POTENTIALS AND CHALLANGES FOR THE SIMULATION OF FIBER-REINFORCED AM COMPONENTS

Dr. Robert Hein and Felix Winkelmann, EmpowerAx Days, 05.10.-06.10.2022

DLR

Agenda

- Motivation
- Use Case 1: Stiffness evaluation of an ankle foot orthosis
- Use Case 2: FFF process simulation
- Summary

Use Case 1: Stiffness behavior of an ankle foot orthosis

- Motivation (In Cooperation with FH Münster)
  - Application: Dynamic support or posture correction
  - Current challenges:
    - Time- and work intensive manufacturing process
    - Success based on experience of orthopedic technician
  - Vision: Digitalization of orthosis manufacturing
    - 3D-Scan
    - Virtuell construction, sizing and testing
    - On-site 3d print of CFRP orthesis
  - Benefits:
    - Much faster availability
    - Customized
    - Lightweight and comfortable
    - Automation and on site production reduce time and cost
    - Technician has more time for patient

[Source: https://www.casimo-ot.de]

- Question: Is it possible to simulate printed fiber-reinforced 3D components with sufficient accuracy?

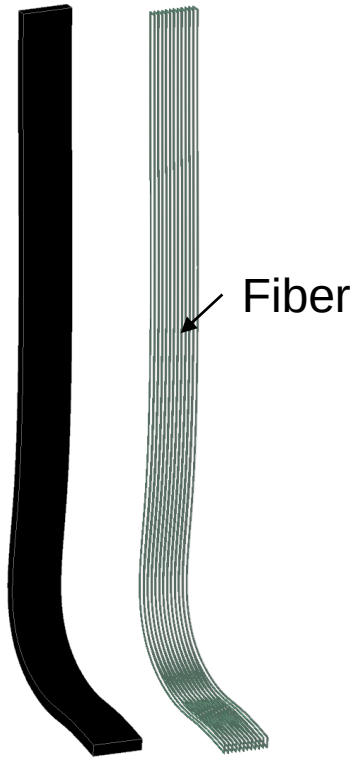
Simulation workflow

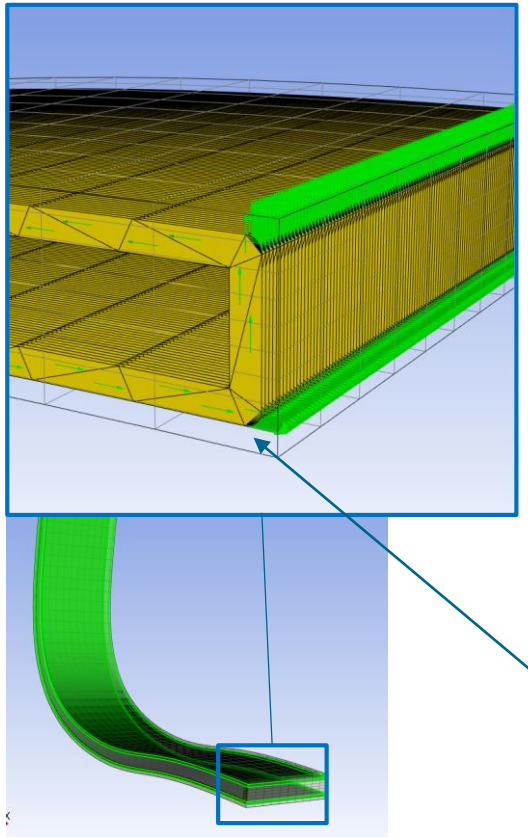
Fiber planning (9T LABS)

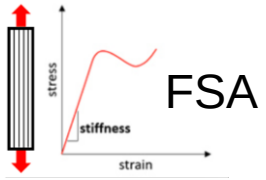
→ Mapping of fiber orientations (hdf5)

→ Material Calibration (Inverse Engineering)

→ Stiffness behavior (3-Point-Bending)







FSA

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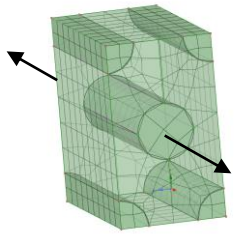

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Name	Value	Unit
Engineering Constants		
E1	57446	MPa
E2	2649,2	MPa
E3	2649,1	MPa
G12	840,86	MPa
G23	811,05	MPa
G31	840,86	MPa
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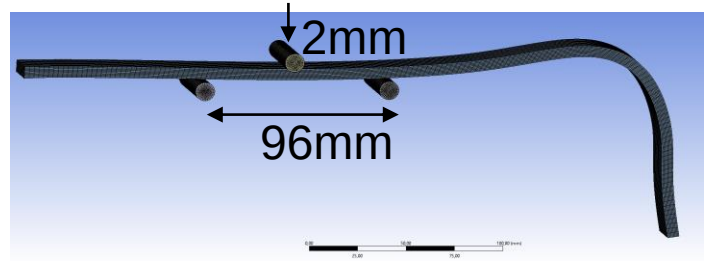
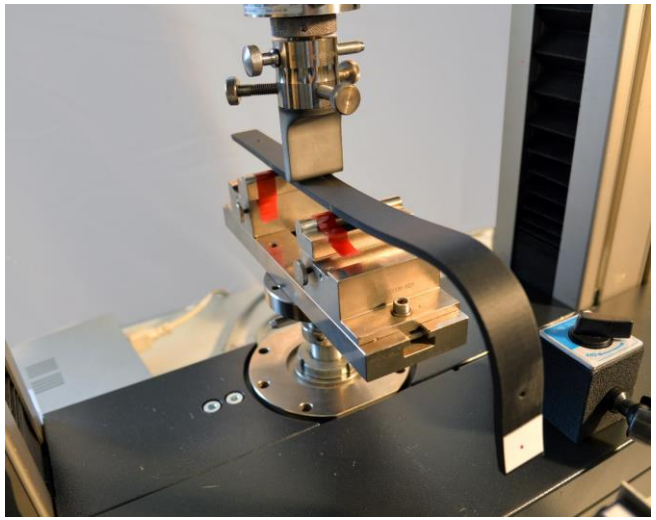
nu13	0,35201	
nu23	0,64543	

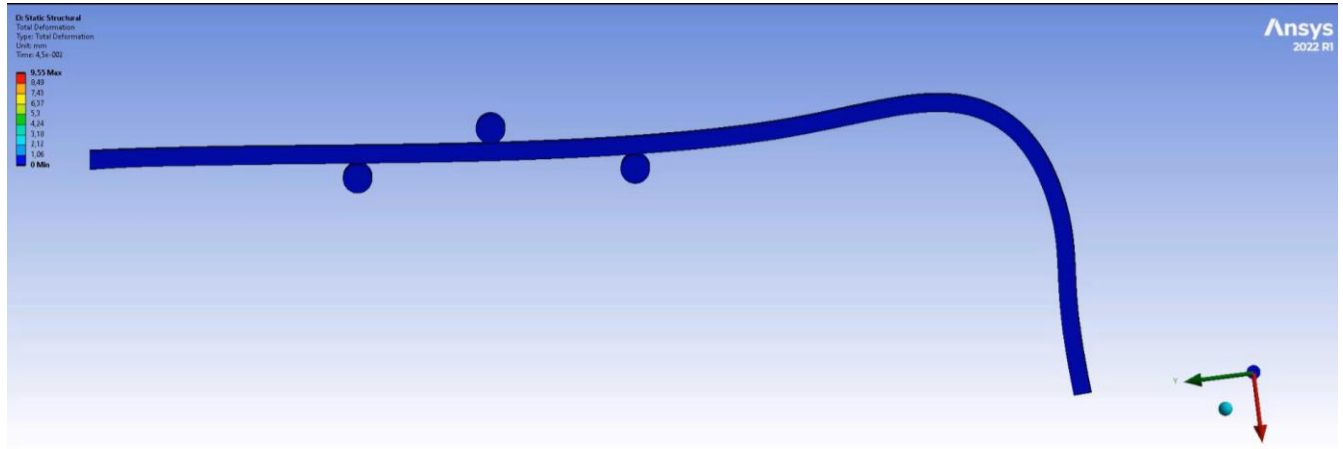


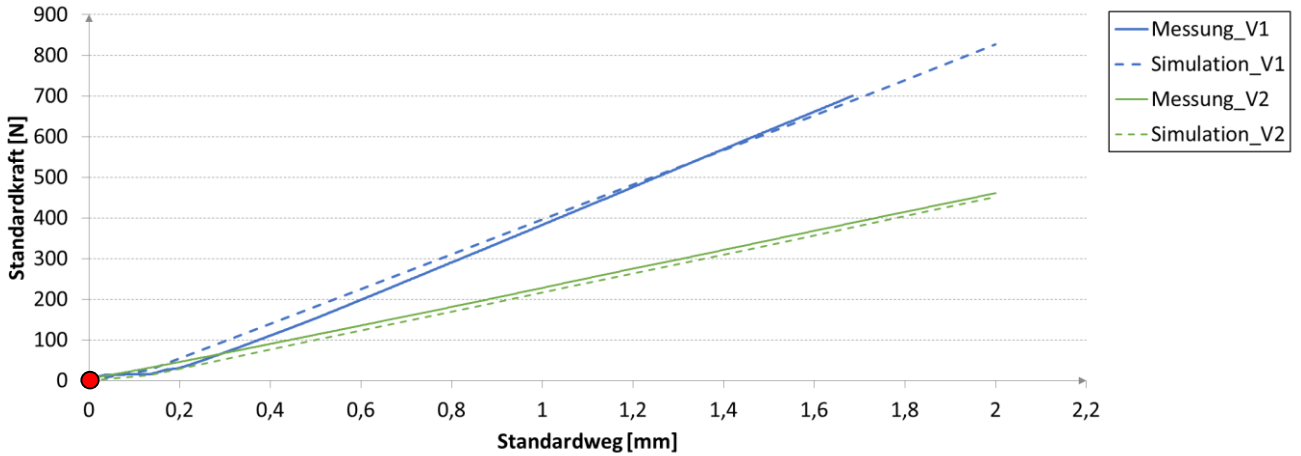


Stiffness evaluation on coupon level

- Good correlation between simulated and measured Force-Displacement-Curve

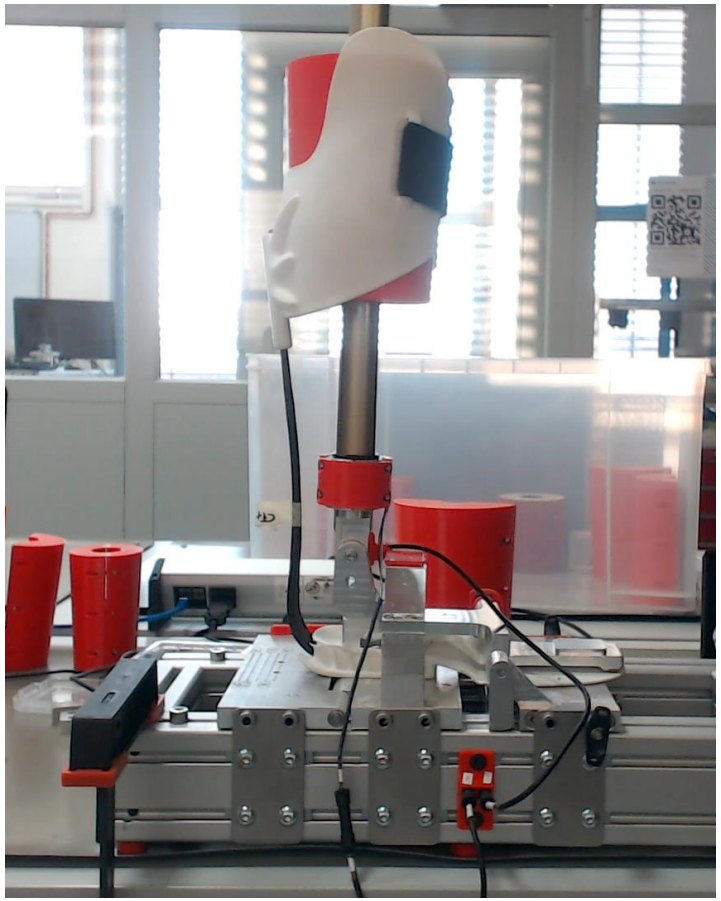
- Stiffness of the component is sufficiently approximated

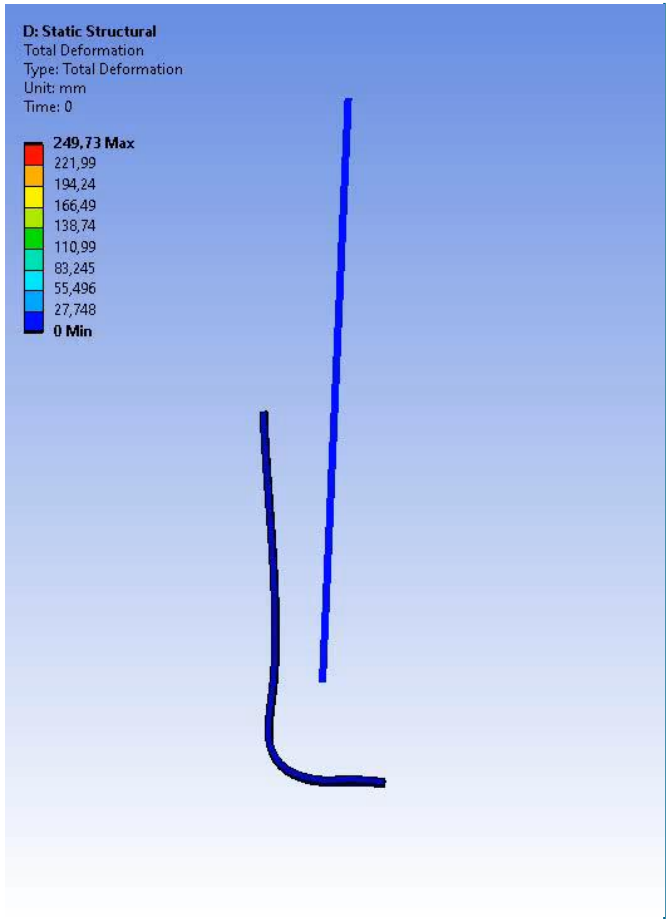




Stiffness evaluation of the overall system

Simplified test bench

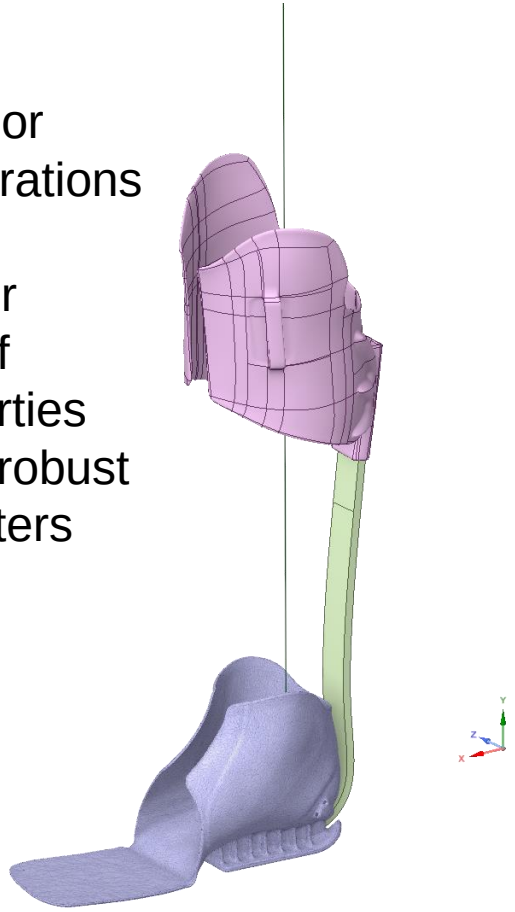




[FH Münster: FABIAN test bench]

Objective: Development of a detailed virtual test bench

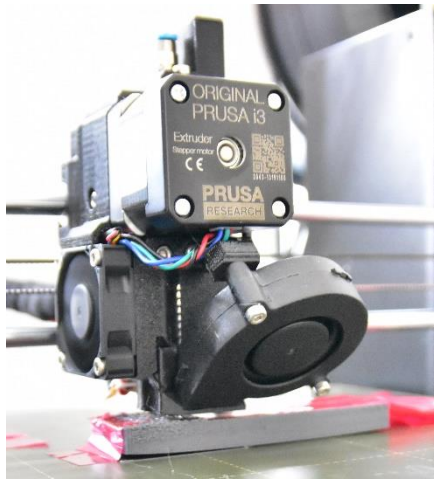
- Sizing
- Dynamic behavior
- Material configurations
- Optimization
- Fatigue behavior
- Consideration of individual properties
- Identification of robust printing parameters

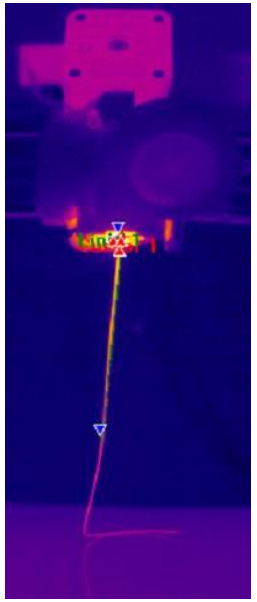


Use Case 2: FFF process simulation

Key challenges and important topics:

- Geometric conformity
- Residual stress management
- Build failure
- Inhomogeneous material properties
- process-dependent material anisotropy
- In-deep process understanding



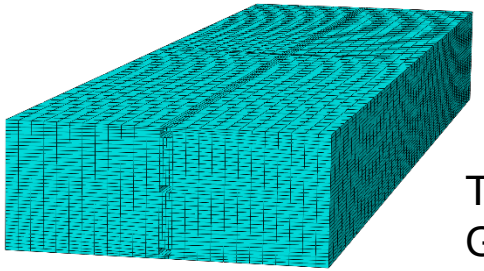


Simulation of the additive extrusion process is a challenging task:

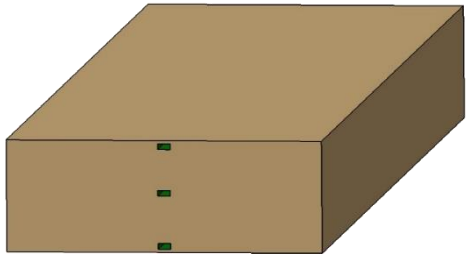
- Phenomena occur over multiple length scale
- Phenomena occur over multiple time scale
- Multiphase problem
- Missing validation

FFF process simulation – Basic concept

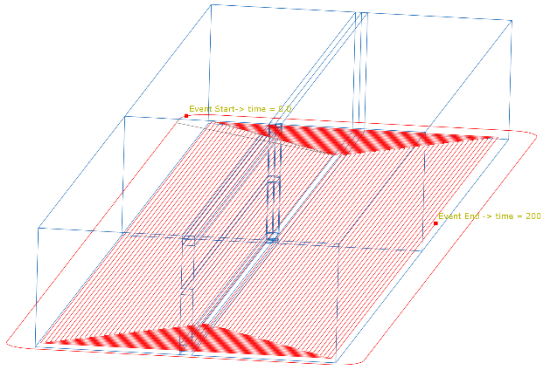
CAD

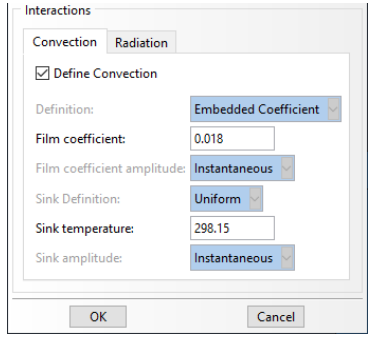


Meshing



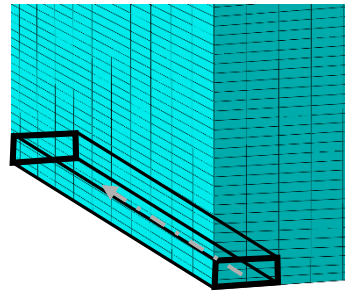
ToolPath Conversation
G-Code->Event-Series



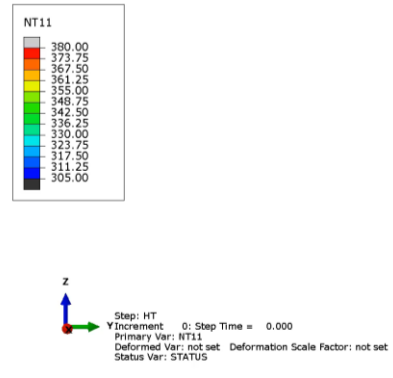


Thermal boundary conditions

Progressive Element Aktivation

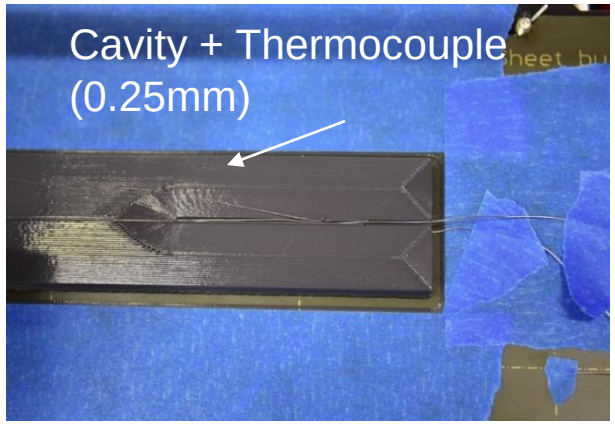


Analysis

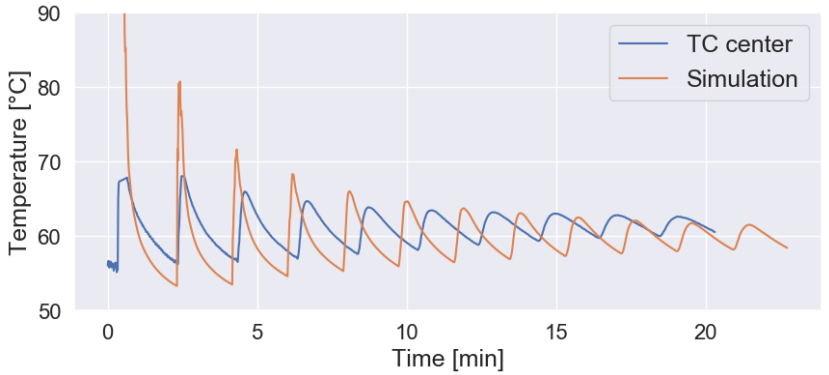


Prediction accuracy of a FFF process simulation

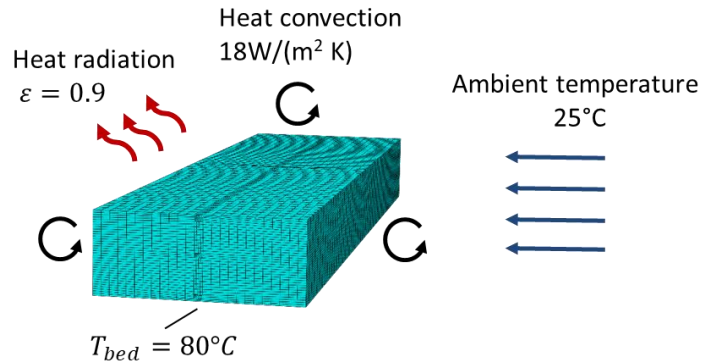
- Validation of the temperature history
  - Bonding ->Strengths
  - Crystallization -> Mechanical properties
  - Residual stresses and warpage -> Dimensional conformity



Integration of the thermocouple



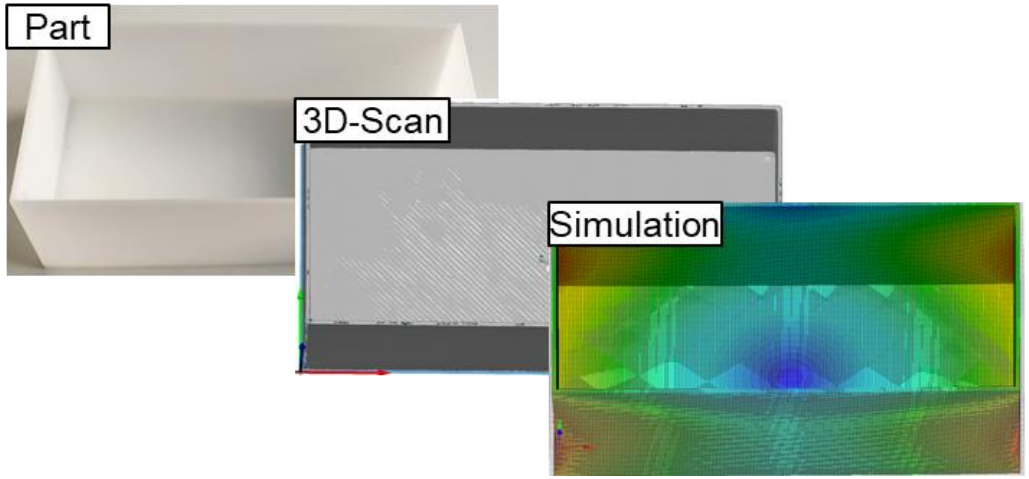
Comparison of simulation and measurement

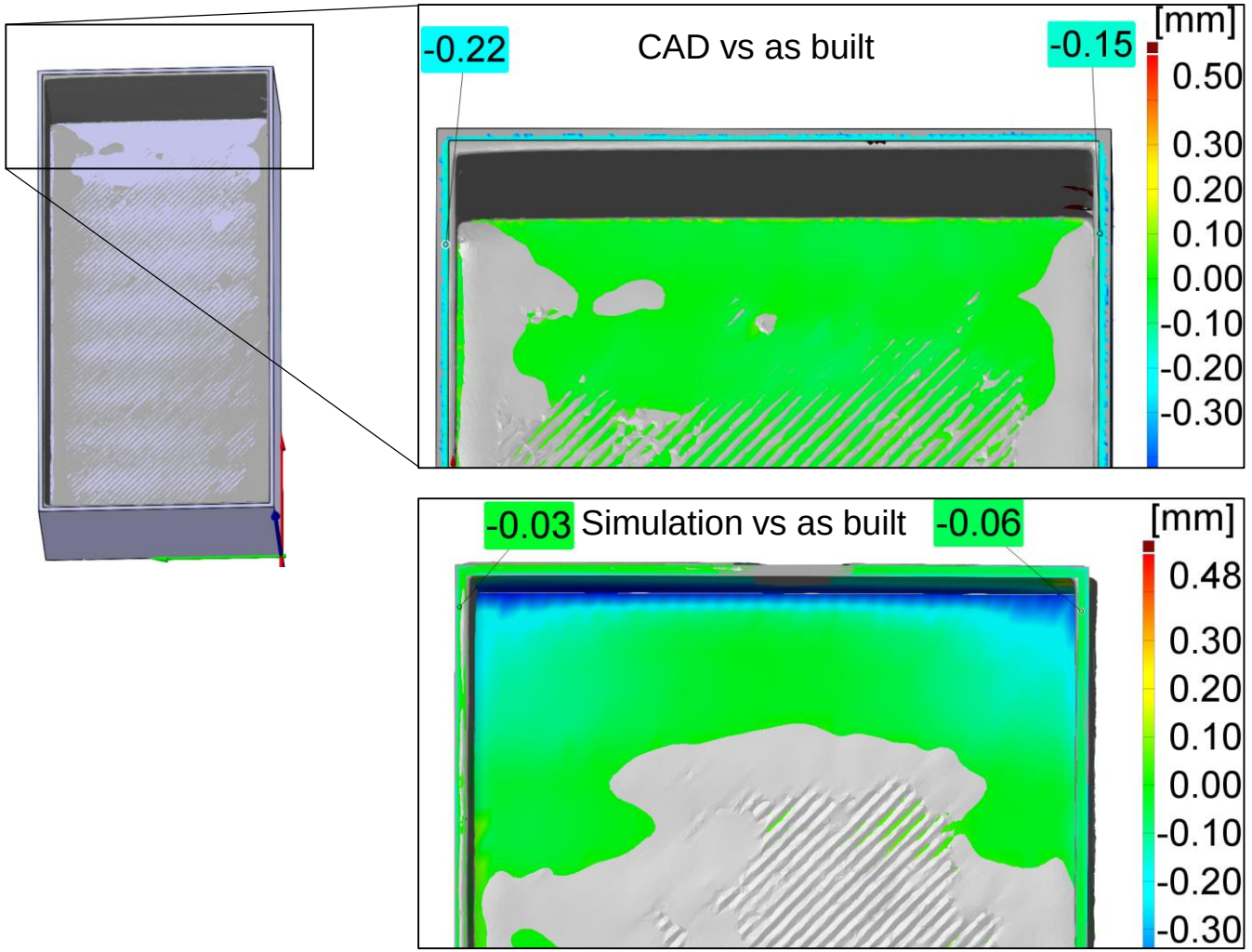


Process simulation

Prediction accuracy of a FFF process simulation

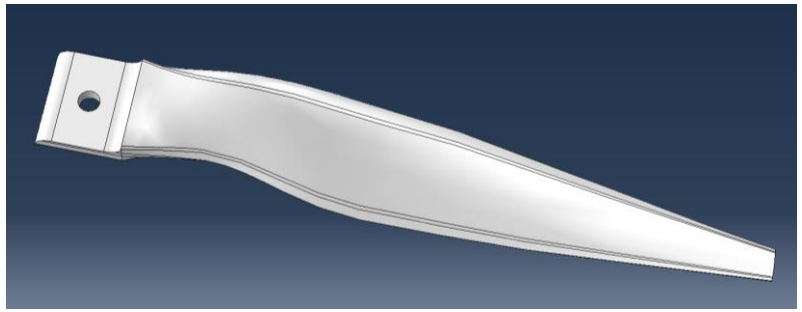
- Validation of the warpage behavior



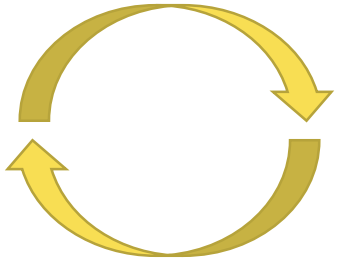


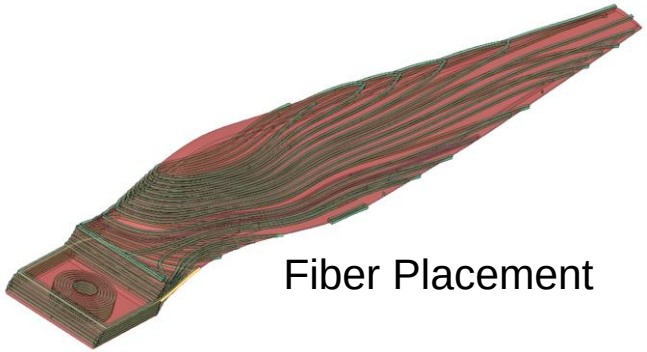
Scalability of the simulation: Drone rotor blade

Starting Point: CAD

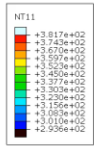


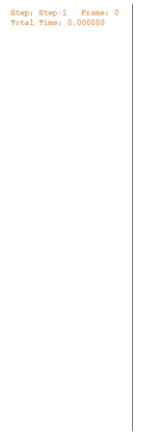
https://www.3dnatives.com/de/3d-druck-drohnen-140720161/#!



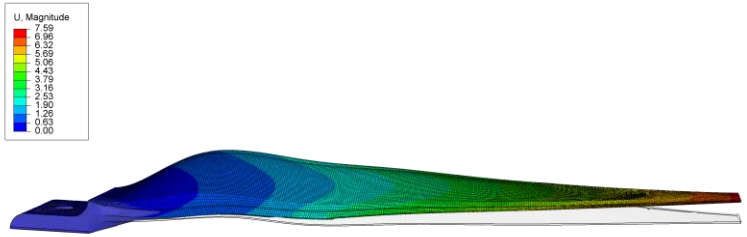


Fiber Placement

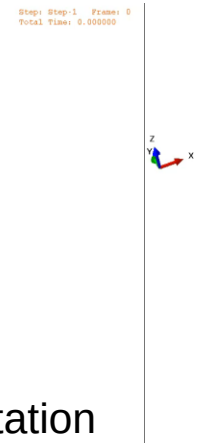




Temperature analysis



Warpage analysis



Material orientation

Summary

- Use case 1, ankle foot orthosis, has shown the structural behavior can be captured by simulation tools
- Use case 2, Process simulation, has shown that the warpage behavior qualitatively can be predicted but improvements are needed for quantitative evaluation
- Simulation can give answers to different questions in advance

- New use cases wanted!
- 3 golden questions: Printable? Load bearing? Economically worth?
- Network of technology and material provider available