Production costs of additive manufacturing

Because it costs

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Contents

- Structure of the AM production costs
- PBF production costs
- Calculation of production costs of a batch of products
- Estimation of production costs of an individual product

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How can we NOT calculate AM production costs?

- Per unit volume of a product
- Per unit mass of a product
- Depending of complexity of the product shape

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How can we calculate AM production costs?

- Depends on the AM technology
  - Technologies based on melted wire
  - Technologies based on solidification of liquids
  - Powder bed fusion (PBF) technologies

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How can we calculate AM production costs?

- Depends on the AM technology
  - Technologies based on melted wire
  - Technologies based on solidification of liquids
  - **Powder bed fusion (PBF) technologies**
    - Selective laser sintering (SLS)
    - Direct laser metal sintering (DMLS)
    - Multi-jet fusion (MJF)

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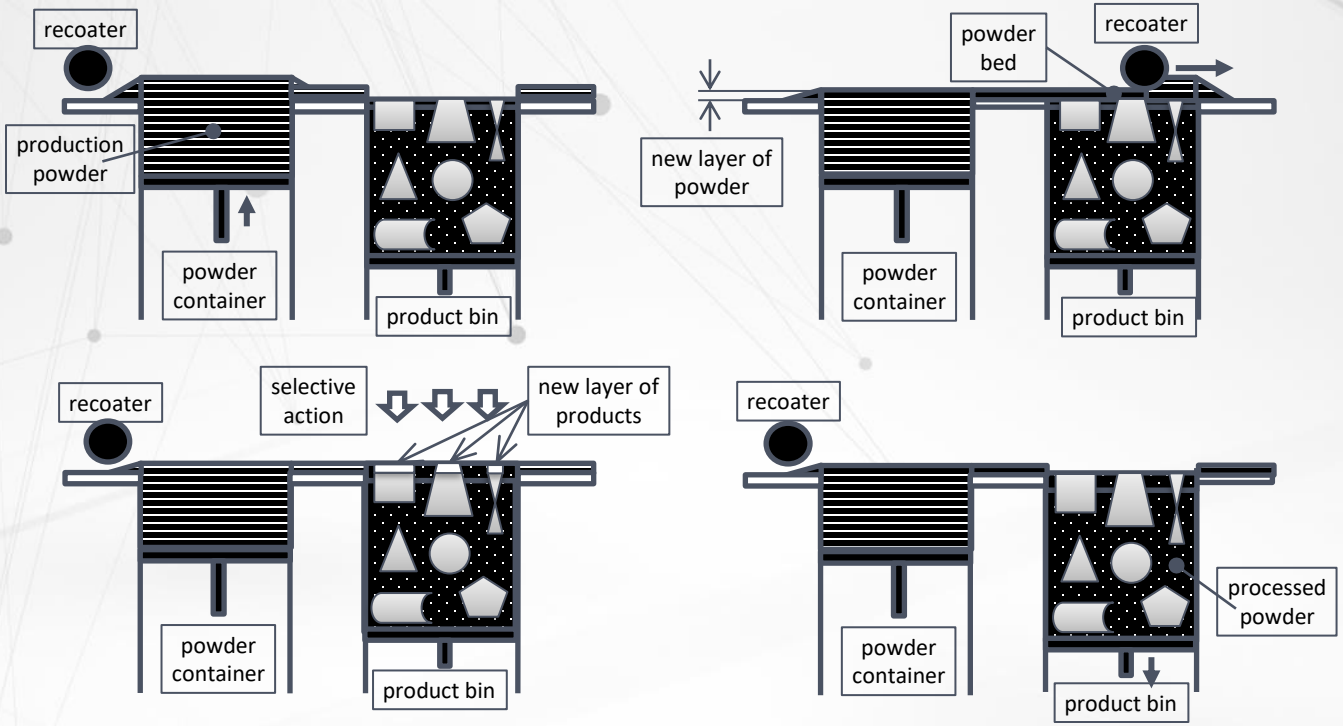
PBF technologies



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PBF technologies

- Simultaneous manufacturing of a set of products (batch) during a single production process in a production chamber
- “Collective” production

THERE ARE NO PRODUCTION COSTS OF INDIVIDUAL PRODUCT

THERE ARE ONLY PRODUCTION COSTS OF A BATCH

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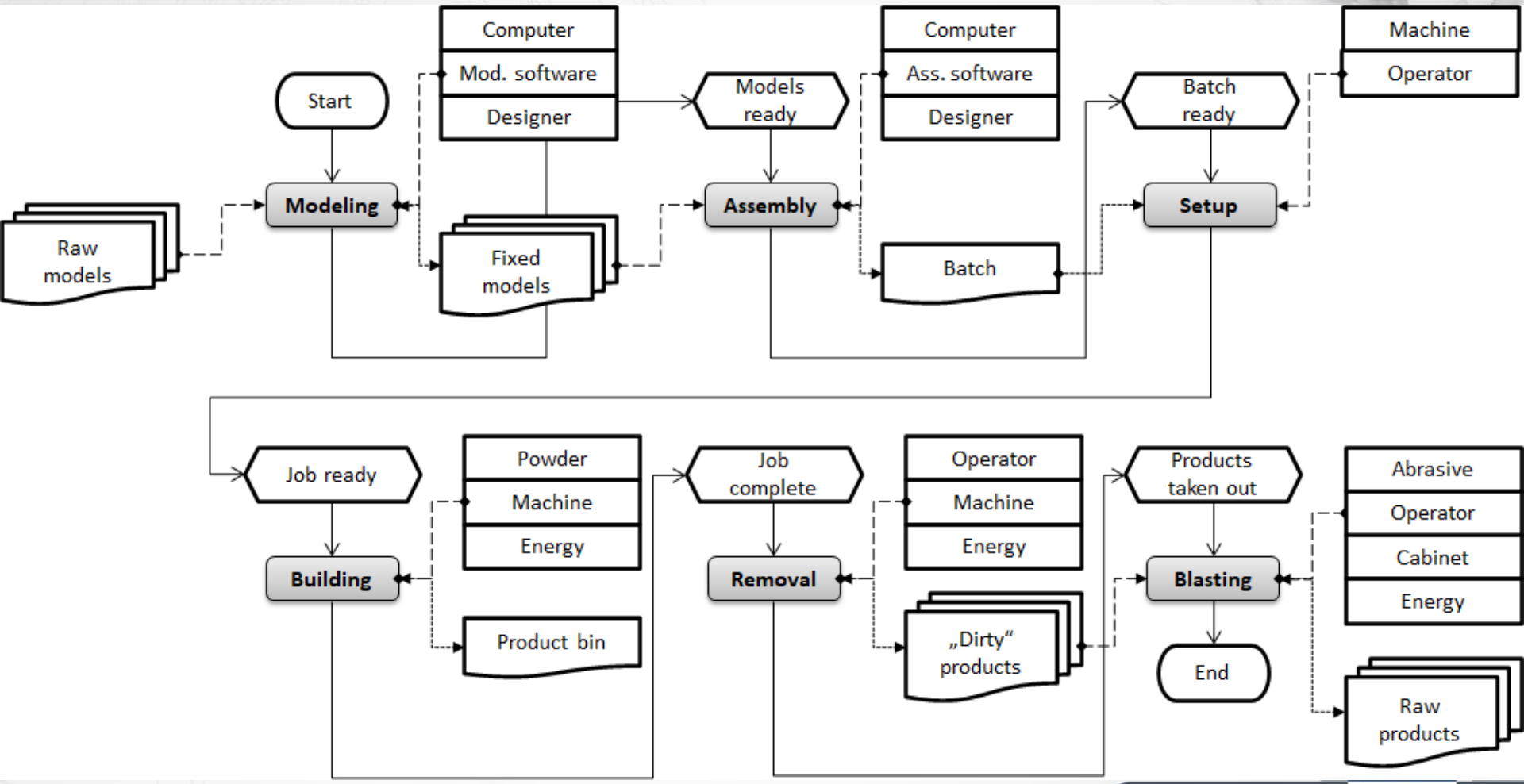
Activity chain model PBF processes



Production costs structure

- Direct production costs
- Indirect production costs

$$C = C_D + C_I$$

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Direct production costs

- Direct production costs
  - Sum of direct costs of all activities

$$C_D = C_{model-D} + C_{ass-D} + C_{setup-D} + C_{build-D} + C_{rem-D} + C_{blast-D}$$

  - Labour costs
  - Material costs
  - Energy costs

$$C_{a-D} = C_{a-L} + C_{a-M} + C_{a-W}$$

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Direct production costs

- Labour costs
  - Designer costs
    - Modeling
    - Assembly
  - Operator costs
    - Preparation
    - Removal
    - Blasting

$$C_{a-L} = C_{des}^{T} \cdot T_a, a = model, ass$$

$$C_{a-L} = C_{oper}^{T} \cdot T_a, a = setup, rem, blast$$

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Direct production costs

- Material costs
  - Building
    - Powder
    - Fusion agent and detailing agent (MJF)
  - Blasting
    - Abrasive

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Direct production costs

- Material costs - building
  - Mixture
    - Used powder
    - Fresh, non-used powder ($r \cdot 100\%$)
  - Fixed consumption
  - Variable consumption

$$C_{build-M-powder} = C^{Q}_{powder} \cdot r \cdot \rho_{powder} \cdot \left(S_{bin} \cdot h + V_{fix} \right)$$

    - Decisive role of the height of a batch
      - Assembly designer skills
      - Inter-part distance limitations
      - Anisotropy of accuracy of production process
      - Number of products in a batch
      - Requested production time

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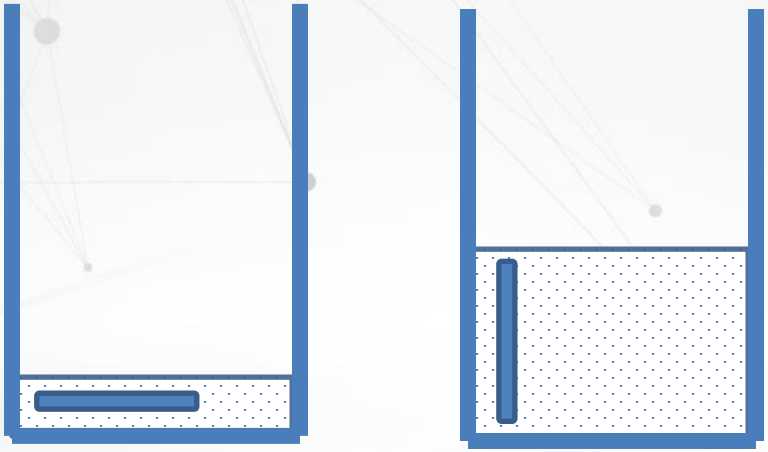
Direct production costs

- Variable material costs - orientation



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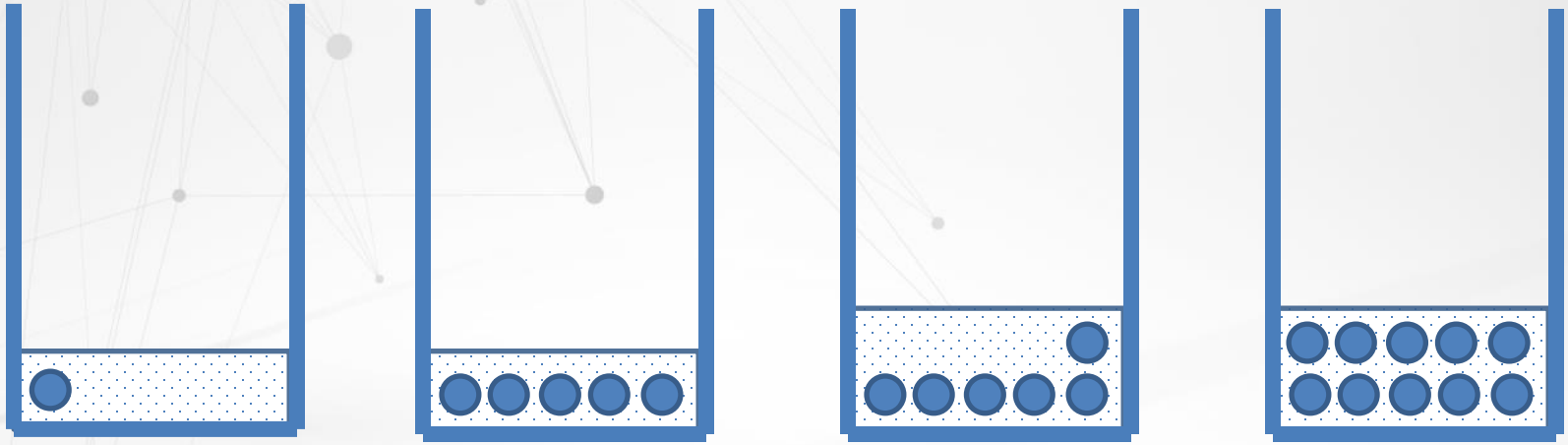
Direct production costs

- Variable material costs - assembly



15 EUR/part | 3 EUR/part | 5 EUR/part | 3 EUR/part

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Direct production costs

- Energy costs
  - Preparation
    - Fixed energy costs
  - Building
    - Duration
      - Height of a batch
      - Spatial distribution of the products in a batch
  - Blasting
    - Blasting cabinet consumption
    - Air compressor consumption

$$C_{prep-W} = C_W^{kWh} \cdot T_{prep} \cdot P_{prep}$$

$$C_{build-W} = C_W^{kWh} \cdot T_{build} \cdot P_{build}$$

$$C_{blast-W-cab} = C_W^W \cdot T_{blast} \cdot P_{cab}$$

$$C_{blast-W-comp} = C_W^W \cdot T_{blast} \cdot P_{comp} \frac{v_{cab}^T}{v_{comp}^T}$$

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Indirect production costs

- Equipment costs
- Overhead costs
- Other indirect costs

- **Exceptionally high with all AM technologies**

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Indirect production costs

- Equipment costs
  - Machine costs
  - Software costs
  - Consumables costs

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Indirect production costs

- Time unit costs of equipment
  - Machine time unit costs
    - Purchase and deprecation costs
    - Maintenance costs
  - Software time unit costs
    - Number of licenses
    - Purchase costs
    - Annual re-activation costs
  - Consumables time unit costs
    - Estimation of annual consumption

$$C_e^T = \frac{C_{e-p} / d_e + C_{e-m}^{ann}}{u_e T^{ann}}$$

$$C_{soft}^T = \frac{C_{soft-p} / d_{soft} + C_{soft-m}^{ann}}{N_{soft-lic} u_{soft} T^{ann}}$$

$$C_{cons-k}^T = \frac{C_{cons-k}^1 \cdot n_{cons-k}^{ann}}{u_e \cdot T^{ann}}$$

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Indirect production costs

- Overheads
  - Existing without production
  - Management and administration
  - Renting/purchase of rooms
  - Heating, water, electricity
  - …
- Other indirect costs
  - Connected to production
  - Material handling and disposal
  - Transport
  - …

$$C_{over} = R_{over} \cdot \left(C_D + C_E + C_X \right)$$

$$C_{X-k} = \frac{C_{X-k}^{per}}{u_e \cdot T_k^{per}} T_{build}$$

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Product costs

- A single product costs?!
  - Common costs independent of production volume
  - Number of products relevant, but not straightforward
  - Batch volume and height
- Rough estimation assumptions
  - Modelling and overhead costs increase with number of types of products
  - Assembly, preparation, removal and other indirect costs increase with number of products
  - Building costs increase with volume of products
  - Blasting costs increase with surface of products

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Product costs

- t product types
- n_k products of type k (k=1,2,..,t)
- V_k total volume of products of type k
- S_k total surface of products of type k

$$x_{n-k} = \frac{n_k}{\sum_k n_k} \qquad x_{V-k} = \frac{V_k}{\sum_k V_k} \qquad x_{S-k} = \frac{S_k}{\sum_k S_k}$$

$$c_k = \frac{1}{n_k}\left\{\frac{C_{model} + C_{over}}{t} + \left(C_{ass} + C_{prep} + C_{rem} + C_X\right)\cdot x_{n-k} + C_{build}\cdot x_{V-k} + C_{blast}\cdot x_{S-k}\right\}$$

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Production costs calculation

- SLS technology 66 parameters
- MJF technology 76 parameters
- DMLS technology
  - Support costs
  - Inert gas consumption
  - up to 130 parameters

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amadam

additive manufacturing

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Thank you!

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