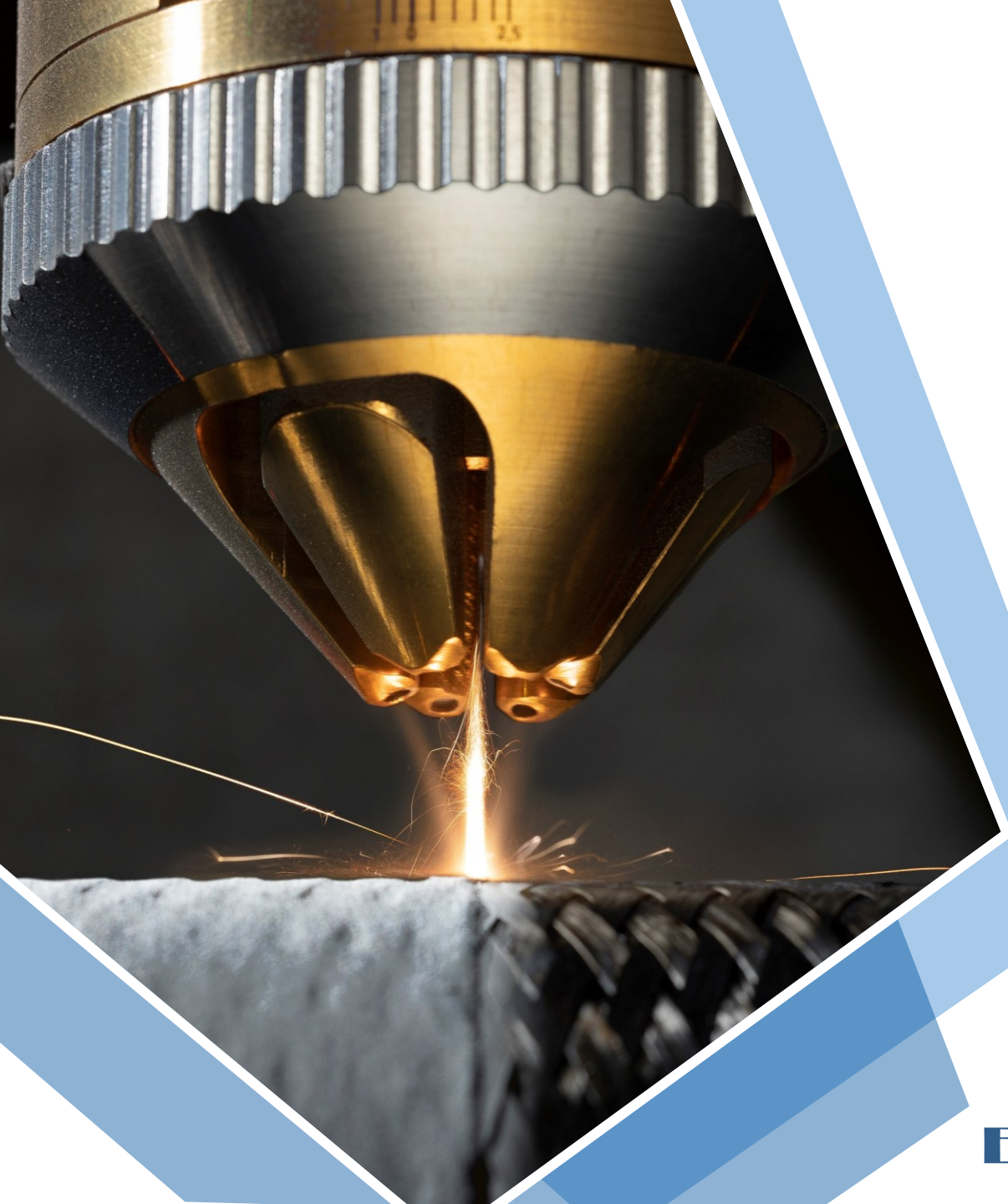


Adaptive Process Control Strategies for Variable Wall Thickness in Laser Metal Deposition

H. Kruse, A. Kulkarni, J.H. Schleifenbaum

03.06.2026

RWTH Aachen University
Digital Additive Production DAP
Campus-Boulevard 73, 52074 Aachen

EMPOrIA 2026

Adaptive Process Control Strategies for Variable Wall Thickness in Laser Metal Deposition

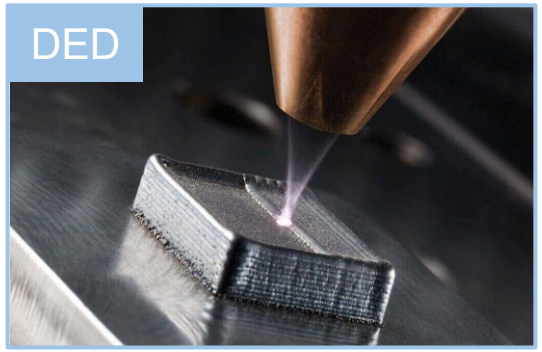
1	**Background in CRC1120**
2	**Overview of Framework**
3	**Results and discussion**
4	**Summary and outlook**

© RWTH Aachen Chair DAP

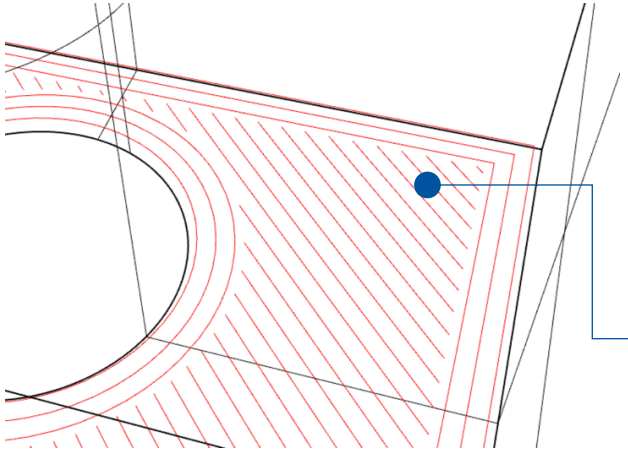
Background

Limitations of DED

- powder-based directed energy deposition (DED) is used for **fabrication, repair, and functional enhancement** of metallic components
- reliable manufacturing of **geometrically accurate structures remains a major challenge**

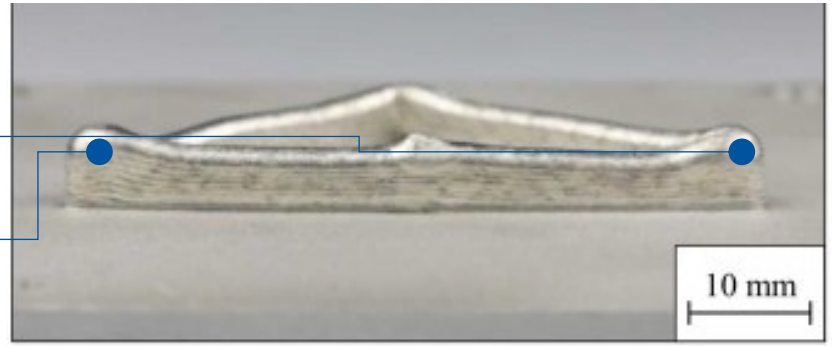


Key Challenge
Lack of adaptive, geometry-aware path planning leads to poor part precision and inefficient material use in DED processes.



constant spacing + unflexible process parameters

Inefficient and imprecise filling



Excess material

Overlaps and superelevations

© RWTH Aachen Chair DAP

Background

State of the art: Volume deposition

- a) Conventional configuration

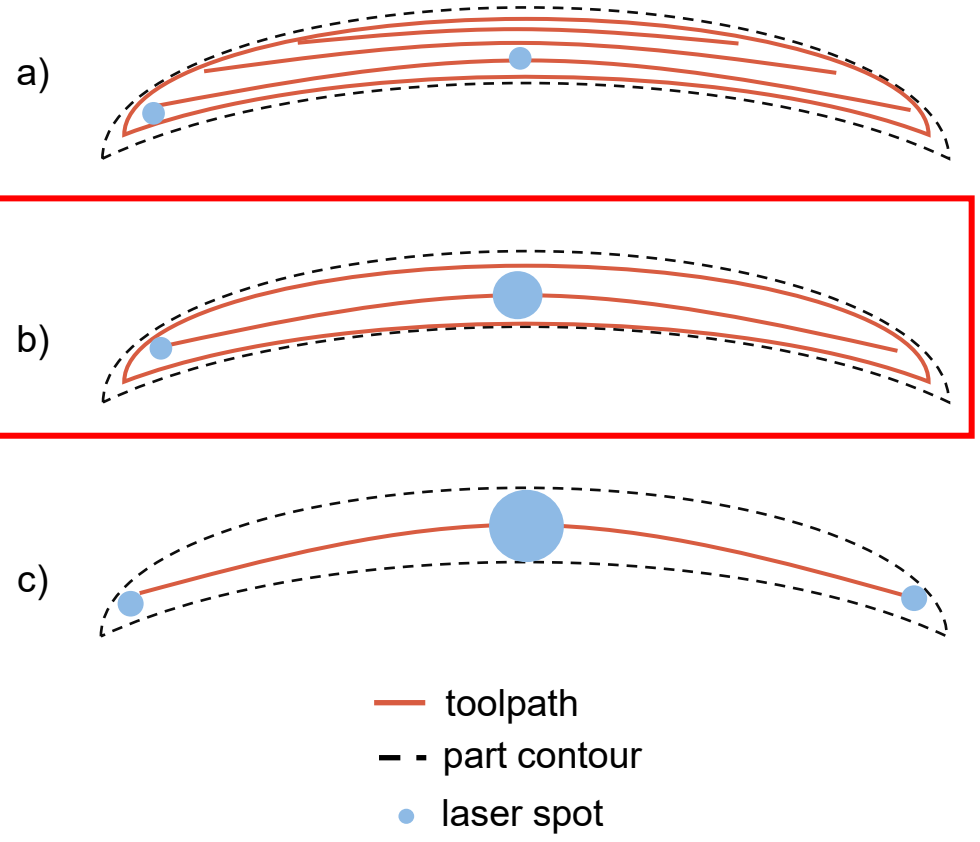
  multiple tracks with constant track width, Tracks begin and end at different positions leading to **step formation,** Contour tracks can partially compensate for step formation

- b) Variable inner track

  Contour tracking with tracks of constant width, **Inner track with variable width**, Different track widths achieved by **varying process parameters**

- c) Variable laser beam diameter

  Single track with variable width per layer, Contour tracking not necessary, Different track widths achieved by **varying laser beam diameter, Zoom optics required**



Objective

Compensation of dimensional deviations in laser metal deposition using adaptive process control (**machine learning-based parameter prediction**).

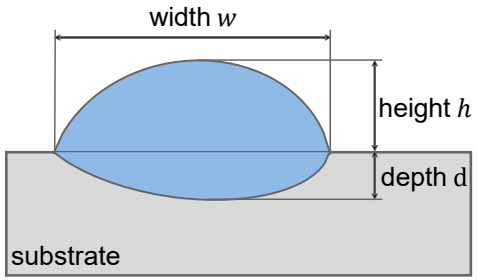
© RWTH Aachen Chair DAP

Overview of Framework: ANN Setup

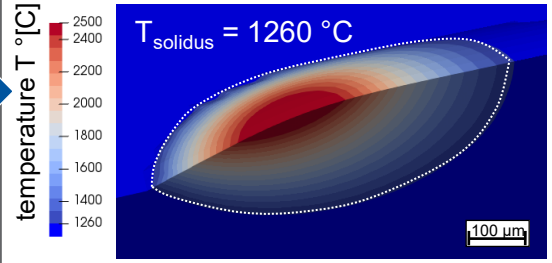
Approach

- Setup of ANN-Framework to enable prediction of process parameters for a predefined single-track geometry
- Dataset: Experiments + Simulation
  - 150 experimental cross-sections + 2160 simulations
- Prediction Framework: ANN + Validation
  - multilayer perceptron (MLP) with a 256–128–64–32 neuron topology
  - Supervised learning on combined dataset
  - L2 regularization
  - 80/20 split into training and validation subsets

Experimental measurements of track dimensions

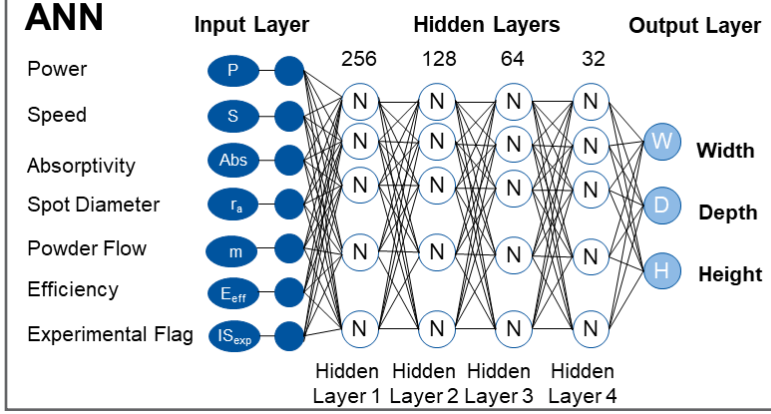


Simulation based measurement of tracks

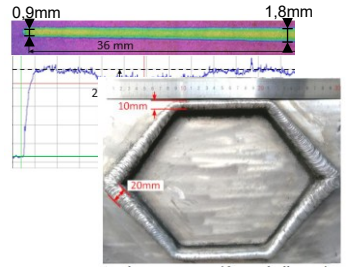


dataset

ANN



Parameters for Variable Wall Thickness

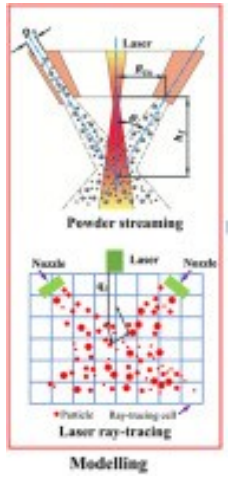


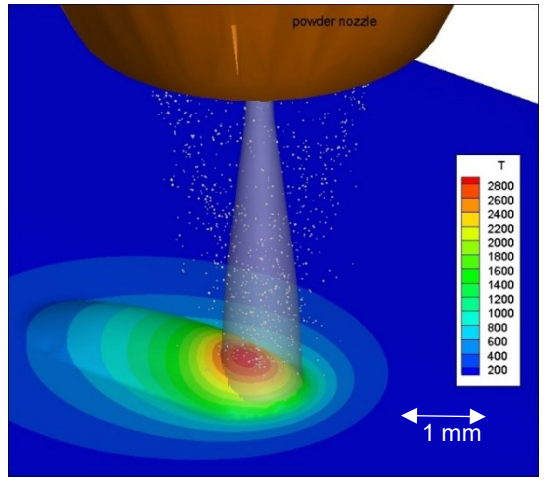
© RWTH Aachen Chair DAP

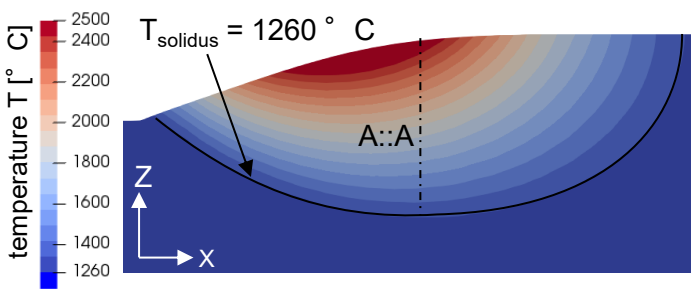
Overview of Framework: FEM Simulation

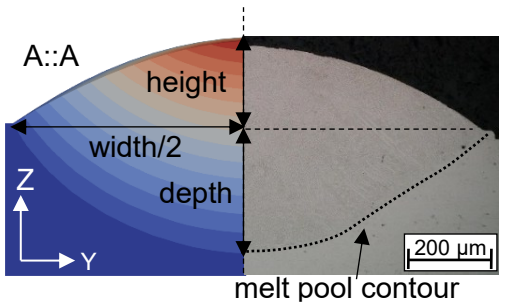
Data generation with DED meltpool model

- FEM model: track formation from thermo-physical problem, accounting for heat conduction, mass addition and free surface evolution with mass conservation [1]
  - ➔ 3D-temperature distribution of single track
- Boundary conditions:
  - LID (Laser intensity distribution in x, y, z)
  - PID (Powder intensity distribution in x, y, z) → Shielding of LID
  - Process parameters (laser power, feed rate, powder efficiency, absorption)
- Deviations between simulated and experimentally measured below 10 % [2]





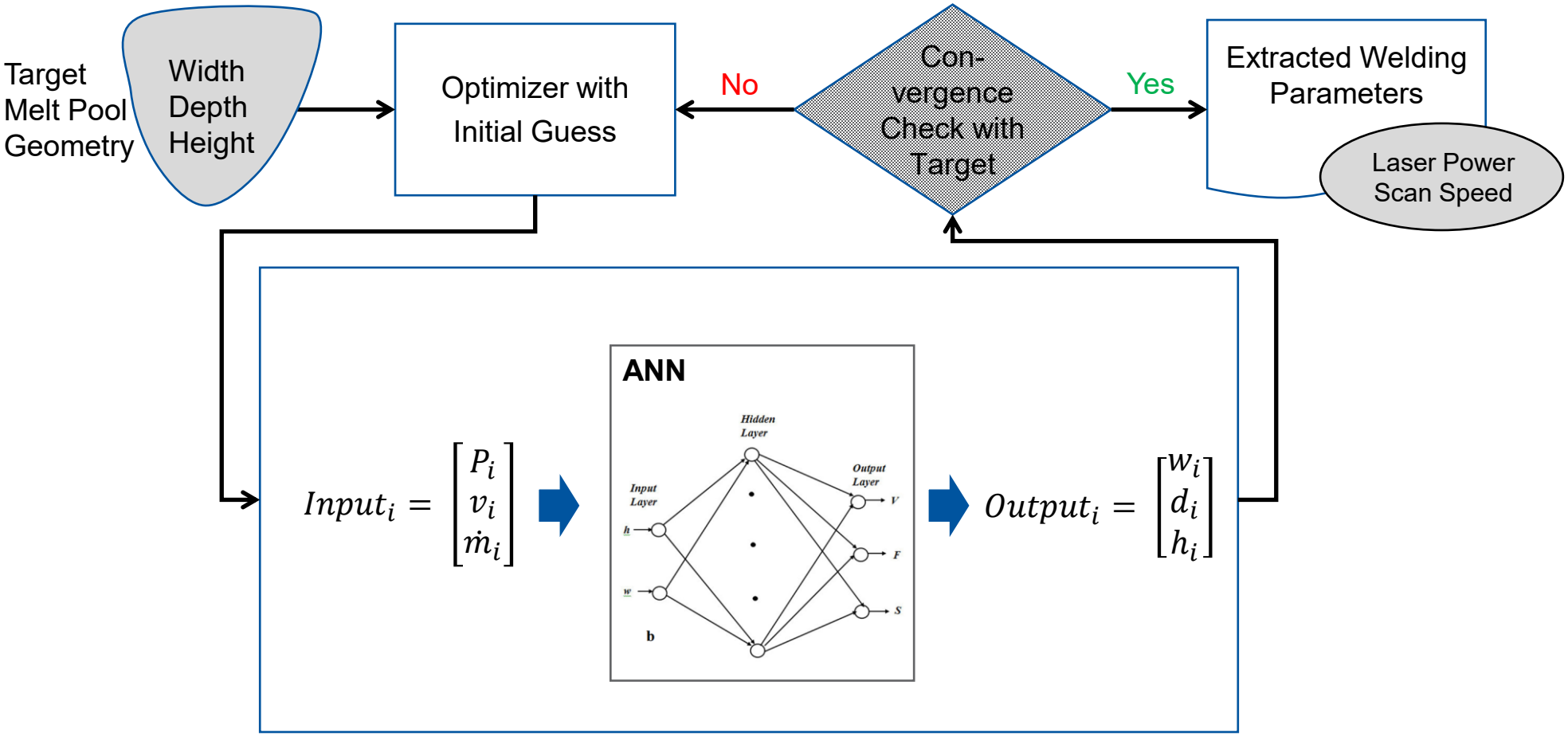




[1] Zielinski, A holistic approach to understand laser additive manufacturing from melt pool to microstructure. dissertation, 2022
[2] Zielinski, H. Kruse, M.-N. Bold, G. Boussinot, M. Apel, J.H. Schleifenbaum, Melt Pool Formation and Out-of-Equilibrium Solidification During the Laser Metal Deposition Process (2021)113–122. doi:10.1007/978-3-030-70332-5

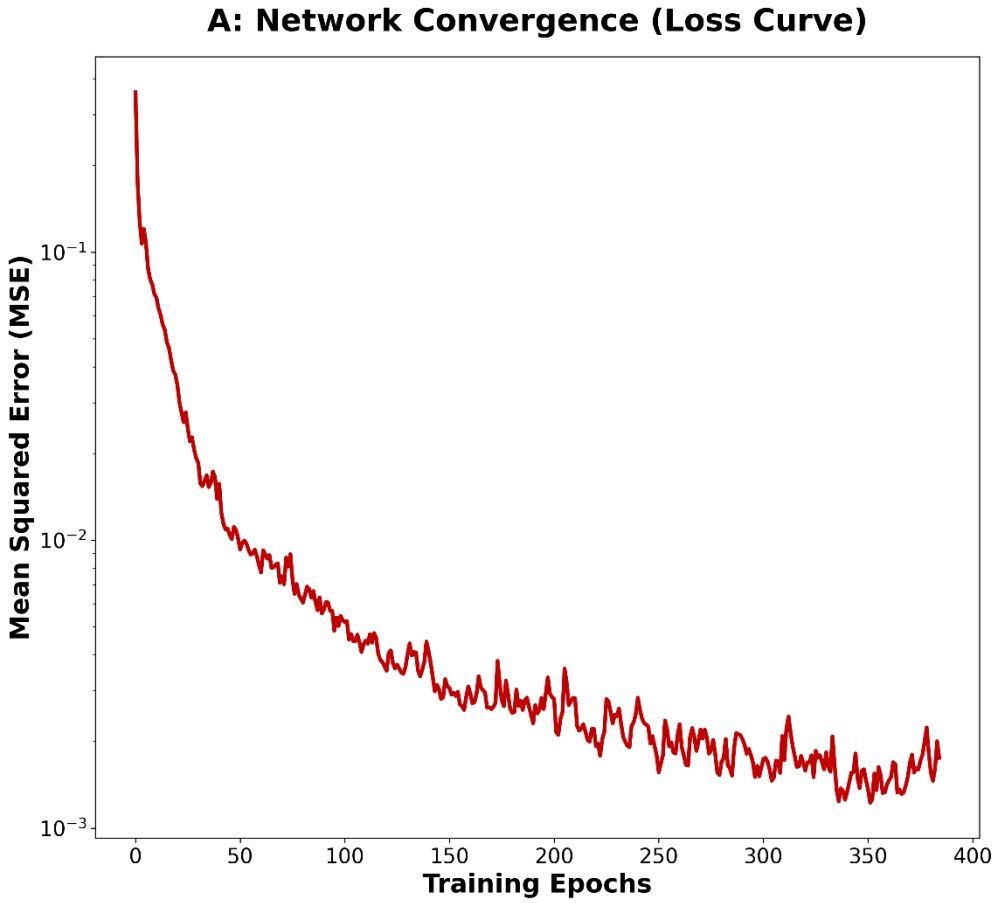
© RWTH Aachen Chair DAP

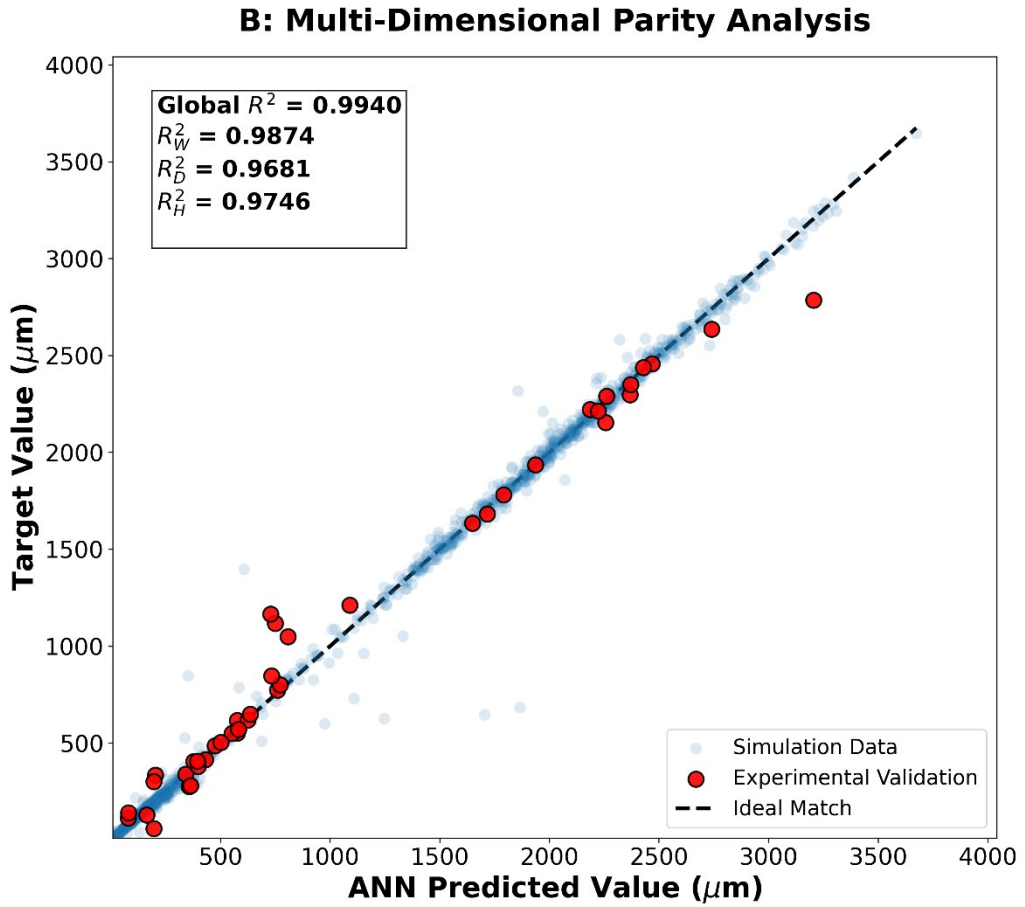
Overview of Framework: Summarized Network



© RWTH Aachen Chair DAP

Results and Discussion

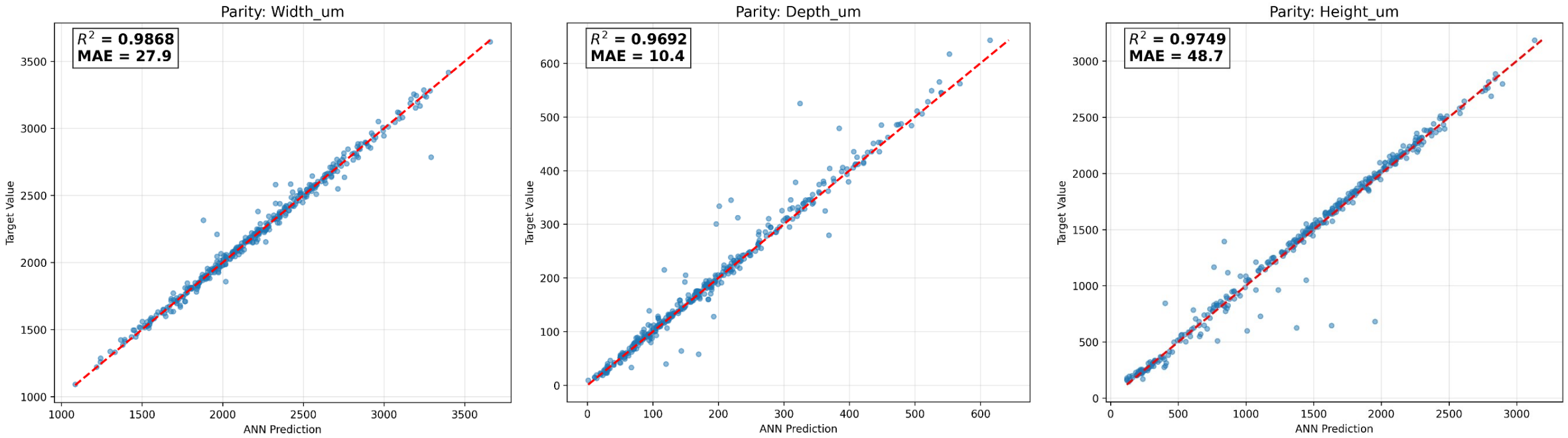




- Loss curve converges after 300 epochs to plateau
- Overall CoD of R^2 = 0.994 for predictive performance

© RWTH Aachen Chair DAP

Results and Discussion



Target	R²	MAE(µm)	% ±100
Width	0.9874	27.9	96.5 %
Depth	0.9681	10.4	98.9 %
Height	0.9746	48.7	93.3 %

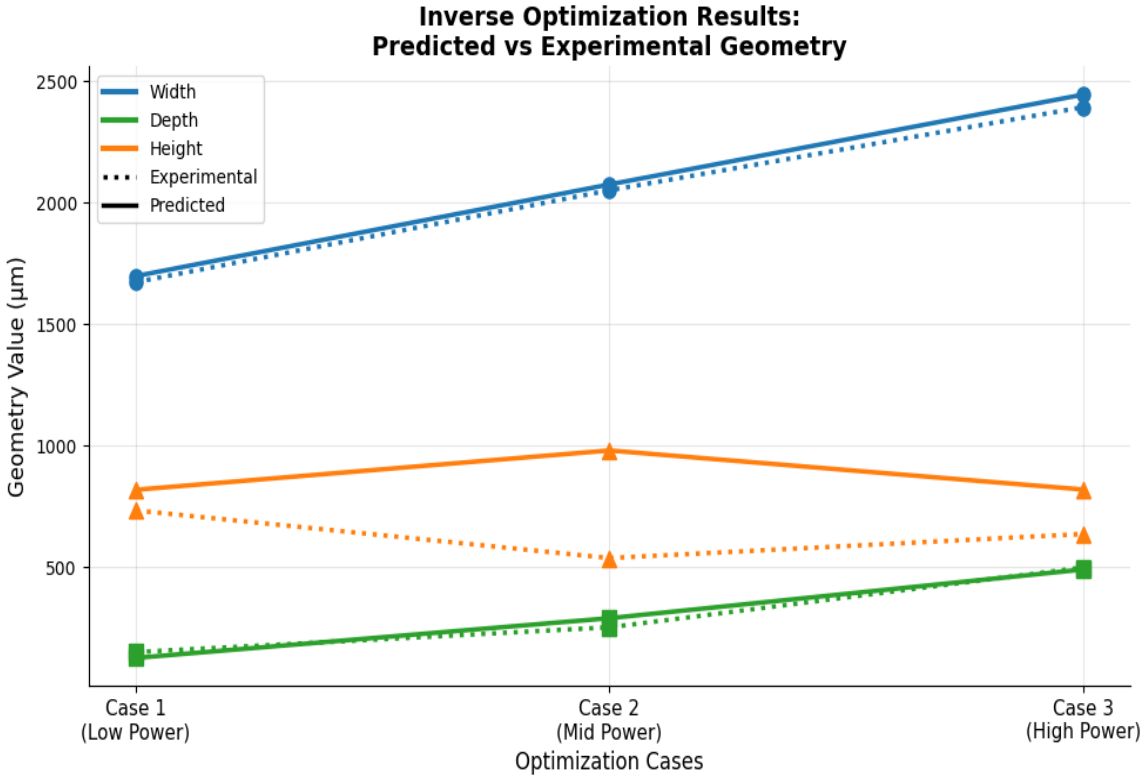
- ANN captures the dominant process relationships, most challenging prediction is height

© RWTH Aachen Chair DAP

Results and Discussion

Inverse Optimization Results

Parameter	Case 1 (Low power)	Case 2 (Mid power)	Case 3 (High power)
Target (W/D/H)	1800/150/600	2000/300/800	2500/450/800
Power (W)	1000	1587.6	2074
Speed (mm/s)	23.83	33.33	26.67
Absorptivity (%)	50	50	50
Powder efficiency (%)	60	60	70
Experimental Power (W)	1000	1600	2000
Experimental Speed (mm/s)	23.23	33.33	26.67
Error Width (%)	+1.5	+1.2	+2.2
Error Depth (%)	-16.0	+14.9	-1.6
Error Height (%)	+11.6	+42.5	+28.8



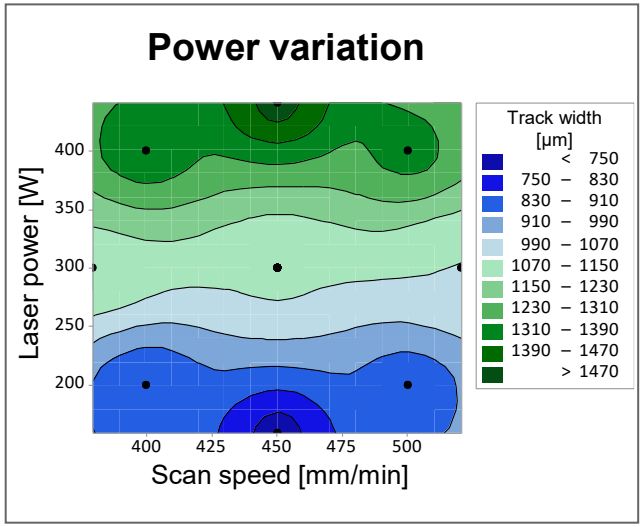
- Prediction of width is very accurate and sufficient for wall thickness predictions

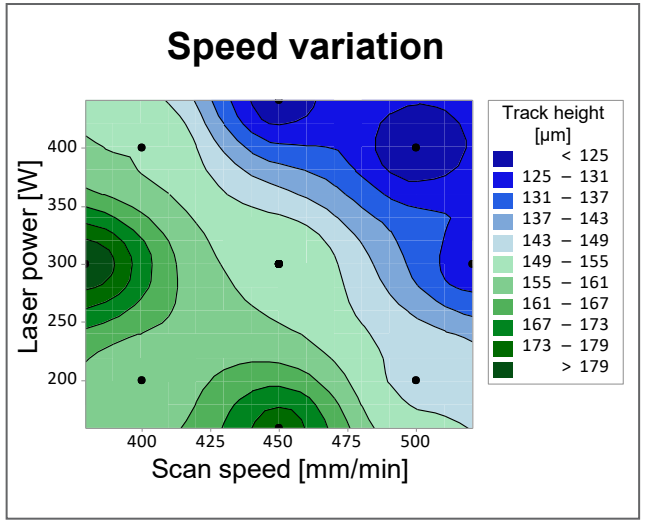
© RWTH Aachen Chair DAP

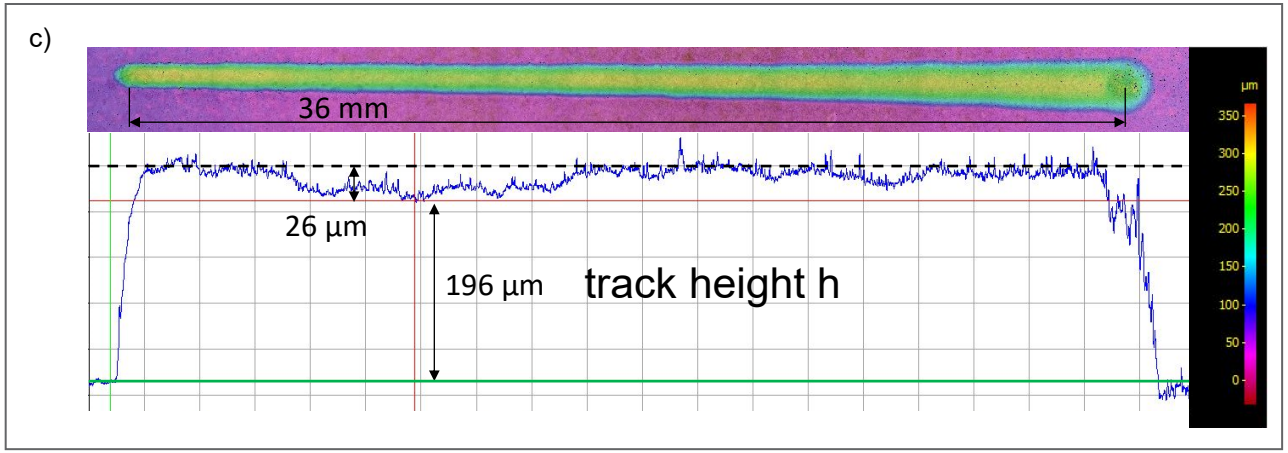
Results and Dicussion

Experimental Validation and Demonstration of Variable Wall Thickness

- Controlled adjustment of the track width is achieved by only adjusting the laser power and feed rate
- for 200 µm height controllable width range from 0.9 mm to 1.95 mm is achieved
  - corresponding to an adjustment factor of 2.2 with relative error below 13% for height
- 500µm: adjustment factor 1.31
- 900µm: adjustment factor 1.63
- Although deviations remain, particularly for melt pool height, the **overall geometric trends are reproduced reliably**







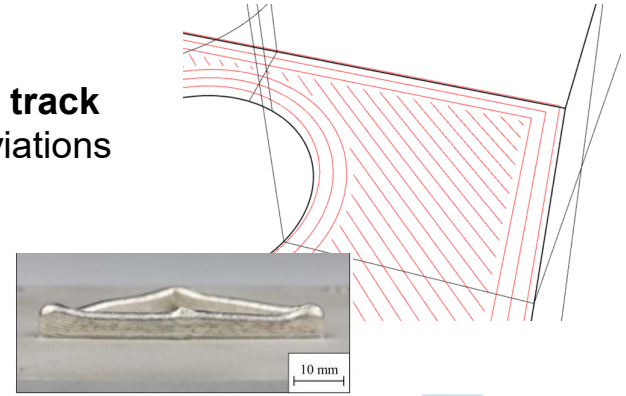
© RWTH Aachen Chair DAP

Summary and Outlook

Research Question and Approach

How can previously unknown **relationships between process parameters and track geometry be identified** using data and utilized to compensate for geometric deviations in DED?

Coupling of FEM-based meltpool simulation workflow with ANN for meltpool predictions

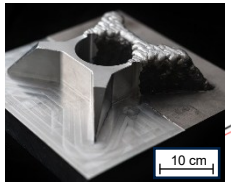


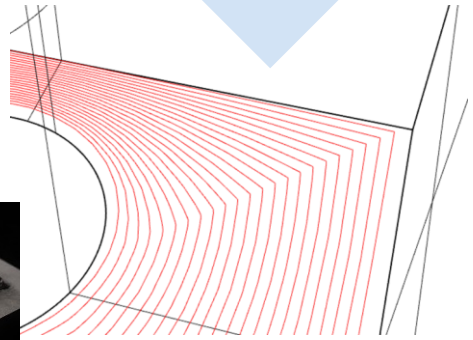
Added Value and Outlook

data-driven framework for geometry-based process parameter selection in directed energy deposition (DED), enabling the controlled variation of track geometry and the realization of variable wall thickness

Improving **component quality and process stability**

Automation of the process parameter assignment from ML model to geometry





© RWTH Aachen Chair DAP