Packing simulation applied to thermoplastic composite wastes

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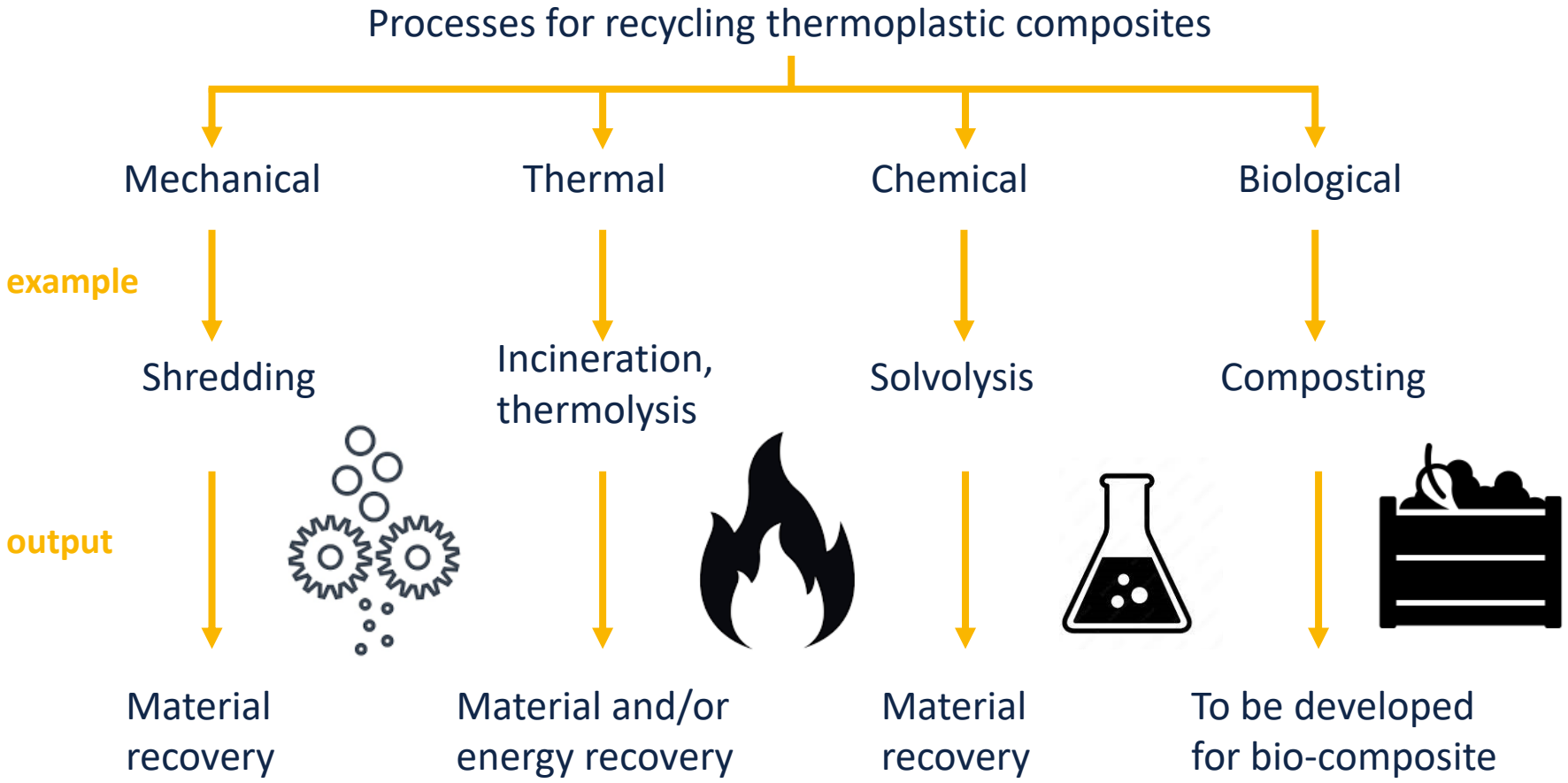
3 : CETIM-Mulhouse, Mulhouse, France

Content

- Context
- Manufacturing process description
- Numerical simulation
- Descriptors of packing
- Perspectives

Context

Current composite recycling routes



Adapted from : R. Bernatas, S. Dagréou, A. Despax-Ferreres, and A. Barasinski,
"Recycling of fiber reinforced composites with a focus on thermoplastic composites," Cleaner Engineering and Technology, p. 100272, 2021.

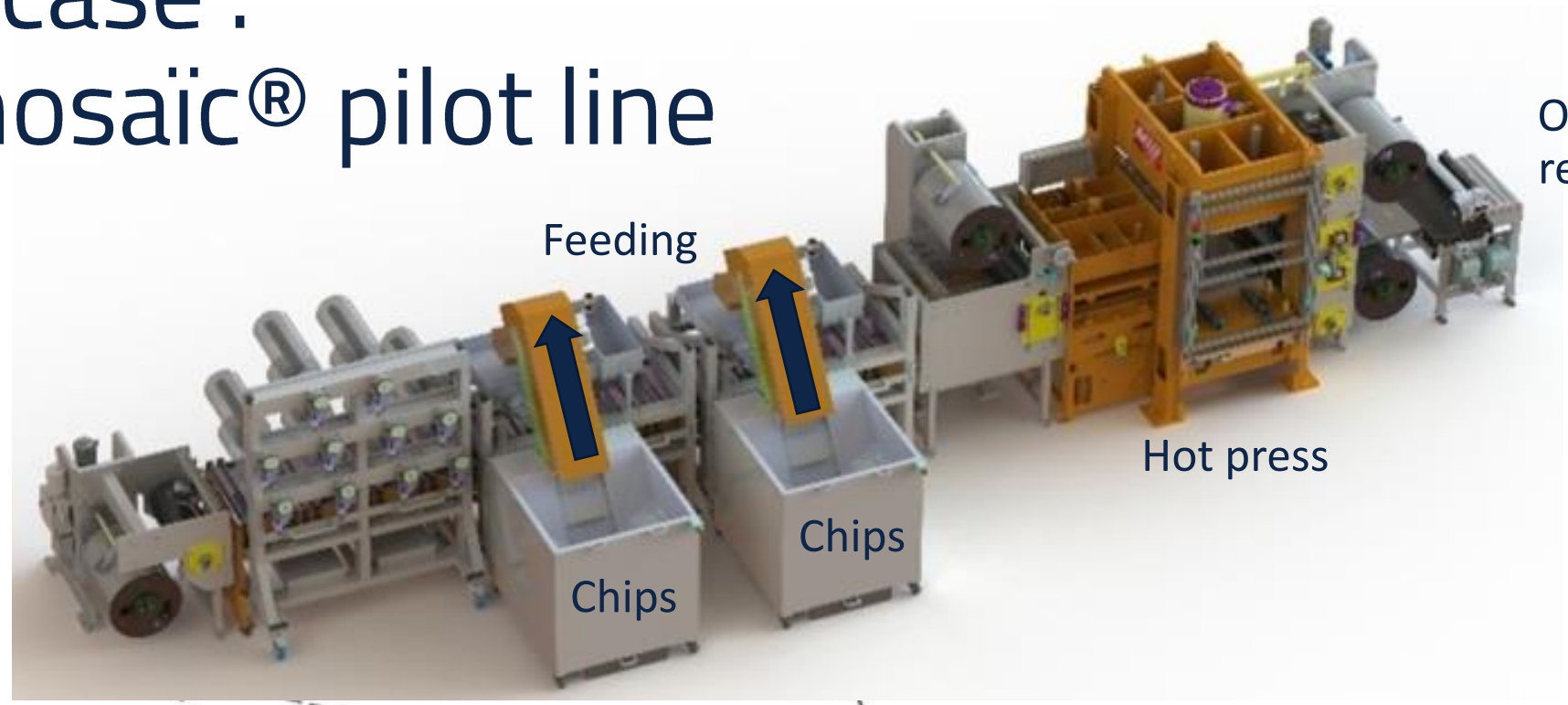
and bottlenecks

- Economic viability ?
- Lower mechanical properties
- Uncertainty of properties

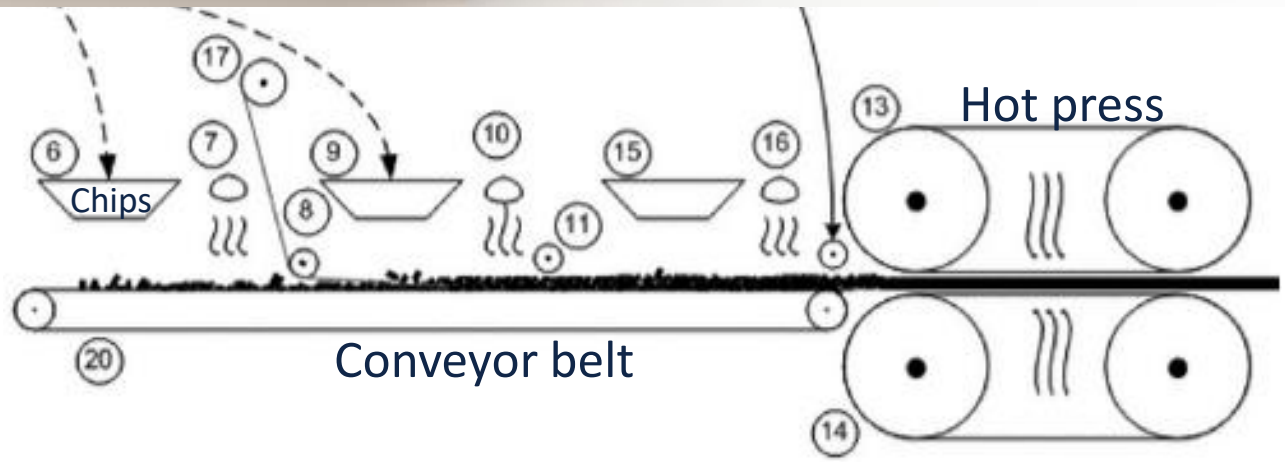
→ Lack of models to understand and optimize recycling processes

Manufacturing process description

Study case : Thermosaïc® pilot line



Output : recycled panel

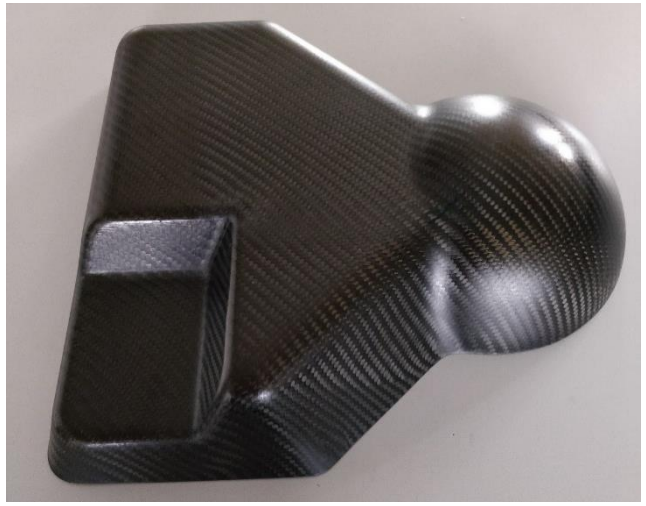


Manufacturing direction
Semi-continuous panels

Patent FR3007684A1 : PROCEDE DE RECYCLAGE DE PIECES EN COMPOSITE THERMOPLASTIQUE

Video presentation : https://www.youtube.com/watch?v=Ga-Pm9KJ6ms

Recycling cycle : CoDiCoFRP



Final product / End of life

Shredding

Stamping

Discontinuous chips

Thermosaïc®

Recycled panel

Current bottlenecks

Input

Material

(Discontinuous chips made of continuous fibers)

Geometry and position can vary

Thermosaïc® Process

Black box with many variables, with uncertain link between input and output

Output

Mechanical properties

Global stiffness and strength

Objectives

Input

Material

Understand the influence of shape, size and orientation

Decompose the process

Model each step

Better process understanding

Define and track descriptors of packing

Output

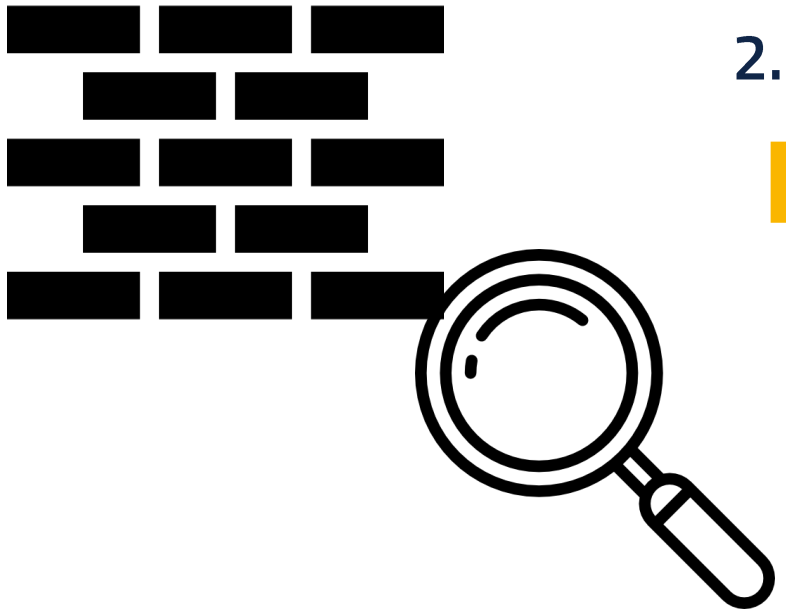
Mechanical properties

Ensure improved global properties

Objectives

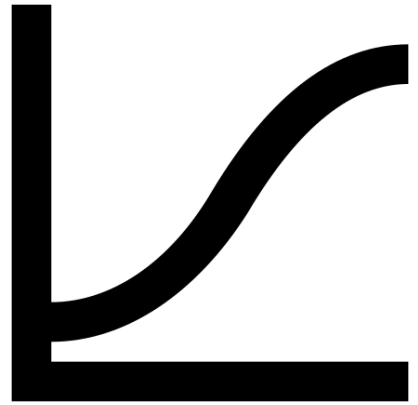
The descriptors have two purposes :

Random stack



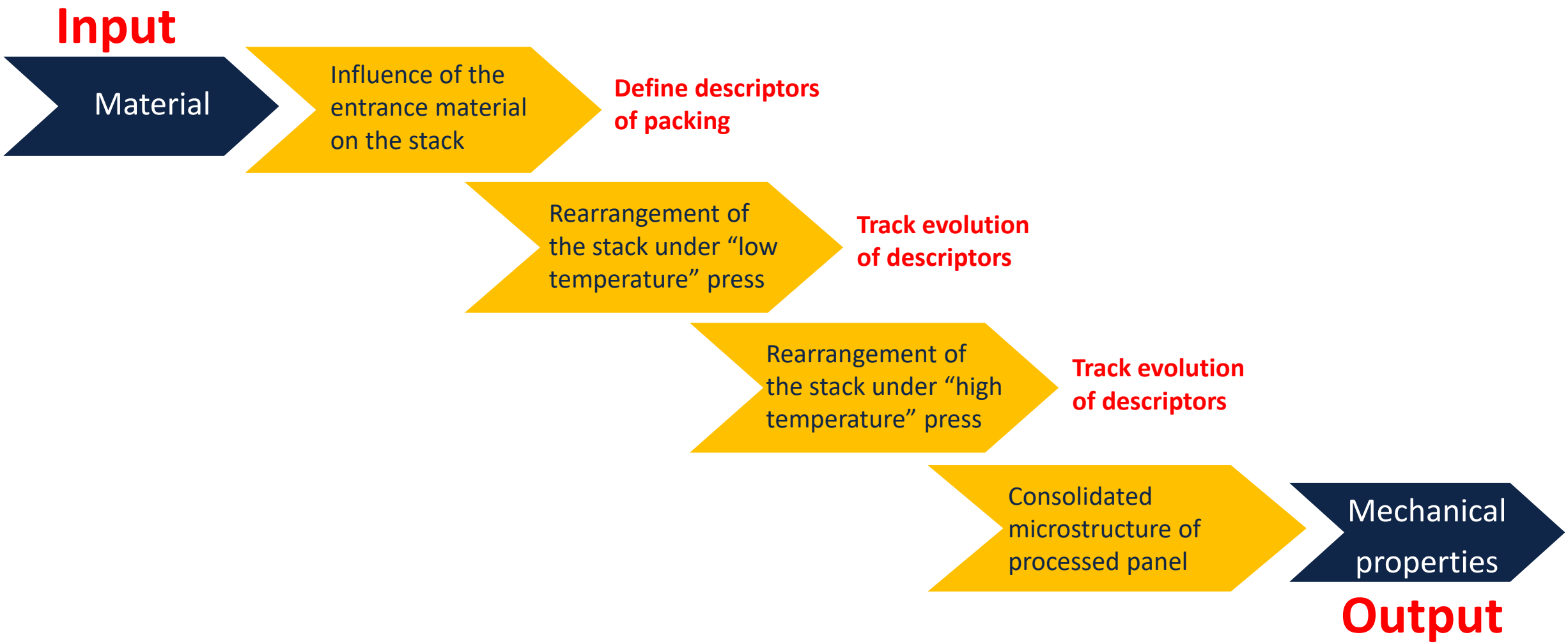
2. Establish a direct link

Mechanical properties of consolidated panels

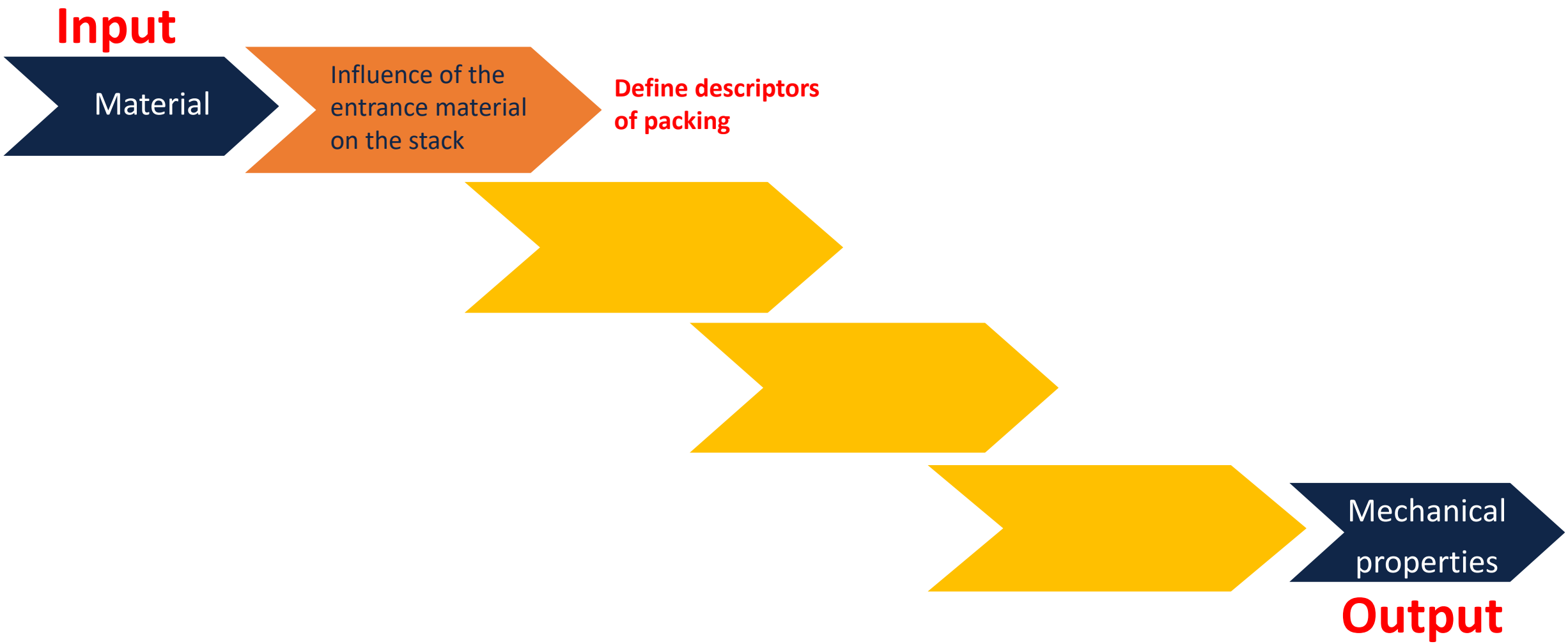


1. Provide a compact and discriminating description

Objectives


Input
Material
Influence of the entrance material on the stack
Define descriptors of packing
Rearrangement of the stack under “low temperature” press
Track evolution of descriptors
Rearrangement of the stack under “high temperature” press
Track evolution of descriptors
Consolidated microstructure of processed panel
Mechanical properties
Output

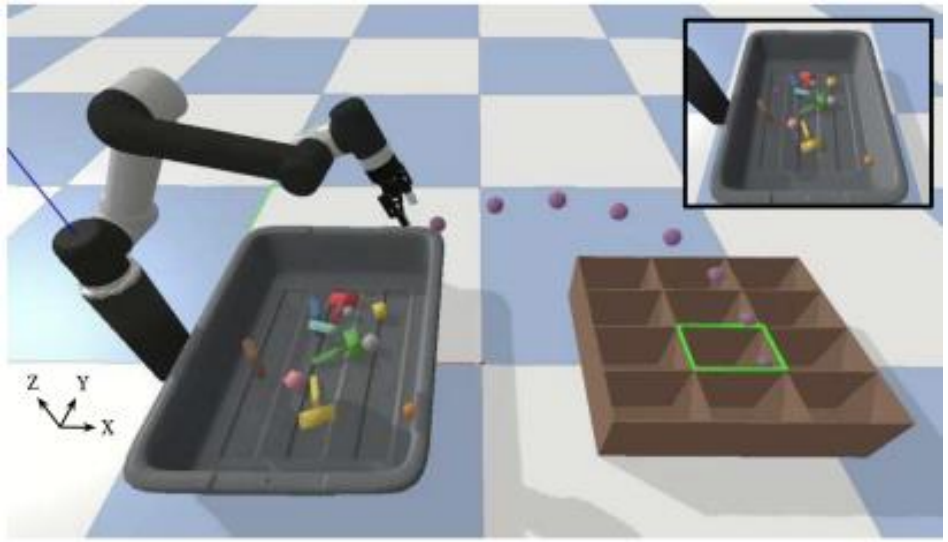
Objectives of today's presentation



Numerical simulation

PyBullet : open source library

- Python interface of Bullet Physics server
- Real time contact detection
- Multi-physics simulation
- Often used in robotics, machine learning …



→ Adaptation from fiber* to chips deposition

*Forró, C. et al. (2020). Visualizing and analyzing 3D metal nanowire networks for stretchable electronics. *Advanced Theory and Simulations*, *3*(8), 2000038

Generation of numerical stacks with PyBullet

- Input :

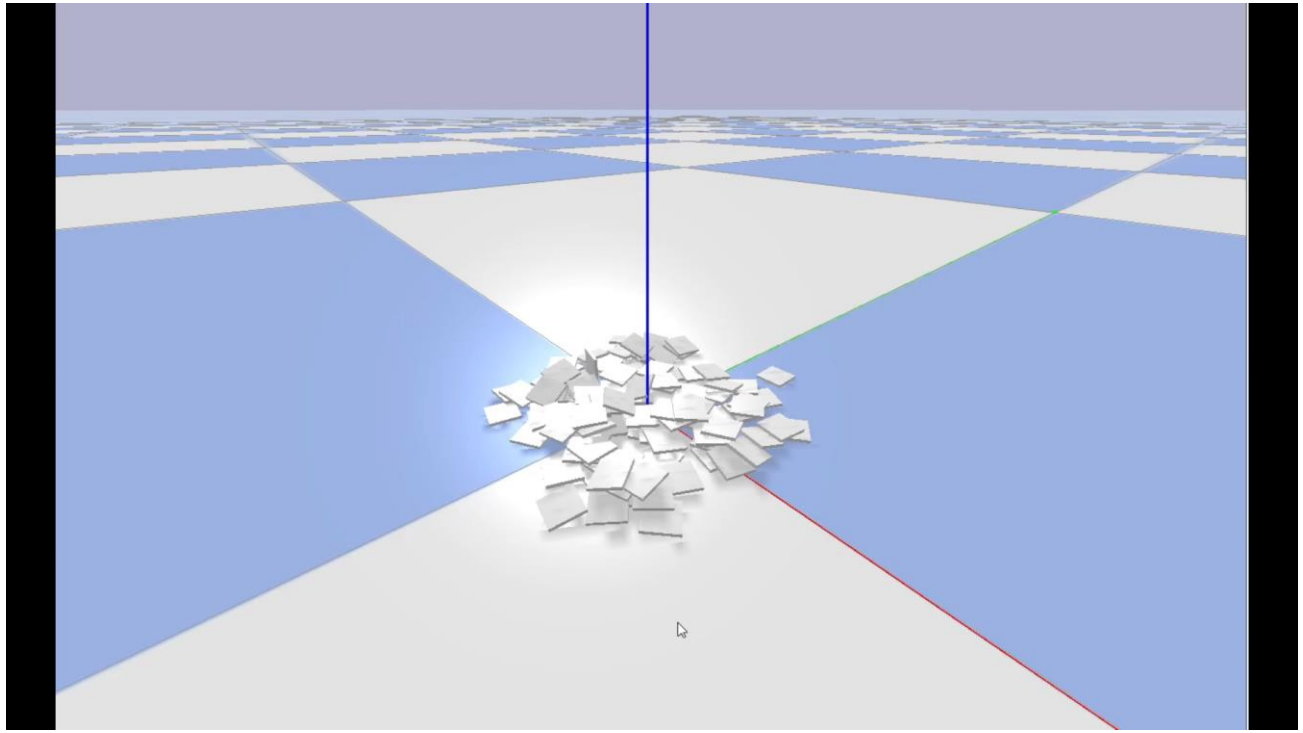
- Chip data (position, orientation, geometry, mass …) **20 mm square chips simplification and mono-material**

- Environment data (gravity, deposition area …), **number of deposition steps**

- Output :

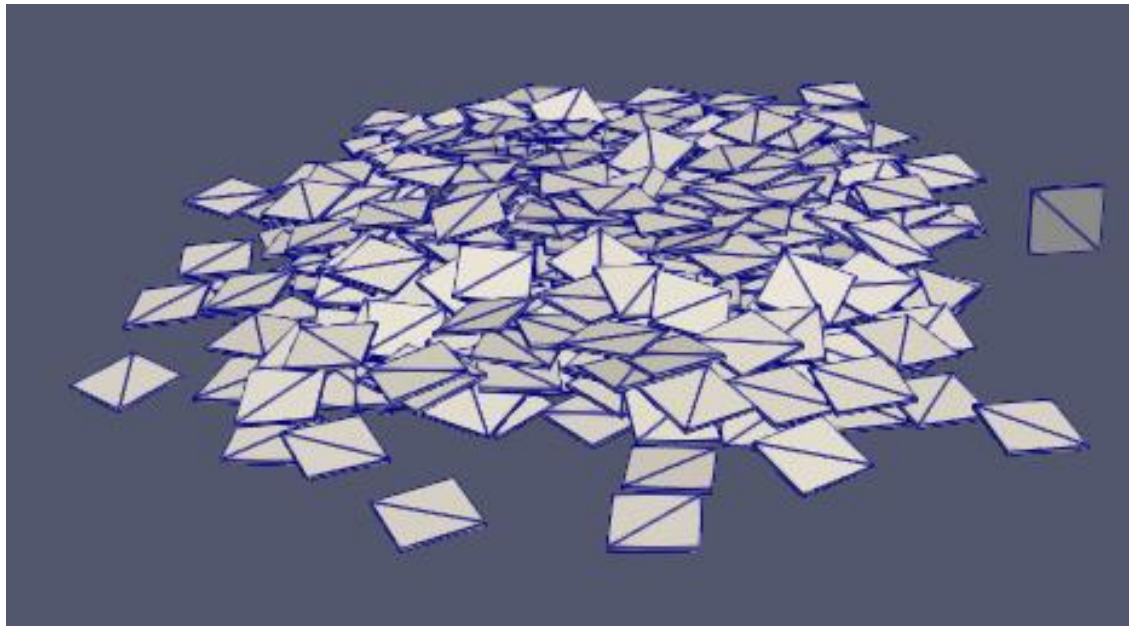
- Position, orientation of chips

- List of generated contacts during packing

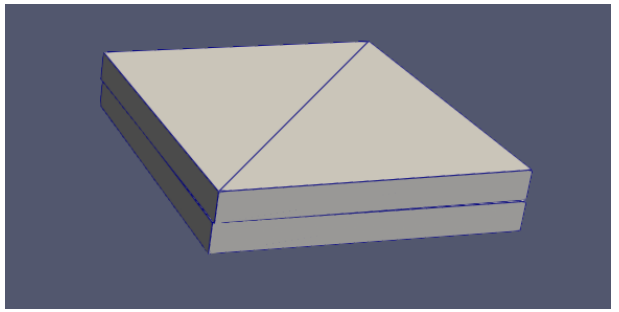


Descriptors of packing

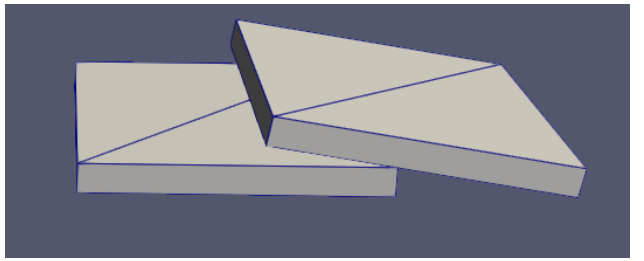
Classification of contacts



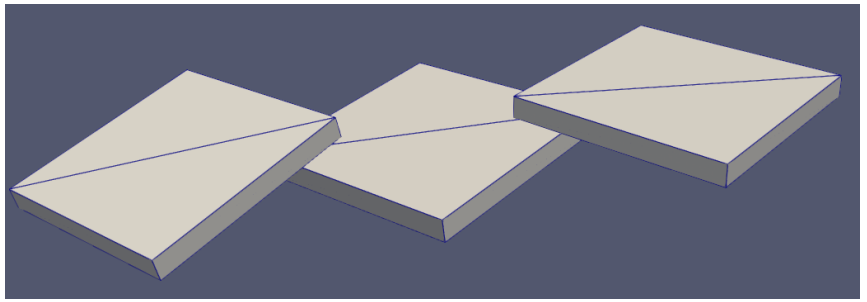
270 chips on a 150 mm * 150 mm deposition square
Size of chips : 20 mm * 20 mm * 2 mm



1 surface of contact

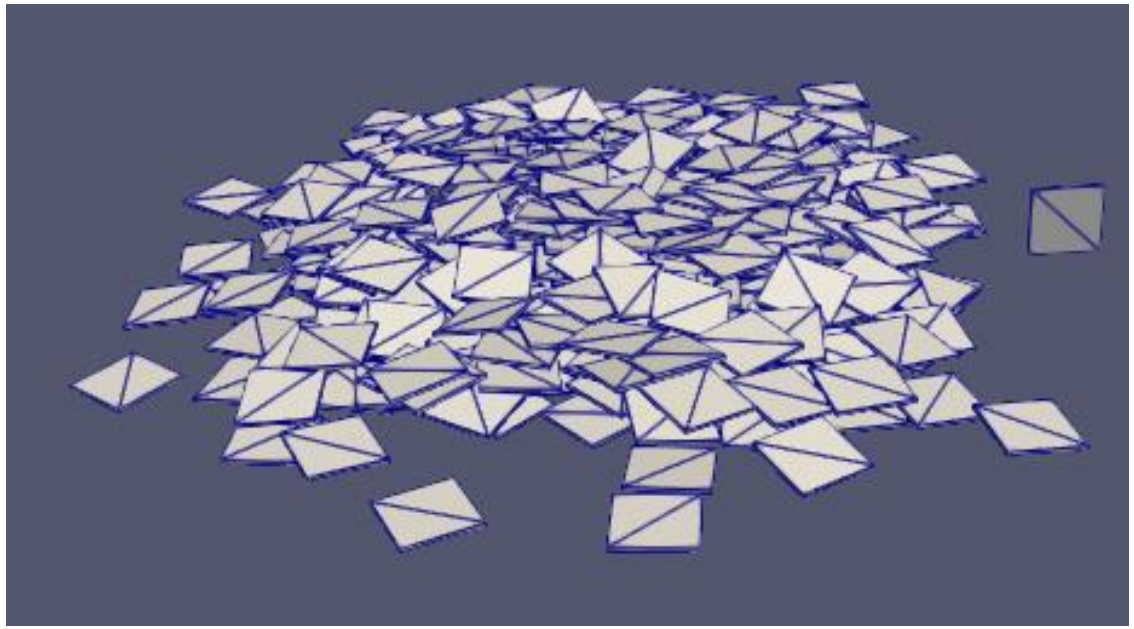


1 line of contact



2 points of contact

Classification of contacts



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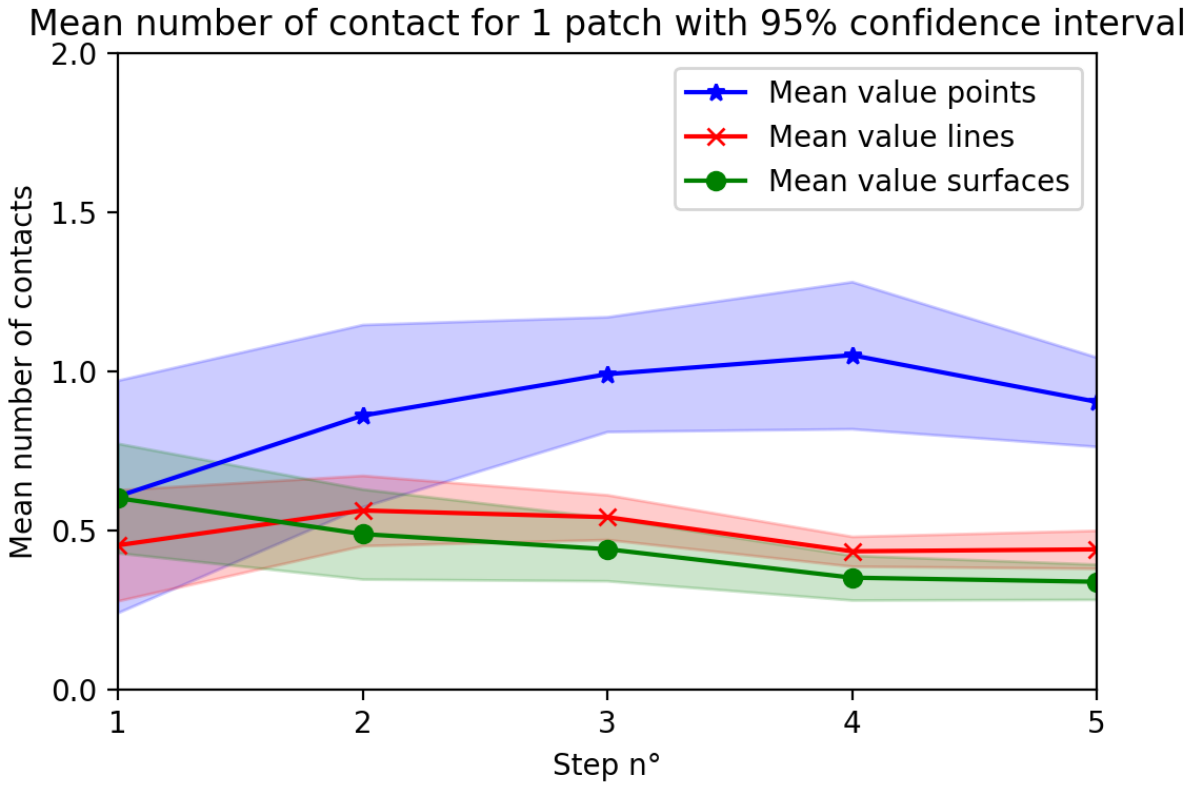
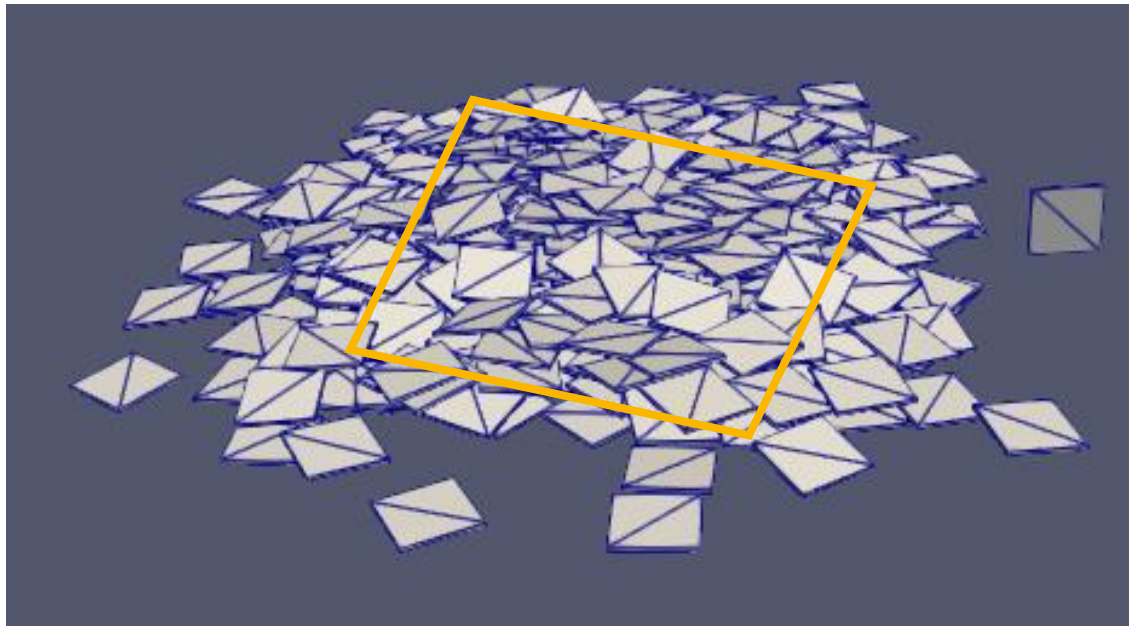


- ≈ 2 contacts for each chip → stability of the stack
- Densification can be tracked with an increase of number of contacs

Through-thickness chips detection



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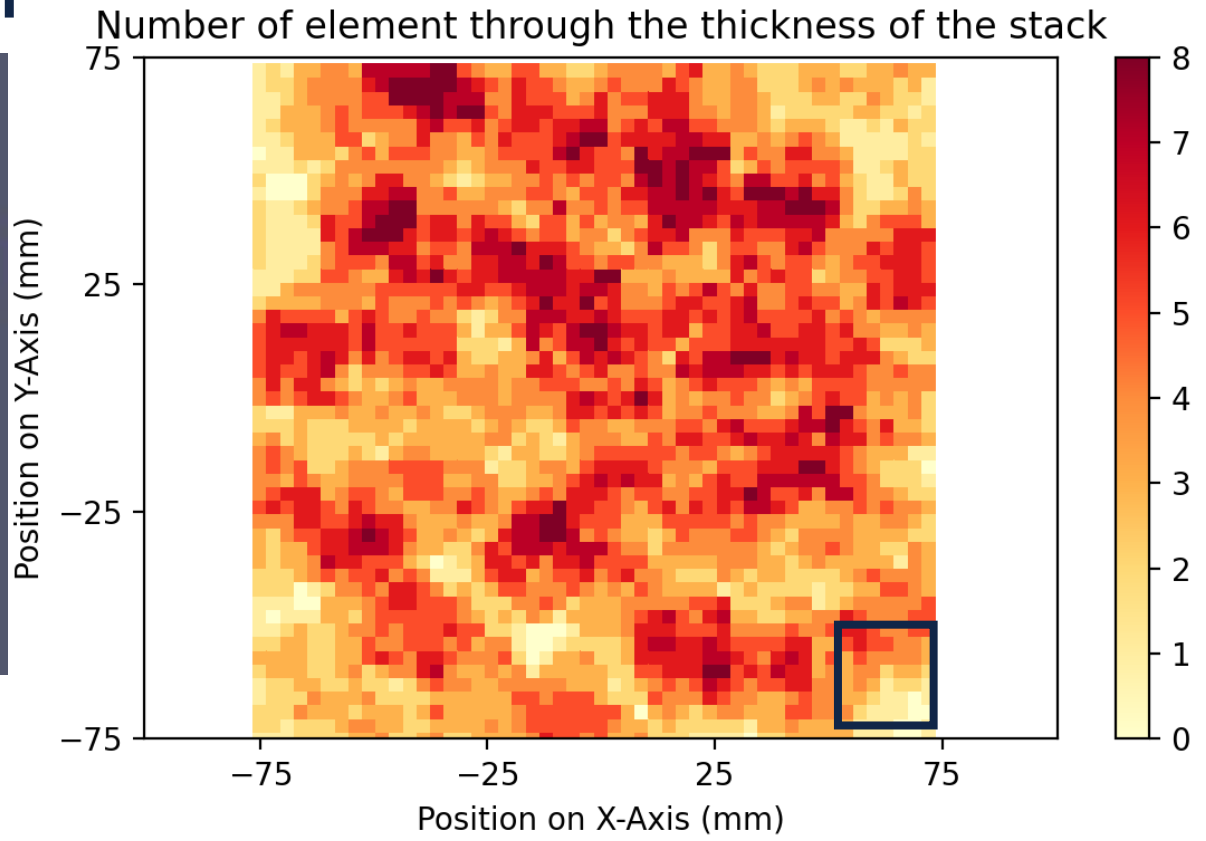
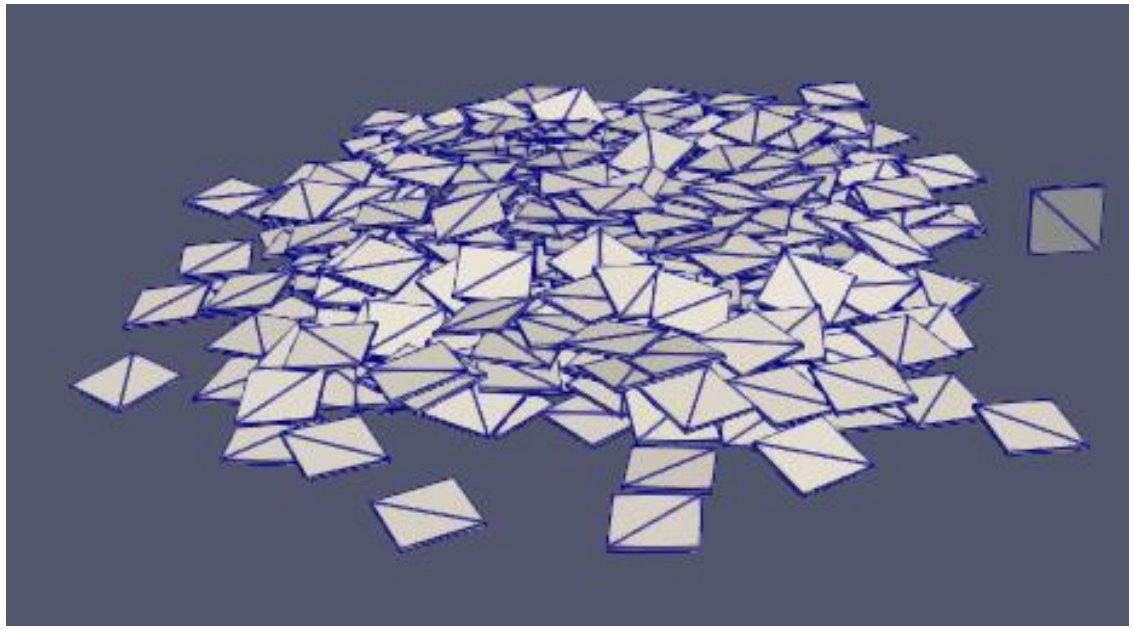


- Mapping of chip surface density
- Indicator of local lack or excess of chips

Level dispersion



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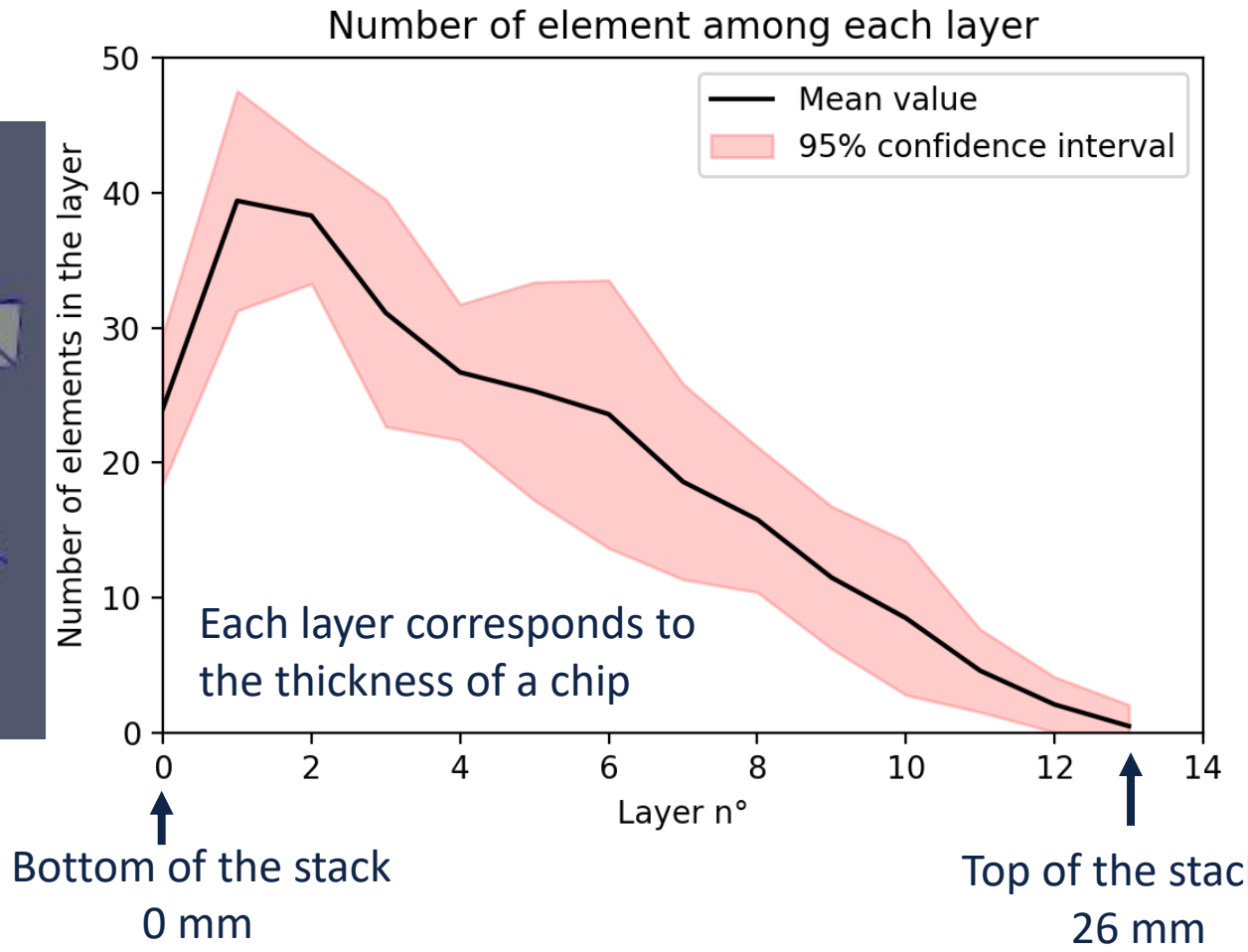
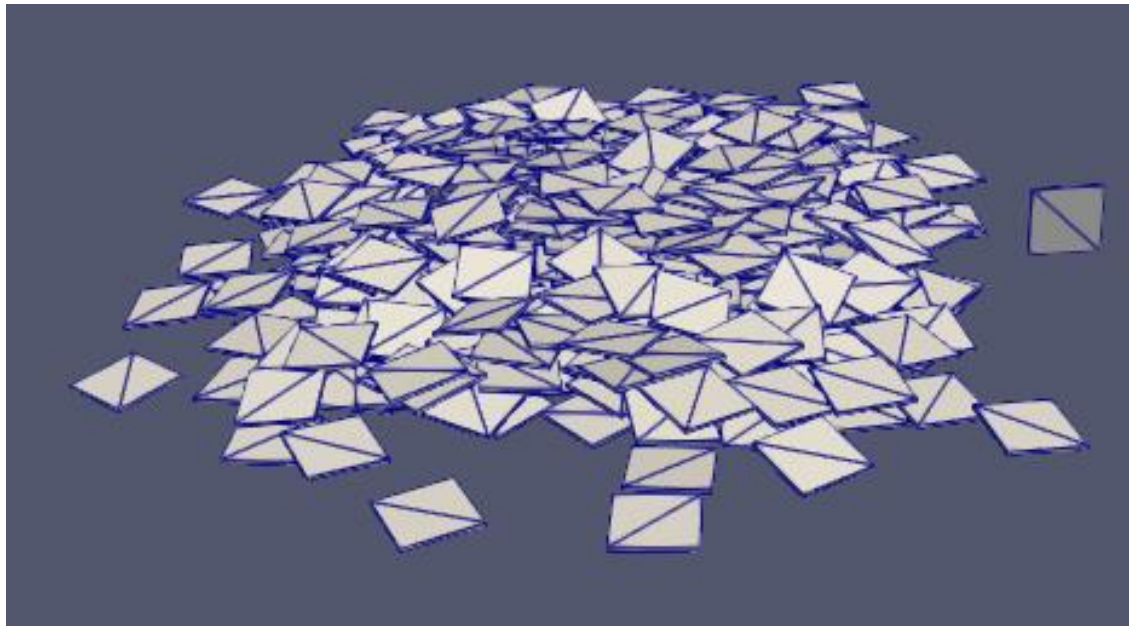


- Evaluation of the filling rate of each layer
- Link with the volume fraction of the stack

Effect of aspect ratio on descriptors

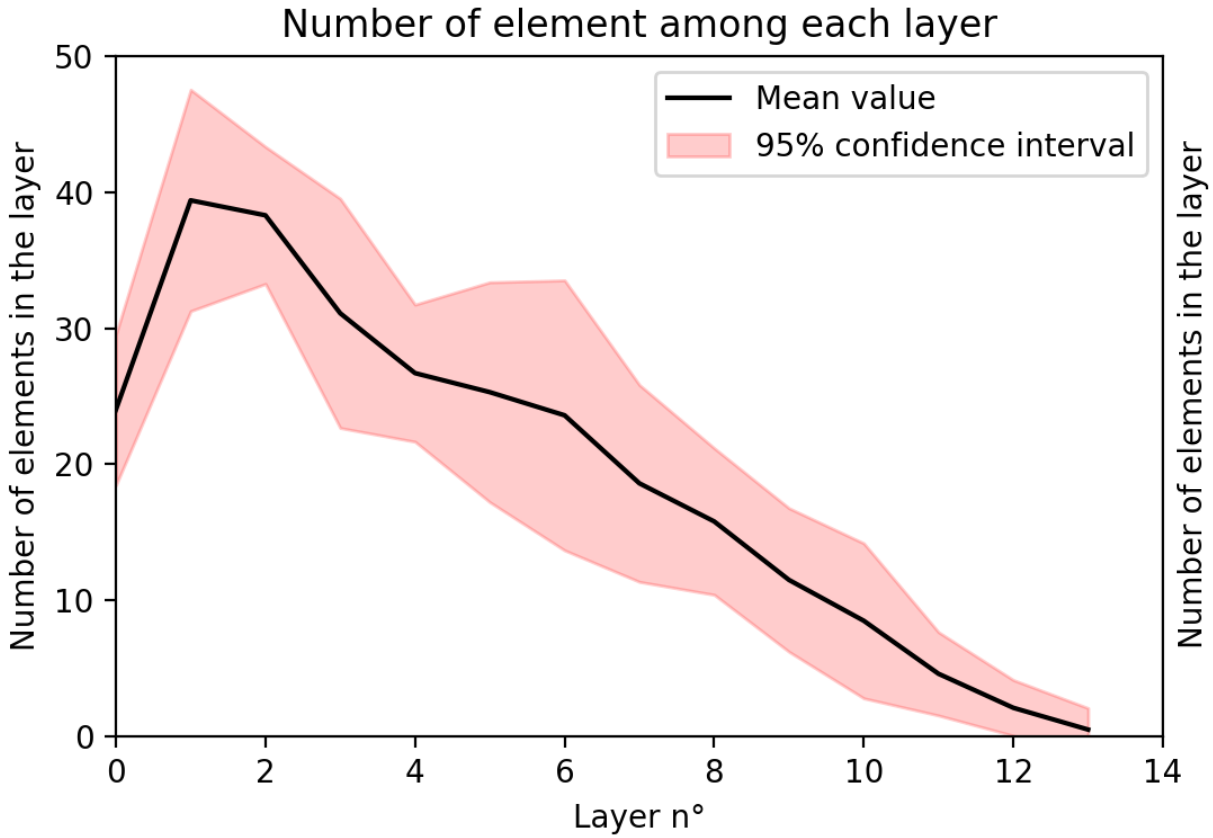


270 chips on a 150 mm * 150 mm deposition square
Size of chips : 20 mm * 20 mm * 2 mm

270 chips on a 150 mm * 150 mm deposition square
Size of chips : 10 mm * 40 mm * 2 mm

- Aspect ratio 1:1 for squares and 1:4 for rectangles
- Iso volume per chip (conservation of thickness and surface)

Effect of aspect ratio on descriptors



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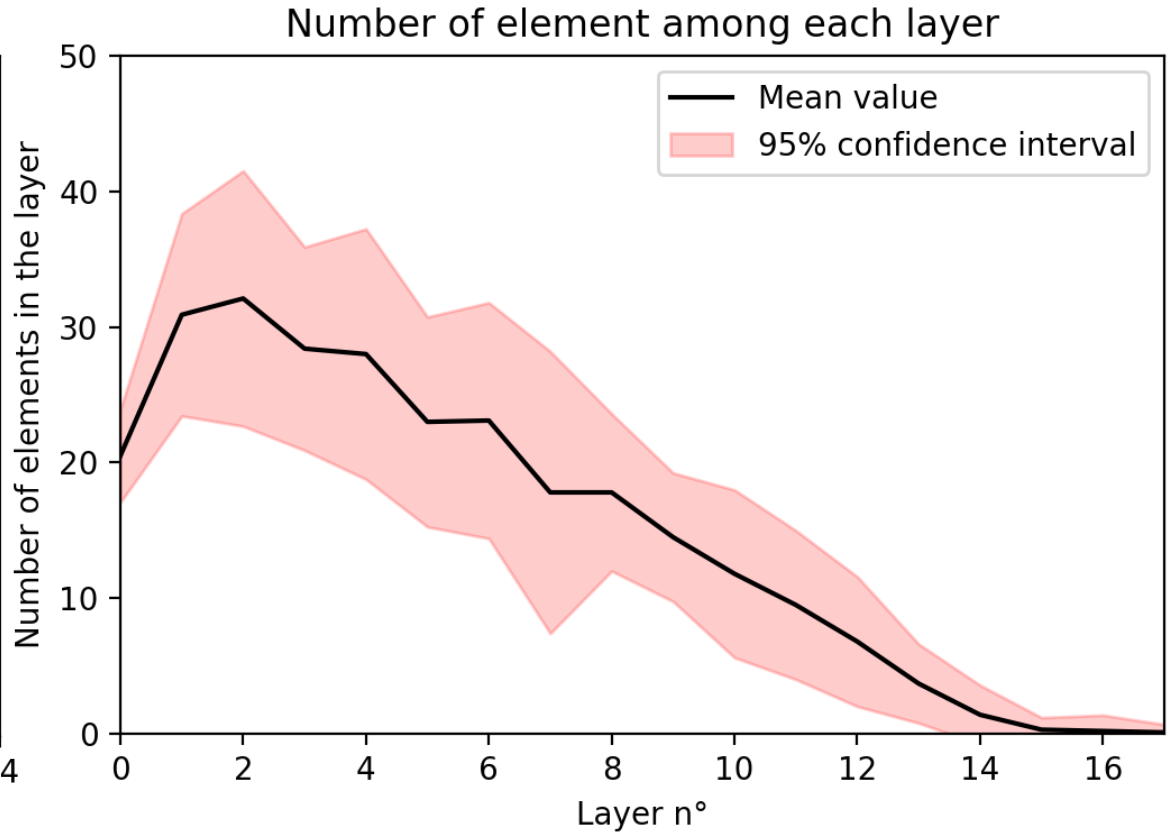
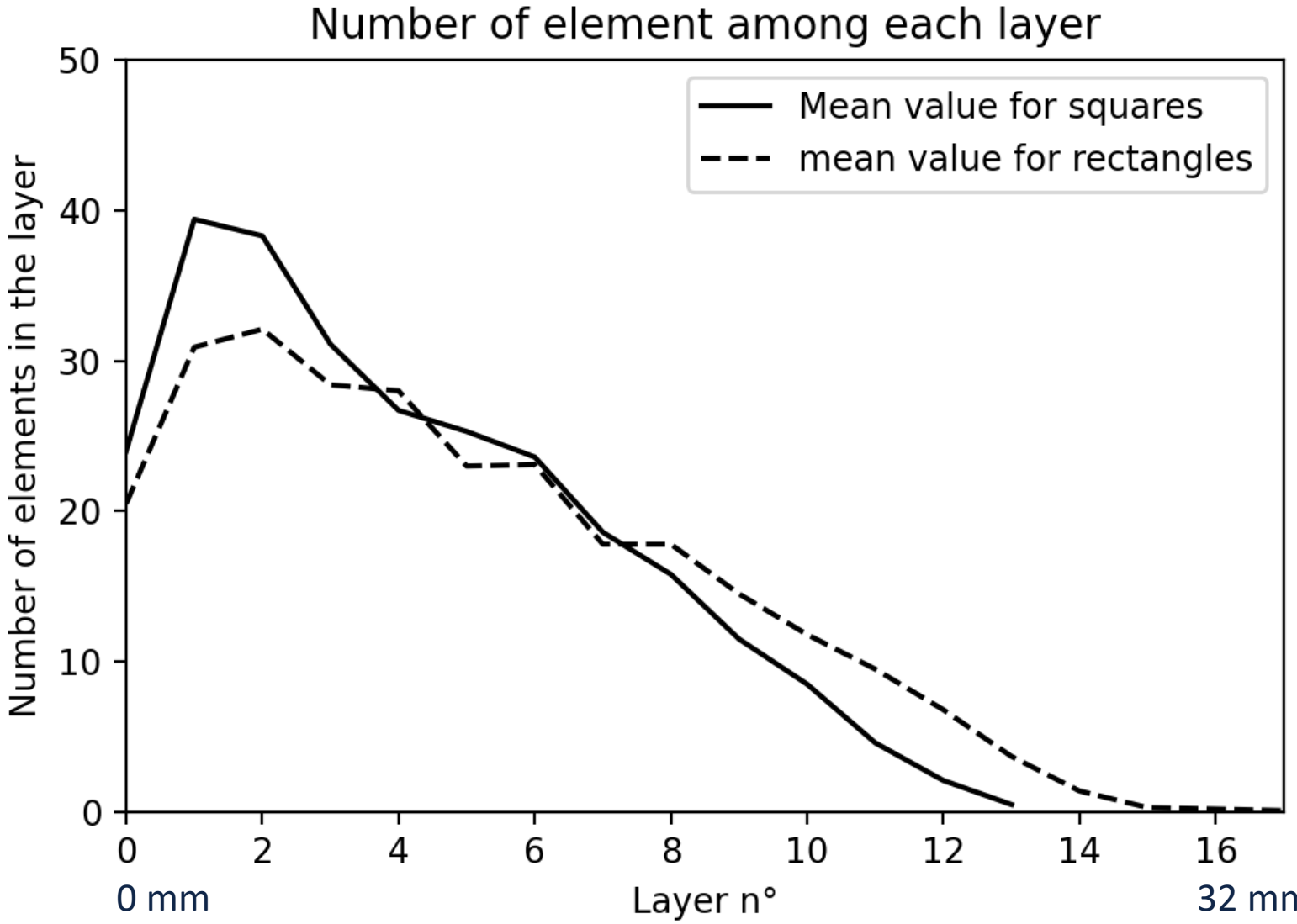
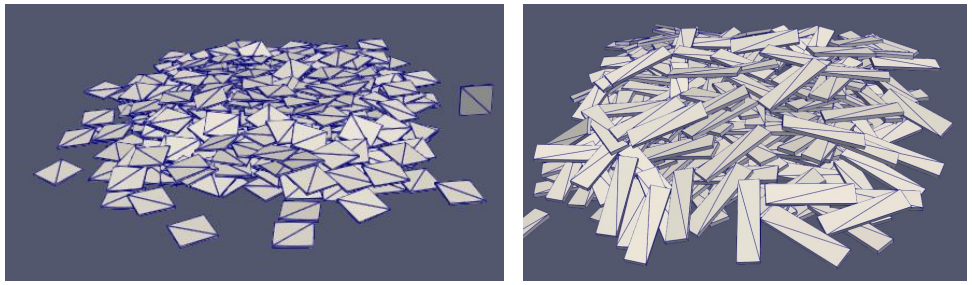
Size of chips : 20 mm * 20 mm * 2 mm



270 chips on a 150 mm * 150 mm deposition square
Size of chips : 10 mm * 40 mm * 2 mm

Effect of aspect ratio on descriptors



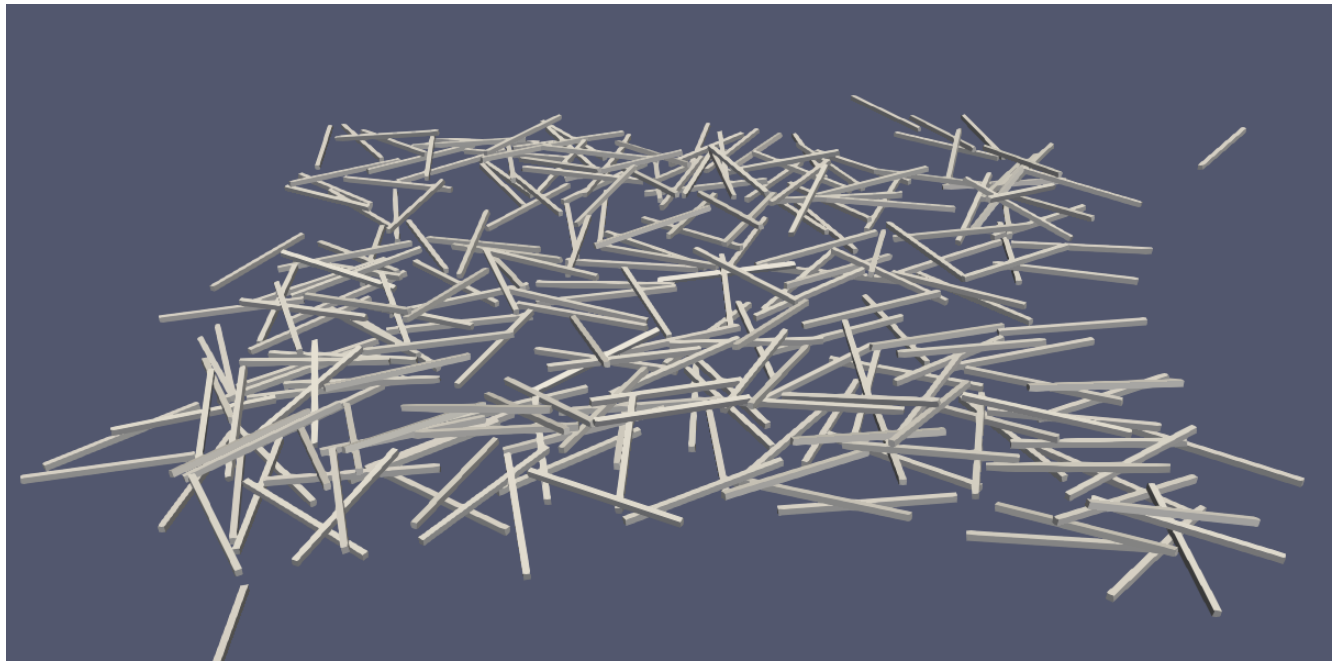


- Lower layer filling rate for rectangles in “low layers”
- Increase of the number of layers for rectangles

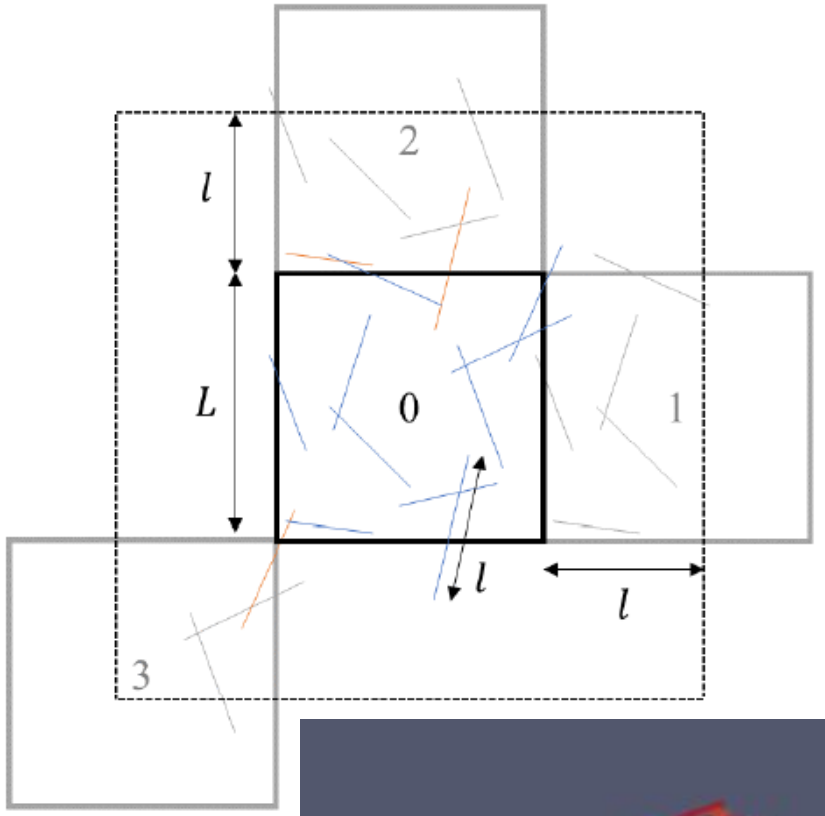
→Lower volume fraction for rectangles

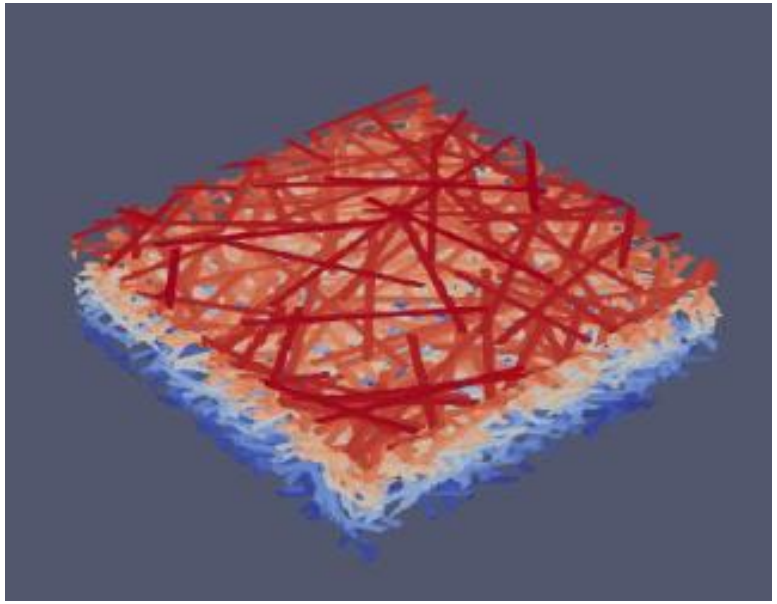
Perspectives

Theoretical validation



270 “fibers” on a 150 mm * 150 mm deposition square
Size of fibers : 1 mm * 25 mm

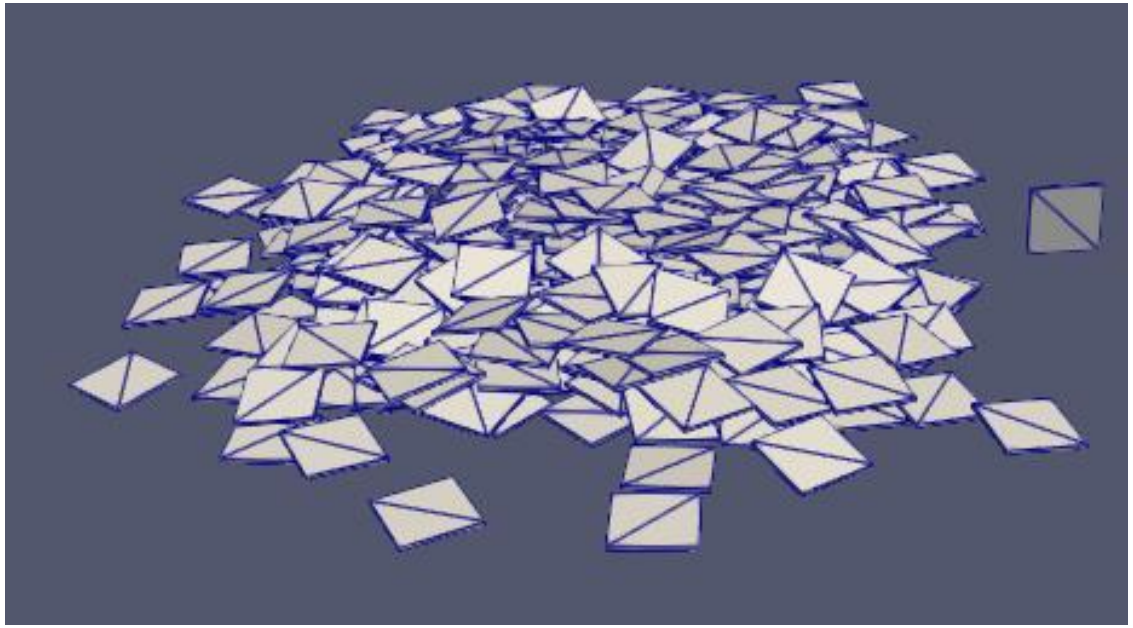




Comparison to analytical models using identical aspect ratio (1:25)

François Mahé, PhD thesis 2023.

Experimental validation



270 chips on a 150 mm * 150 mm deposition square
Size of chips : 20 mm * 20 mm * 2 mm

High speed camera, 1000 images per second

Identify numerical parameters of gravity, friction and bounces to fit experimental behavior

Future work

Input

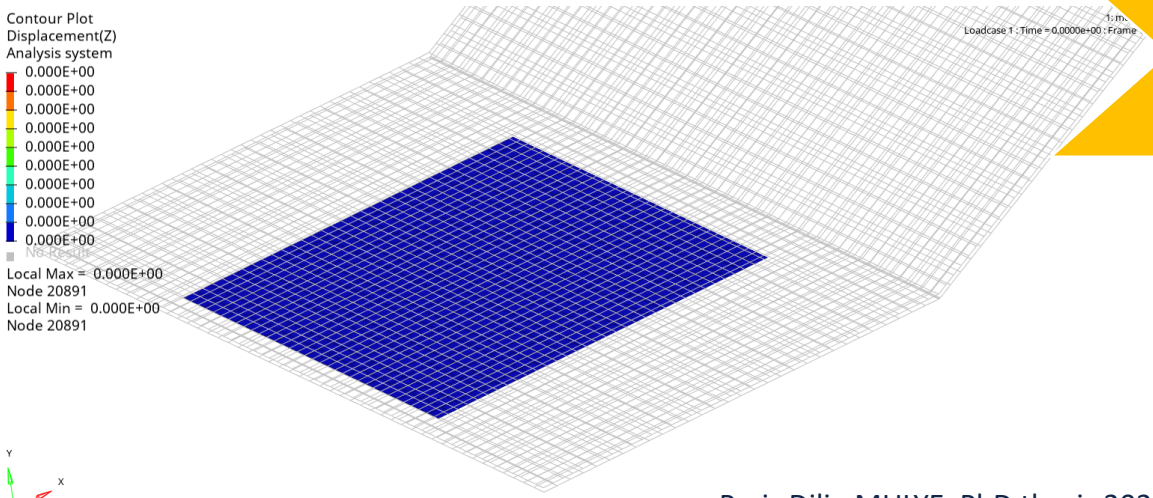
Material

Influence of the entrance material on the stack

Define descriptors of packing

Rearrangement of the stack under “low temperature” press

Track evolution of descriptors



Rearrangement of the stack under “high temperature” press

Track evolution of descriptors

Consolidated microstructure of processed panel

Mechanical properties

Output

Paris Dilip MULYE, PhD thesis 2022.

Thank you for your attention
Any questions?

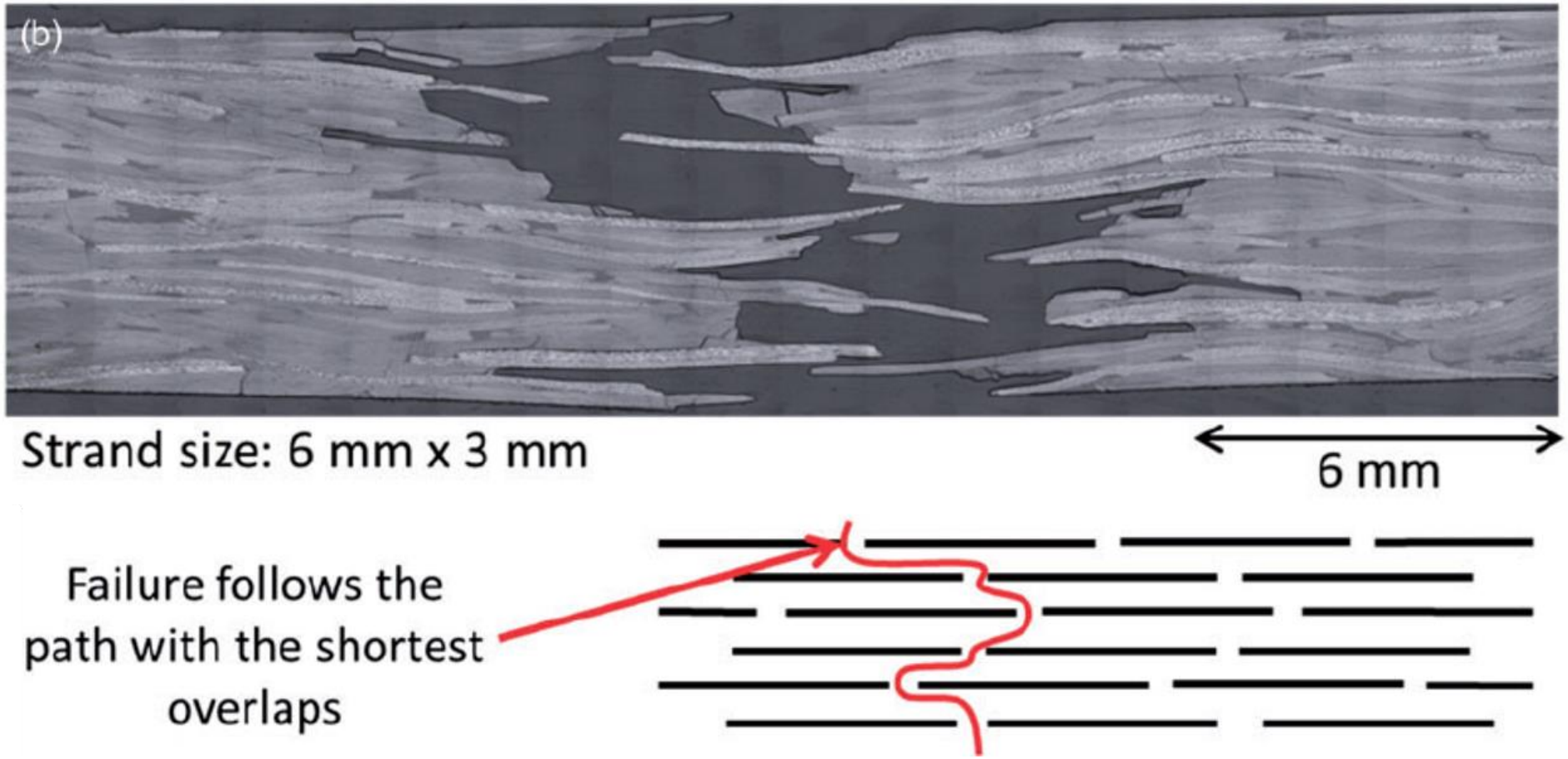
Awen Bruneau – ICCM23

Workshop CoDiCoFRP

Acknowledgments : Funding CETIM and Région Pays de la Loire

Appendices

Overlapping



Selezneva, M., & Lessard, L. (2016). Characterization of mechanical properties of randomly oriented strand thermoplastic composites. Journal of composite materials, 50(20), 2833-2851.

Industrial impacts

Industrial impacts

Composite manufacturers,

Recycling companies

Thermosaïc®
pilot line

Customization

Sell recycled panels

Customers

cetim

Investments in upgrading

the feeding line

Composite

manufacturers

Ensure reliability and controlled

mechanical properties