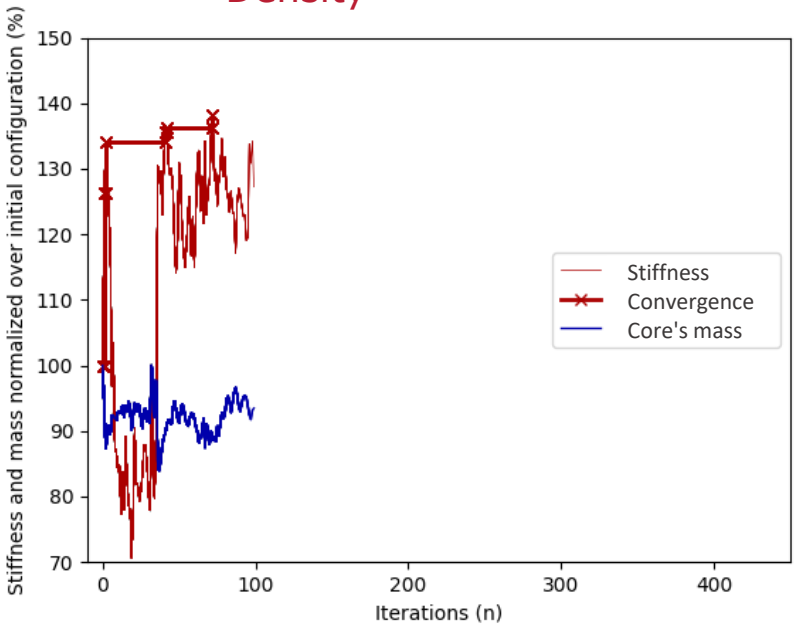

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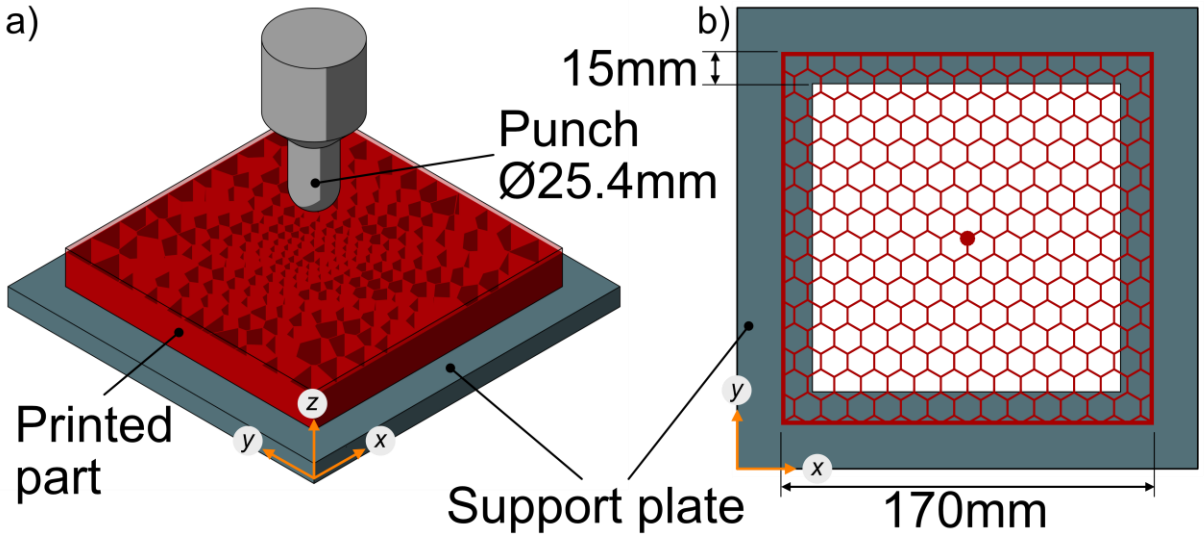

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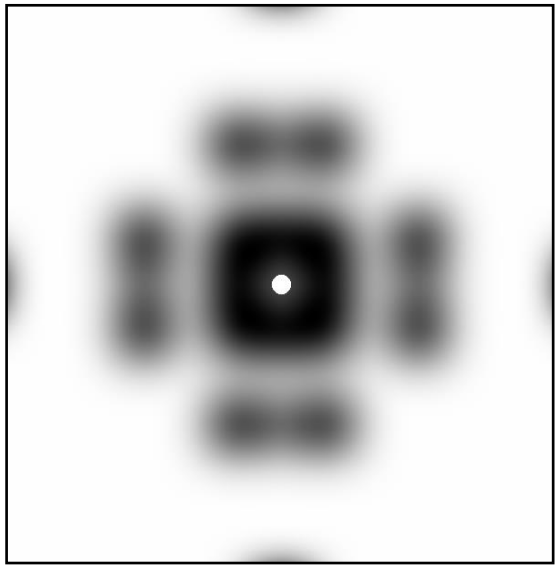

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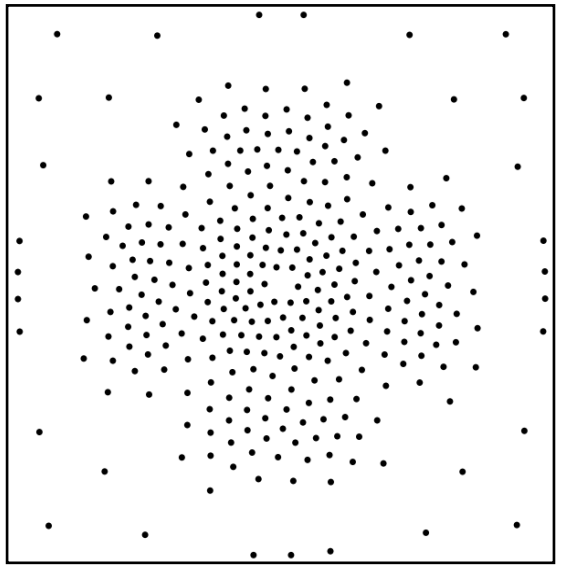

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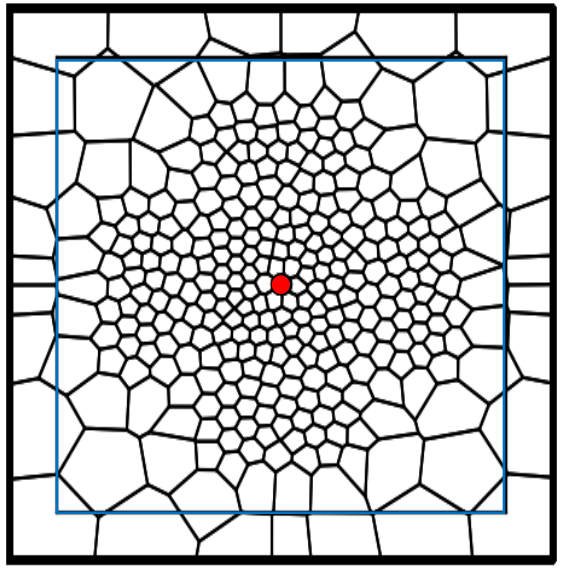

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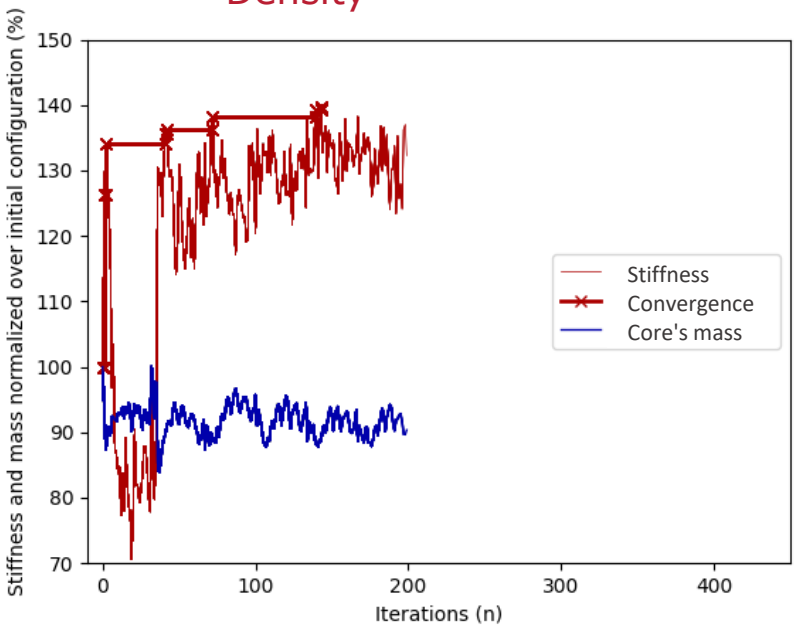
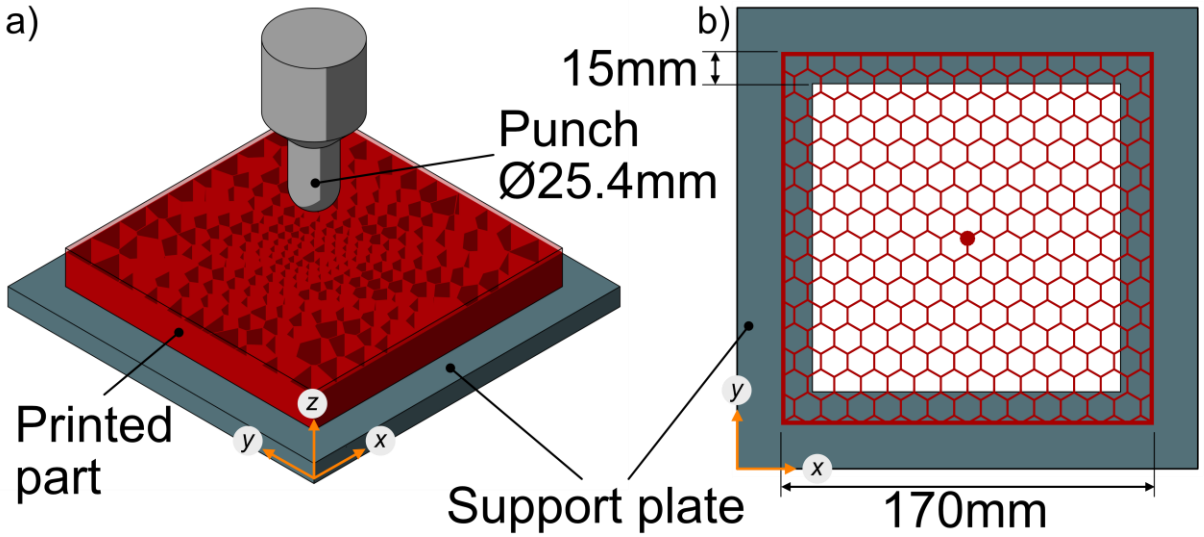


Convergence



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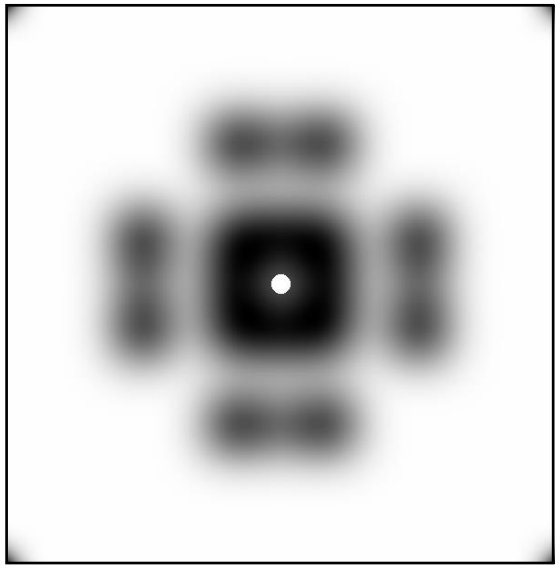
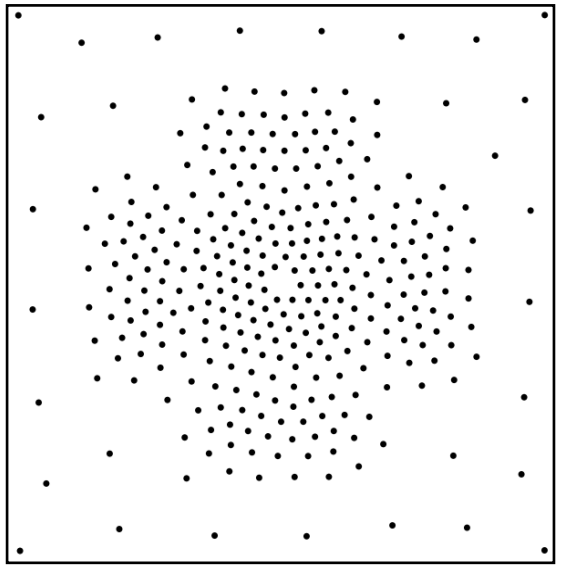


Density



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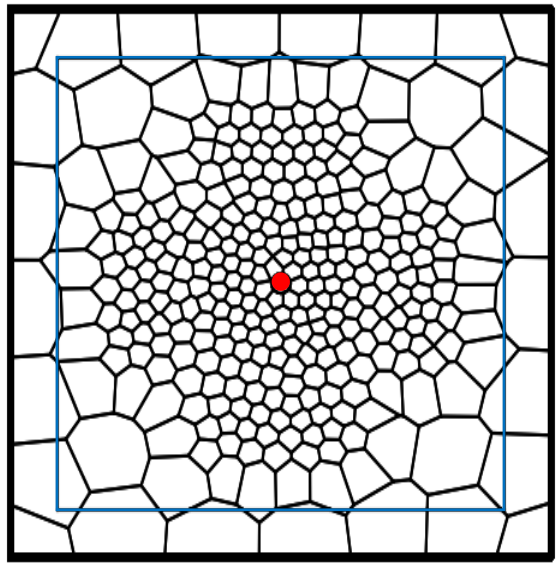

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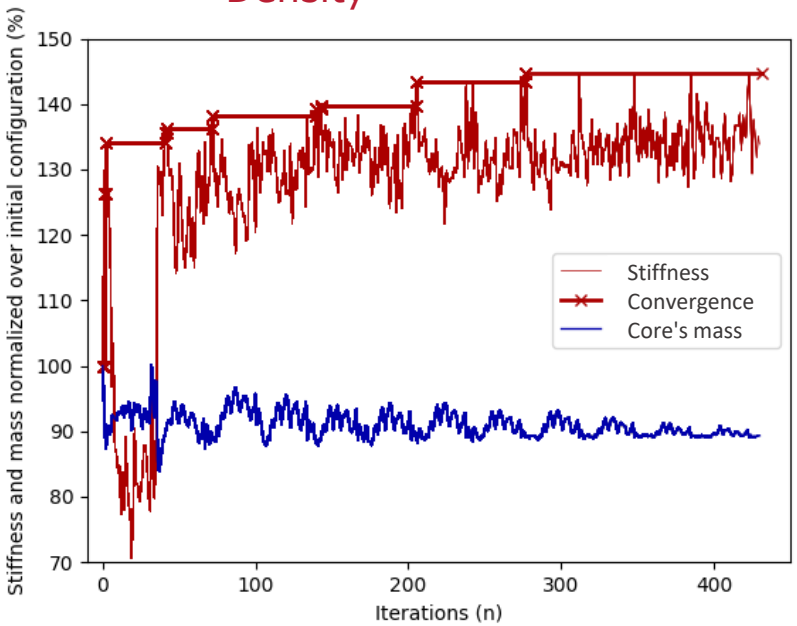
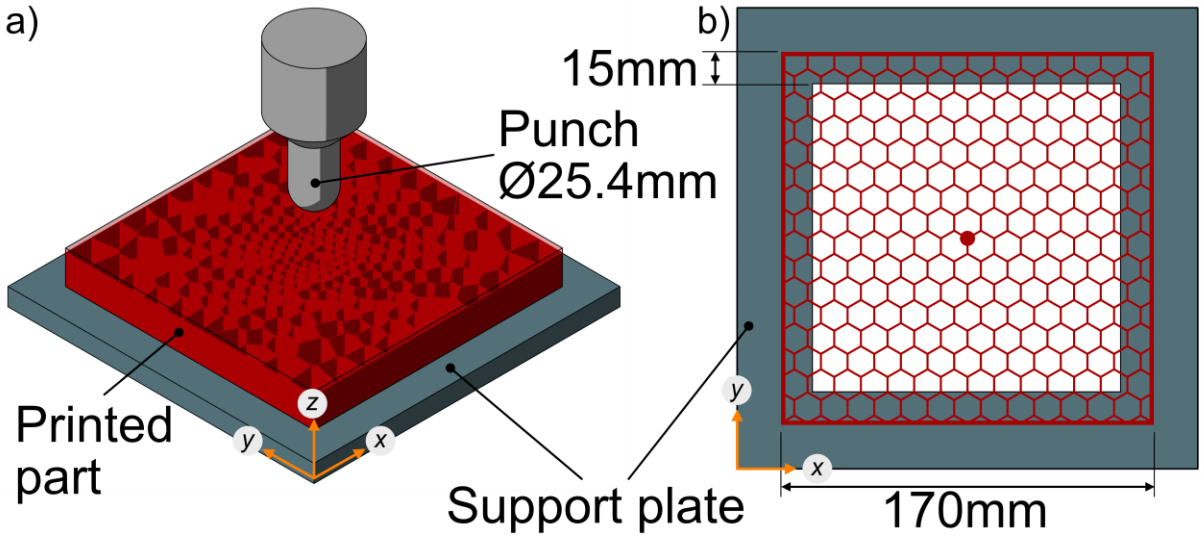
Imposed displacement

Cell distribution

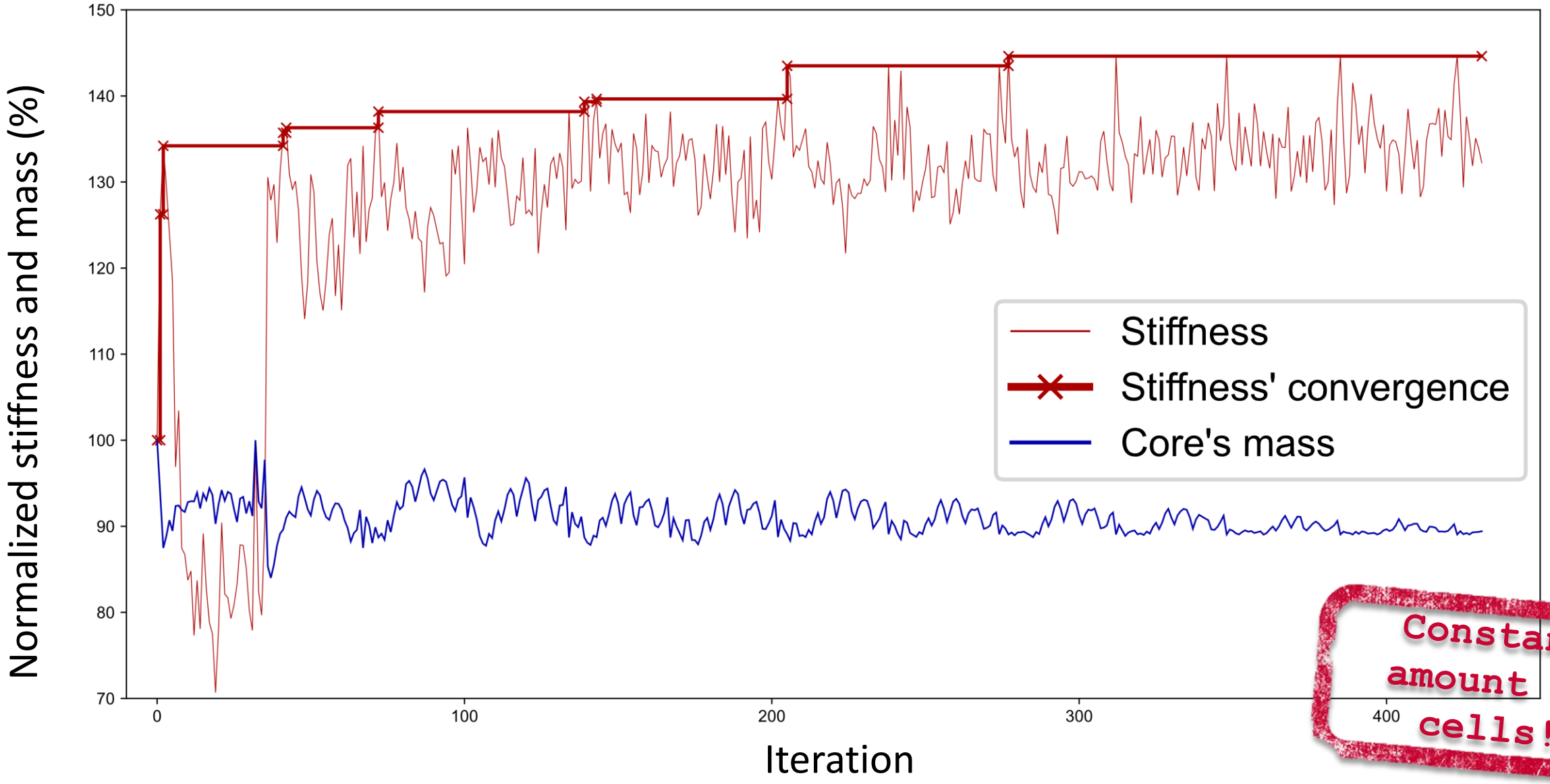


Convergence



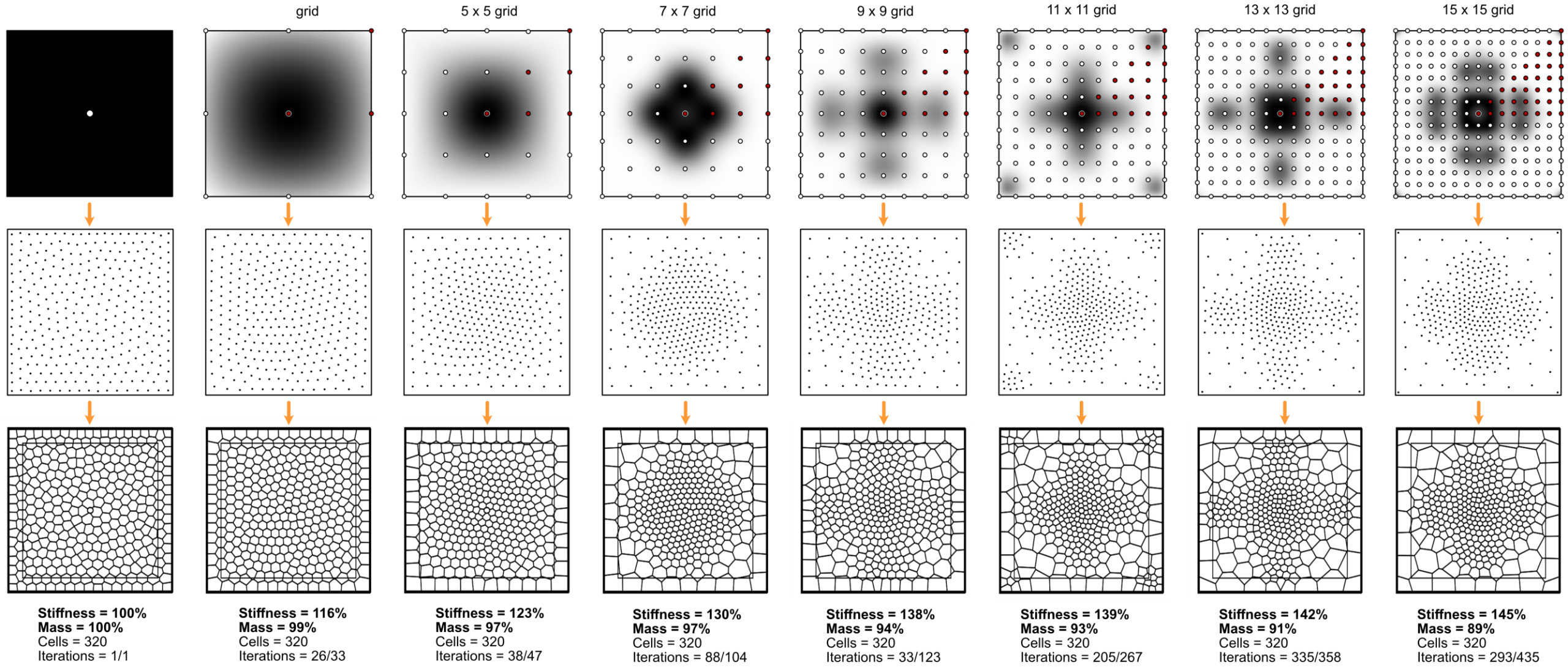
Representation of the experimental setup a) showing the punch applying a central load on the panel b) simply supported on its edges.

CONVERGENCE GRAPH

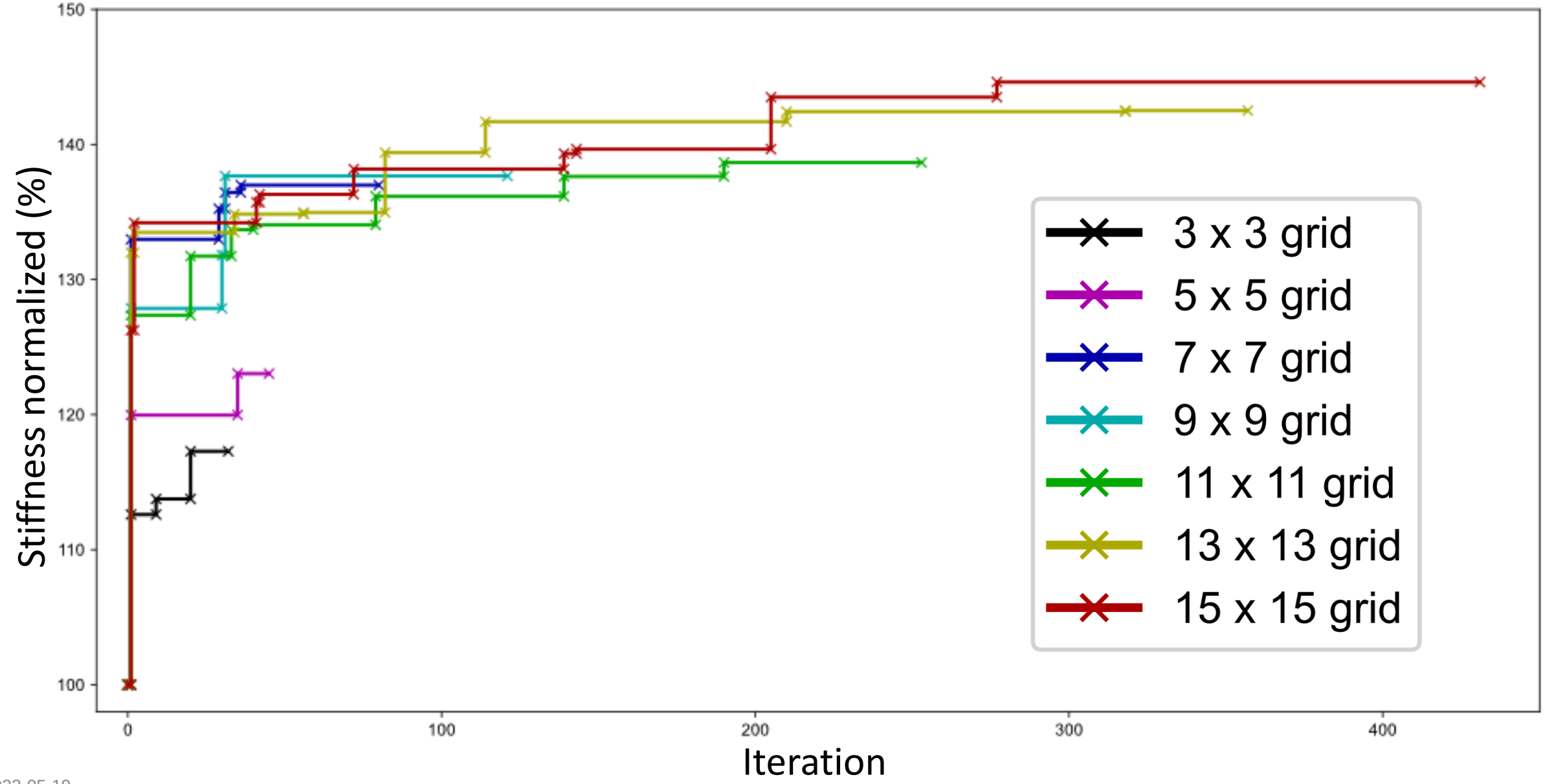


1. Audet et al., « NOMAD version 4: Nonlinear optimization with the MADS algorithm ».

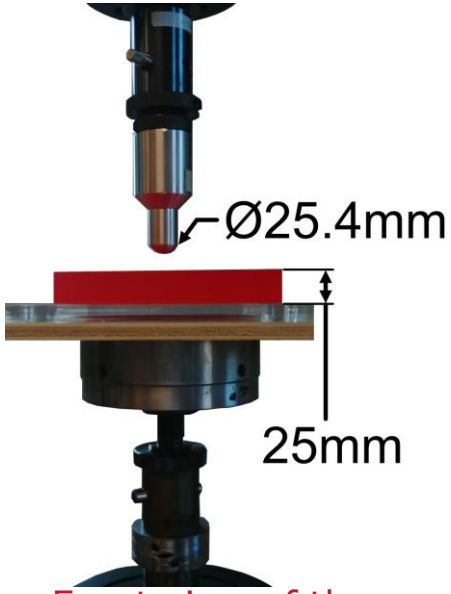
OPTIMIZATION – VARIABLES



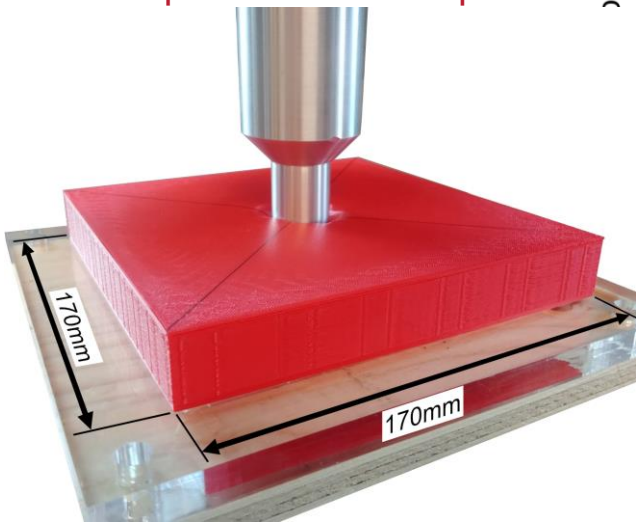
CONVERGENCE COMPARISON



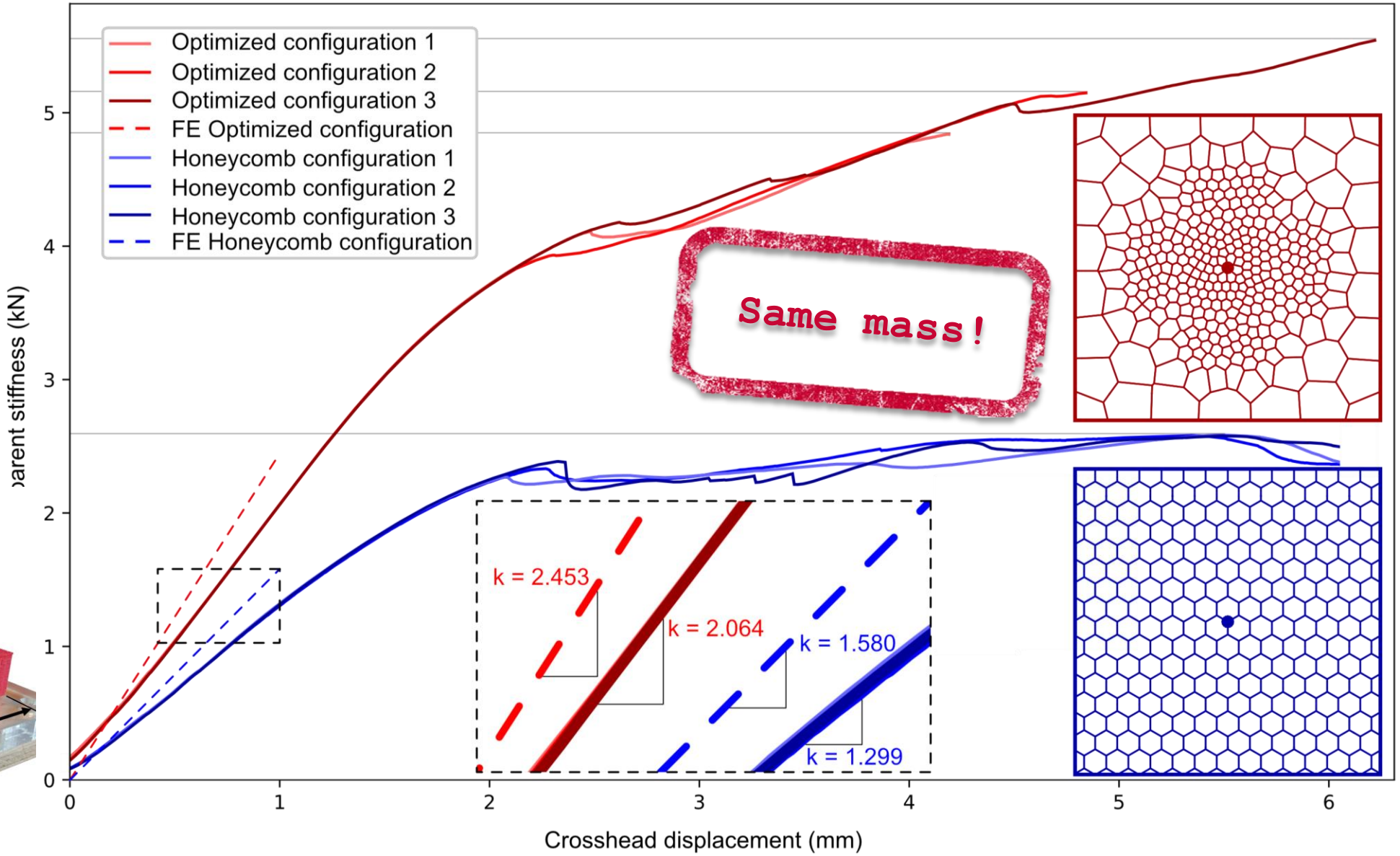
EXPERIMENTAL VALIDATION



Front view of the experimental setup



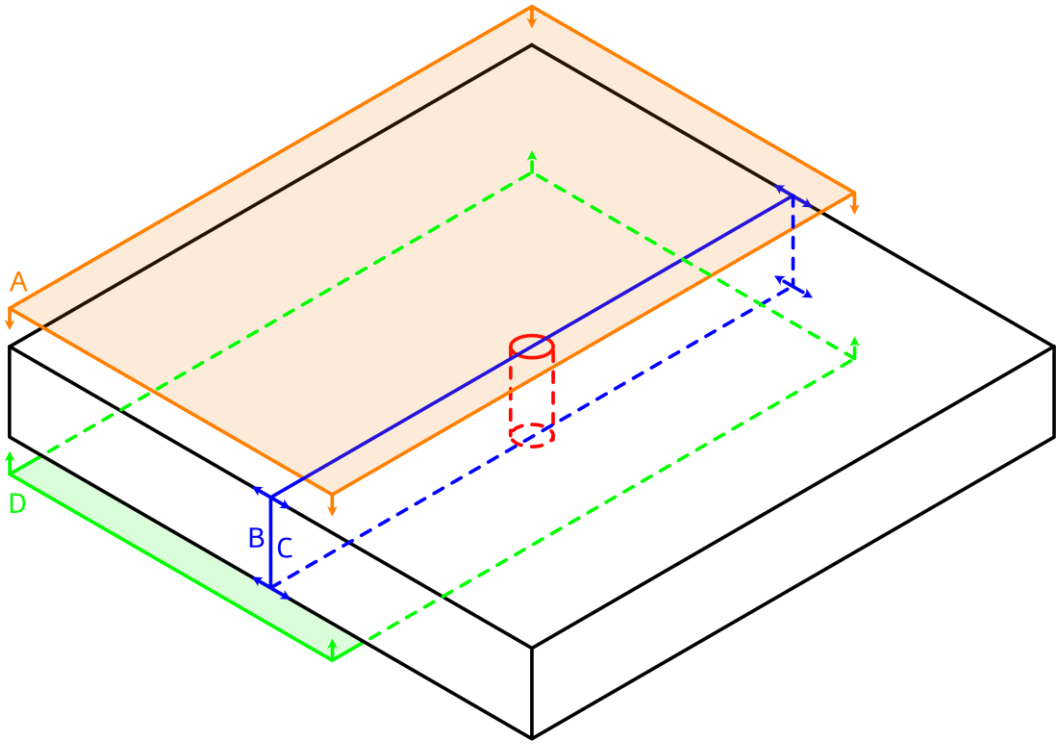
Overview of the punch in the panel after failure



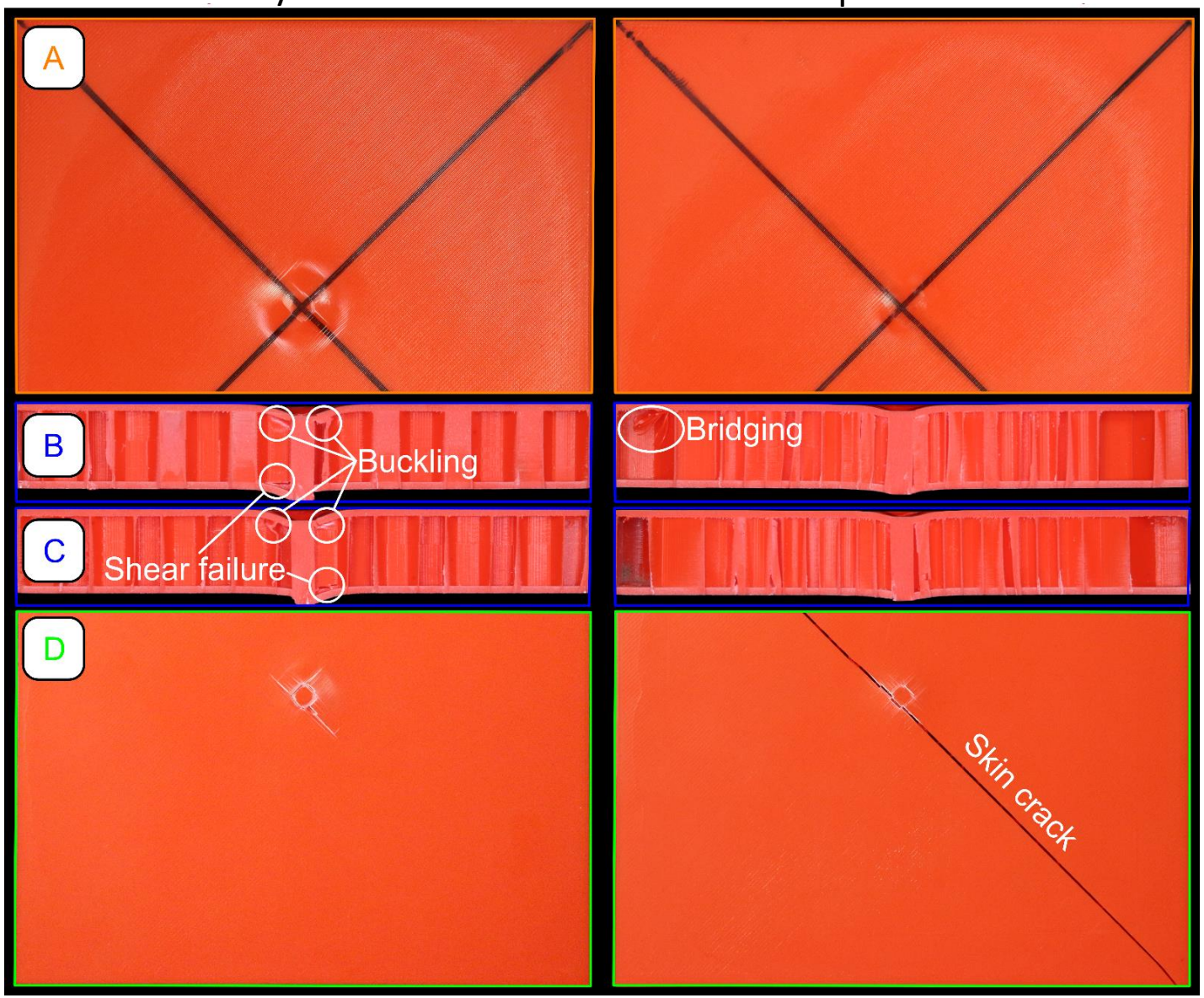
Load-displacement curve comparing two configurations of sandwich panels having the exact same mass

FAILURE MODES

- Honeycomb limitation – core
- Optimized limitation – bottom skin



Sandwich panel views representation

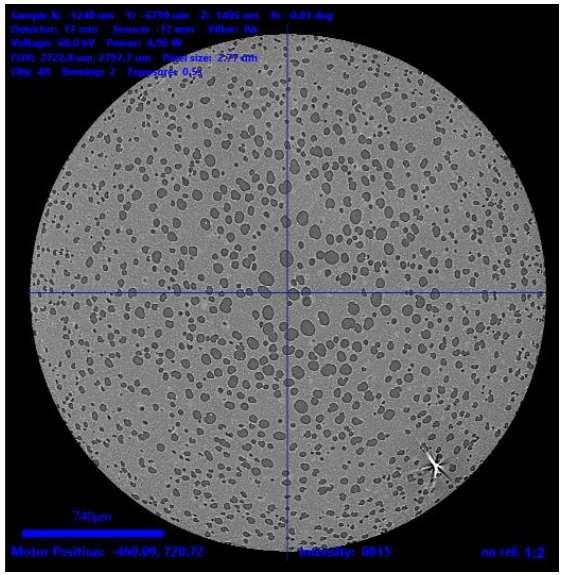


Post failure specimen and failure mode identification

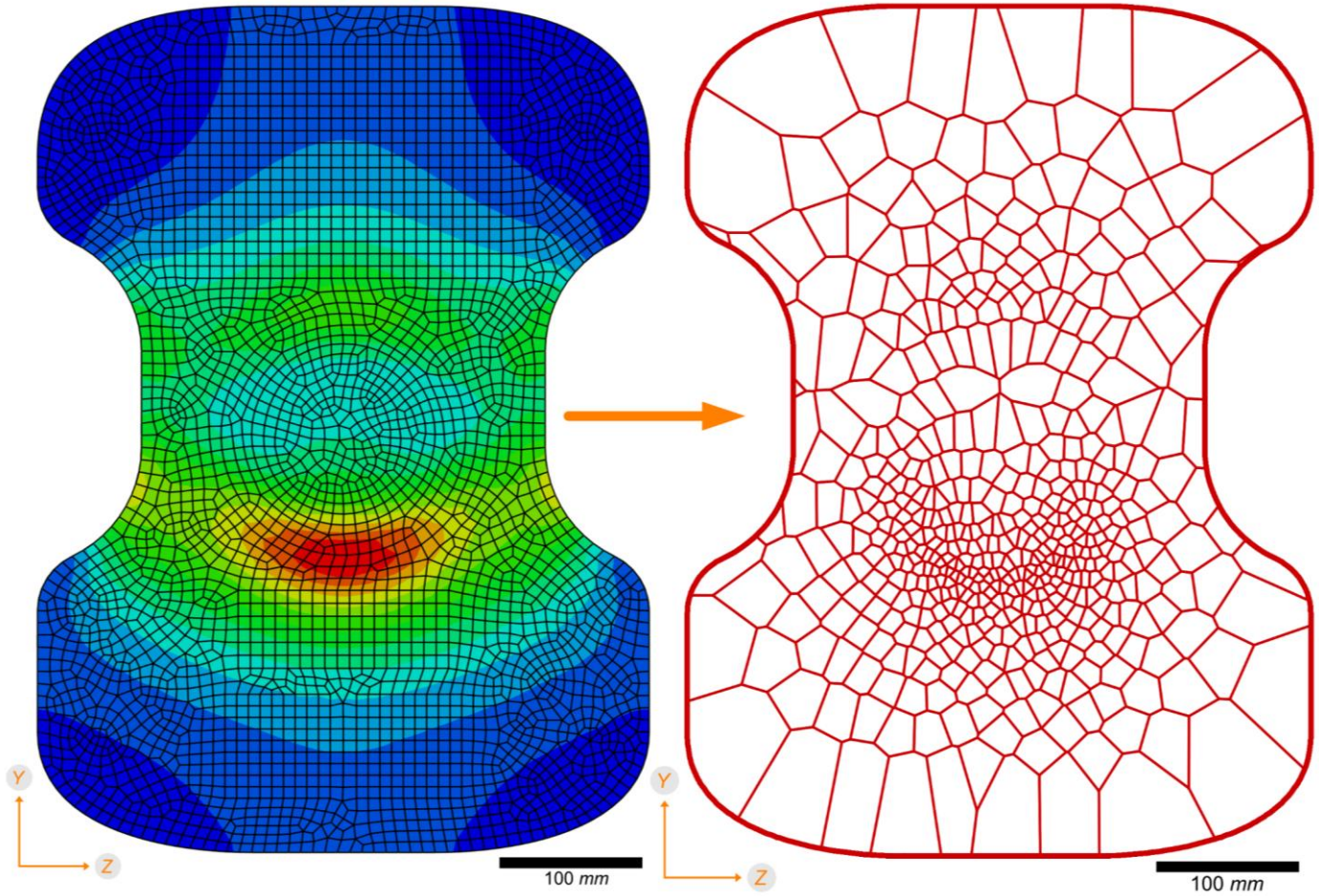
CONCLUSION

- Space industry can benefit from Additive Manufacturing methods to explore efficiently

- Many gaps left
  - Outgassing with porosities
  - Mechanical impact from thermal cycles
  - Degradation from radiations



MicroCT view of a high porosity raw filament of PEEK+CF



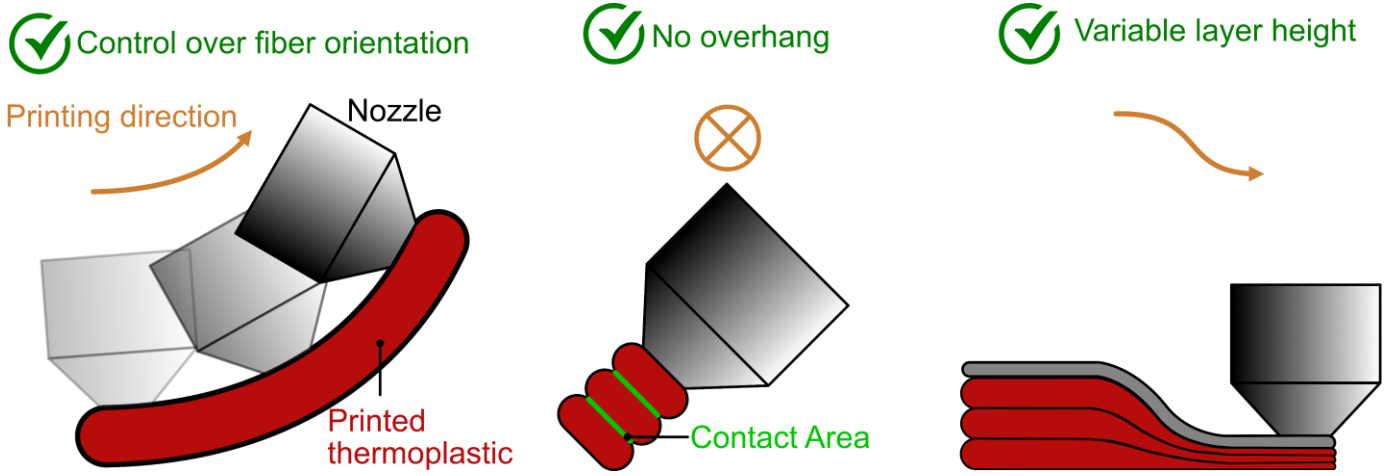
Lunar rover stress concentration and a cell distribution

FUTURE WORK

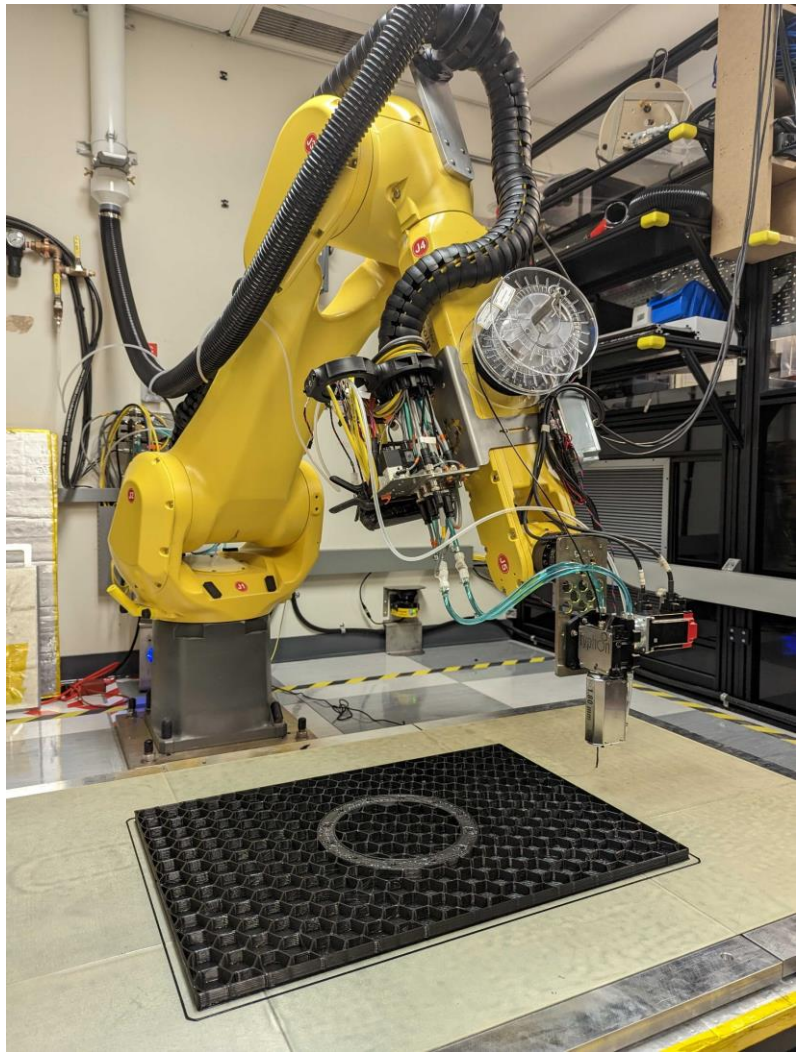
- High volume, high flow and high performance 3D printing

Longboard in PLA, 800mm long

- Benefit from the 6 DOF of a robotic arm



Benefits of developping non-planar adaptive slicers



First 3D printing of a rover's frame - PLA

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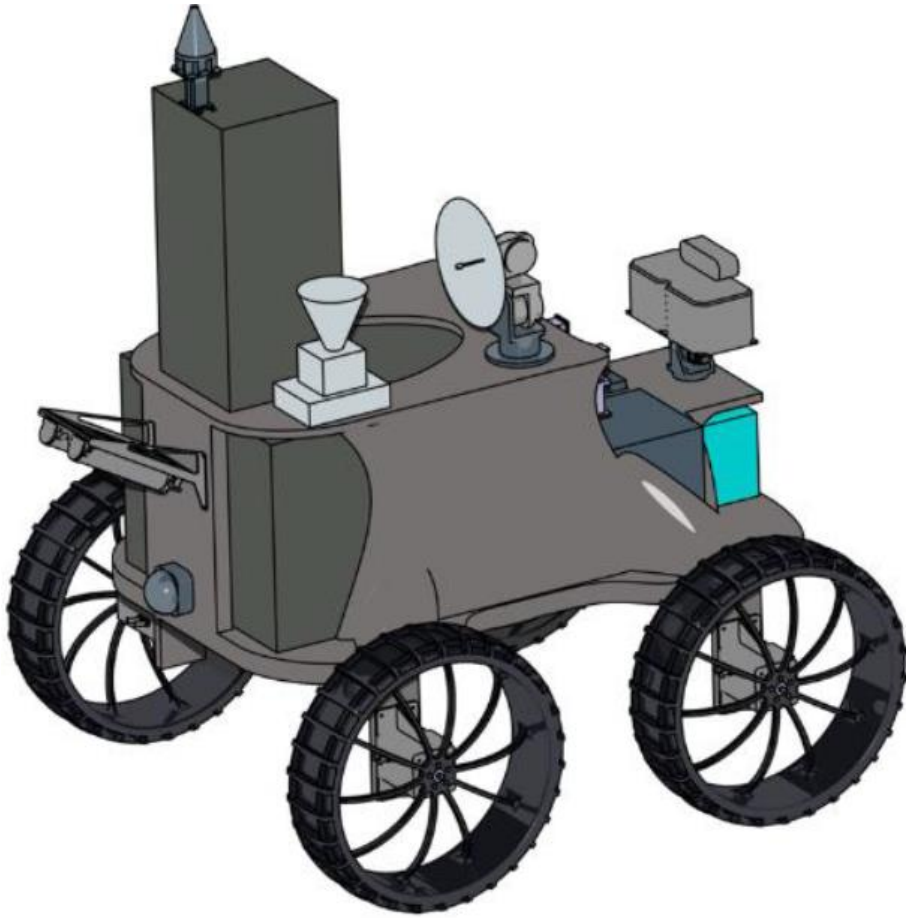
UNIVERSITÉ LAVAL

ÉTS
Le génie pour l'industrie



Actors

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Centre de recherche sur les systèmes polymères et composites à haute performance

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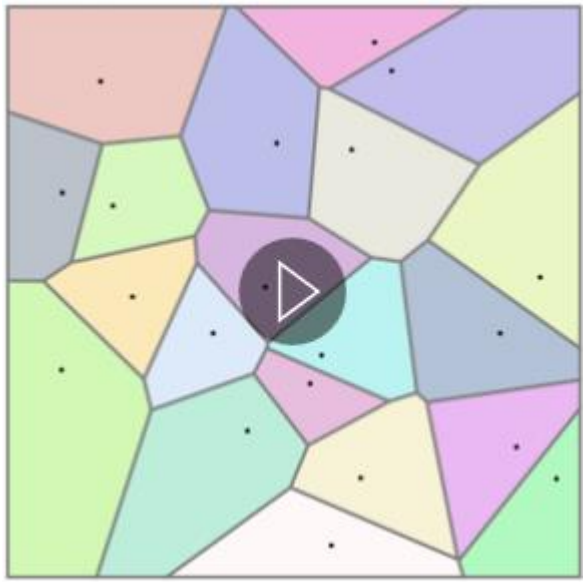
Performance Through Carbon Chemistry

Supplementary Material

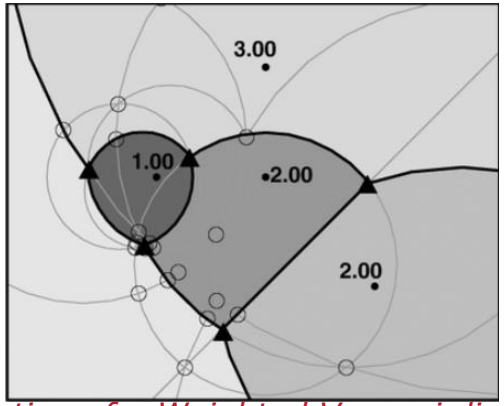
VORONOIS

- Voronoi diagram generation



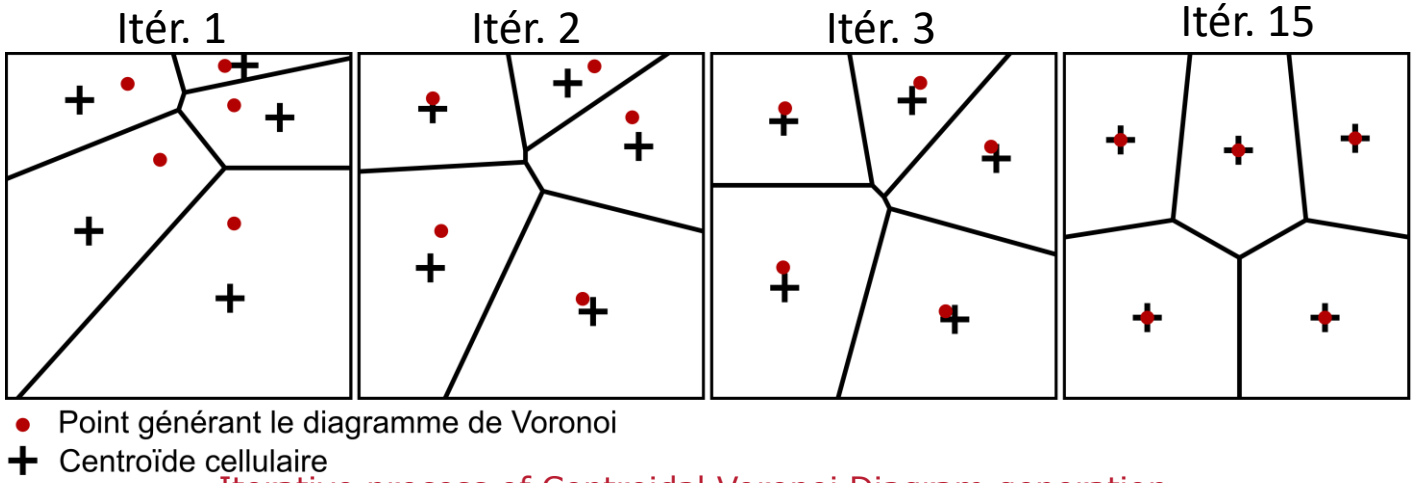
Generation of a Voronoi diagram (*Wolfram*)

- Weighted Voronoi diagram



Generation of a Weighted Voronoi diagram (Mu)

- Centroidal Voronoi Diagram
  - Minimal energy configuration *(Du)*: $\int_A \rho(\mathbf{x})|\mathbf{C}_i - \mathbf{x}|^2$



Iterative process of Centroidal Voronoi Diagram generation *(Moritz)*

- *Weighted Voronoi Stippling* technique

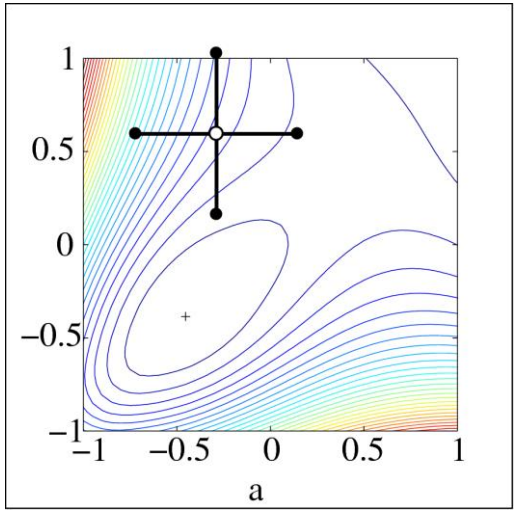
Artistic representation of an object using dots concentration proportional to an image grayness *(Secord)*

NURBS AND BLACK BOX OPTIMIZATION

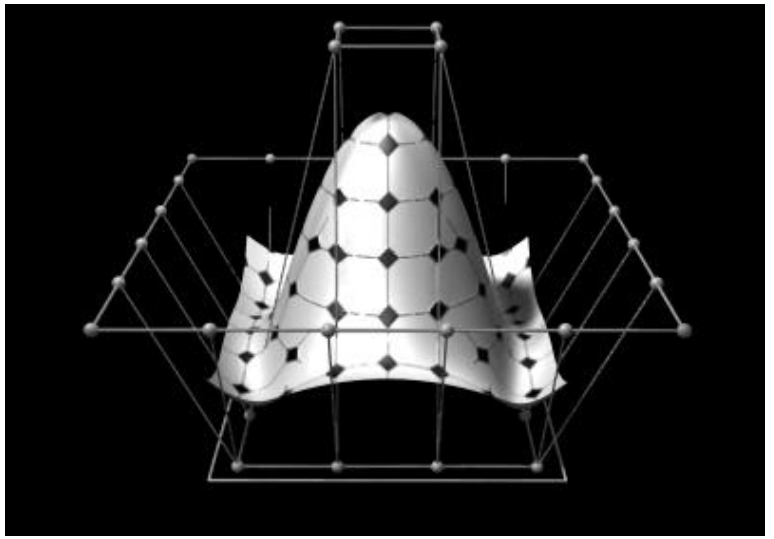
- Black box
  - E.g. complex Finite Element model
    - Parametric geometry, properties, BC
    - Stiffness, max stress, etc

Black box representation *(Krauss)*

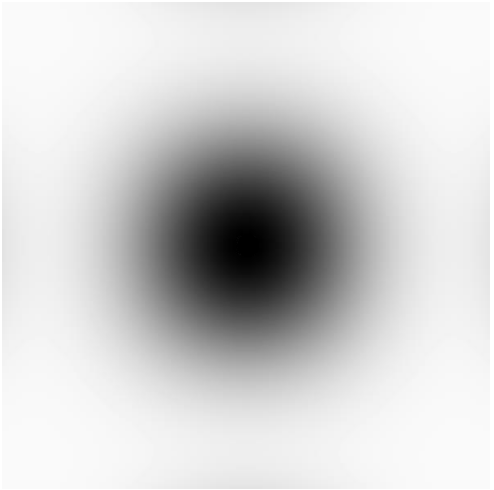
- NOMAD – Black box optimizer



"Generalized Pattern Search" (Jacquenot)



NURBS surface with its control points *(Greg A.L.)*



Grayscale colormap of a NURBS