Additive Manufacturing in Construction
1st funding period: The Challenge of Large Scale

AMC TRR277

B04

Process Control and Adaptive Path Planning for Additive Manufacturing Processes Based on Industrial Robots with an Extended Degree of Freedom

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Main outcome of 1st funding period

Developed offline and online feed back loops for robust additive manufacturing.

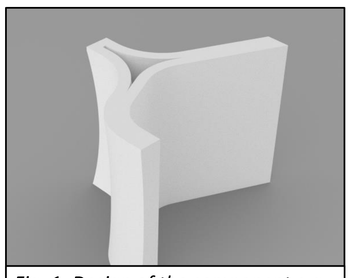

Fig. 1: Design of the component e.g. shelltonic demonstrator wall

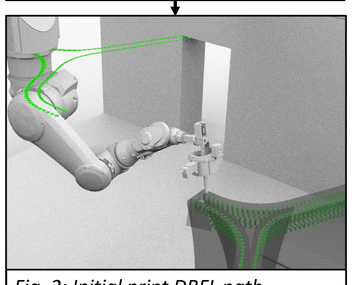

Fig. 2: Initial print DBFL path generation for the wall segment

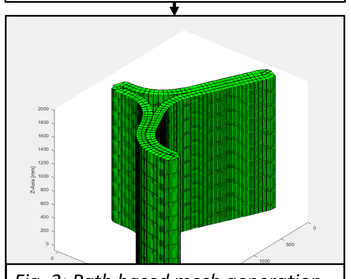

Fig. 3: Path based mesh generation using the points of the first layer

Path adaptation

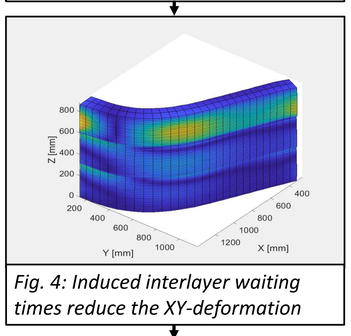

Fig. 4: Induced interlayer waiting times reduce the XY-deformation

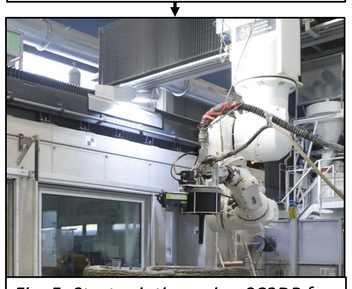

Fig. 5: Start printing using SC3DP for the shelltonic demonstrator wall

Online control

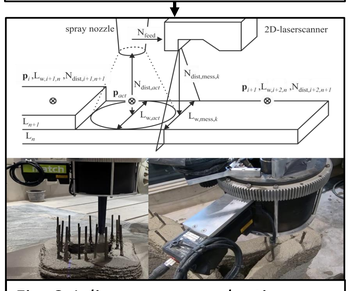

Fig. 6: Inline process evaluation during SC3DP at the DBFL

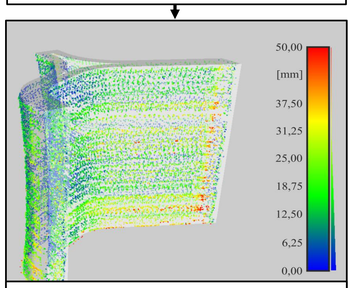

Fig. 7: Width accuracy evaluation of the core of the wall using online data

Project summary

Development of algorithms and methods for adaptive printing, which take into account the material behaviour, the application process, and the robot properties such as an extended degree of freedom, to generate a predictable and reproducible component quality.

Key collaborations in 1st funding period

- A04: Path planning and feedback loop development
- B05: Near nozzle sensing for robot localization and in-place printing
- C05: Near nozzle sensing for specimen digitalization
- C06: Providing process data for quality inspection

Project status

Adaptive path planning and optimization

Objective: Considering process and material boundaries at each path point p_i by development of five methods:

A. Determine material and parameters with a delayed reaction
B. Provide geometry for path planning given the initial process parameters

cross-section model / contour offset algorithm

p_i :
A) $\{V_{air}, V_{con}, Dos_{acc}\}$
B) $\{X_E, Y_E, Z_E, A_E, B_E, C_E\}$
C) $\{L_w, N_d, N_{feed}, L_n, \varphi_S\}$
D) $\{x_p, y_p, z_p\}$
E) $\{t_{wait}\}$

scanner simulation / inverse diff. kinematic / wait-time optimization

C. Calculate set points for online control
D. Solving extended degree of freedom
E. Ensure component stability

Fig. 8: Set of path parameters for SC3DP

Finite element modelling

Model creation:
- Mesh derived directly from printing trajectory
- Including process parameters

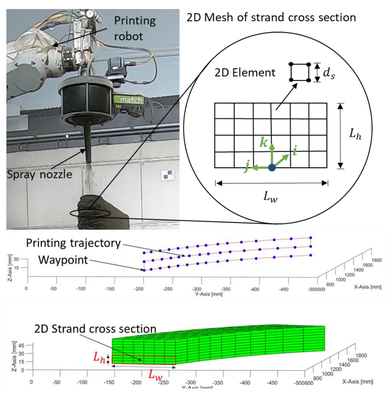

Fig. 9: Mesh creation from path

Material model:
- Drucker-Prager plasticity model
- Time varying elastic properties and yield surface

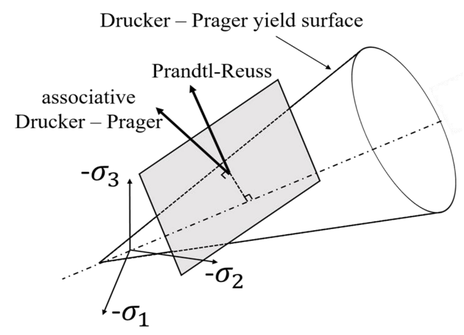

Fig. 10: Drucker-Prager model

Results:
- Accurate prediction of process instabilities
- Lack of thixotropy effects

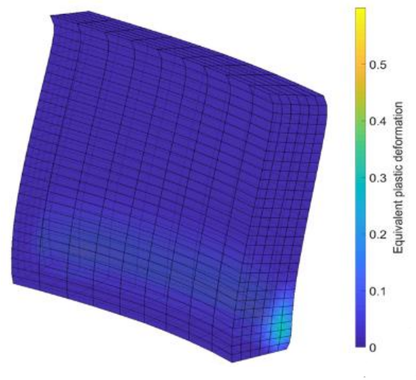

Fig. 11: Plastic deformation while printing

Online control

Process control unit:
- 2D laser scanner for width, distance, and shape evaluation
- 360° endless rotation for closed shapes e.g.: columns

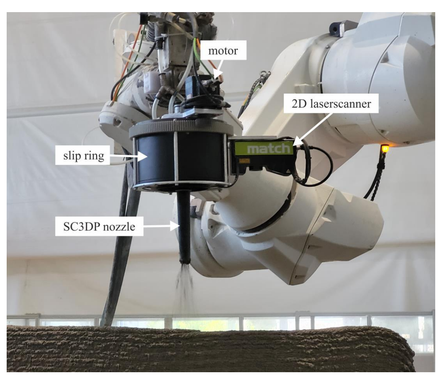

Fig. 12: AM process control unit for construction environments

Control loop design:
- Continuous layer width and height adjustment by nozzle feed rate and spray distance adaptation

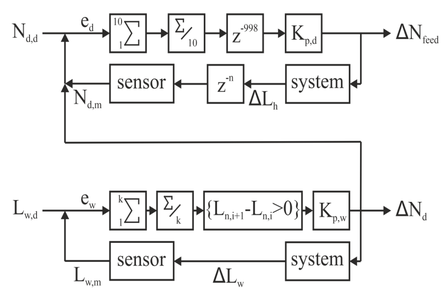

Fig. 13: Control loop design for SC3DP

Results:
- Height deviation ±10 mm
- Width deviation ±10 mm
- Compensation of simple rebar
- Limited 3D capabilities

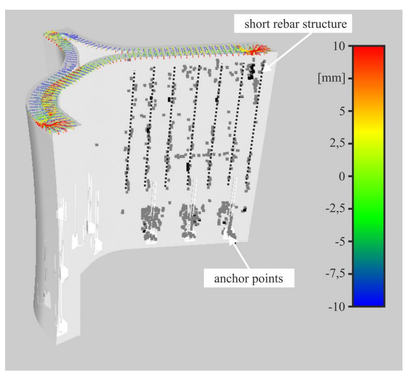

Fig. 14: Height evaluation and rebar localization using online data

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