Adaption of cost calculation methods for modular Laser Powder Bed Fusion (LPBF) machine concepts

Sebastian Dirks
RWTH Aachen University – Digital Additive Production DAP
Aachen, Germany

25.11.2019 @MAMC Sweden

Fraunhofer ILT
dap Digital Additive Production
RWTH AACHEN UNIVERSITY

Agenda

1 Motivation

2 DAP Cost Simulation Model Approach

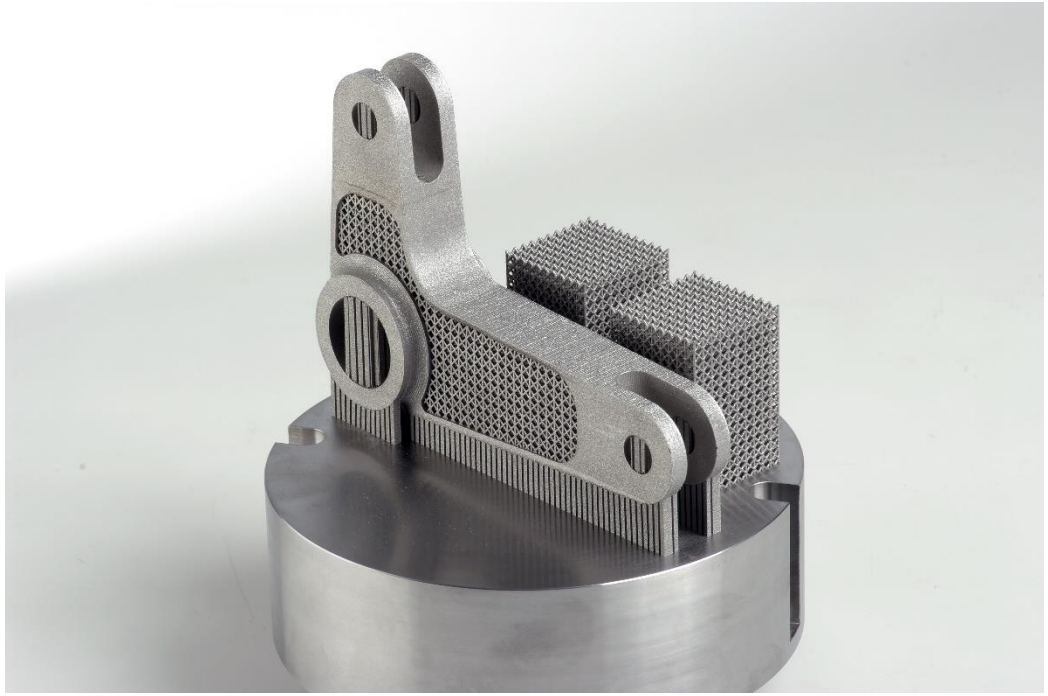
3 Model Perspectives

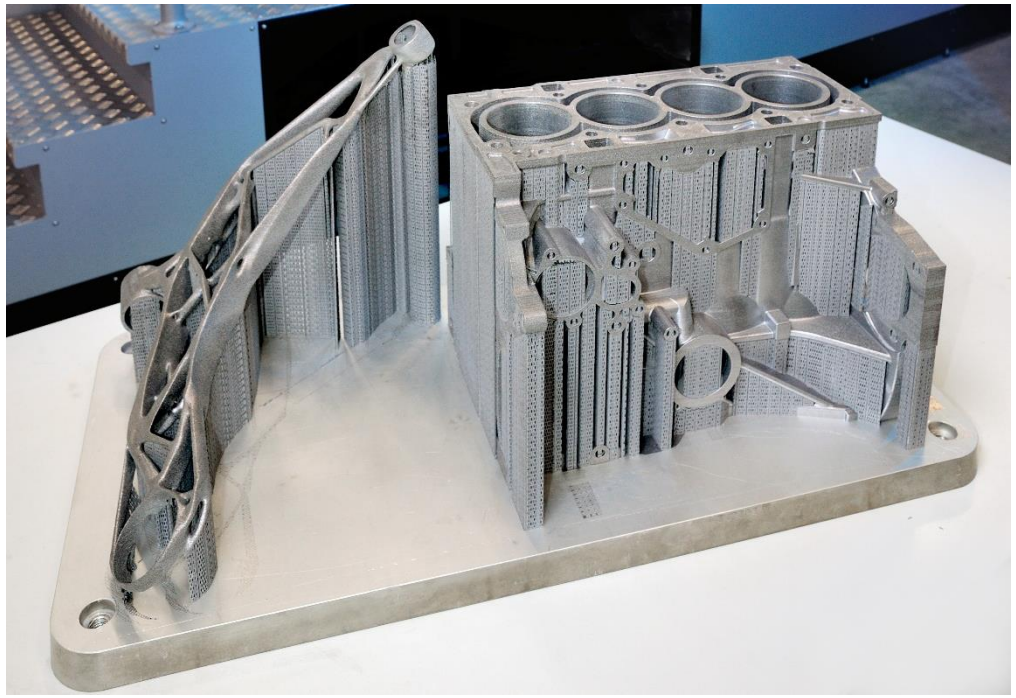
4 Model Verification

5 Outlook

Motivation

Two advantages of Additive Manufacturing (AM) are complexity for free and individualization





Laser AM (LAM) cost calculation is as complex and individual as the geometry and technology itself!

Motivation

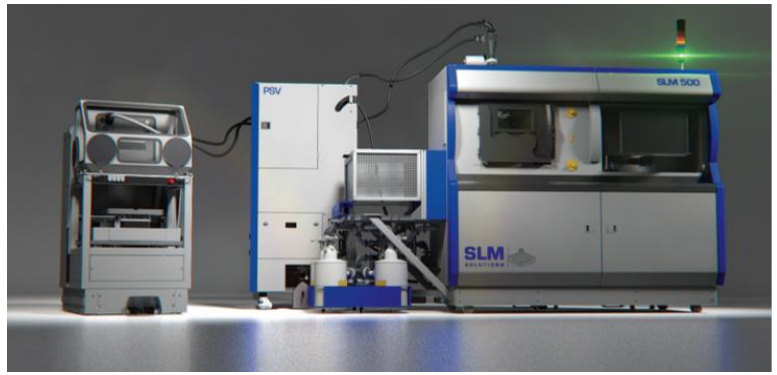
Modular concepts for LPBF series production are emerging

Trumpf

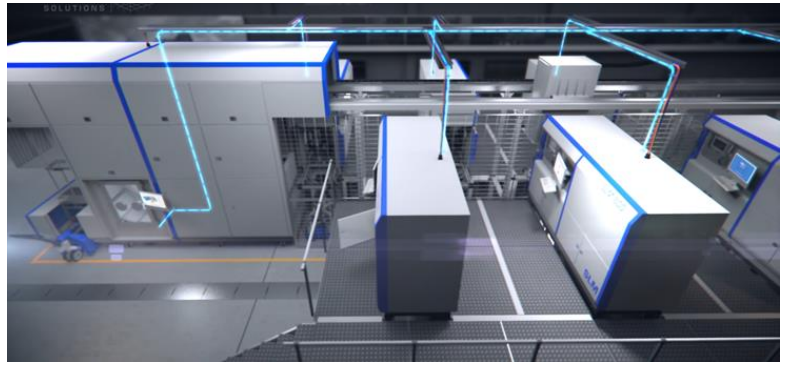
picture: Trumpf

picture: Trumpf

SLM Solutions



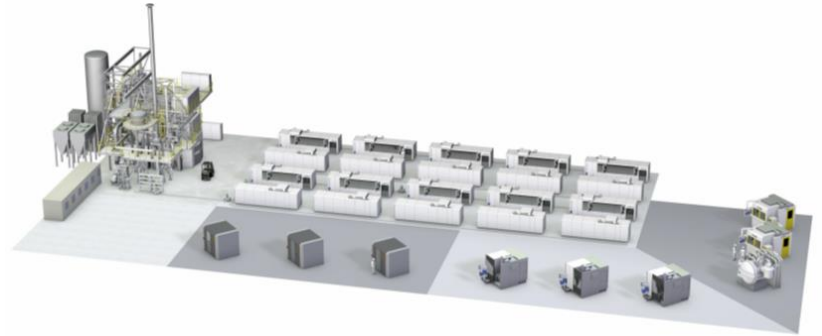
picture: SLM Solutions



picture: SLM Solutions

Additive Industries

picture: Additive Industries



picture: Additive Industries

*no claim for completeness

Fraunhofer ILT | dap Digital Additive Production | RWTH AACHEN UNIVERSITY

Agenda

1 Motivation

2 DAP Cost Simulation Model Approach

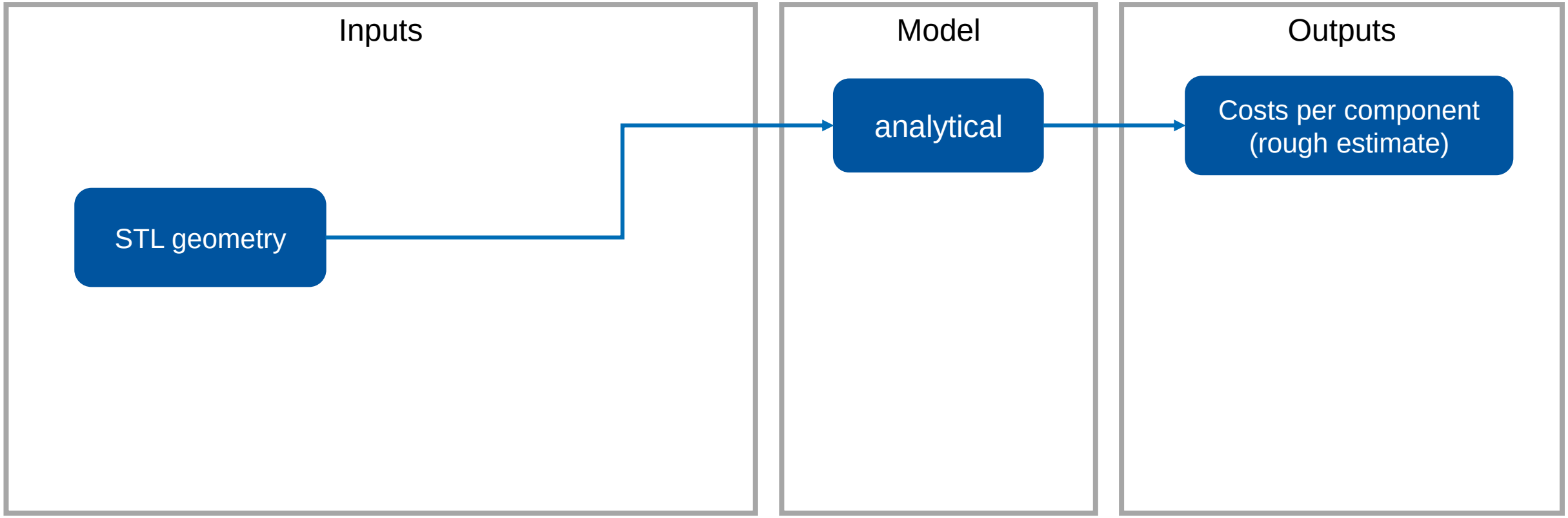
3 Model Perspectives

4 Model Verification

5 Outlook

DAP Cost Simulation Model Approach

Historical approaches: Analytical



analytical approaches are estimates, best suited for use cases based on limited data (e.g. quoting)

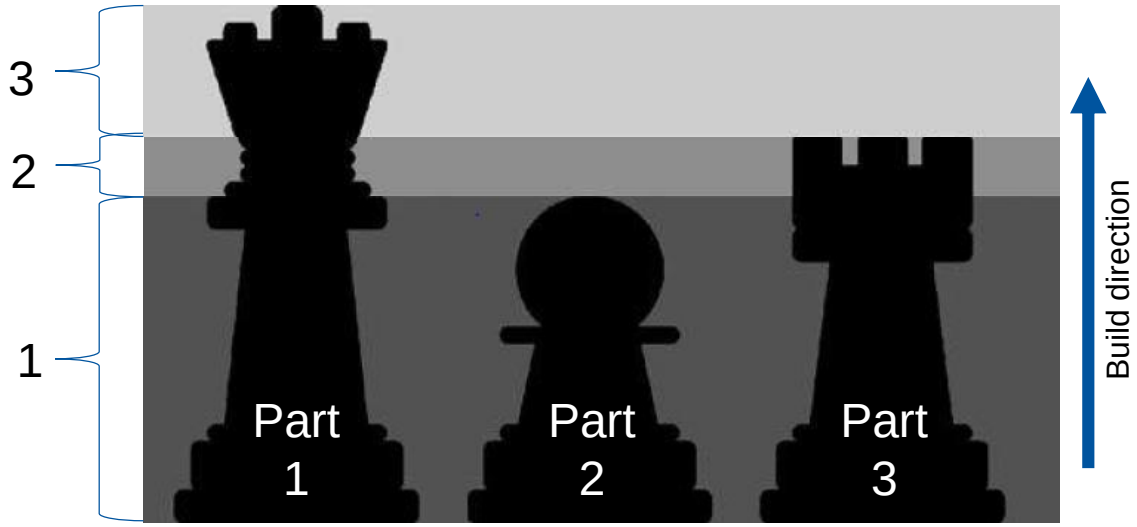
DAP Cost Simulation Model Approach

Historical approaches: Analytical

typical data used

- build height
- build volume
- surface area
- part dimension (bounding box)
- material
- number of pieces
- cross-section (per layer)

[1,2]



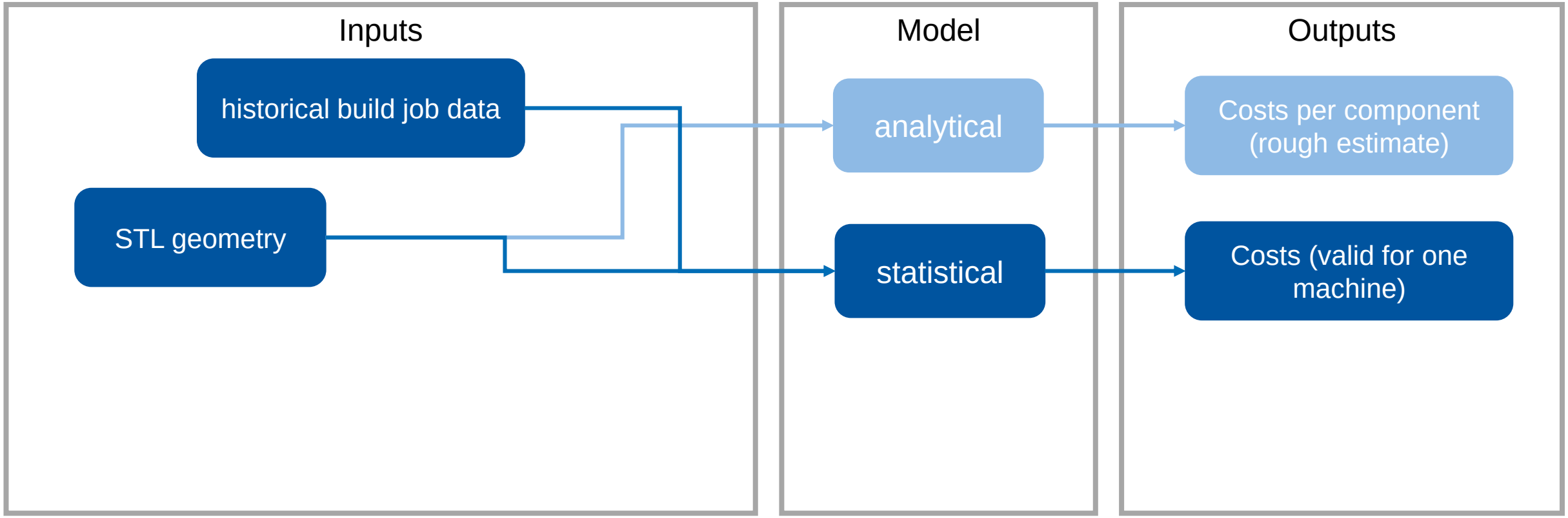
1. Coater costs are divided evenly between all parts
2. Coater costs are divided evenly between parts 1 & 2
3. Coater costs will refer to Part 1 only

[3]

sources:
[1] Alexander, P.; Allen, S.; Dutta, D. (1998): Part orientation and build cost determination in layered manufacturing. In: *CAD Computer Aided Design, 1998, Vol.30(5), pp.343-356* 30 (5). DOI: 10.1016/S0010-4485(97)00083-3.
[2] Rickenbacher, L.; Spierings, A.; Wegener, K. (2013): An integrated cost-model for selective laser melting (SLM). In: *Rapid Prototyping Journal, 19 April 2013, Vol.19(3), pp.208-214* 19 (3). DOI: 10.1108/13552541311312201.
[3] Hopkinson, N.; Dickens, P. (2003): Analysis of rapid manufacturing - Using layer manufacturing processes for production. In: *Proceedings of the Institution of Mechanical Engineers, 2003, Vol.217(1), pp.31-40* 217 (1).

DAP Cost Simulation Model Approach

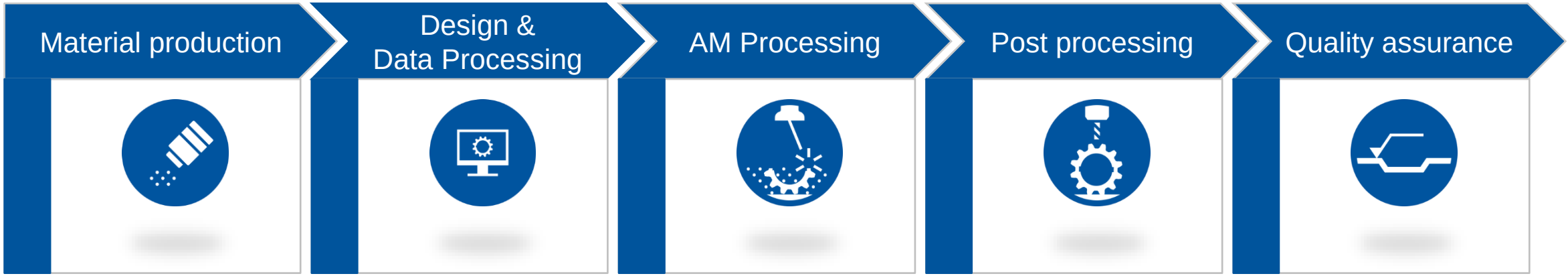
Historical approaches: Statistical



statistical models use regression to adapt to reality, but need machine-specific historical data

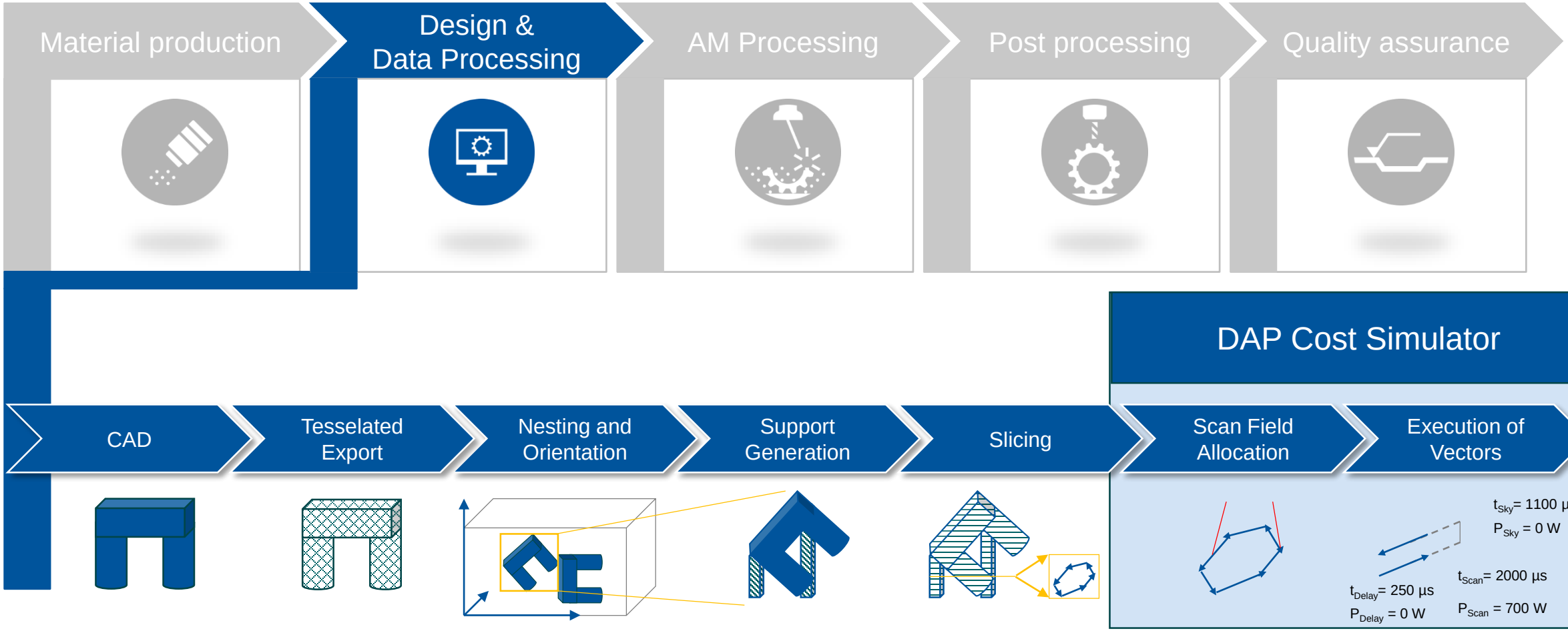
DAP Cost Simulation Model Approach

The AM Process Chain



DAP Cost Simulation Model Approach

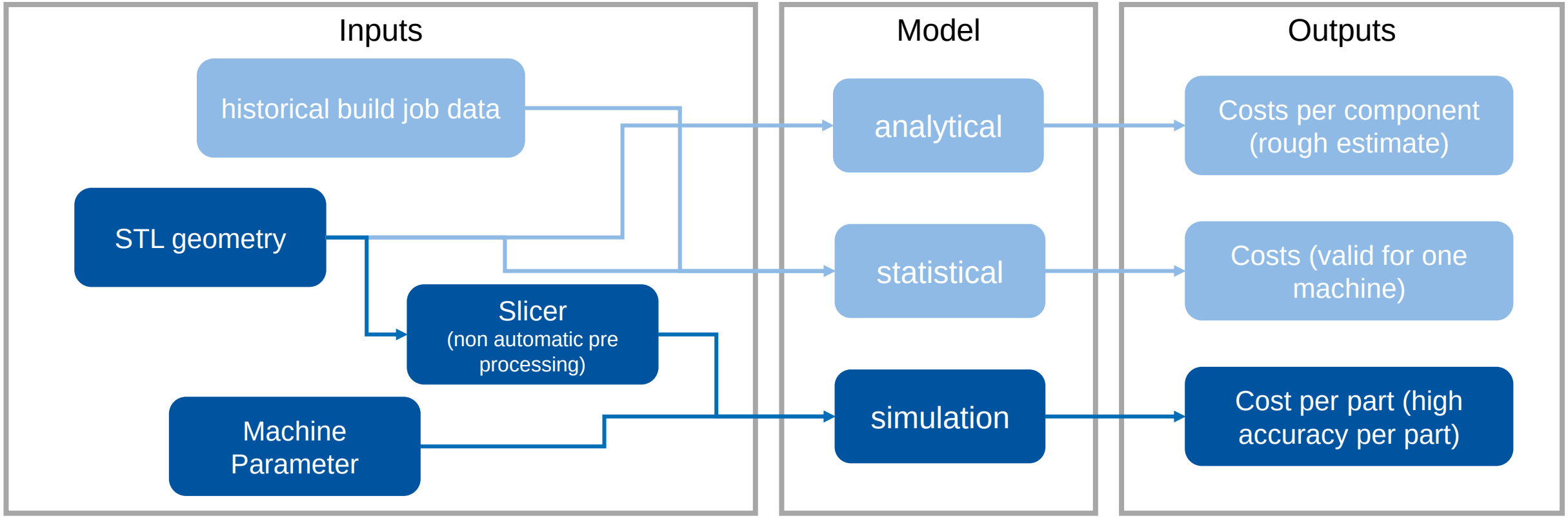
The AM Process Chain



Fraunhofer ILT | dap Digital Additive Production | RWTH AACHEN UNIVERSITY

DAP Cost Simulation Model Approach

DAP Approach: virtual modular simulator



simulation model results are highly accurate, but need more preparation

Agenda

1 Motivation

2 DAP Cost Simulation Model Approach

3 Model Perspectives

4 Model Verification

5 Outlook

Machine View

Service-oriented architecture

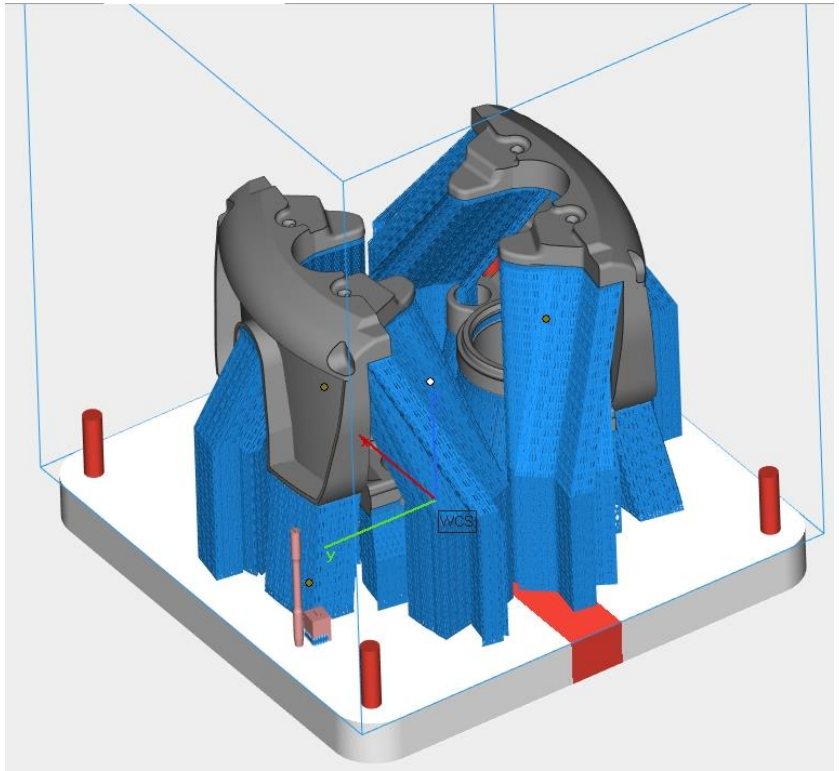
picture: Additive Industries

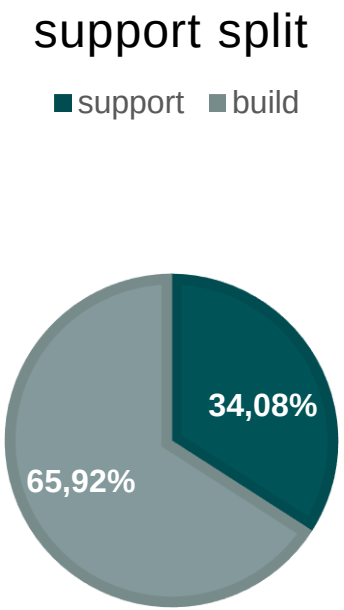
The machine view enables cost driver detection and benchmarking of machine improvements

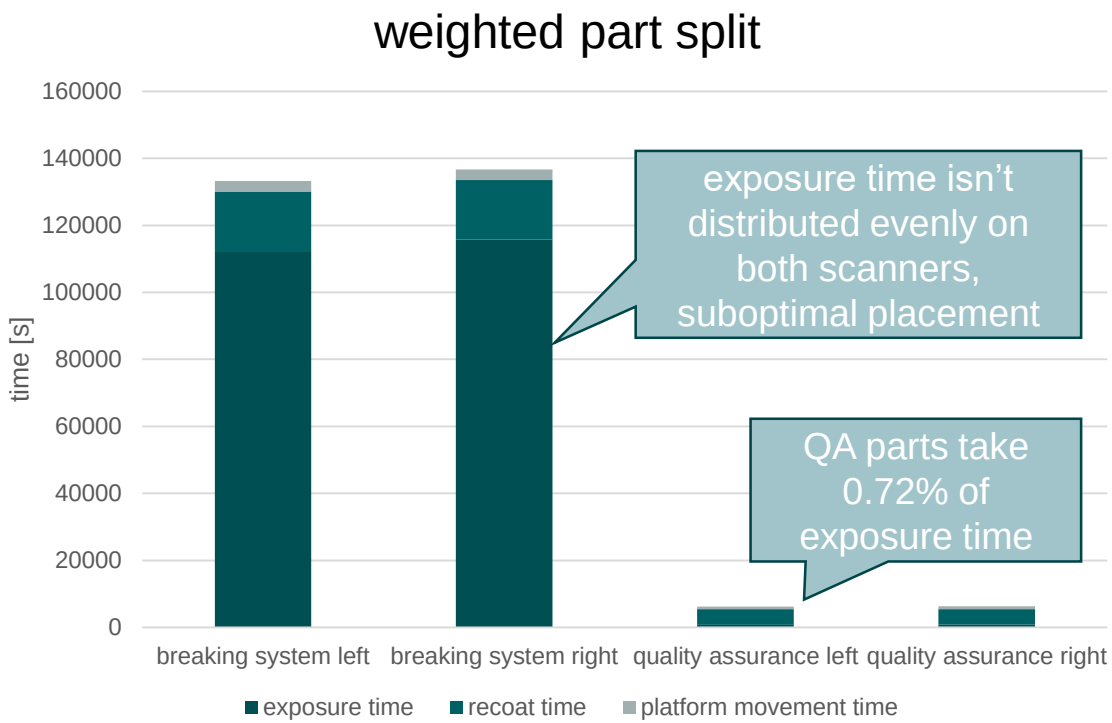
Fraunhofer ILT | dap Digital Additive Production | RWTH AACHEN UNIVERSITY

Product View

Example: Additive manufactured breaking system with quality assurance parts



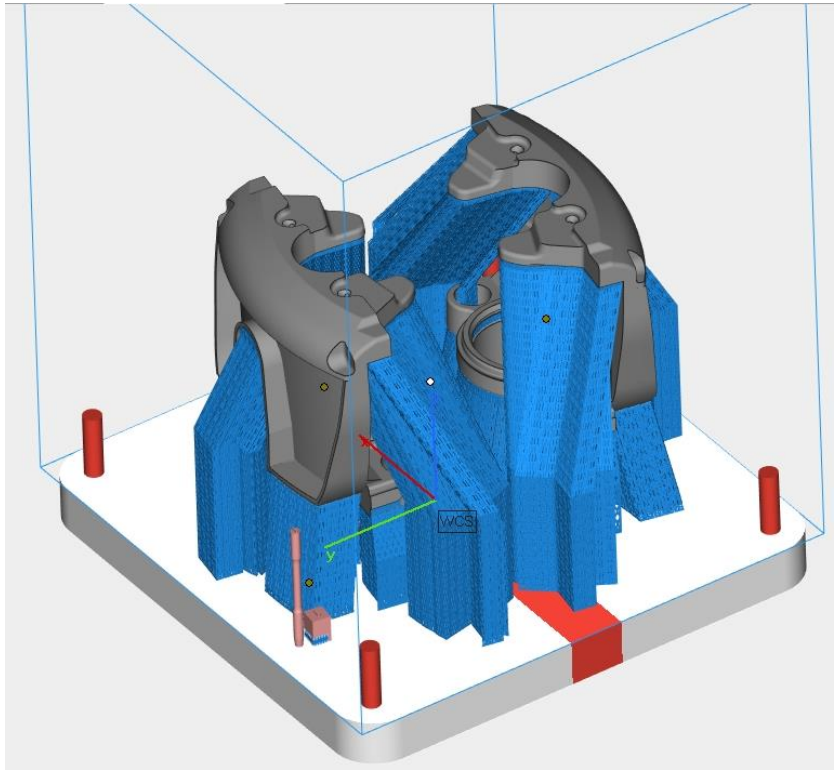


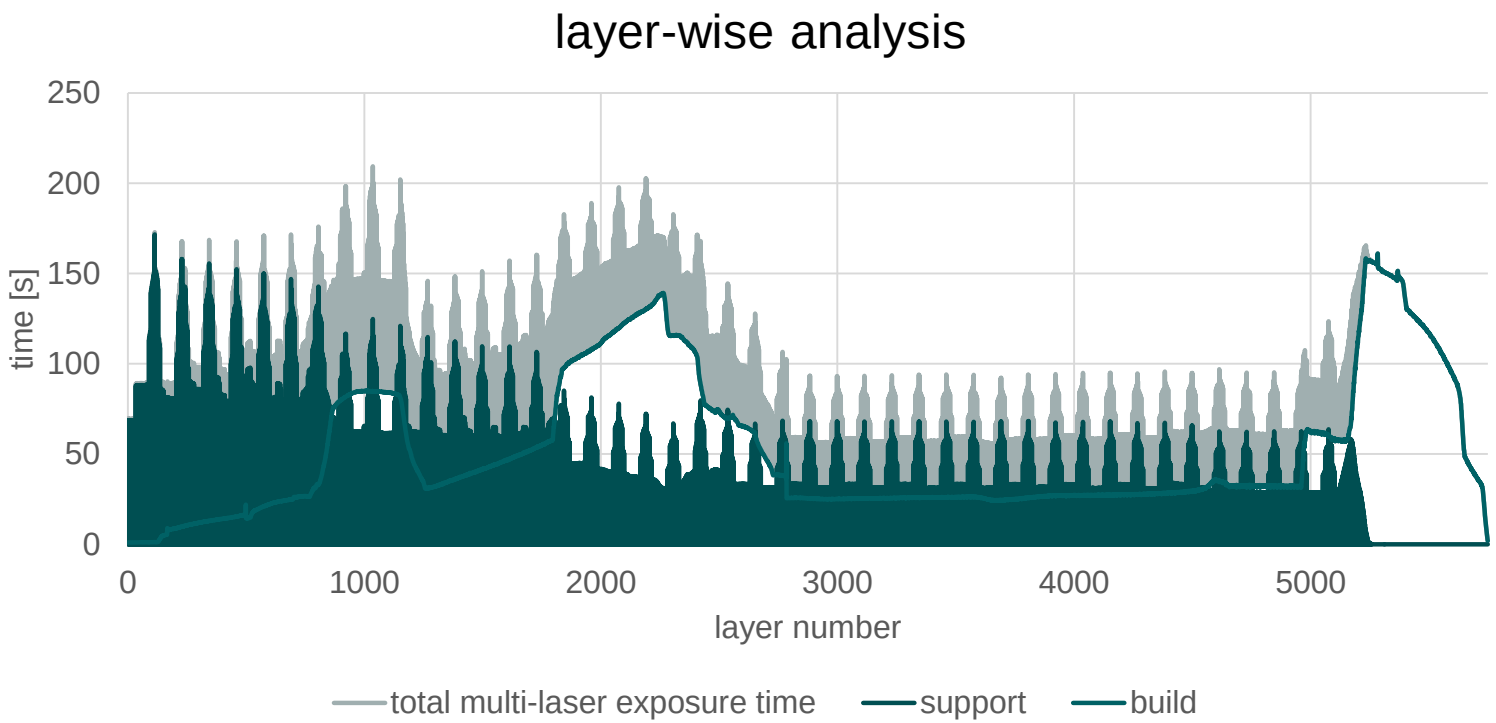


The product view enables benchmarking of part design, supports, placement and orientation

Product View

Example: Additive manufactured breaking system with quality assurance parts





The product view enables benchmarking of part design, supports, placement and orientation

Agenda

1 Motivation

2 DAP Cost Simulation Model Approach

3 Model Perspectives

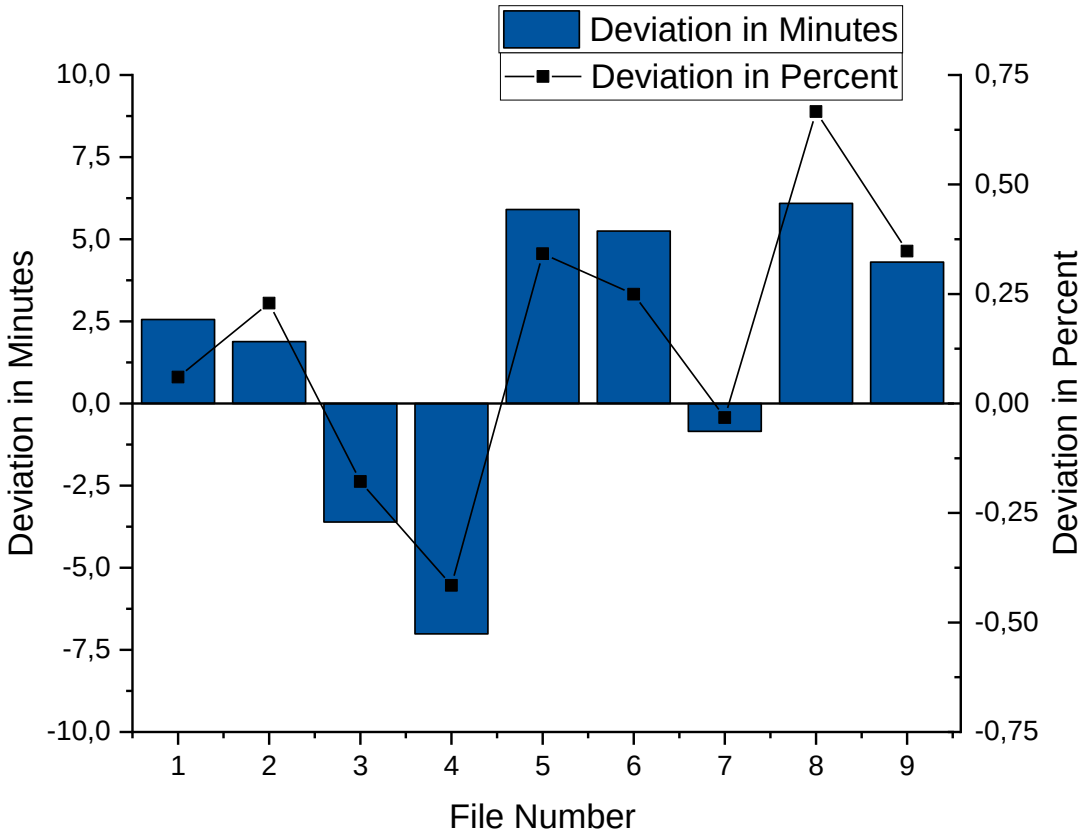
4 Model Verification

5 Outlook

Model Verification

Model performance

- The model was verified by layer-wise analysis of the machine log timestamps of 9 real-word build jobs
- Mean Average Percentage Error (MAPE) of 0.28 %
- example MAPE for statistical approaches found in literature is 8,2% [1]
- Deviation below 7 min for all jobs, including 70 hours run time jobs



The model shows high precision for real world build jobs

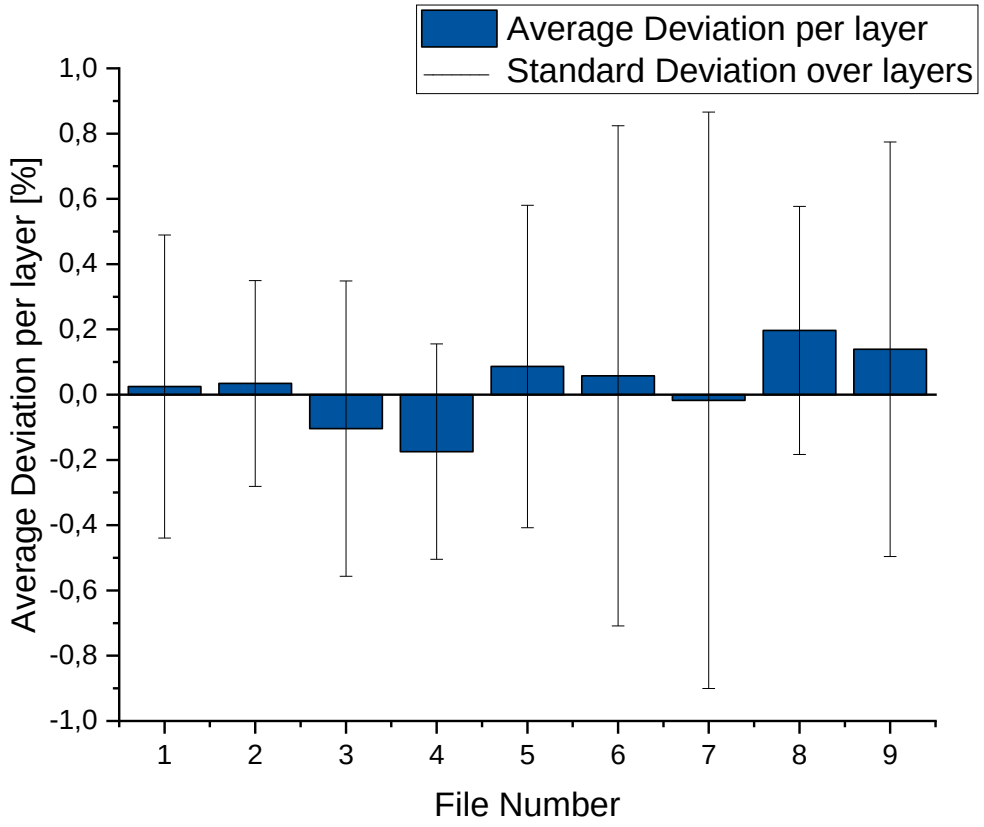
source:

[1] Rudolph, Jan-Peer; Emmelmann, Claus (2017): A Cloud-based Platform for Automated Order Processing in Additive Manufacturing. In: *Procedia CIRP* 63, S. 412–417

Model Verification

Layer-wise performance

- layer-wise comparison of execution time (sum of exposure, recoating and platform movement time) to log timestamps
- average deviation per layer below ±0.2%
- standard deviation below ±1%

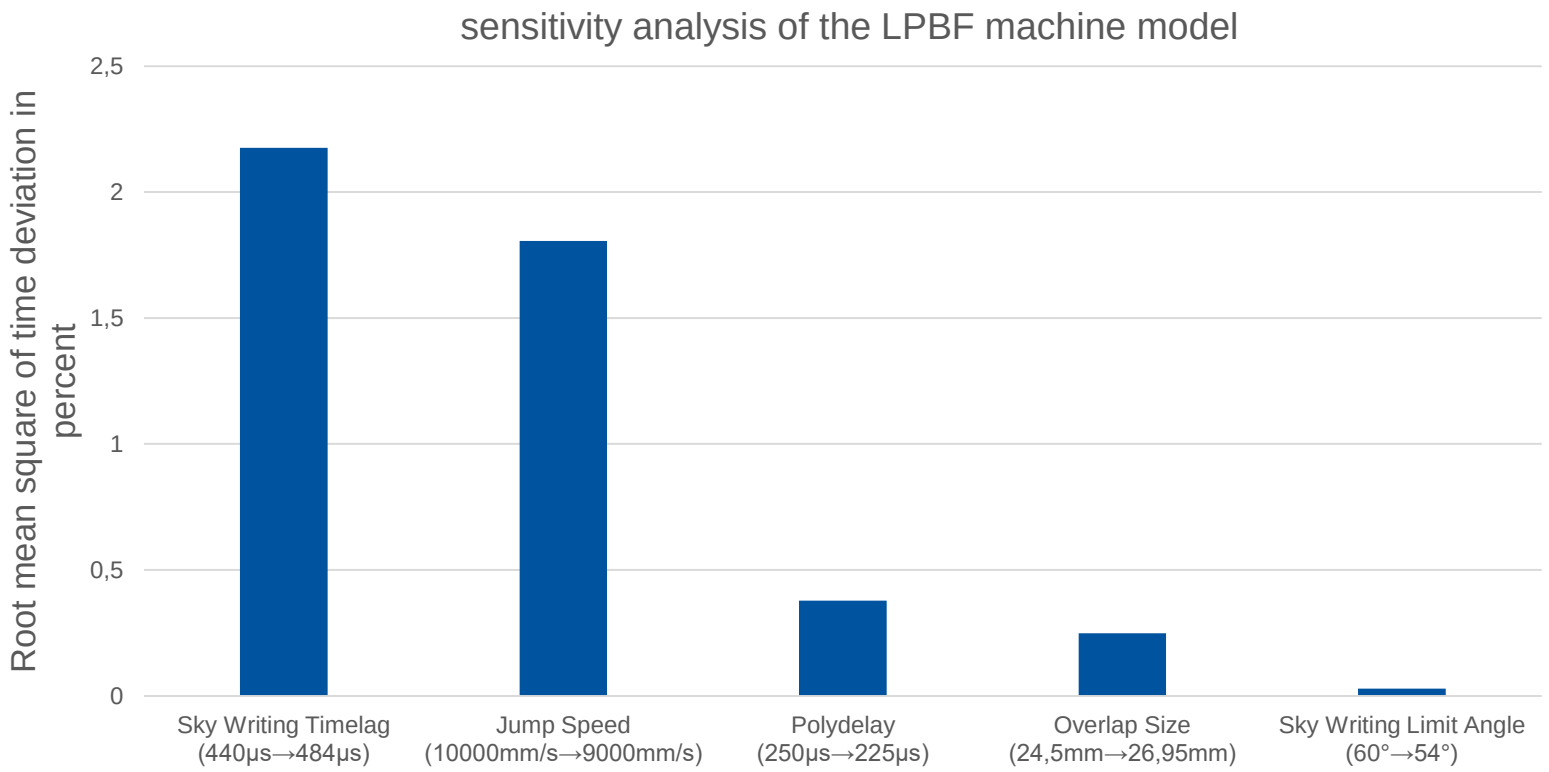


Low standard deviation for all layers shows geometry independence

Model Verification

Analysis of influencing factors

- different model parameters have been varied by ±10% and time deviation to the log timestamps is reavaluated
- the maximum deviation percentage of ± variations on the average time deviation of all test files is shown



sky writing time and jump speed are the most important settings for typical build jobs time calculation

Agenda

1 Motivation

2 DAP Cost Simulation Model Approach

3 Model Perspectives

4 Model Verification

5 Outlook

Outlook

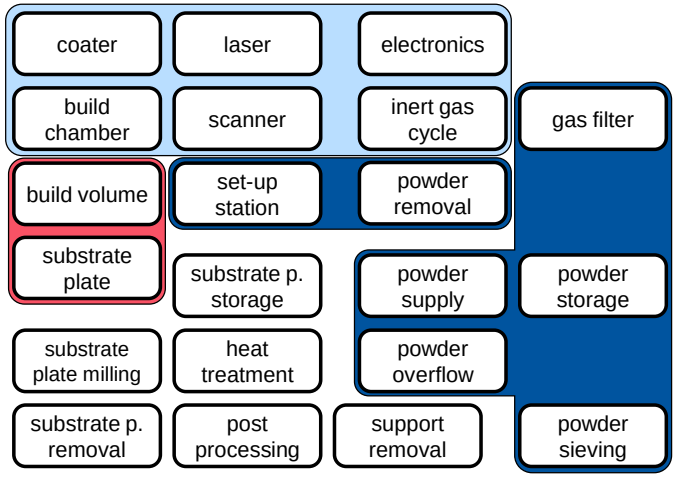
Future use cases

digital shadow of real machines

OPC UA™

coupling with factory and material flow simulation

improvement prediction and optimization of modules



Fraunhofer ILT | dap Digital Additive Production | RWTH AACHEN UNIVERSITY

Acknowledgements

This research has been financed by the German ministry of Research and Education in the Digital Photonic Production Direct (13N13710) project as part of the “Research Campus – Public-Private Partnership for Innovation” initiative and continued in the Industrialization and Digitalization of Additive Manufacturing for automotive serial processes (13N15084) project.

Thank you for your attention!

M.Sc. Sebastian Dirks
RWTH Aachen University – Digital Additive Production DAP
Steinbachstraße 15
52074 Aachen
+ 49 241 8906-8325
sebastian.dirks@dap.rwth-aachen.de