Internship at the RWTH Aachen University

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Faculty of Mechanical Engineering
BUT

Brno, 24th April 2019

INSTITUTE OF **MACHINE**
AND **INDUSTRIAL DESIGN**

Content

- Project Overview
- Aachen
- Aachener Cathedral
- RWTH (Rheinisch-Westfälische Technische Hochschule) Aachen University
- Campus Melaten
- Trips to „nearby“ surroundings
- Research activities
- Published papers
- Joint events
- Conclusion

Project Overview

International mobility of researchers at the Brno University of Technology

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6 month, 1st June – 30th November 2018

DAP Digital Additive Production | RWTH AACHEN UNIVERSITY

Fraunhofer ILT

Prof. Loosen

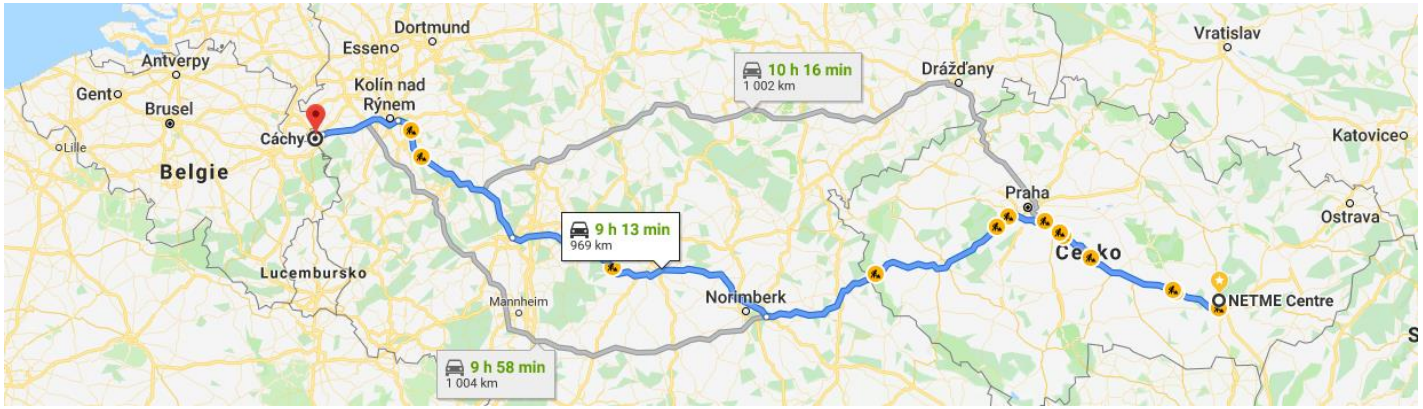
Prof. Schleifenbaum

Aachen

- The most westen city in Germeny
  - Population – 246 000 people
  - Area – 161 km^2

Aachen

- The most westen city in Germeny
  - Population – 246 000 people
  - Area – 161 km^2
- Travelling by Car Ford Focus (2000)
- The closest airport – Cologne (100 km)
- The Germany's highway

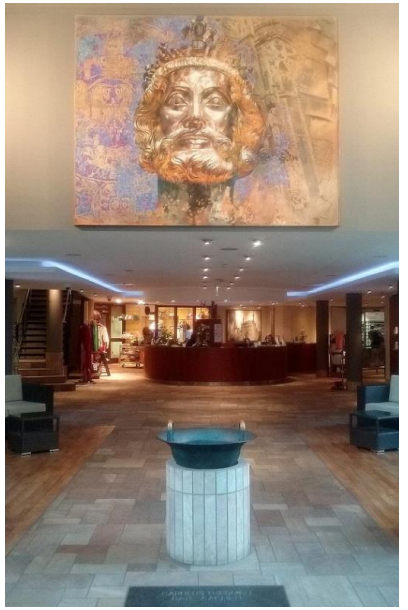


Aachen

- Cáchy, Aachen, Aken, Aix-la-Chapelle
- North Rhine-Westphalia country
- In the1st century – Romans found thermal spring
  - *Aquæ Granni* → Aachen
- The first note about Aachen in 765
- In 768 Charles the Great choosed Aachen as Royal City
- In Aachen, he was crowned as the Holy Roman Emperor in 800 and is buried in the city cathedral
- In 1656, the city burned down completely
- The city was build again as the Spa town
  - Russian Tsar Peter I the Great
  - Prussian King Frederick II.

Aachen

- In World War II, 65% of the city was bombed
- After 6 weeks of siege, 21th October 1944 the city was liberated as the first German city

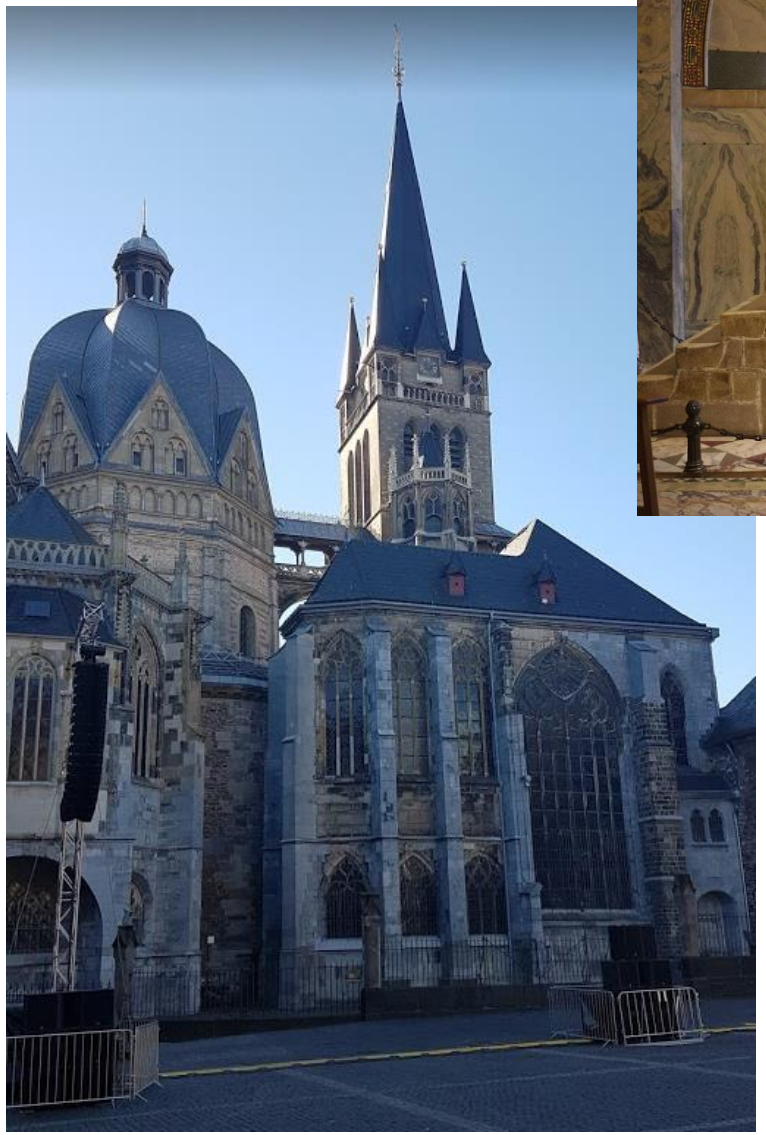


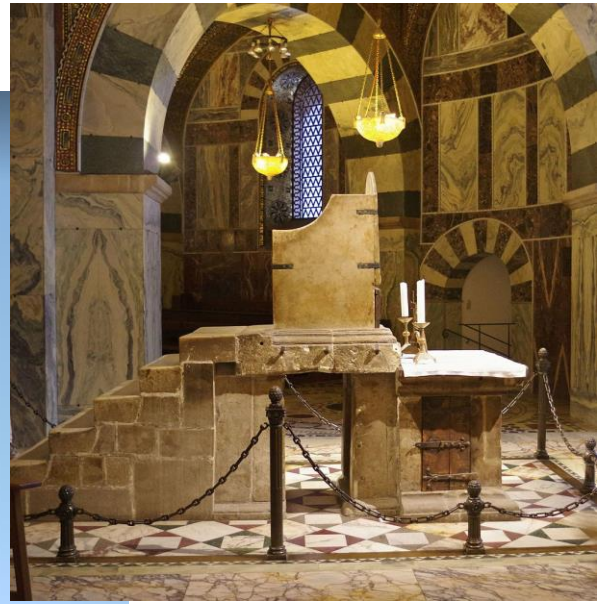
- The Aachen city awards **Charlemagne Prize** for work done in the service of European unification.
  - In 1991 Václav Havel
  - In 2000 Bill Clinton

- Aachener Printen
- Carolus Thermen Bad Aachen
- CHIO Aachen

Aachener Cathedral

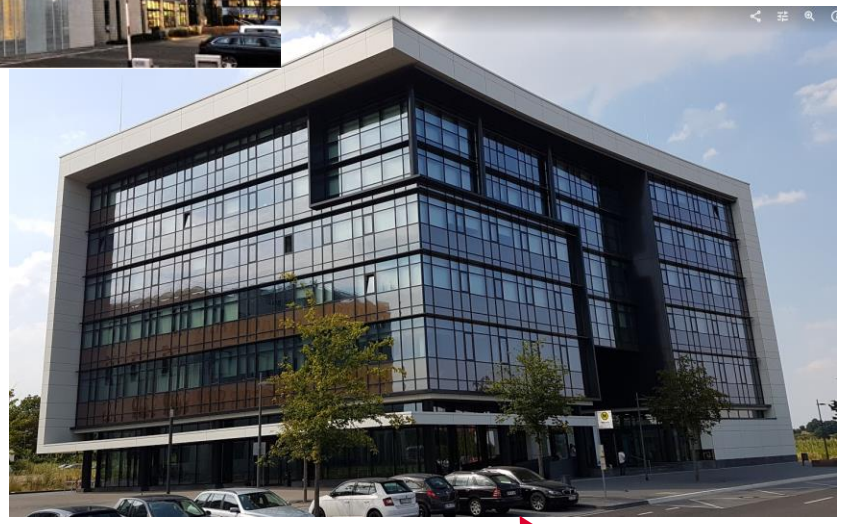
- The first part of the chapel was build between 786 and 800 by Charles the Great which is also buried there.
- Octagonal chapel with 32 m high cupola
- Place of coronation of German kings
- Charles IV. was crowned here by the Pope
- From 1978 in UNESCO
- The one of the most important church monuments in Germany
  - From 1349, Christian pilgrimage every 7 years
  - Next in 2021





RWTH Aachen University

- The largest technical university in Germany
- Founded in 1870
- More than 42 000 students
- Department of Digital Additive Production
  - Head of department **Prof. Schleifenbaum**
- ACAM – Aachen Center for Additive Manufacturing
  - Strong cooperation with industry
  - Most of the team work in Fraunhofer ILT



Campus Melaten

- New Campus Melaten Nord
- At the outskirts of the city
- Still under construction

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- Student housing Melaten

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- New Campus Melaten Nord
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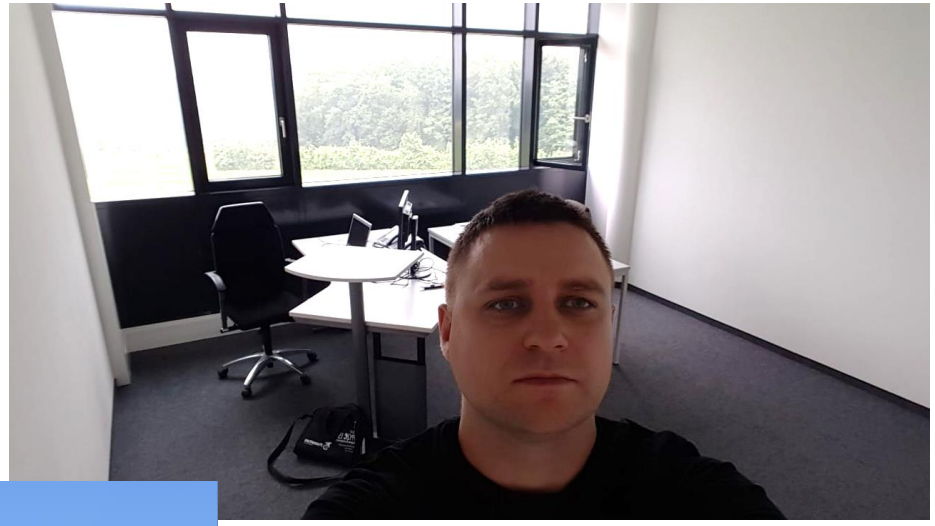
- Student housing Melaten
  - 50m to RWTH - DAP
  - 100m to Fraunhofer ILT
- DAP building
  - Connection between university and industry

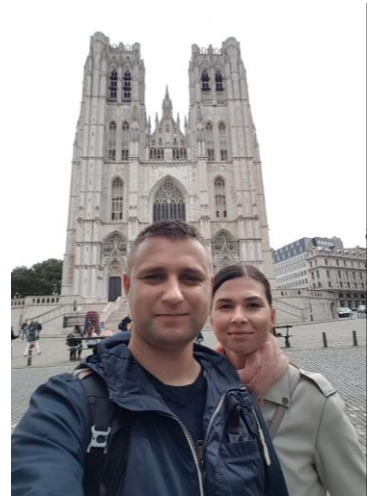


Trips to „nearby“ surroundings

- AMA Conferece – Bremen, Germany (2)
  - Additive Manufacturing in Aerospace
  - Serial production of the AM parts
  - Bremen – Junkers W 33 the first transatlantic flight from east ot west from Ireland to Greenly Island, Canada

Trips to „nearby“ surroundings

- Brussel, Belgium (3)
  - Cathedral of St. Michael and St. Gudula
  - Manneken Pis
  - Atomium



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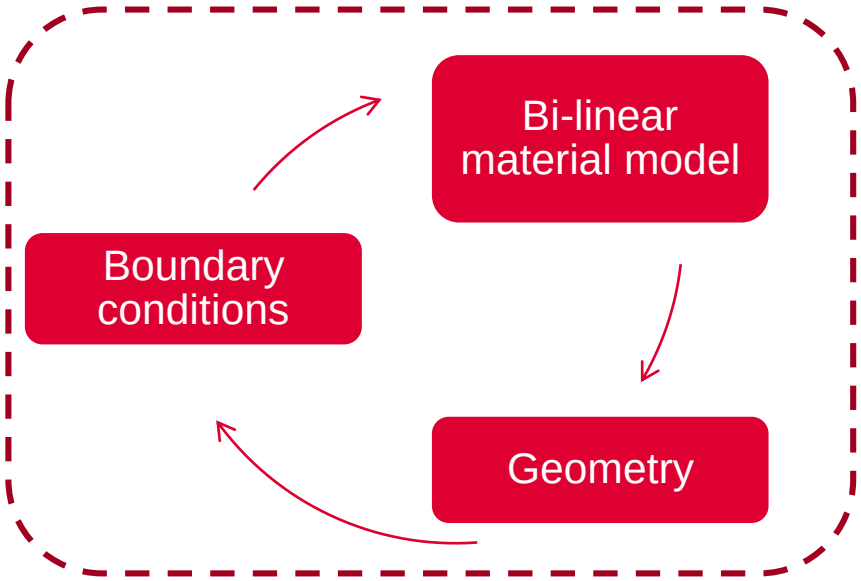
  - Cathedral of St. Michael and St. Gudula
  - Manneken Pis
  - Atomium
- Amsterdam, Netherlands (4)

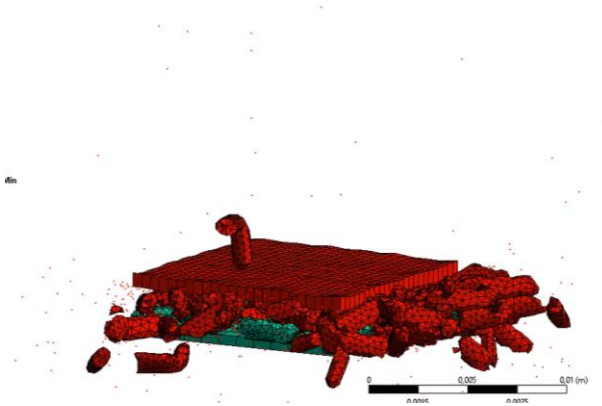
Trips to „nearby“ surroundings

- Brussel, Belgium (1)
  - Cathedral of St. Michael and St. Gudula
  - Manneken Pis
  - Atomium
- Amsterdam, Netherlands (2)
- Cyclo trips around Aachen

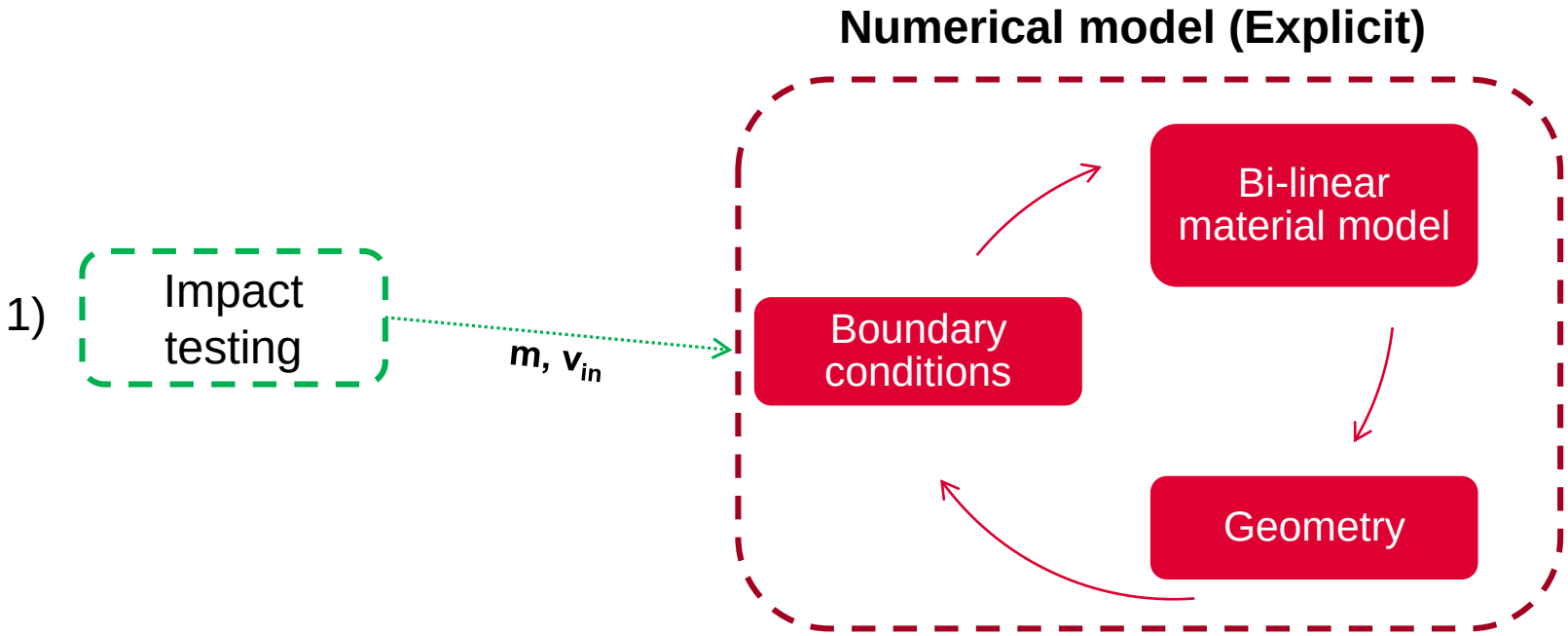
Research activities – Numerical model of impact

Numerical model (Explicit)





Research activities – Numerical model of impact



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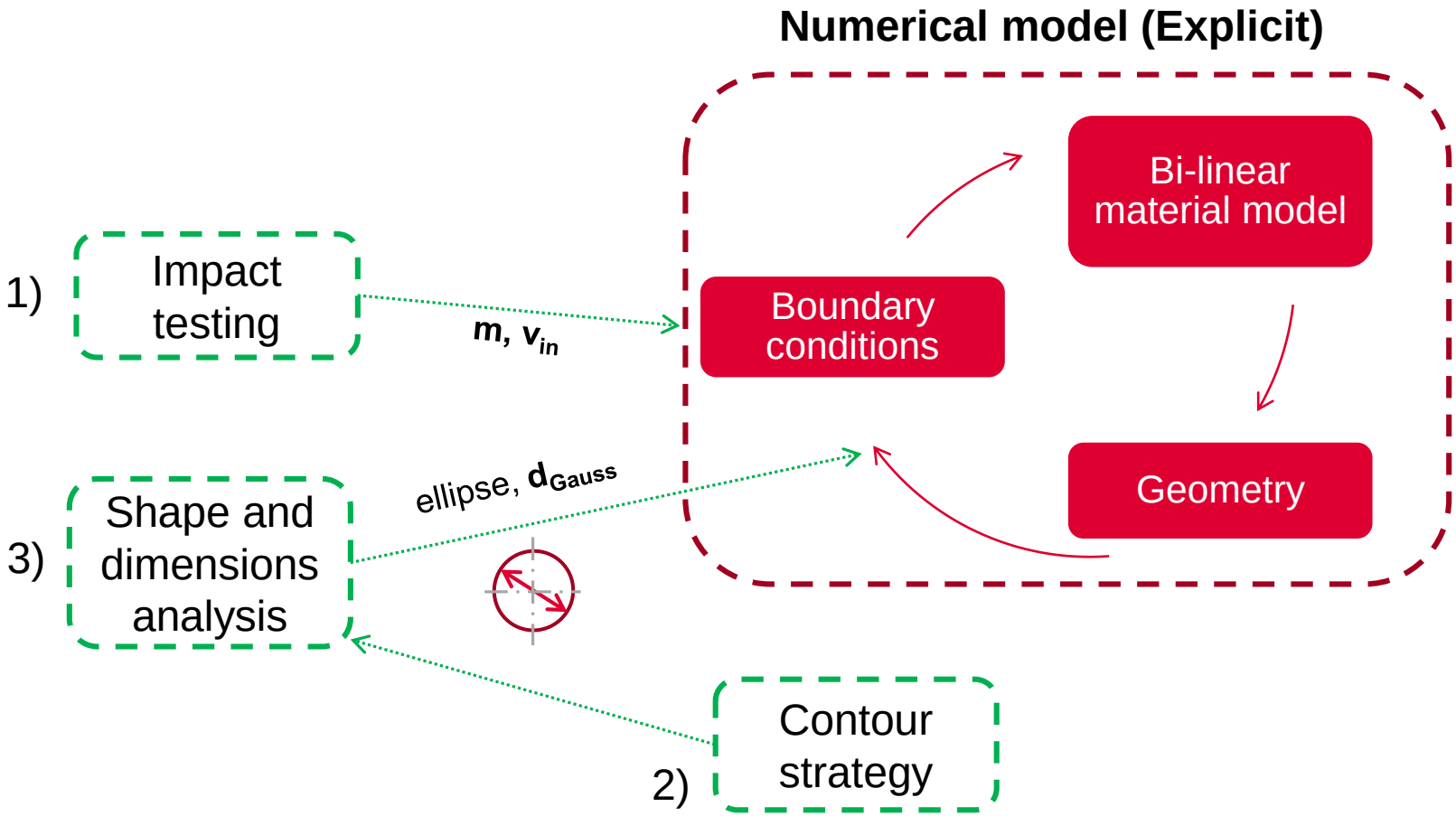

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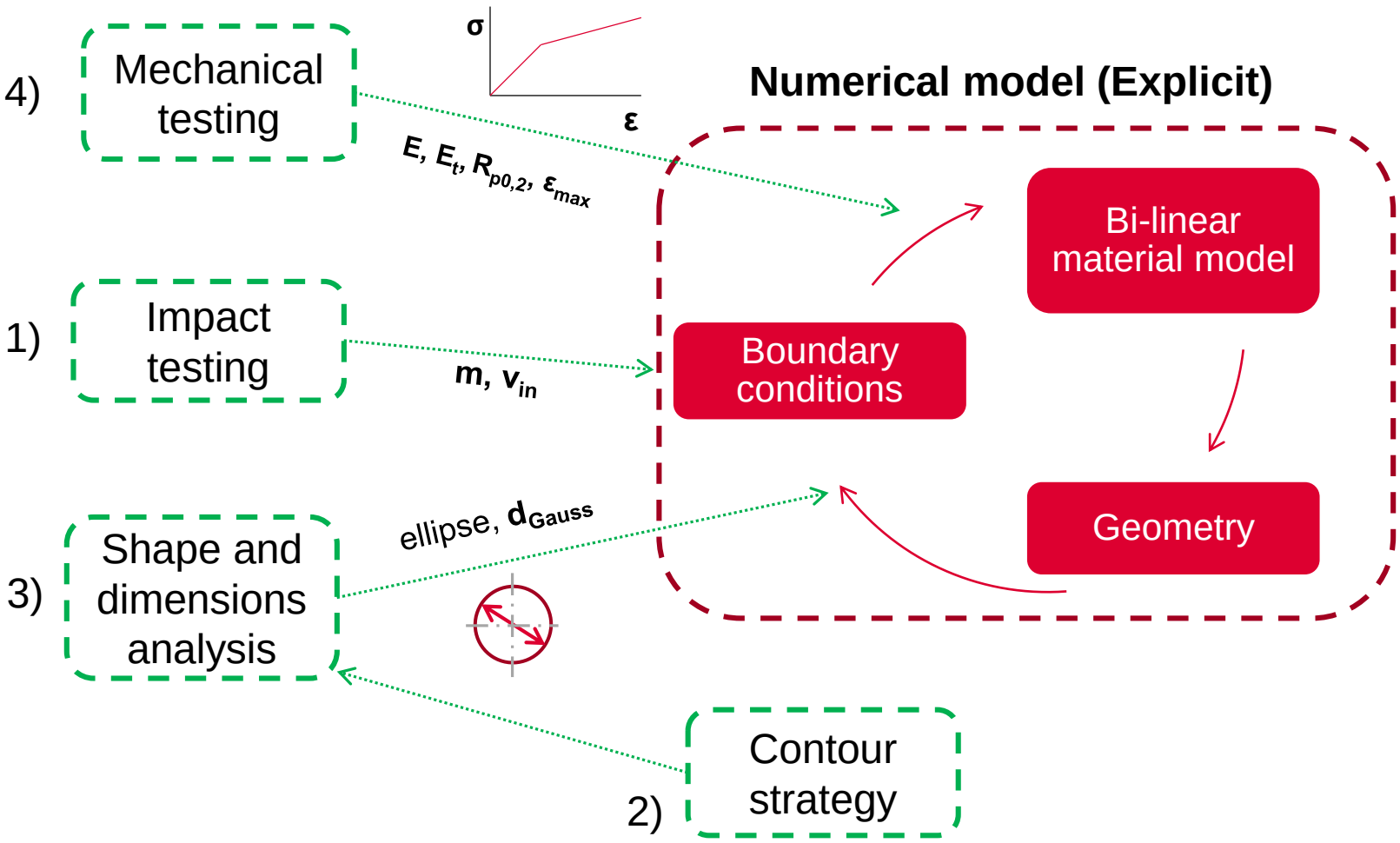

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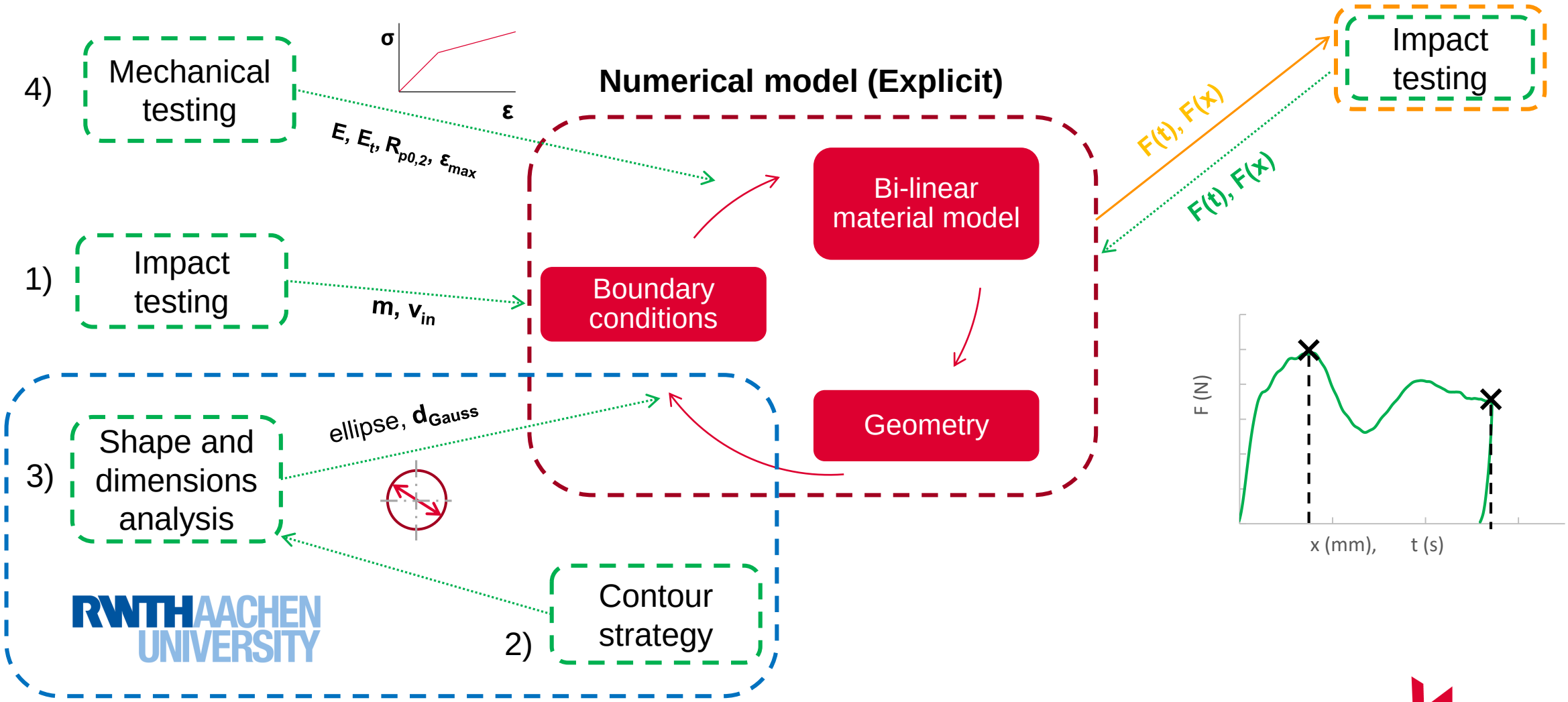
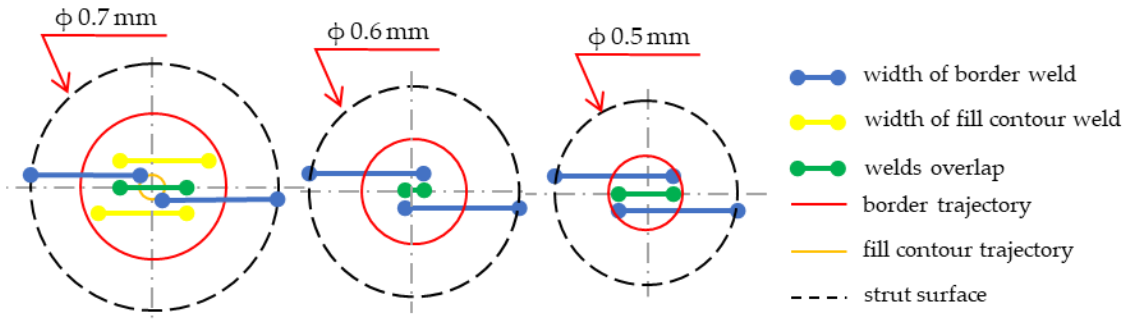
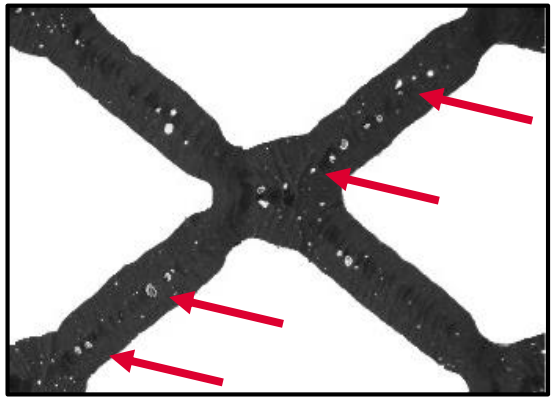


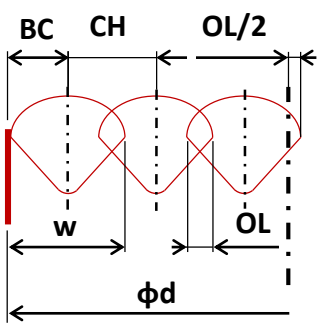
Research activities - Novel Contour Strategy

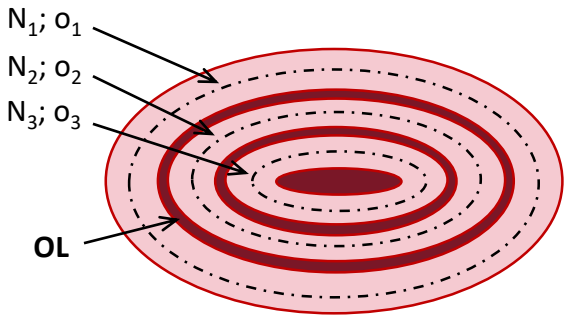
- No SLM standard production strategy for lattice structures
- Constant OL in whole strut cross-section
- Based on the single tracks geometry





d (mm)/ strategy	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm
Contour					
Standard					

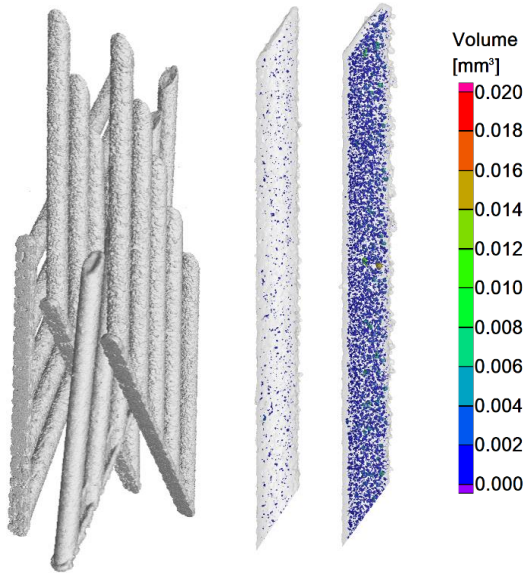


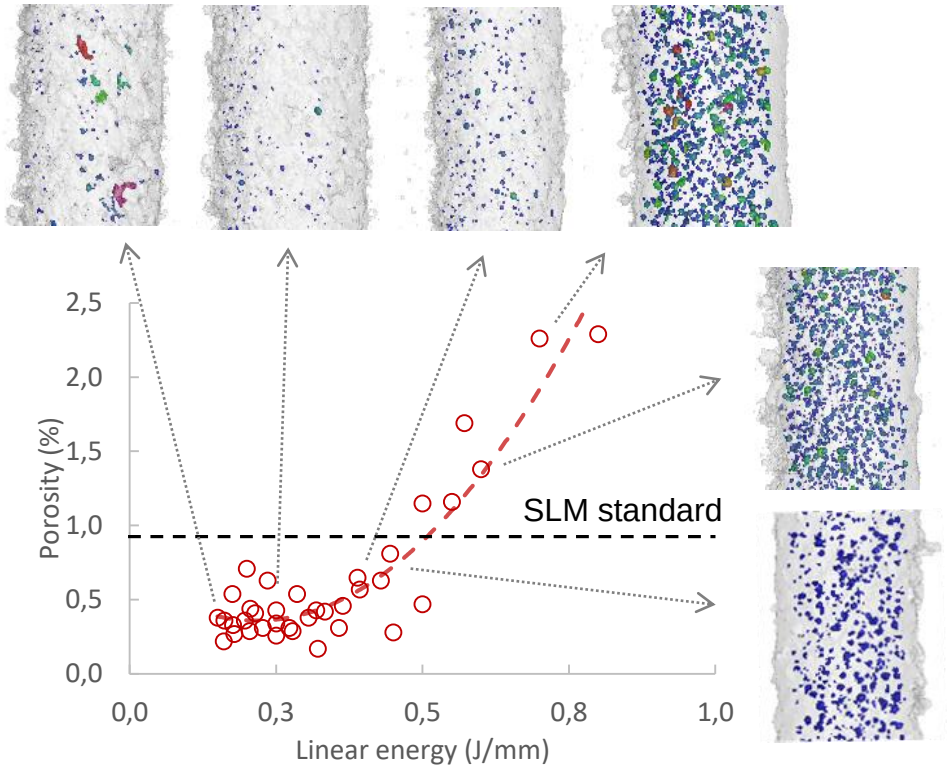


Research activities - Novel Contour Strategy

Lattice structure Internal porosity and Surface roughness

- Computed tomography analysis
- Strut shape of the samples
- Linear resolution **15 µm**
- Each strut was evaluated individually

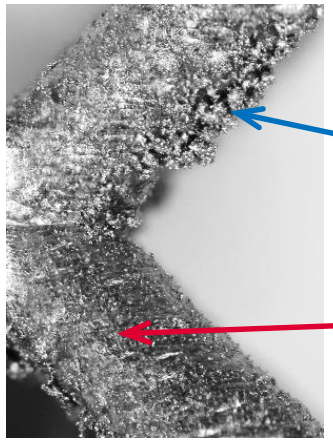


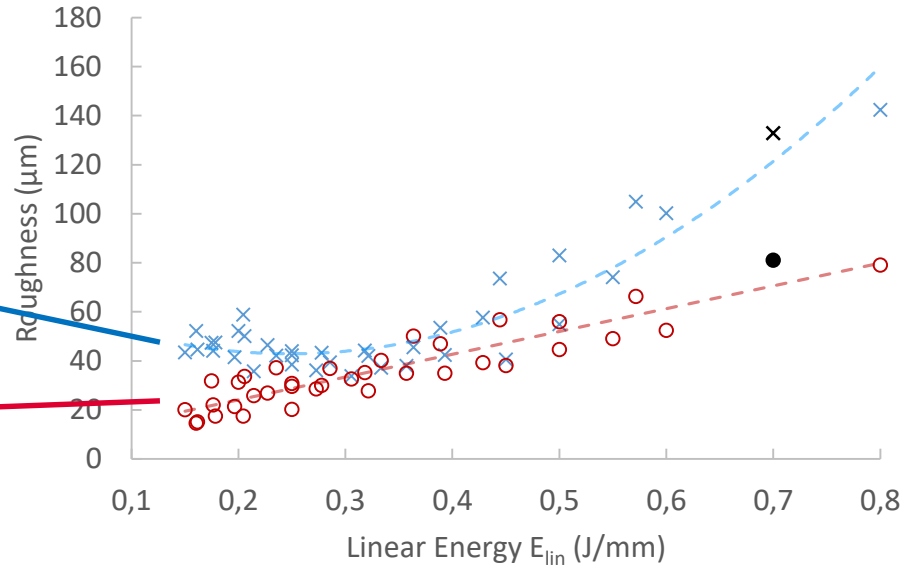


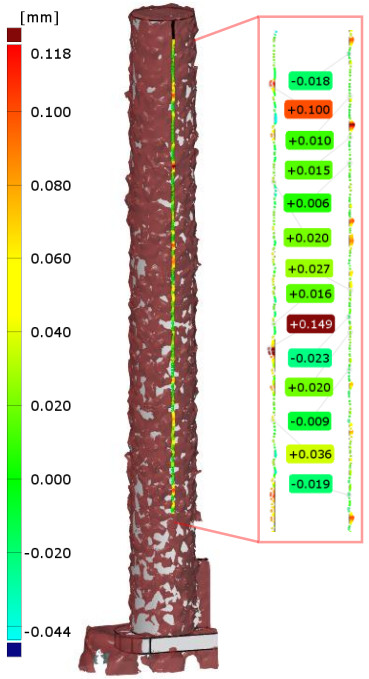
Research activities - Novel Contour Strategy

Lattice structure Internal porosity and Surface roughness

- Computed tomography analysis
- Strut shape of the samples
- Linear resolution **15 µm**
- Each strut was evaluated individually
- Surface reconstruction for surface analysis
- Roughness analysis in GOM Inspect



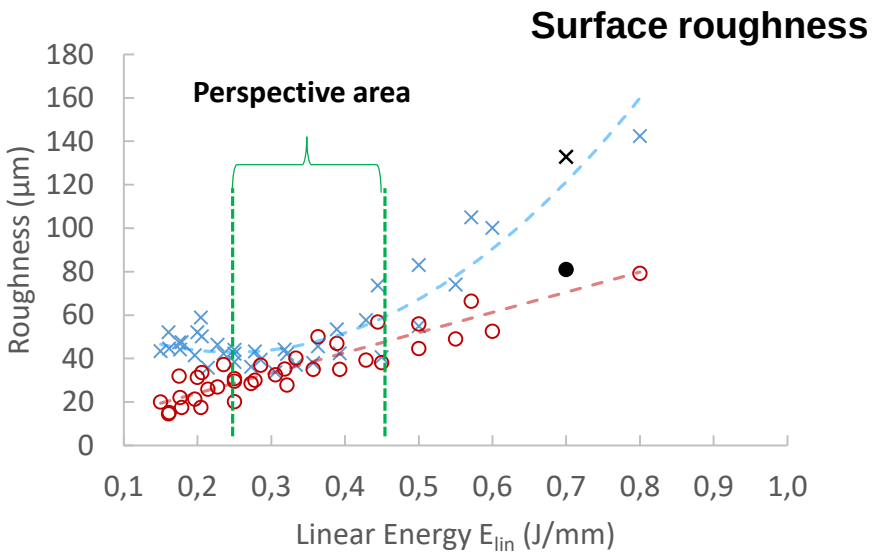


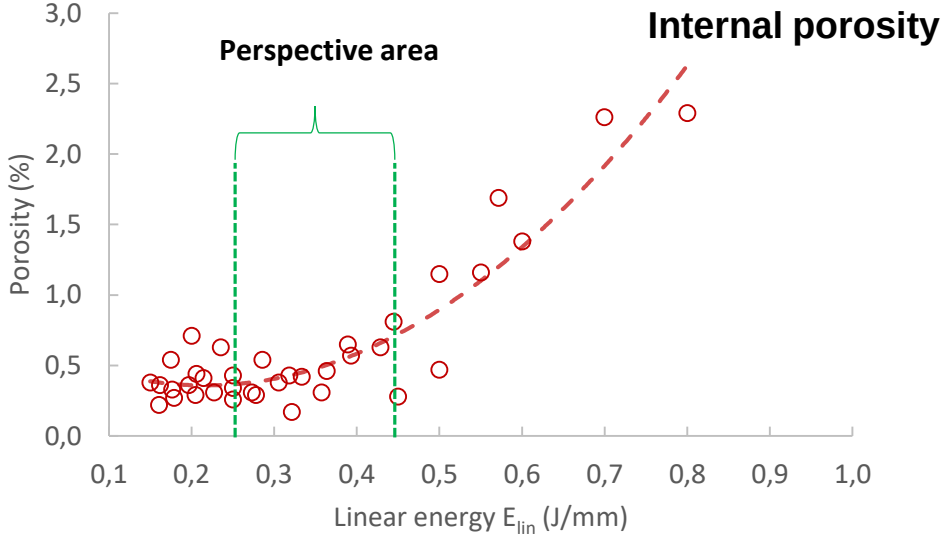


Research activities - Novel Contour Strategy

Lattice structure Internal porosity and Surface roughness

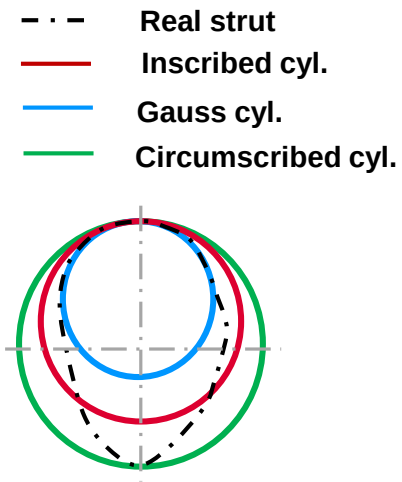
- SLM laser parameters with lower linear energy
- **Limit for linear energy – 0.25 J/mm**
- LP in range – 225W – 300W
- LS in range – 900 mm/s – 1400 mm/s

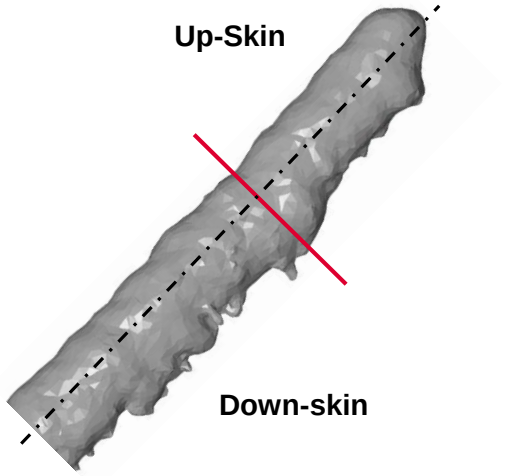


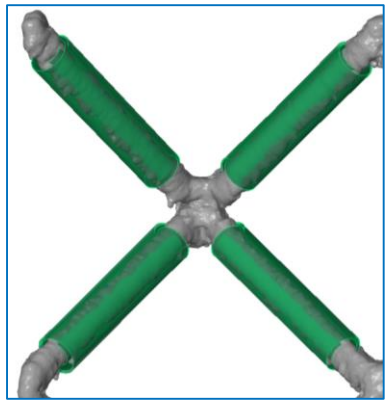


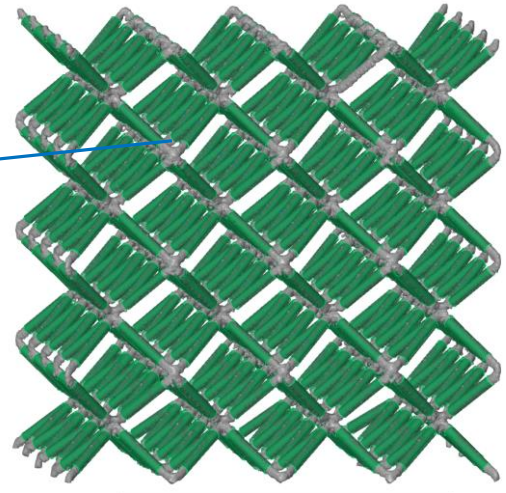
Research activities - Shape and dimensions analysis

- Irregular struts cross-section
- Computed tomography
- Script for evaluation of statistic values
- Measurement by fitting of cylinders







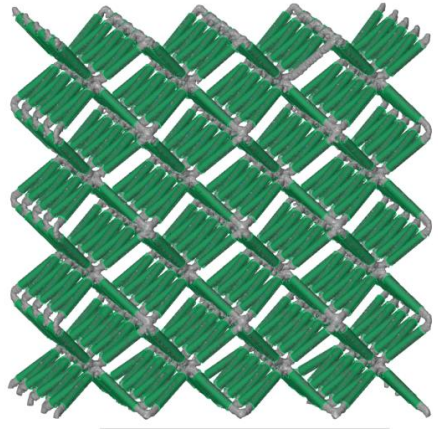


```
krok = 1
cislo=0

while (cislo<=1000):

    cislo += krok
    jmeno = "Point " + str(cislo)
    jmenoGauss = "Point " + str(cislo)+ "-Ga
    jmenoMaxIn = "Point " + str(cislo)+ "-Ma
    jmenoMinOut = "Point " + str(cislo)+ "-M

    gom.script.selection3d.select_inside_sp

    center=gom.app.project.inspection[jmeno],
                    radius=2.50e+00)

    ...
```

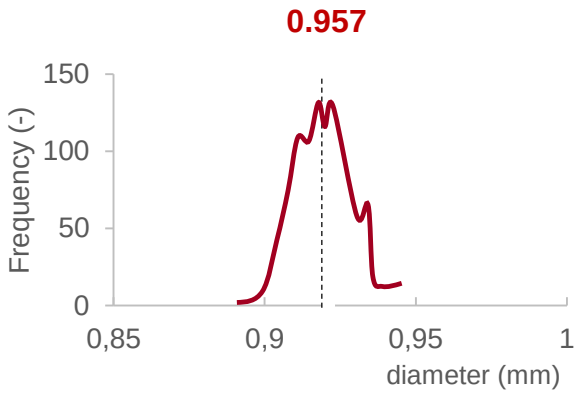
Results and Disscusion

Study of the SLM produced lattice structures

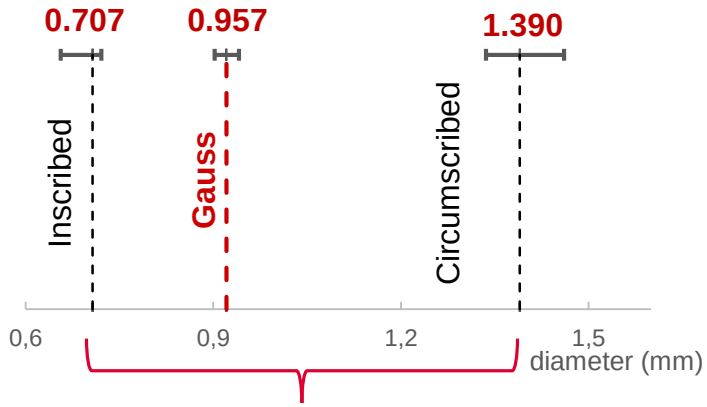
- Study of real lattice struts dimensions – d_{nom} = 0.8 mm
- Statistics population N = 1000



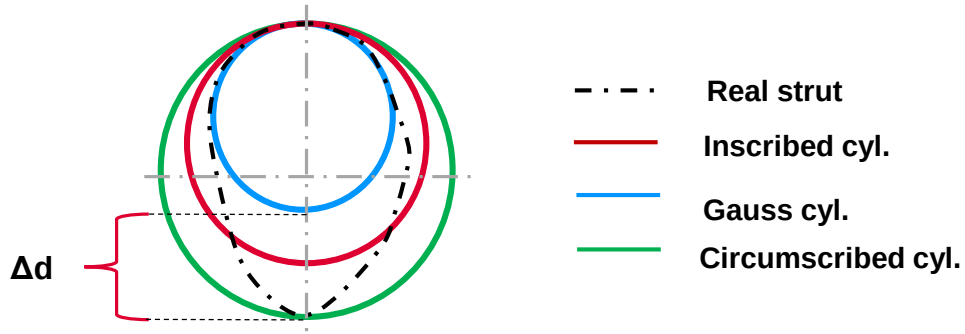
Gauss cylinder



Nominal d = 0.8 mm



Δd = 0,683 mm



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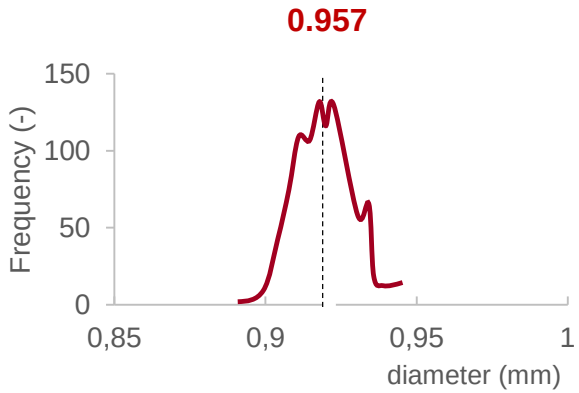

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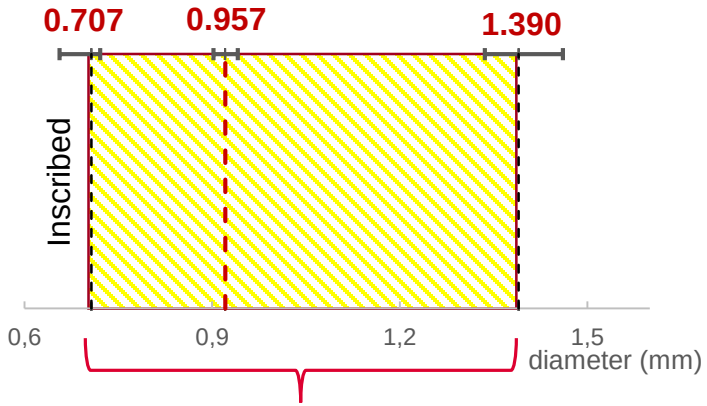
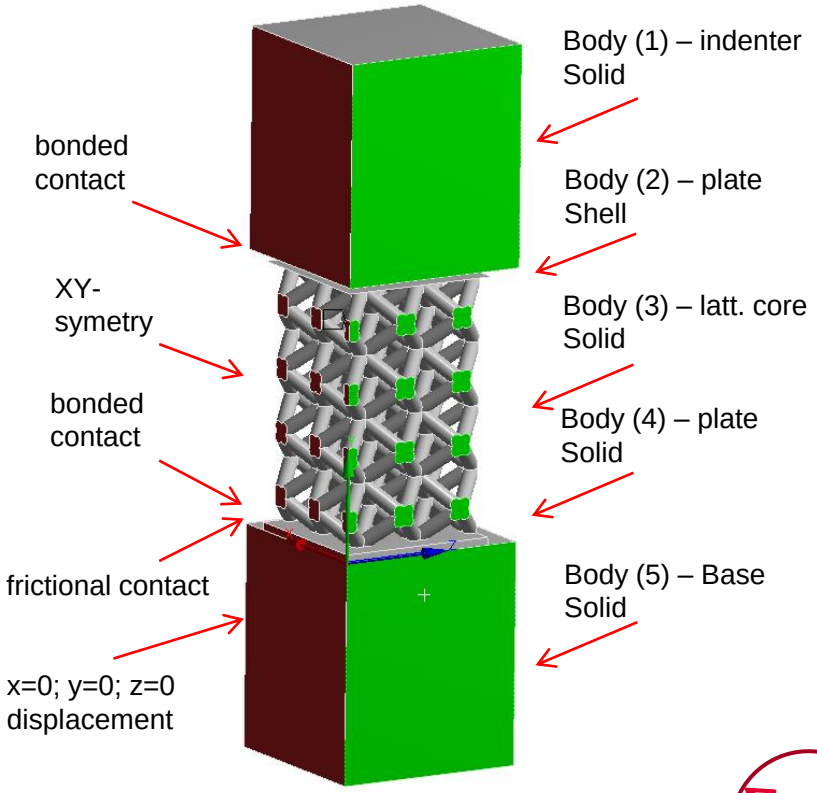
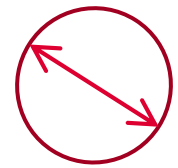


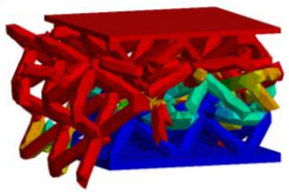
Δd = 0,683 mm





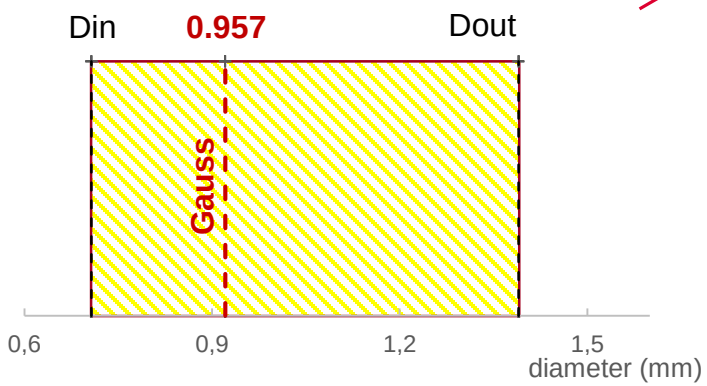
Imput for calibration of numerical model geometry

Results and Disscusion



Numerical model calibration – Strut Diameter

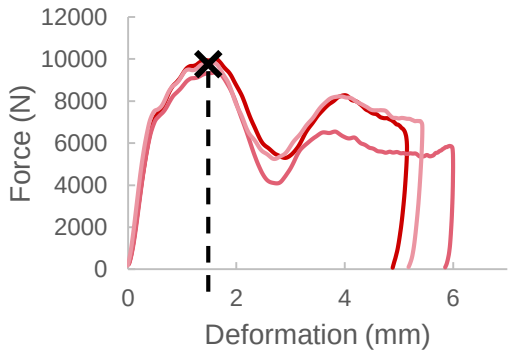
- **Which diameter the best describe the mechanical properties of lattice structures?**
- **Parametric calibration for d = 0.8 mm**
- Imput parameters
  - Range of strut diameters from inscribed to circumscribed – **Δd**

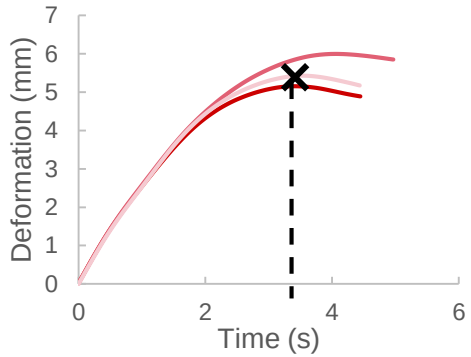


d = 0.95 mm

Experimental results ⇄ Numerical analysis

F_{max}; x_{max}

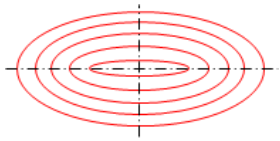


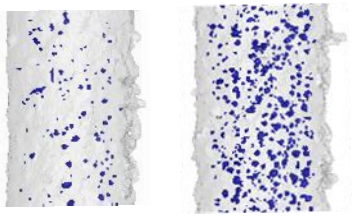


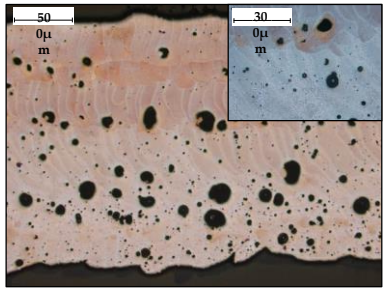
Publications - Published

VRÁNA, R.; KOUTNÝ, D., PALOUŠEK, D., PANTĚLEJEV, L., JAROŠ, J., ZIKMUND, T. and KAISER, J. Selective Laser Melting Laser Strategy for Fabrication of Thin Struts Usable in Lattice Structures. *Materials* **2018**, 11 (9), DOI: 10.3390/ma11091763. ISSN 1996-1944.

- *Materials MDPI* - IF 2.467, Q2
- Authors contribution 65%







VRÁNA, R.; ČERVINEK, O., MAŇAS, P., KOUTNÝ, D. and PALOUŠEK, D. Dynamic Loading of Lattice Structure Made by Selective Laser Melting - Numerical Model with Substitution of Geometrical Imperfections. *Materials* **2018**, 11(11), DOI: 10.3390/ma11112129. ISSN 1996-1944.

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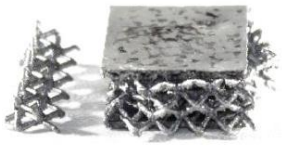
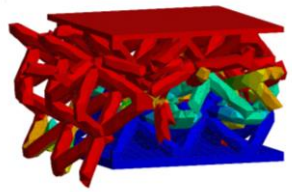
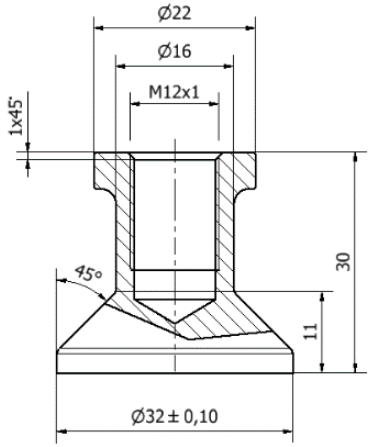




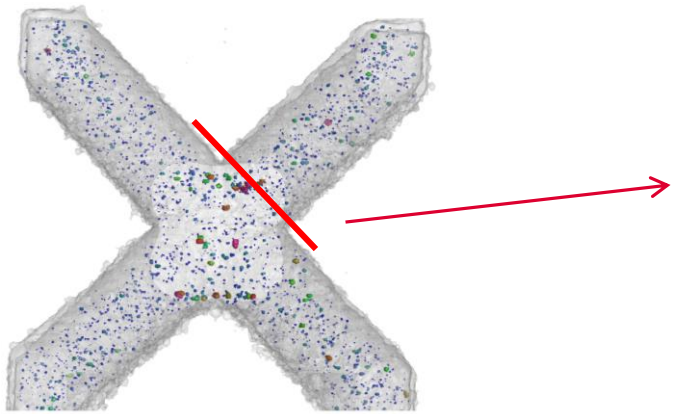


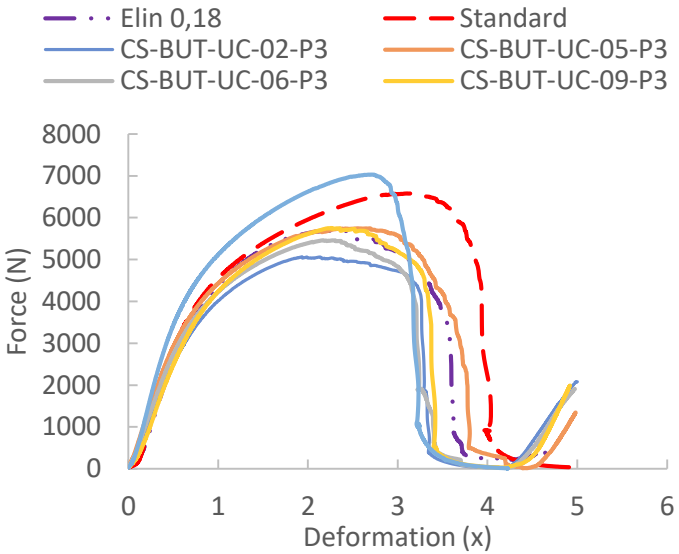
Publications – In Progress

VRÁNA, R.; EWALD, S., JAROS, J., KOUTNÝ, D., VOSHAGE, M., SCHLEIFENBAUM, J.H., ZIKMUND, T. , PANTĚLEJEV, L. and PALOUŠEK, D. Development of a novel contour exposing strategy for lattice structure manufacturing by Selective Laser Melting. *Materials* **2019**, XX (X), DOI: XXX. ISSN 1996-1944.

- Finished 60% of the results

LP - 250 W
LS - 700 mm.s-1
E_{lin} - 0.36 J.mm-1
Porosity - 0.4 %



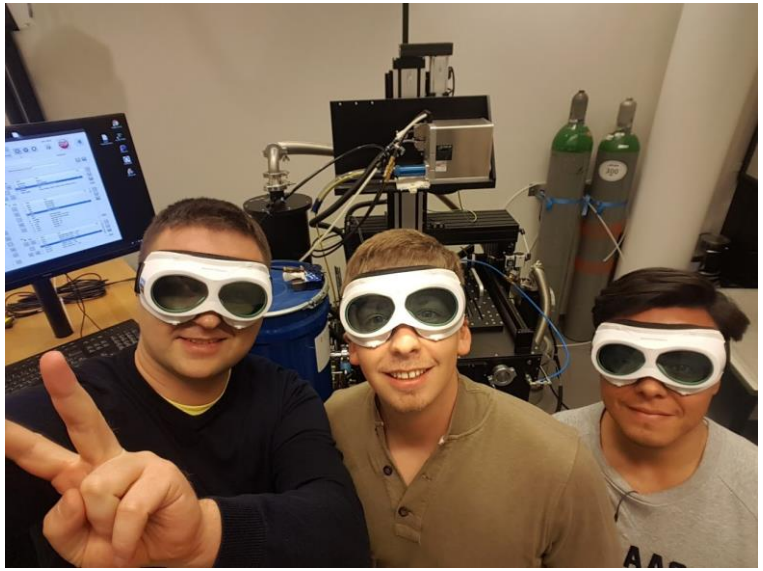


Joint events

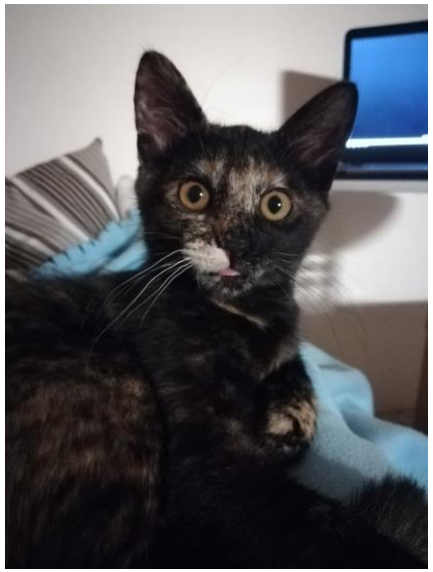
- Goodbye party
  - Aachener Weihnachts Markt
- Czech-German project discussion at BUT

Conclusion

- New contacts in AM
- Possibilities for further cooperation
  - Submitted proposal of German – Czech project
- Joint publication in 2019
- Comparison of the BUT and RWTH results



- Time to finish Ph.D. study
- New friends
- My girlfriend's cat „Kuki“



Thank you for your attention

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Radek.Vrana@vut.cz

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