TFPA PhD FIRST YEAR FINAL REPORT

Advanced Design for Additive Manufacturing Approaches for Cutting-edge Applications in Physics and Engineering

PhD PROGRAM: Tecnologie per la Ricerca Fondamentale in Fisica e Astrofisica
CURRICULUM: Mechanics
UNIVERSITY / RESEARCH CENTRE:
Università degli Studi di Padova (DFA) / INFN Sezione di Padova

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SUPERVISOR: Prof. Serena Graziosi (PoliMi)
CO-SUPERVISOR: Dr. Pietro Rebesan (INFN-PD)

Padova, 23/09/2025

AGENDA

- ***INTRODUCTION:*** *Research topics and objectives**;***
- ***LASER POWDER BED FUSION TECHNOLOGY AND SCANNING STRATEGIES;***
- ***CELLULAR STRUCTURES:*** *Properties and Classification;*
- ***DIMENSIONAL ACCURACY OF LATTICE STRUCTURES AND PROCESS-INDUCED DEFECTS:*** *State of the Art**;***
- ***RESEARCH ACTIVITY CARRIED OUT AND FIRST EXPERIMENTAL RESULTS;***
- ***NEXT PLANNED ACTIVITIES;***
- ***RESULTS ON DTT MIRROR MBTL REDESIGN AND SIMULATIONS.***

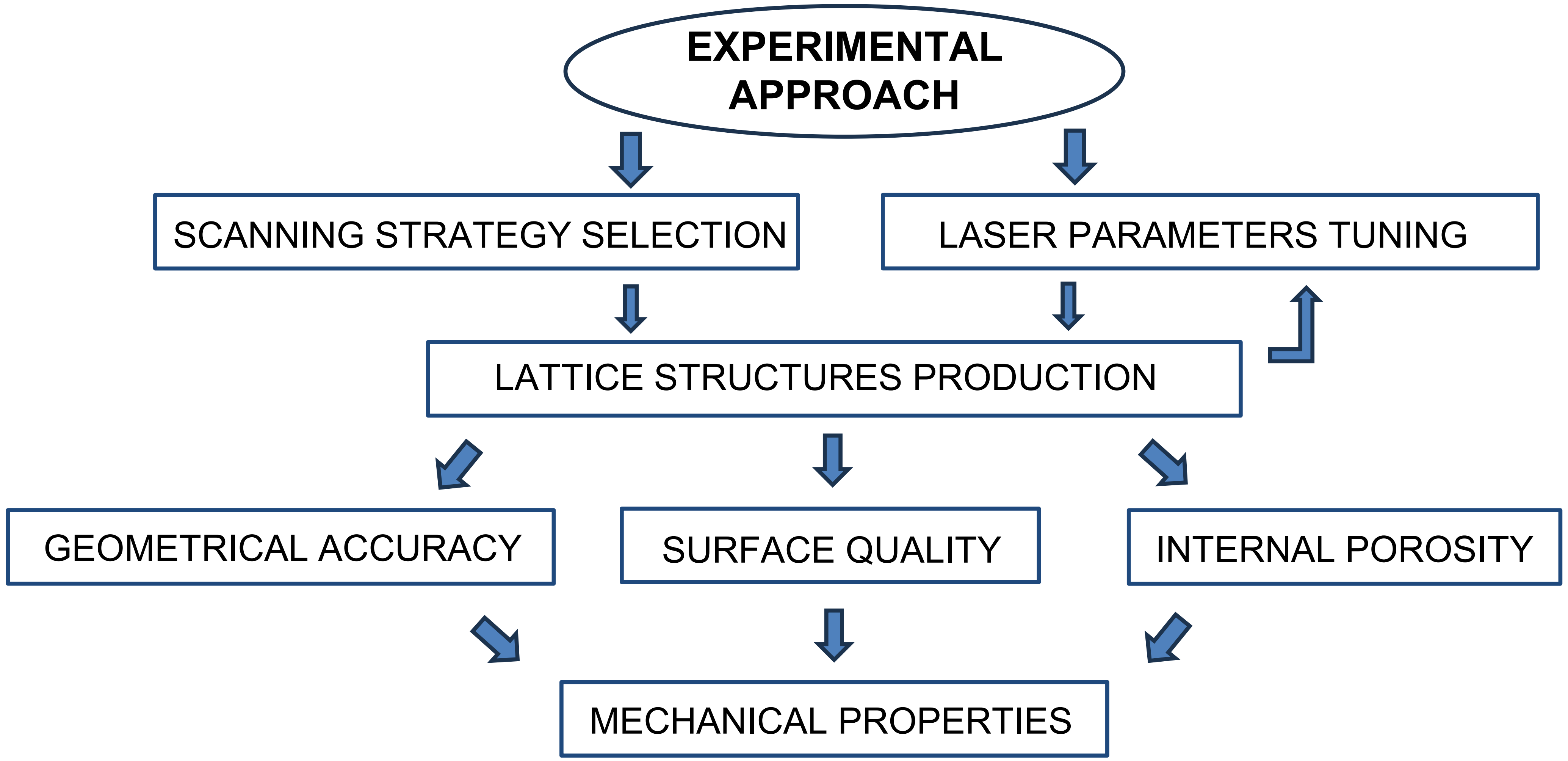
RESEARCH TOPIC AND OBJECTIVES

RESEARCH TOPIC:

Lattice structures design, optimization and production using **PBF-LB/M technology** (commonly known as LPBF technique).

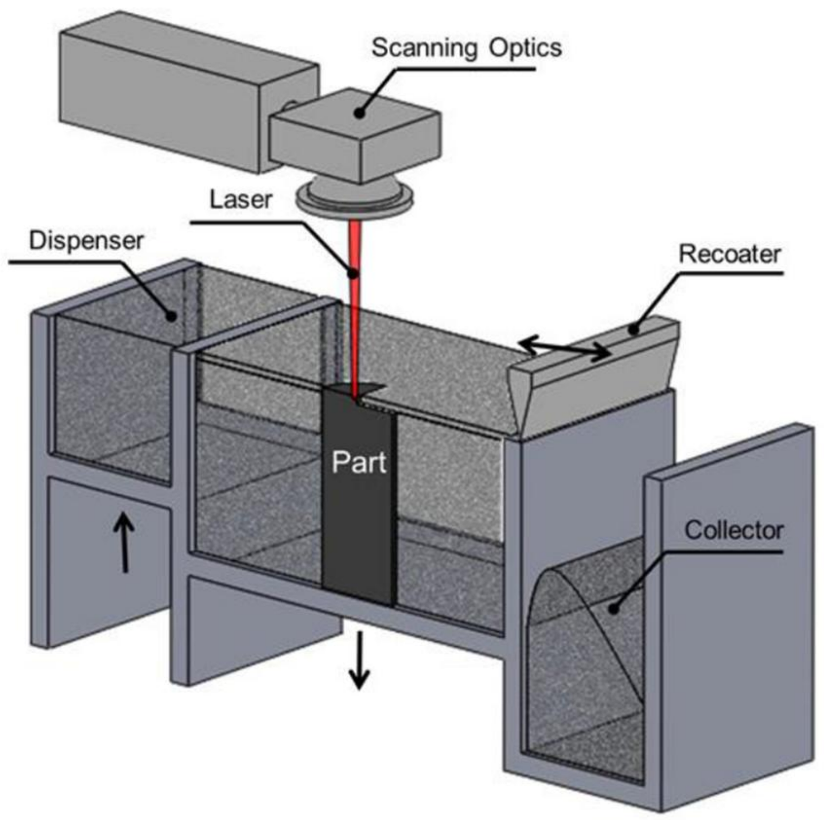
OBJECTIVES:

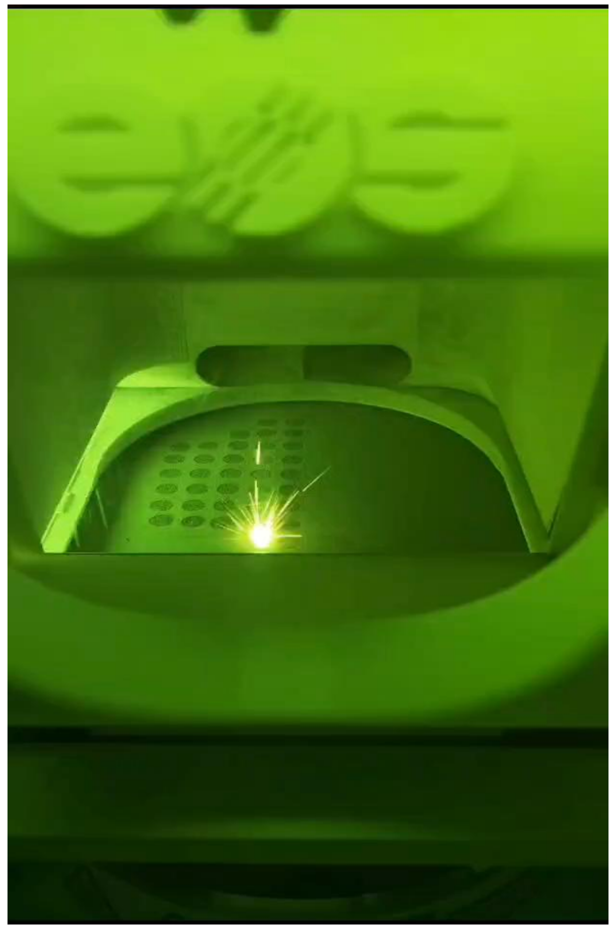
- *Design and production* of the first lattice structures;
- *Dimensional accuracy, surface quality and mechanical properties* evaluation;
- *Optimization of process parameters* and scanning strategy;
- *Design* and validation of *more complex lattice structures* with increased mechanical properties.



This is the map fixing the main points on the experimental approach for the first part of the PhD. At the moment, we are investigating the production of the first lattice structures..

LPBF TECHNOLOGY OVERVIEW





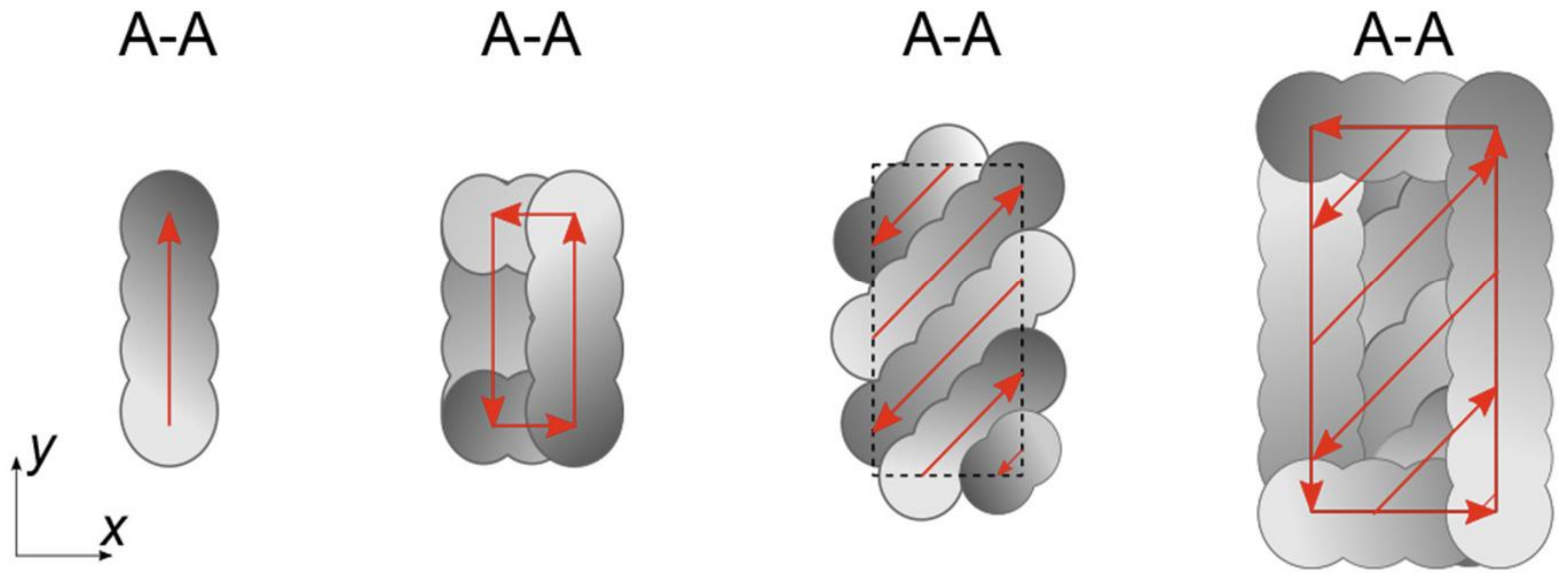
ADVANTAGES

- Net shape process;
- Better geometrical control and precision;
- No tools needed;
- Possibility to realize very complex shapes.

DISADVANTAGES

- Process-induced defects (porosity, lack of fusion, keyhole ecc);
- Residual stresses;
- Powder and Supports' removal;
- Limited dimensions.

MAIN EXPOSURE STRATEGIES USED FOR LATTICE STRUCTURES PRODUCTION



SINGLE SCAN TRACK ***CONTOUR EXPOSURE*** ***HATCH EXPOSURE*** ***HATCH + CONTOUR EXPOSURE***

Alexander Großmann et al., 2020, 'Dimensionless process development for lattice structure design in laser powder bed fusion', https://doi.org/10.1016/j.matdes.2020.108952

At the moment the focus is to compare the '**HATCH' and 'HATCH + CONTOUR' exposures**.

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CELLULAR STRUCTURES

PROPERTIERS OF CELLULAR STRUCTURES

Properties of lattice structures are mainly influenced by the following aspects:

- MATERIAL OF THE STRUCTURE;
- CELL TOPOLOGY AND SHAPE;
- RELATIVE DENSITY;
- PROCESS-INDUCED DEFECTS.

APPLICATIONS

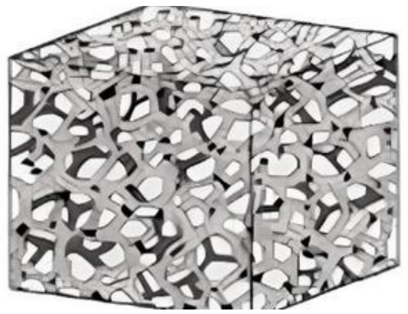
- Lightweight components;
- Heat exchangers;
- Thermal/acoustic insulation;
- Optics;
- Damage tolerant components;
- Biomedical implants.

CLASSIFICATION OF CELLULAR STRUCTURES

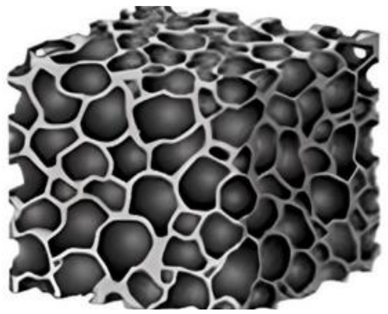
According to their connectivity (topology) and pore morphology, cellular structures can be divided in:

FOAMS (stochastic topology)

OPEN CELLS

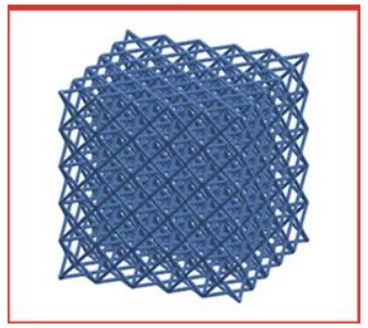


CLOSED CELLS

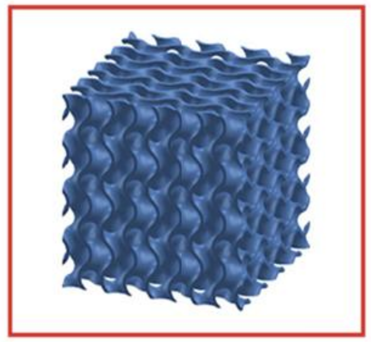


LATTICE OR ARCHITECTED CELLULAR MATERIALS (non-stochastic topology)

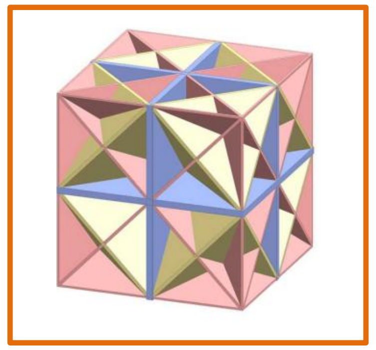
VORONOI



STRUT AND NODE



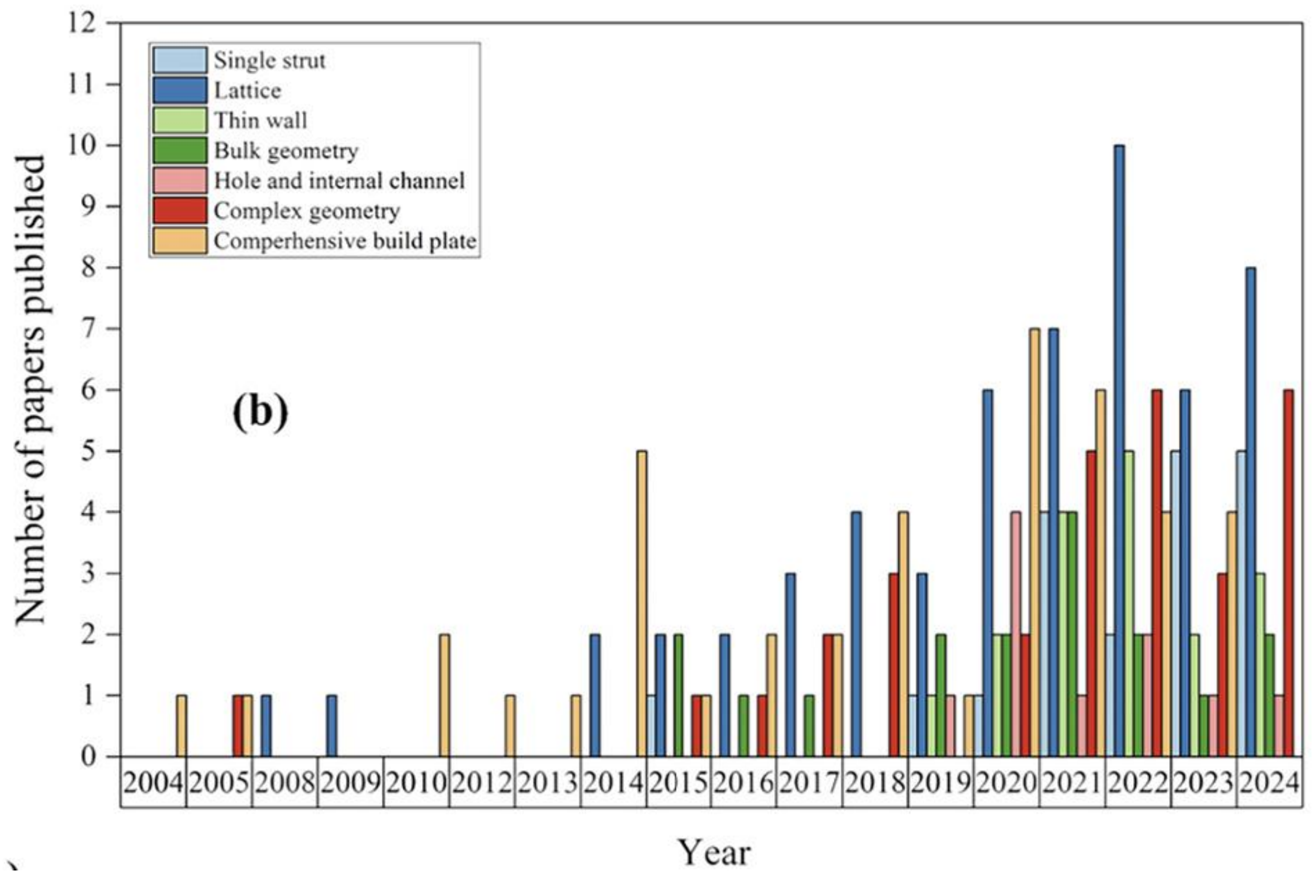
SURFACE-BASED



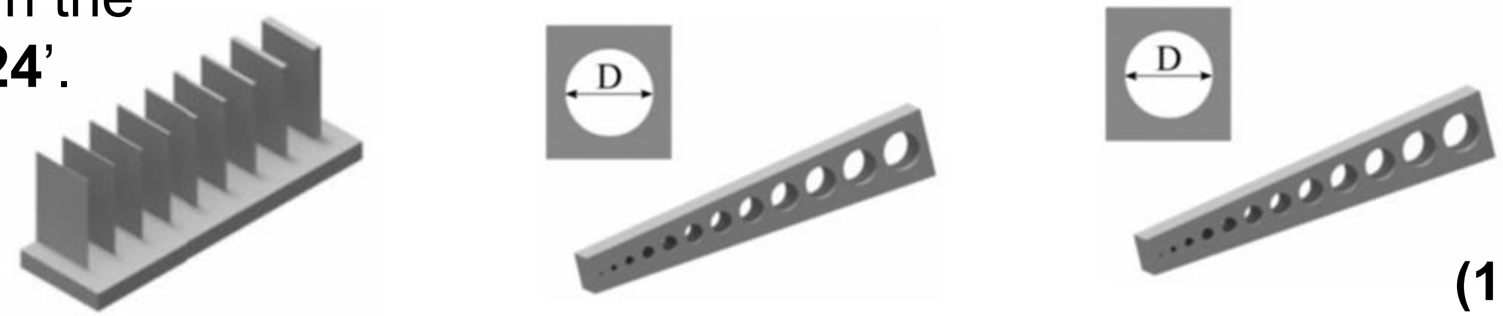
PLATE

STATE OF THE ART

‘The issue of **dimensional accuracy** of PBF parts **has gained significant interest** in the last few years. This is evident from the greater number of research studies **up to 2024**’.

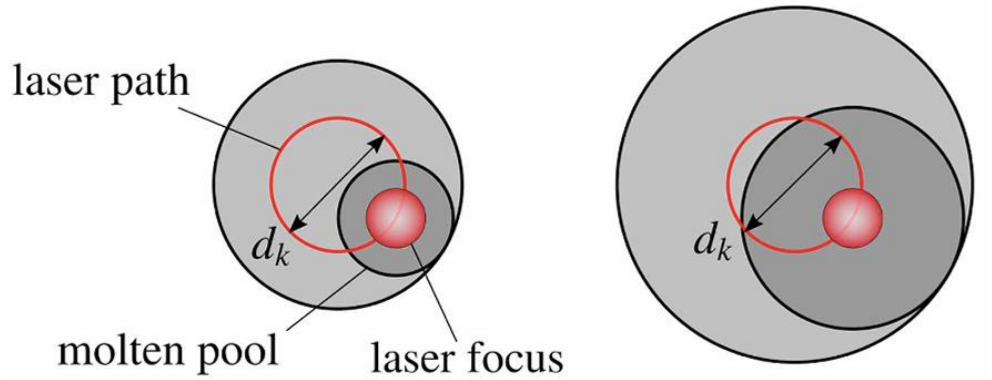


Erfan Maleki et al., ‘Dimensional accuracy of fabricated geometries through powder bed fusion: An overview and a new benchmark artifact proposal’, (2025)’ https://doi.org/10.1016/j.matdes.2025.114361

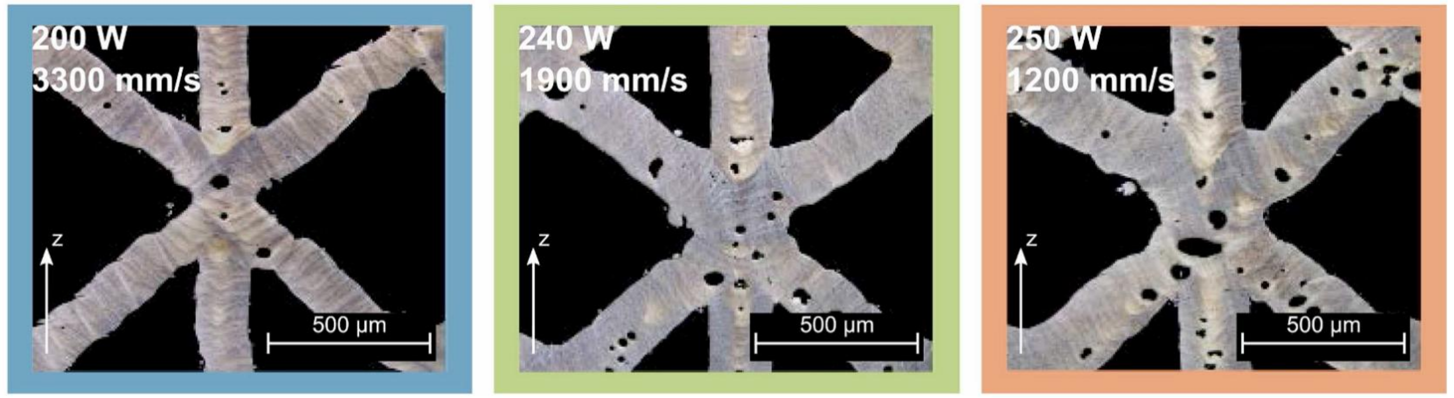


(1)

Dirk Herzog et al., 2021, ‘Design guidelines for laser powder bed fusion in Inconel 718’, https://doi.org/10.2351/7.0000508



(2)



Alexander Großmann et al., 2019, ‘Lightweight lattice structures in selective laser melting: Design, fabrication and mechanical properties’, https://doi.org/10.1016/j.msea.2019.138356

- Many studies focus on **benchmark samples** production, useful to find best parameters to match dimensional tolerances and reliability of complex parts (1).
- Other studies focused on lattice structures **parameters and scanning strategy optimization**, evaluating the impact of **porosity and surface roughness on mechanical properties** strut-based and surface-based lattices (2).

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EXPERIMENTAL RESULTS: DENSITY CUBES

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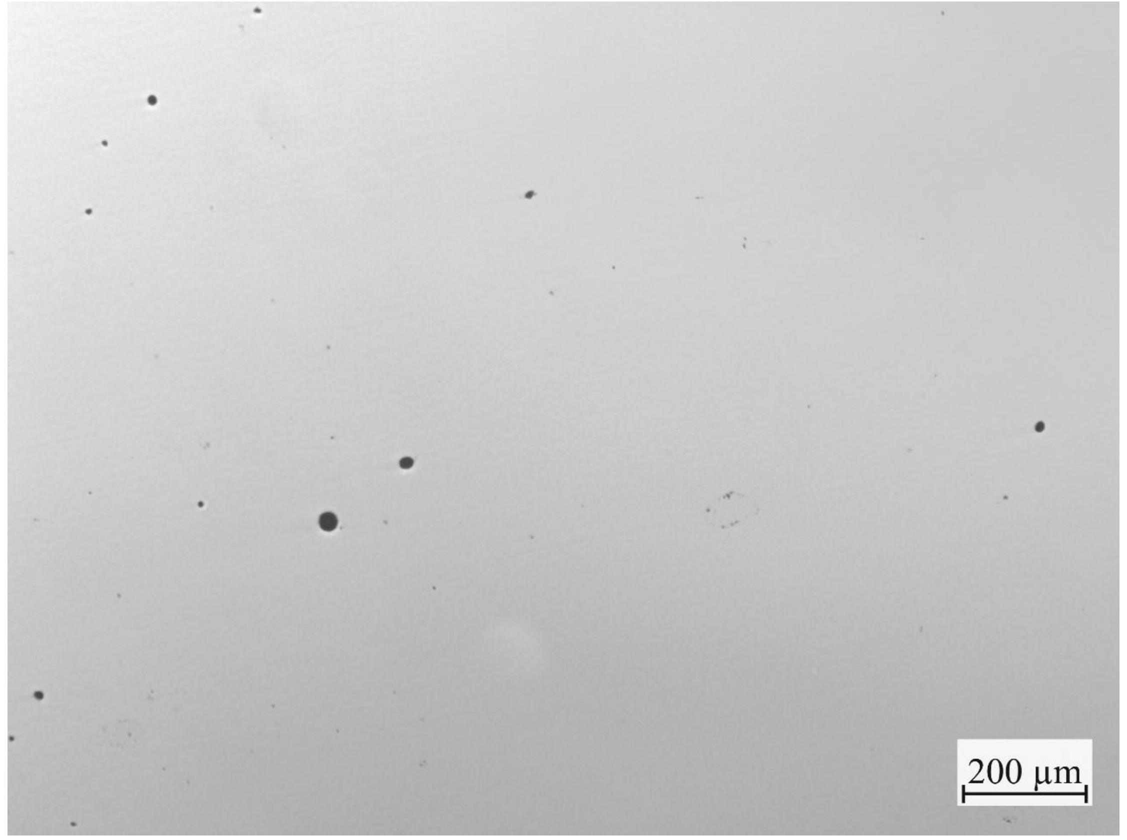
SAMPLE	POWER [W]	SPEED [mm/s]	HATCHING [mm]	THICKNESS [µm]	ENERGY DENSITY [J/mm^3]
1	90	750	0,06	30	66,67
2	90	725	0,07	30	59,11
3	90	800	0,06	30	62,50
4	105	725	0,07	30	68,97
5	100	750	0,06	30	74,07
6	100	750	0,07	30	63,49
7	100	800	0,06	30	69,44
8	100	700	0,07	30	68,03
9	110	750	0,06	30	81,48
10	110	750	0,07	30	69,84
11	110	800	0,06	30	76,39
12	110	800	0,07	30	65,48

- **12 cubic samples were produced** using 'Hatch' exposure, to find the best parameters' window in terms of relative density.
  This is the first step to find the best printing parameters for a specific material.
- **Optical microscope measurements** were conducted, and **Cube_6** showed remarkable results (**around 99.6 RD**). Other samples showed lower RD values, between 97.0% and 98.5%.
- Range values of **Power, Speed and Energy density** were chosen for this first attempt according to scientific publications related to Inconel 718 LPBF.

EOS M100 MACHINE



CUBE 6 internal porosity image

From these results, **parameters of cube 6 are taken as reference** for 'Hatch' exposure.

EXPERIMENTAL RESULTS: SST ANALYSIS

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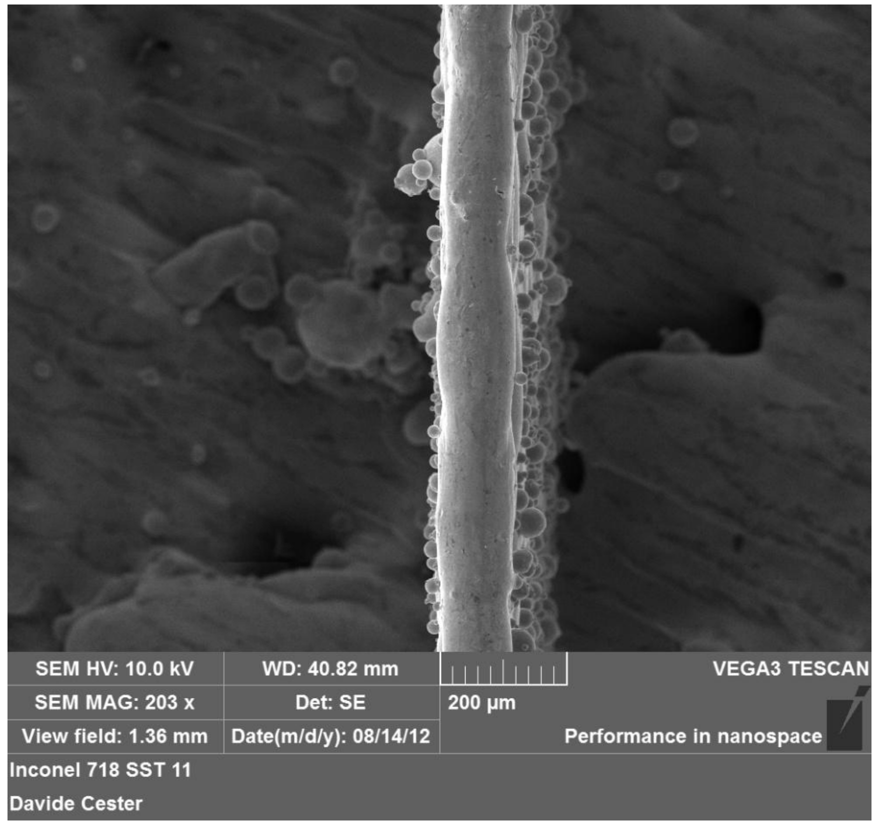


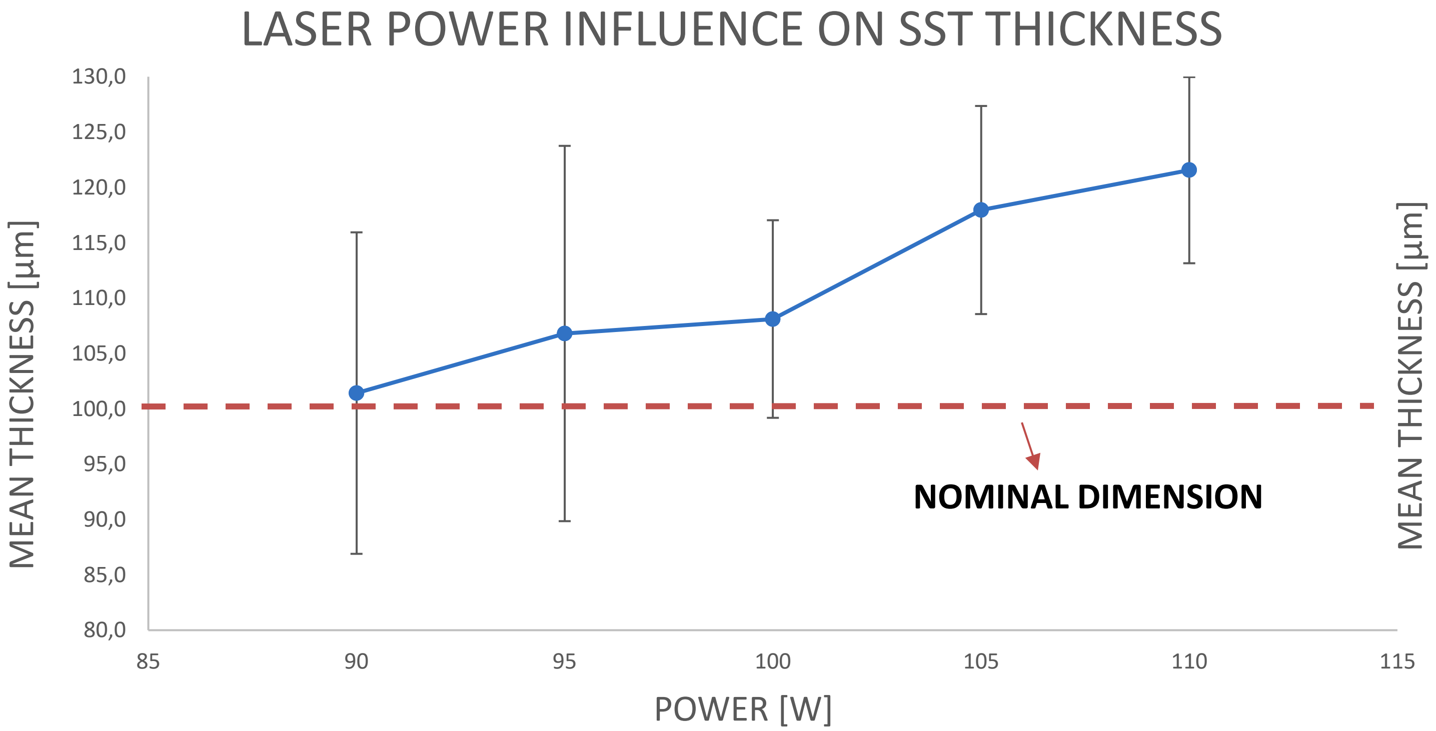
- **Imagej** software was used for thickness' measurements;
- **7 measures for each SST** at different locations of the stripe were taken;
- Reference scale was set at 200 µm.

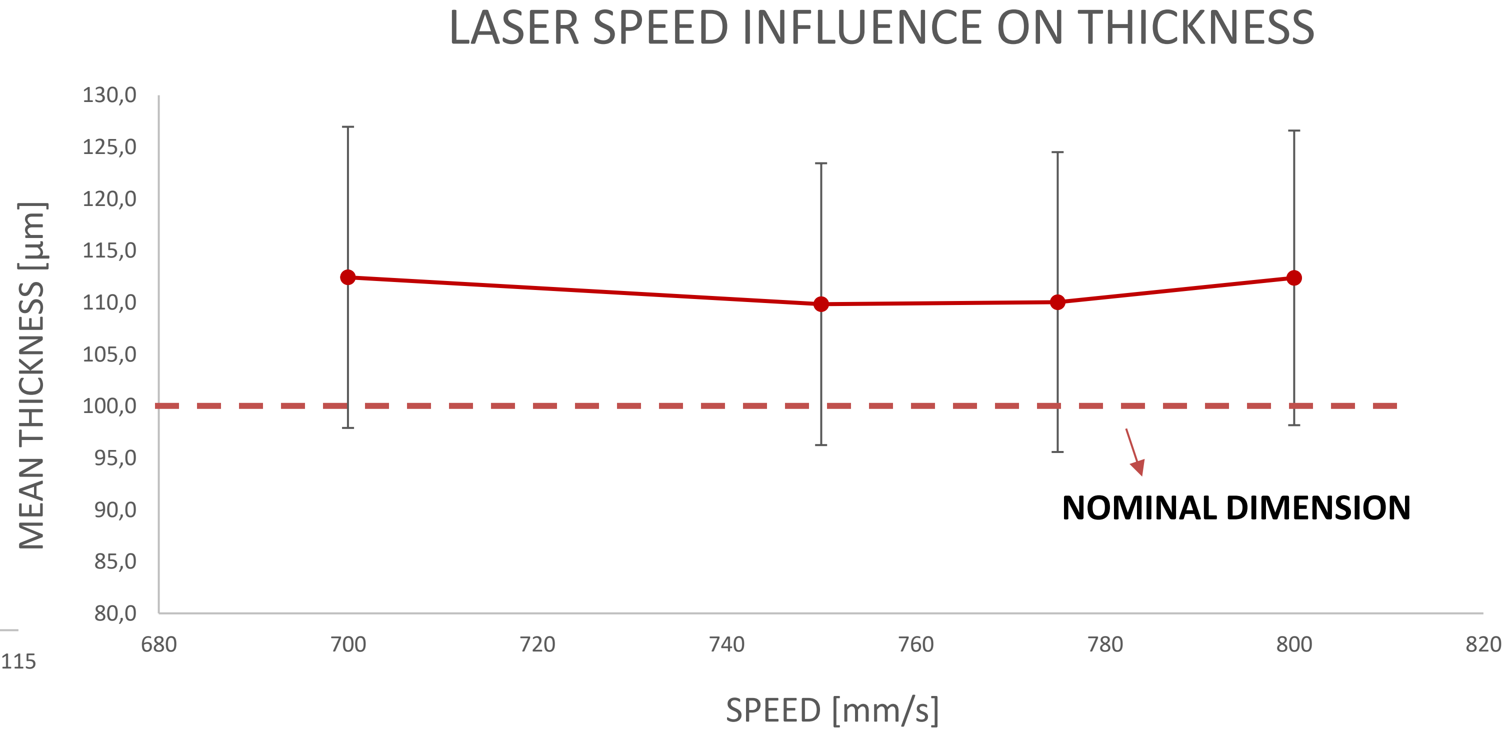
- **Single Scan Tracks (SST):** thin walls of **0,1mm thickness** printed with **one single stripe**. Here the **main parameters** are **Power and Speed. Best parameters** will be taken as reference **for 'Contour' exposure** study.

	SST																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
P [W]	90	90	90	90	95	95	95	95	100	100	100	100	105	105	105	105	110	110	110	110
v [mm/s]	700	750	775	800	700	750	775	800	700	750	775	800	700	750	775	800	700	750	775	800
t [mm]	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03

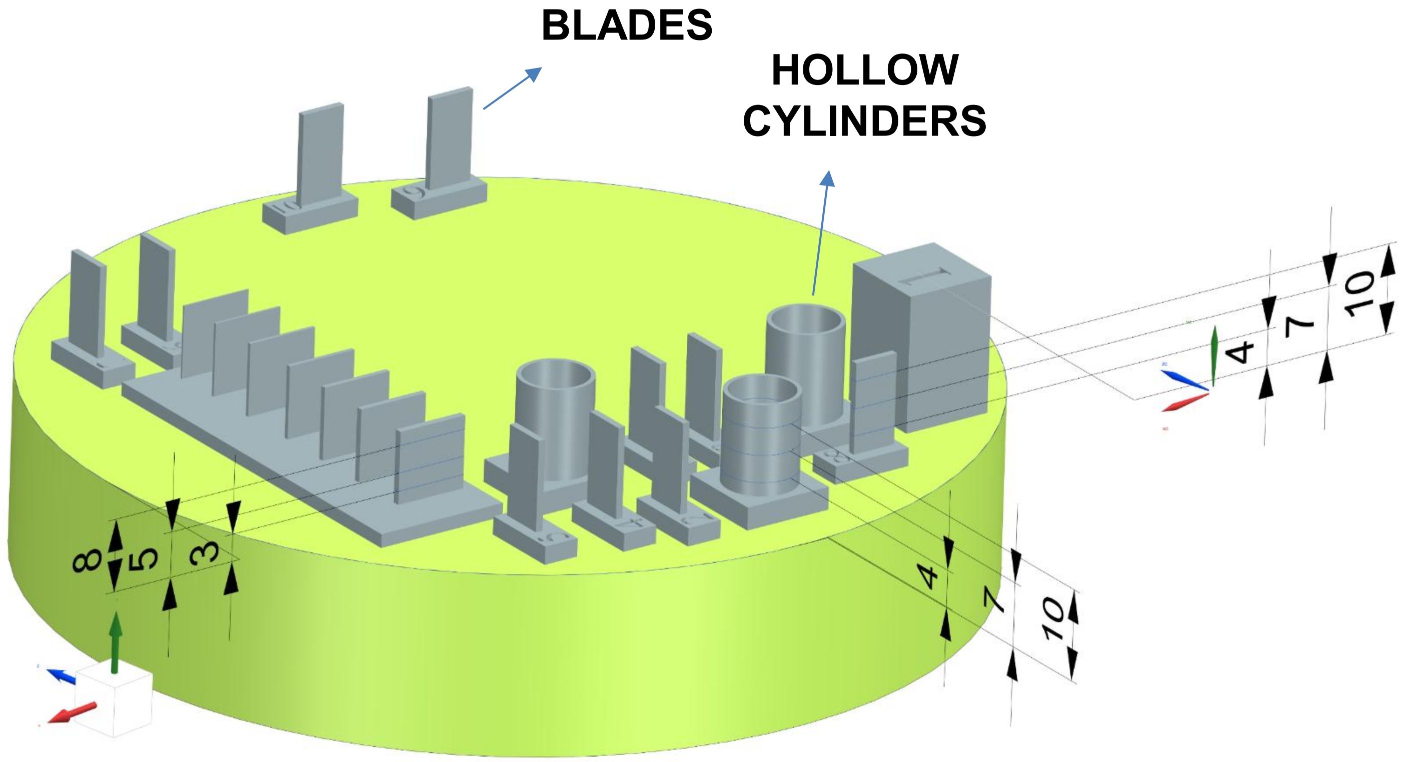
- **5 values of Laser Power**; **4 values of Laser Speed**; **Layer thickness is fixed at 0,030 mm**.

- Increasing the Laser Power, the mean thickness increases;
- Almost no influence of Laser speed on mean thickness variation.
- Best results for **P = 100 W and Speed = 750mm/s; 775 mm/s and 800 mm/s**





EXPERIMENTAL RESULTS: FIRST CONTOUR STUDY



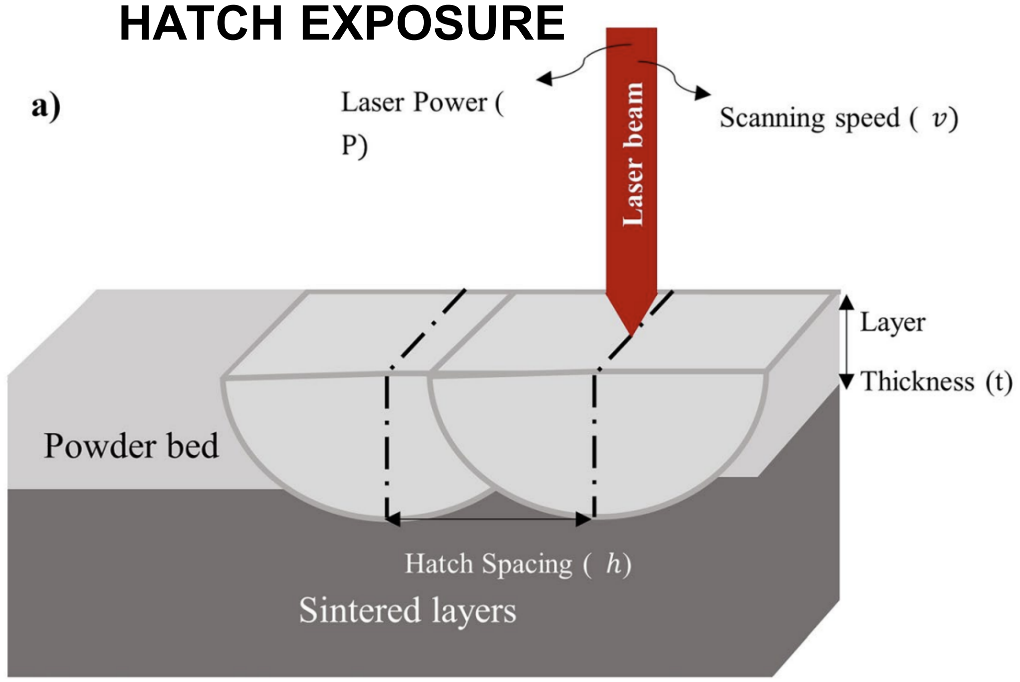
HOLLOW CYLINDERS: 3 specimens produced using **'Hatch' + 'Contour' strategy**.

SPECIMEN	POWER[W]	SPEED [mm/s]	CONTOUR OFFSET [µm]
CYLINDER_1	100	750	60
CYLINDER_2	100	750	55
CYLINDER_3	100	750	65

Control on the **geometrical accuracy**

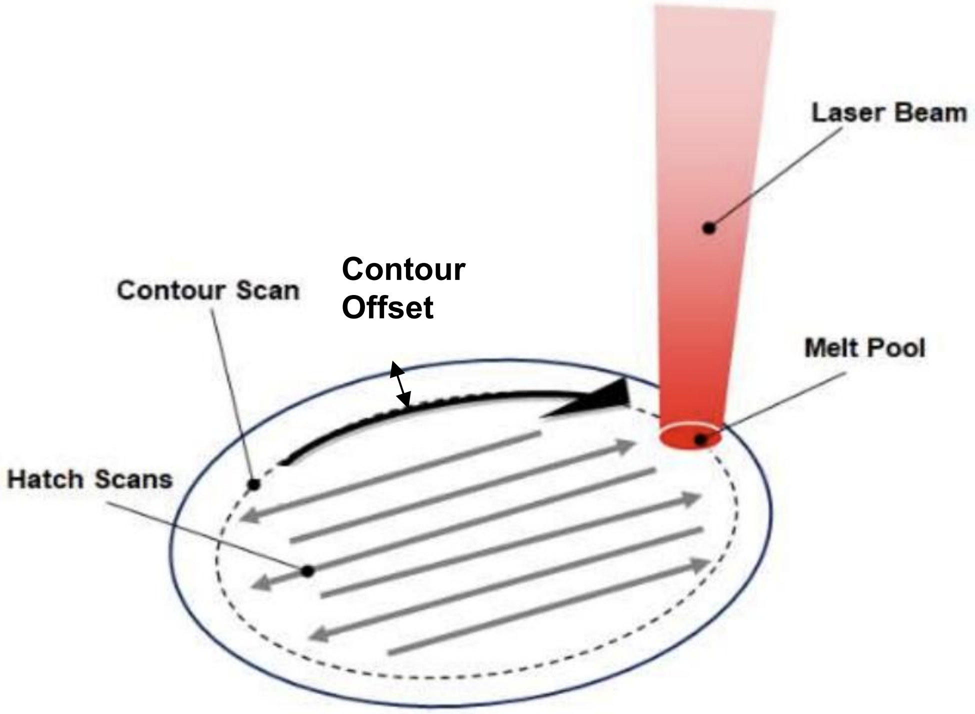
Best values in terms of **geometrical accuracy** found for **65 µm Contour Offset**.

HATCH EXPOSURE

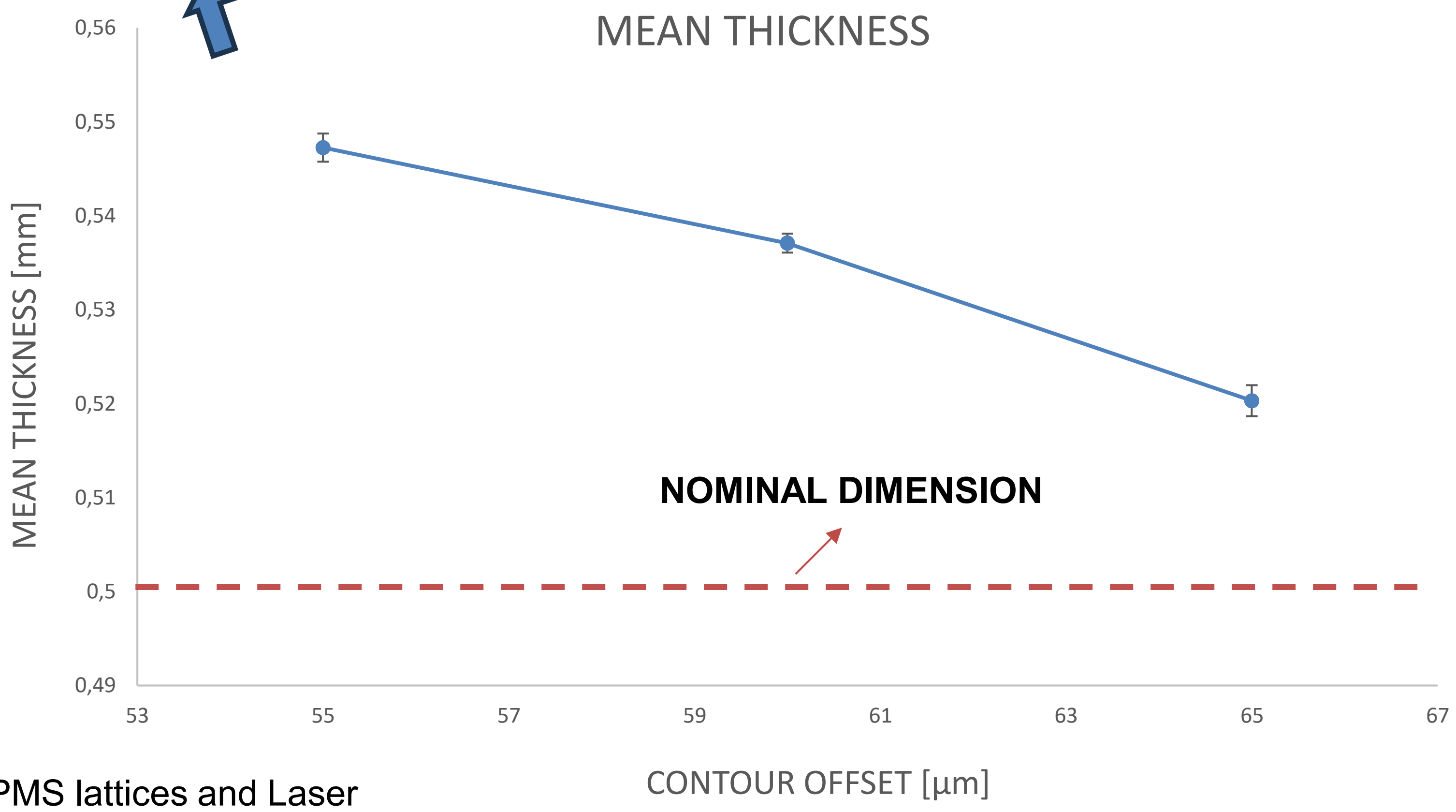


Ana Marques et al.,2022,'Inconel 718 produced by laser powder bed fusion: an overview of the influence of processing parameters on microstructural and mechanical properties', https://doi.org/10.1007/s00170-022-09693-0

CONTOUR EXPOSURE



Avez Shaikh et al.,2024, 'Towards Gradient Design of TPMS lattices and Laser Powder Bed Fusion Processing– Role of Laser Strategies and Lattice Thickness'.



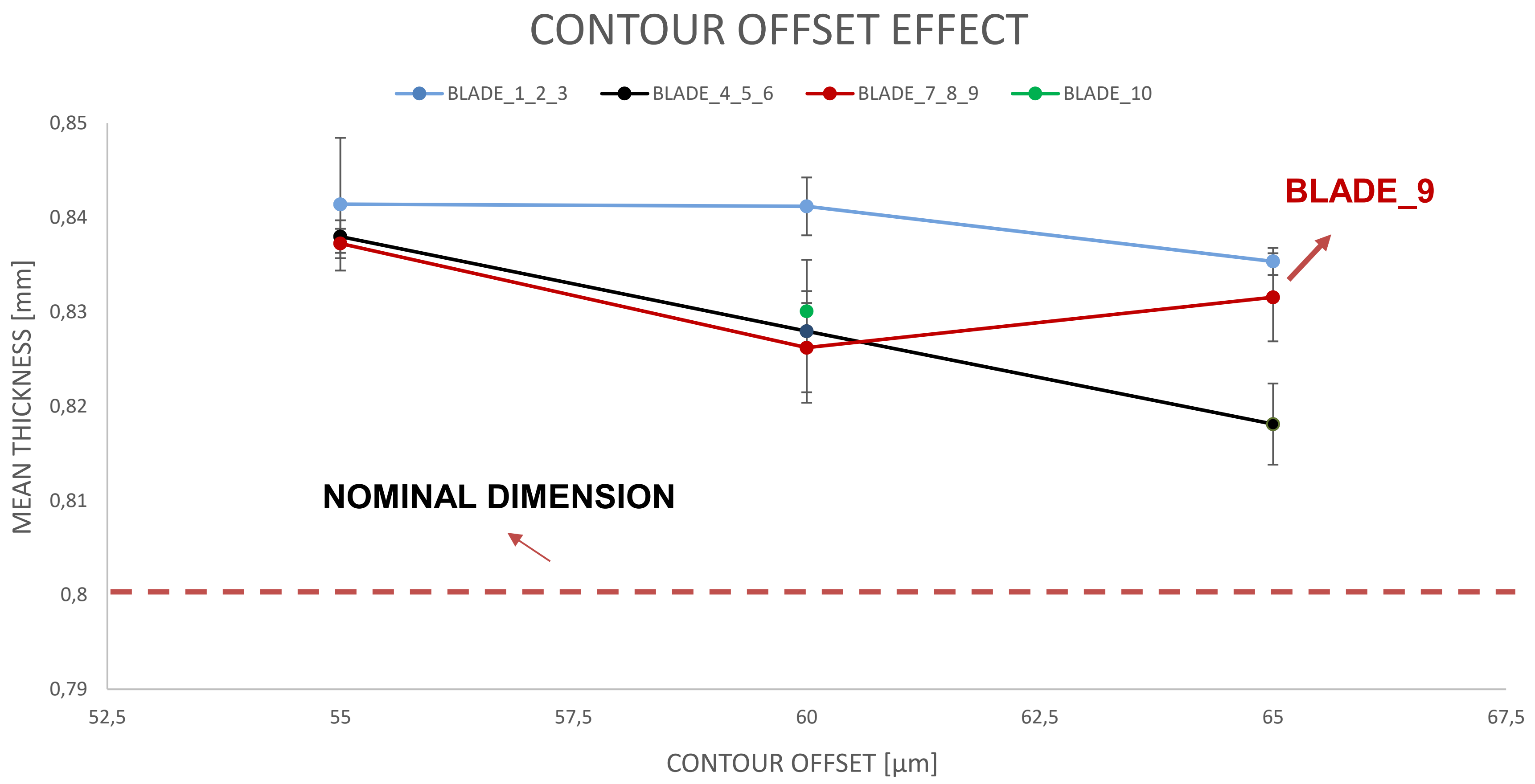
EXPERIMENTAL RESULTS: FIRST CONTOUR STUDY

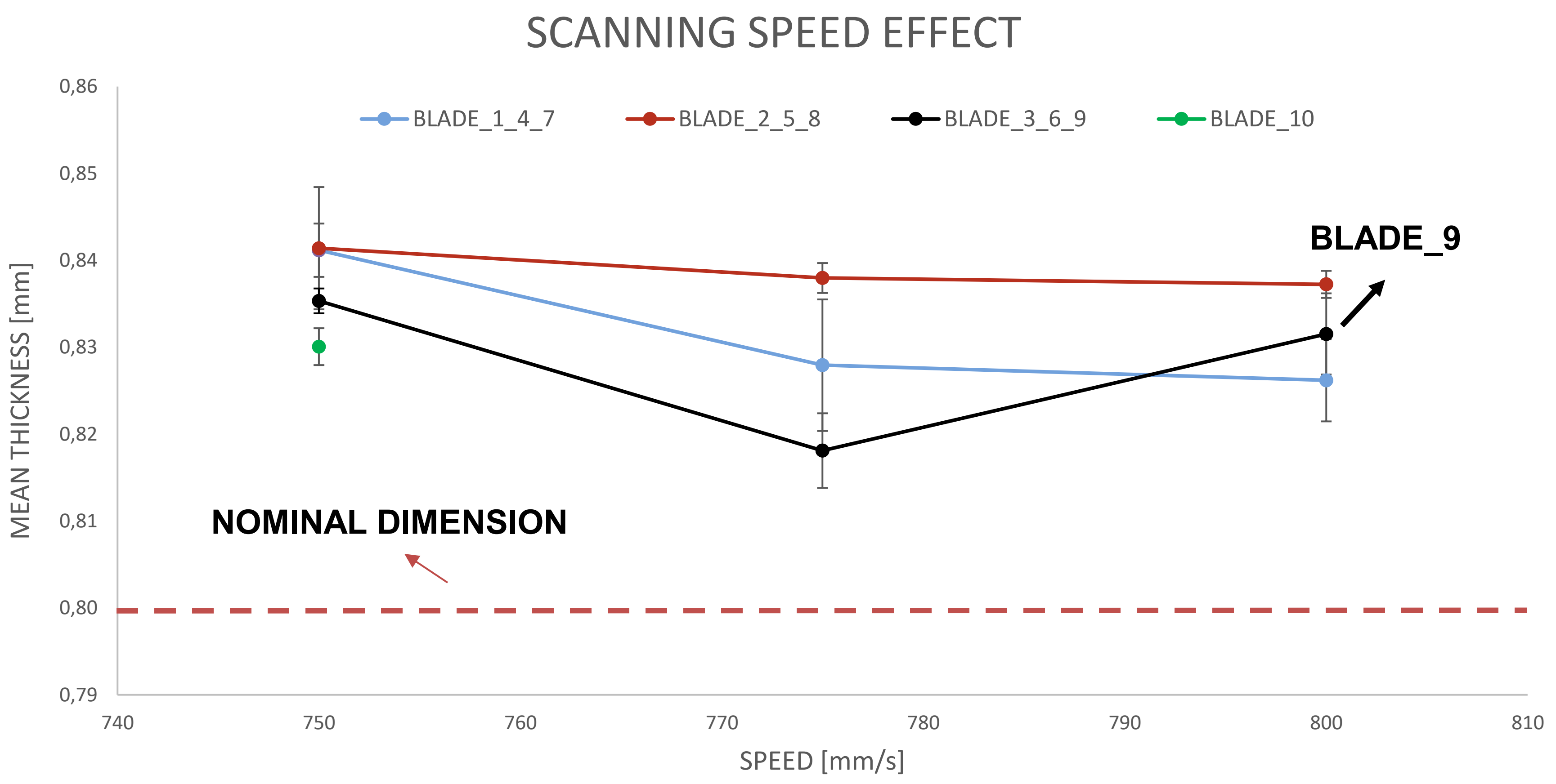
BLADES: 10 THIN WALLED SPECIMEN
with 0.8 mm nominal thickness.

- Combination of **3 contour offset** as in the previous case;
- **3 speed values** from previous SST analysis (750 mmm/s – 775 mm/s – 800 mm/s);
- **Power was fixed** at 100 W;
- **Blade_10** was produced **without Contour exposure**.

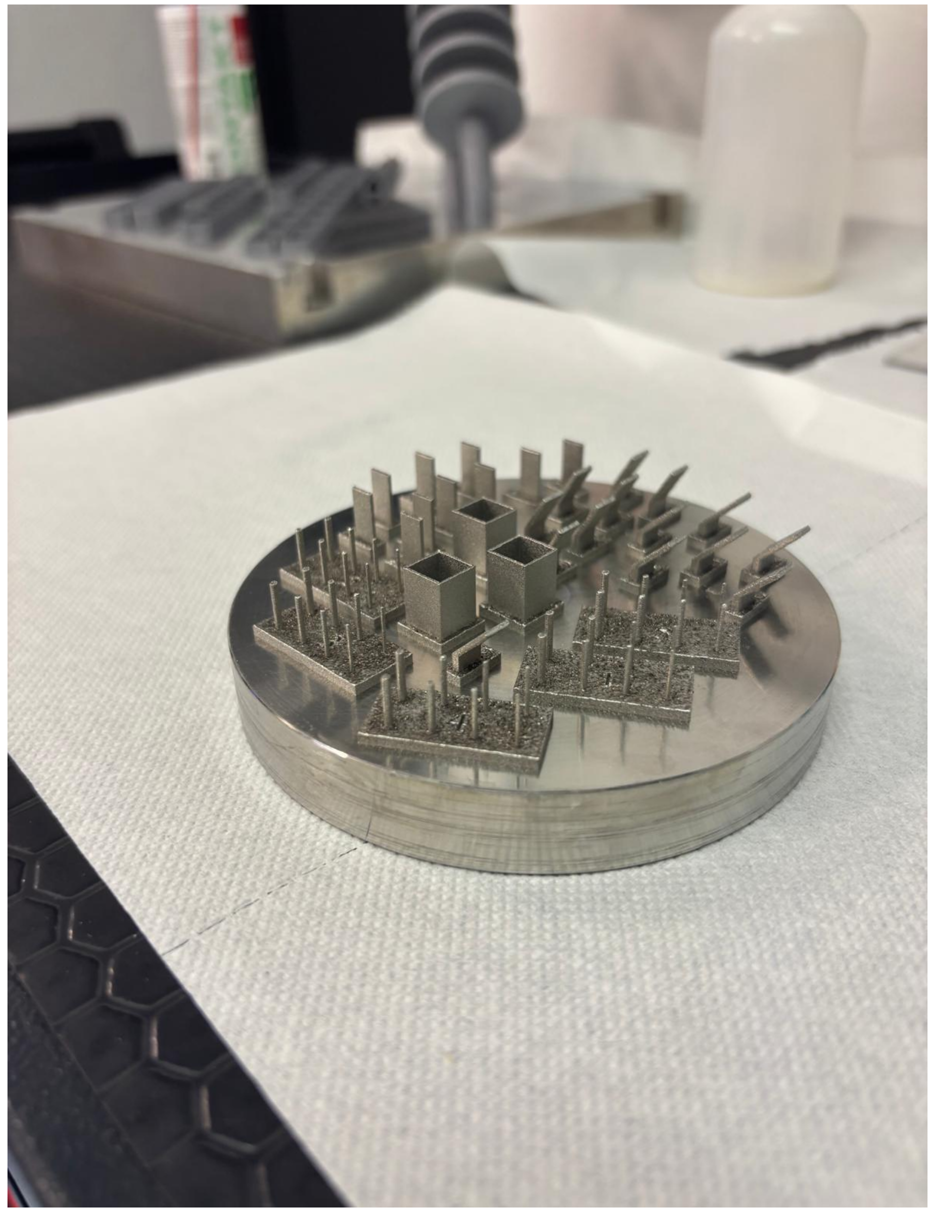
Higher Contour Offset values (65 µm) and higher Laser Speed (800 mm/s) lead to **closer results** in terms of dimensional accuracy respect to nominal dimensions.

SPECIMEN	POWER [W]	SPEED [mm/s]	CONTOUR OFFSET [µm]
BLADE_1	100	750	60
BLADE_2	100	750	55
BLADE_3	100	750	65
BLADE_4	100	775	60
BLADE_5	100	775	55
BLADE_6	100	775	65
BLADE_7	100	800	60
BLADE_8	100	800	55
BLADE_9	100	800	65
BLADE_10	100	750	/





EXPERIMENTAL RESULTS: ONGOING ACTIVITIES

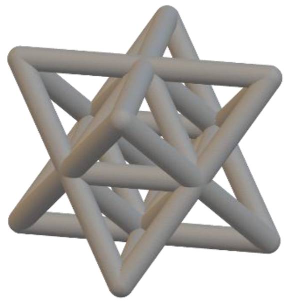


Starting from previous dimensional accuracy results, other **benchmark samples** were produced and need to be studied:

- **Hollow Cubes**;
- **Thin inclined Baldes**;
- **Vertical struts** with 1.2 mm – 0.6 mm diameter.

NEXT PLANNED ACTIVITIES

- CMM and optical analysis for benchmark samples;
- Optical and SEM analysis for Diamond TPMS structures;
- Solve the issues related to *OCTET* lattice structures fabrication;

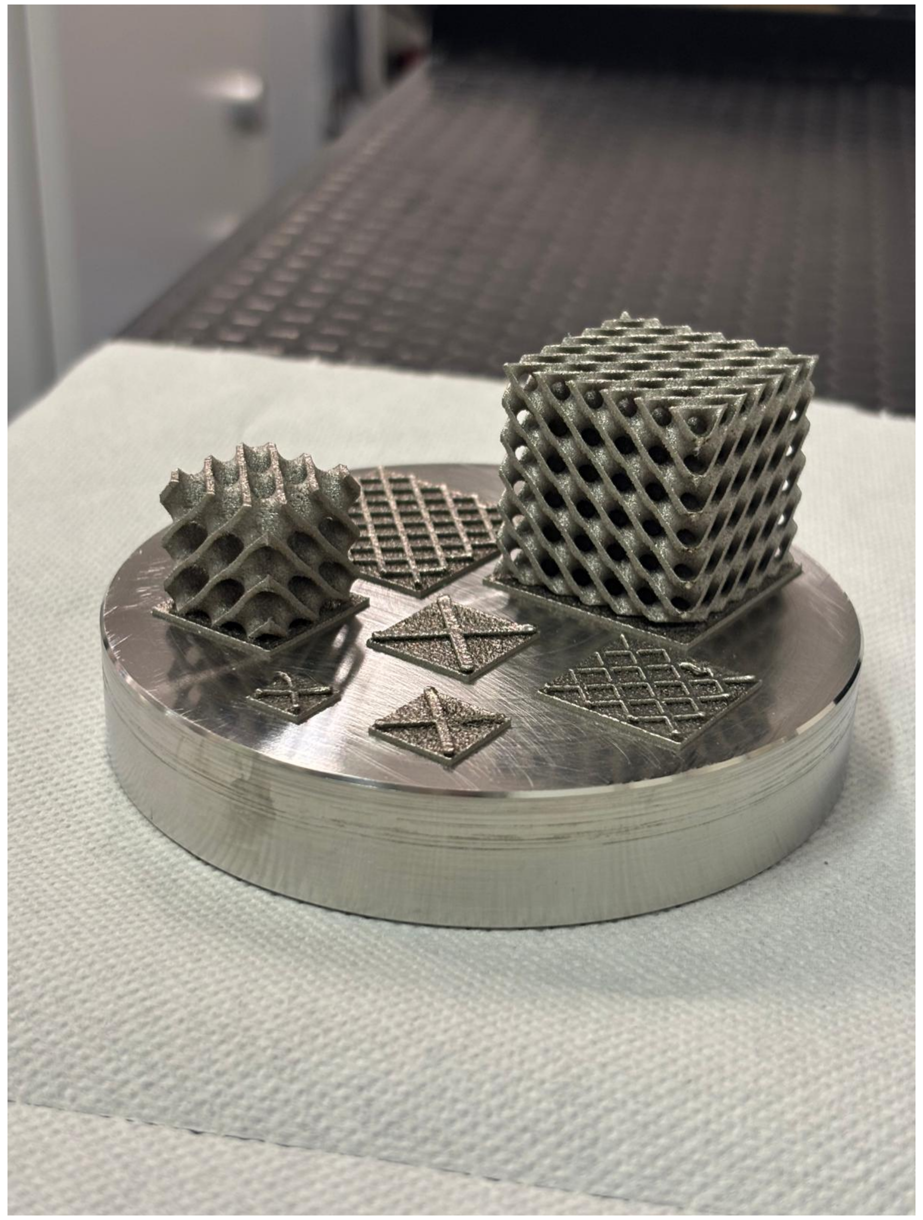


Octet unit cell.

- Fix best contour exposure parameters for further studies.

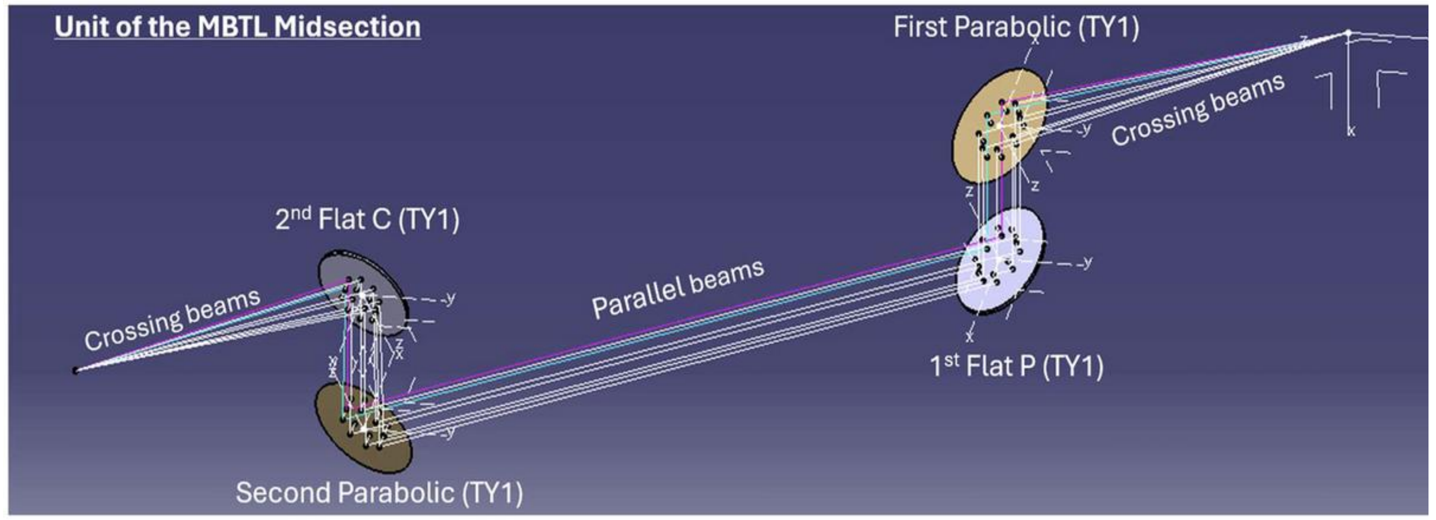
First attempt for Lattice structures fabrication:

- **'Hatch' strategy only was used** (best density parameters);
- **Diamons TPMS** structures with different unit cell dimensions successfully produced;
- **Problems for Octet lattices** due to base plate adhesion.



DTT MIRROR MBTL REDESIGN

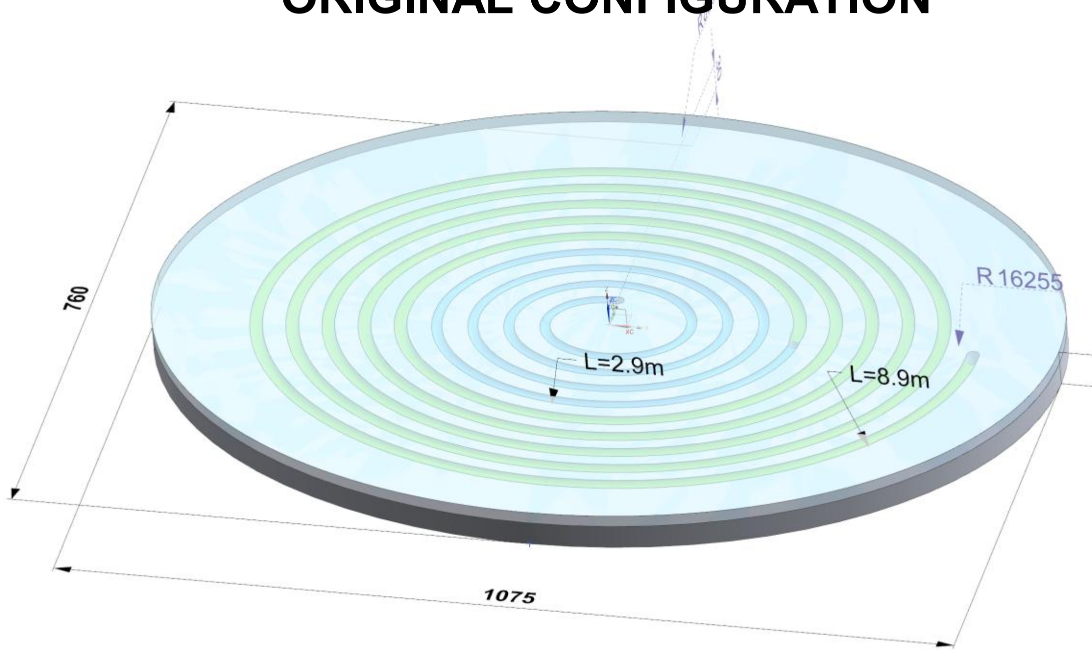
Example of a unit of the midsection of the MBTL, with 4 reflecting mirrors (2 focusing and 2 flat mirrors).



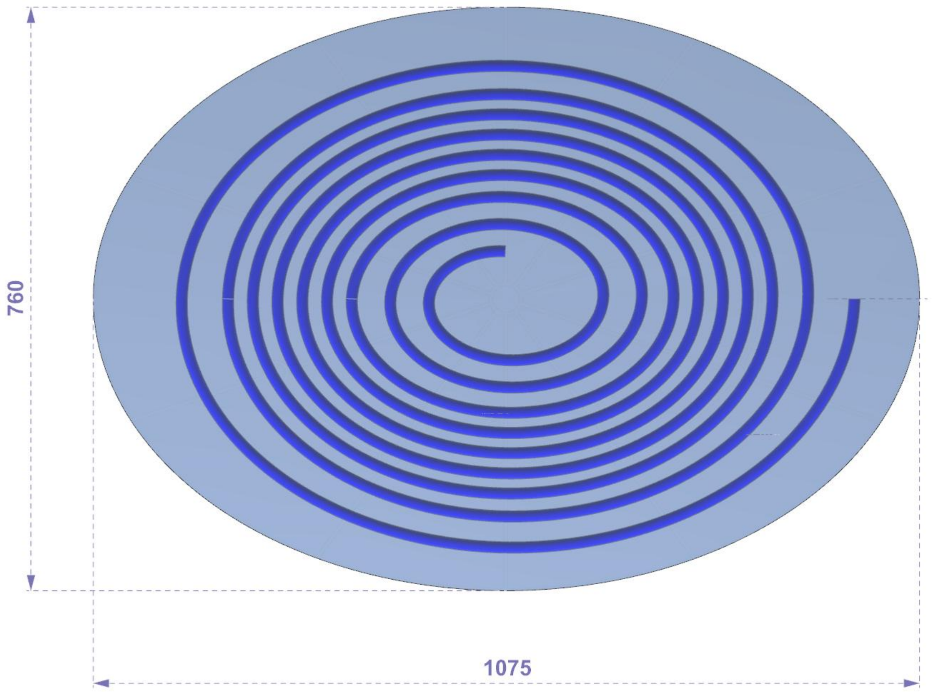
***First Parabolic TY1** is the mirror studied in this case.*

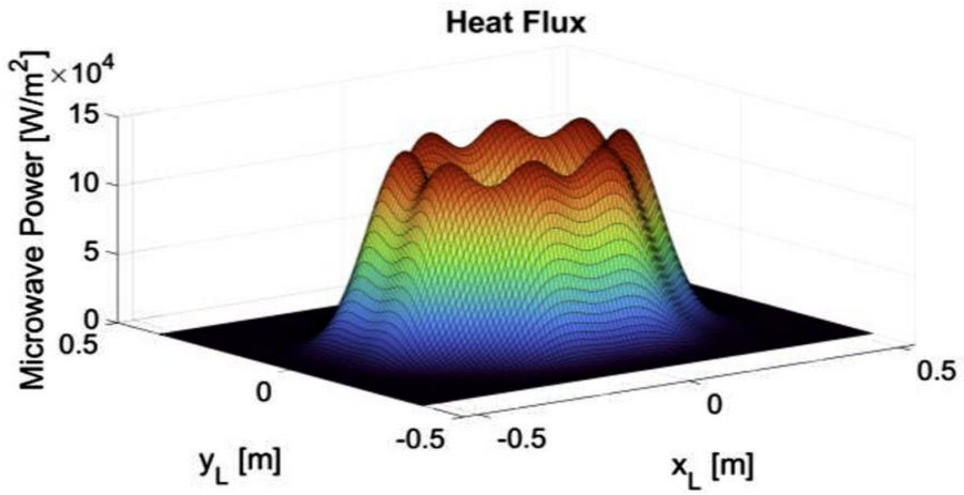
A. Salvitti et al., 'Thermal and structural analyses on different mirrors of the Multi-Beam Transmission Line of DTT ECH system', (2024), https://doi.org/10.1016/j.fusengdes.2024.114228

ORIGINAL CONFIGURATION



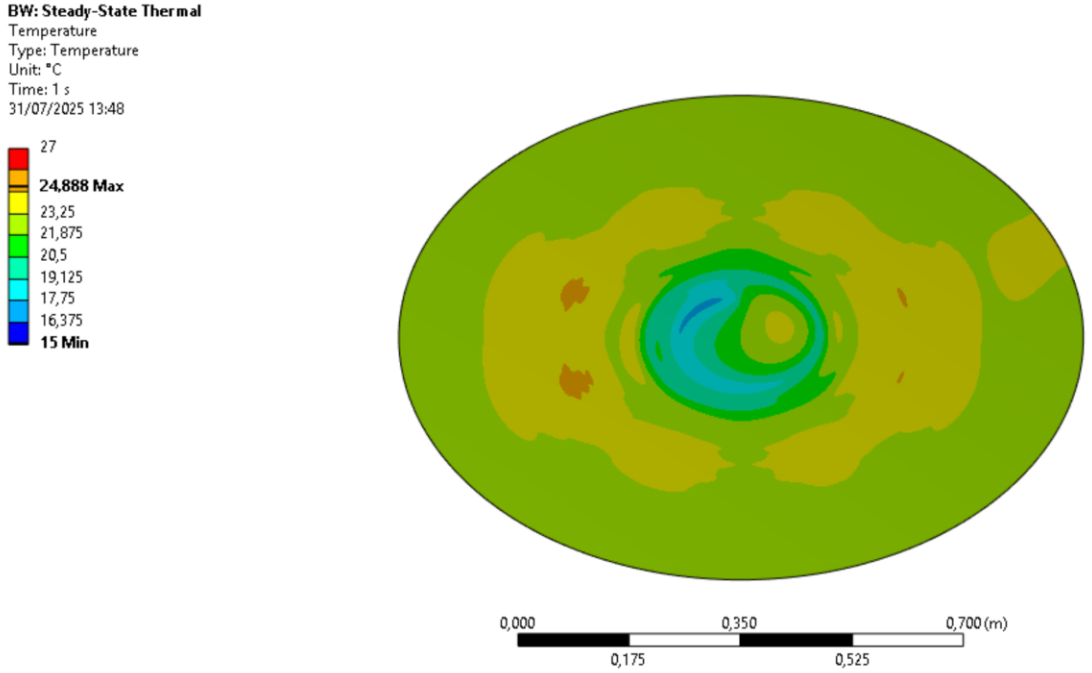
ACTUAL CONFIGURATION





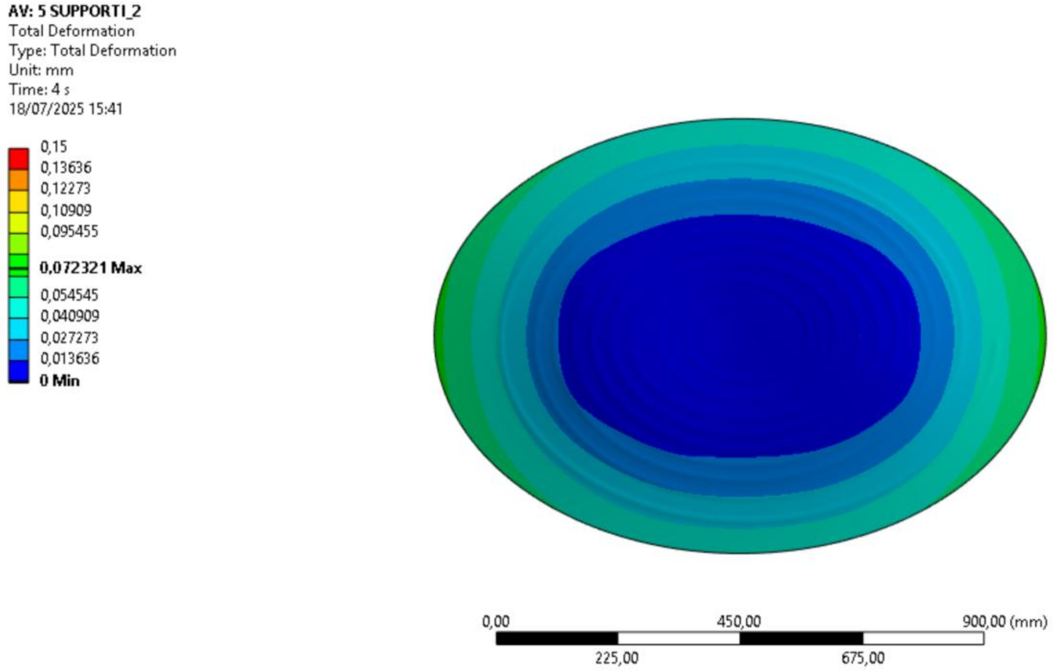
HEAT MAP
distribution due to 8 incident microwave beams.

STATIC THERMAL ANALYSIS



More uniform temperature distribution and lower peak value.

STATIC STRUCTURAL ANALYSIS



72 µm of MAX total deformation obtained.

COURSES AND SCHOOLS ATTENDED

COURSES FROM PREVIOUS STUDY PLAN

1. Python for numerical heat transfer modeling and building physics (12 hours, 3 CFU, attended and passed) ✓
2. Optimization Methods for Mechanical Design (12 hours, 3 CFU) → **To be attendend next year in March/April 2026**
3. Generative Design for smart Additive Manufactruing (12 hours, 3 CFU) ✓
4. Lattice Structures via Additive Manufacturing for Multifunctional Aerospace (15 hours, CFU not indicated) → **At the moment i'm attending the lectures.**

- CONFERENCES, SEMINARS, SCHOOLS

1. Granada "International Doctorate School Geometrical Aspect of Architecture and Structural Mechanics" ✓

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Thank you for your attention