Presentation

“Exploring The Capabilities And Costs Of Additive Manufacturing Technologies For Production“

Date: 19.11.2013
3D Printing & Additive Manufacturing Summit 2013
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Dipl.-Wirt-Ing. Christian Lindemann
Introduction

DMRC - Direct Manufacturing Research Center

Cooperation with the Industry and the UPB and the State of North Rhine Westphalia

Aim of the DMRC
→ Show advantages to potential users
→ Continuous development of DM-Technologies

Direct Manufacturing System
→ Reliable
→ Repeatable
→ Production Capable
Difference between Systems

3D- (Home)Printing

Professional Systems (DMRC Equipment)

sources: Makerbot, Fabster, EOS, SLM Solutions, Stratasys
Key Factors For Successful Use

Design for AM from scratch → Don’t use existing parts

Selection of an appropriate process and material

Use Proper Design Rules

Consider production only if utilization rate is high

Get inspired by existing solutions – e.g. bionik

Always be aware of the existing limitations of the process.
Define build direction at the beginning.
Consider necessary post processing steps.
Take additional values during product lifecycle into account!
## Example for Design rules

### Basic Elements

**Plates**
- **Thickness**
  - Description: Plates should be so thick that each layer can be structured of a contour with inscribed raster to minimize dimensional deviations and to avoid defects.
  - **LS:** $S > 1.0$ mm
  - **LM:** $S > 0.6$ mm
  - **FDM:** $S > 1.5$ mm

### Element transitions

**Firmly bonded**
- **Inner corners**
  - Description: Interior corners should be rounded to remove disperse support material more easily.

### Sources

**Source:** Adam, Zimmer; Project Direct Manufacturing Design Rules; DMRC Yearly Report 2012
Important Influence Factors

Influence of Cost Drivers

Product Complexity → Process Change → Machine Rate Costs → AM Costing Curve

Product Requirements → Machine Rate Costs → AM Lifecycle Costs

Costs

Traditional Manufacturing → Additive Manufacturing

Quantity

AM Lifecycle Costs

Preliminary departments:
- Engineering
- Supply
- Product Scheduling

Performance departments:
- Production
- Logistics
- Quality Management

Subsequent departments:
- Service
- Sales
- Product Recycling

Administration

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Nov. 19th 2013
LCC Overview – Cost Model

Concept and definition
- Requirements
  - Functional Specification
- Analysis Costs

Design and development
- Techn. Drawing (CAD)
- Comp. Design (FEM)
- QM-Planning
- Production Planning
  - Prototyp (1/2)
  - Testphase (1/2)

LCC
- Manufacturing
- Developed Production Model
  - Assembly
  - Transport

Installation

Operation and Maintenance
- Operating Costs
- Warehousing Costs
- Maintenance

Disposal
- Disassembly

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Nov. 19th 2013
Cost Model for Build Process

- Main problems:
  - Exact build time estimation
  - Build rate estimation
  - Fixed amount for labor
  - Material costs are not part of build costs
  - Calculation by volume and density
  - Machine rate costs from 35 - 80 €
Impact of Placement

- Two identical parts
- Price difference of 25%
- Post processing of minor interest
- Consider stair stepping
- Building rates increase with load factor

Variation of placement

<table>
<thead>
<tr>
<th>Layout A</th>
<th>Layout B</th>
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<tbody>
<tr>
<td>Material</td>
<td>Bauvorgang</td>
</tr>
<tr>
<td>Vorbereitung</td>
<td></td>
</tr>
</tbody>
</table>

Variation of placement graph:

- Material
- Bauvorgang
- Vorbereitung

Building speed in ccm/h

- Ti6Al4V
- 316 L

Occupancy rate of Building Chamber in %
### Variation on Different Parameters

#### Costpreparation
- Buildingprocess_fix
- Oven
- Material Costs
- Postprocessing
- Machine Costs

#### Costbreakdown

**Building rate**: 6.63% of 63ccm, 10.20% of 12ccm, 22.88% of 20ccm, 11.35% of 4500h, 13.59% of 6000h, 15.75% of 7800h, 11.35% of 89€, 15.78% of 40€, 13.65% of 600€, 6.63% of 500000€, 7.95% of 200000€, 9.23% of 320000€

**Utilisation rate**: 3.86% of 63ccm, 6.63% of 12ccm, 17.44% of 20ccm, 11.35% of 4500h, 6.63% of 6000h, 9.23% of 7800h, 11.35% of 89€, 15.78% of 40€, 13.65% of 600€, 6.63% of 500000€, 7.95% of 200000€, 9.23% of 320000€

**Material Costs**: 6.63% of 63ccm, 10.20% of 12ccm, 22.88% of 20ccm, 11.35% of 4500h, 13.59% of 6000h, 15.75% of 7800h, 11.35% of 89€, 13.65% of 40€, 15.78% of 600€, 6.63% of 500000€, 7.95% of 200000€, 9.23% of 320000€

**Machine costs**: 6.63% of 63ccm, 10.20% of 12ccm, 22.88% of 20ccm, 11.35% of 4500h, 13.59% of 6000h, 15.75% of 7800h, 11.35% of 89€, 13.65% of 40€, 15.78% of 600€, 6.63% of 500000€, 7.95% of 200000€, 9.23% of 320000€

#### Breakdown by Volume and Time

<table>
<thead>
<tr>
<th>Volume</th>
<th>Costbreakdown</th>
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<tr>
<td>6.3ccm</td>
<td>6.63%</td>
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<tr>
<td>12ccm</td>
<td>10.20%</td>
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<tr>
<td>20ccm</td>
<td>22.88%</td>
</tr>
<tr>
<td>4500h</td>
<td>11.35%</td>
</tr>
<tr>
<td>6000h</td>
<td>11.35%</td>
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<td>7800h</td>
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### Building rate in ccm/h

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<tr>
<td>6.3ccm</td>
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<tr>
<td>12ccm</td>
<td>2.91 €</td>
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<tr>
<td>20ccm</td>
<td>1.75 €</td>
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<td>40€</td>
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<td>600€</td>
<td>5.77 €</td>
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#### Material Costs in €

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<td>5.77 €</td>
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<td>500000€</td>
<td>5.54 €</td>
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### Machine Investment costs in €

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<tr>
<td>89€</td>
<td>0.86 €</td>
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<tr>
<td>600€</td>
<td>0.38 €</td>
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<tr>
<td>500000€</td>
<td>0.86 €</td>
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<tr>
<td>200000€</td>
<td>0.86 €</td>
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<tr>
<td>320000€</td>
<td>0.86 €</td>
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</table>
Complexity of Parts as Advantage

- Flexible production
- Integration of functions
- Freedom of design
- Less assembly/monolithic design
- Less time-to-market
- Individualization
- Fast deployment of changes
- No production tools necessary
- Safety against product piracy
Sample Part for Considerations
FEA – Optimized Part

- Weight reduction from 515 g to 305 g (40%)
- Original block was around 16 kg
- Waste of 15.5 kg
- AM material need was 0.72 kg
- Costs down from 1000 € to 400 € (60%)
- Reduction potential in minimizing supports
- No consideration of longstanding

Material Costs 43.20 € in AM (60 € / kg)
Material Costs Milling 162 € (10€ / kg)
Costs per Piece

- Build Rate: 6.3 cm³/h
- Build Material: Stainless Steel 316L
- Material Price: 89 €/kg
- Part Volume: 38.5 cm³
- Layer thickness: 30 µm
**Product Examples**

Example developed in the DMRC consortium focusing a wheel of a water pump generating an air-water mixture

- High batch production feasible
- Higher Efficiency
- No Product Piracy

- Production in Aerospace feasible for high buy to fly ratios
- Profitable for complex parts

Source: [www.airliners.net](http://www.airliners.net)  [www.fst.tu-harburg.de](http://www.fst.tu-harburg.de)
**Branch dependency**

- A lot of data needed for exact and dependent calculations
- Application strongly dependent on branch and application
- Development of adoptable standard models required
- Option to create standard models for different branches
- Production quantities and innovation cycles vary strongly
- Development of application scenario profiles

Source: [http://econolyst.co.uk](http://econolyst.co.uk)
**Scenario Description Profiles**

### Scenario Description: Aeronautics

**Application**
- The wheel carrier is interpreted as a part of the alighting gear.
- Boeing B757 has one nose landing gear and two tailwheel units.
- The alighting gears enable the plane to move on the ground.

**Analyzed Object**
- Boeing B757
- **Need:** 1.050 (NLG) bzw. 2.100 Pc. (TU)
- **Lifetime (Mileage):**
  - 50,000 flight hours (30,500 km)
  - 10,000 flights

### Weight Impact
- Average reduction of 0,041 kg fuel per kg weight each flight
- Every consumed kg fuel causes about 3,12 kg CO₂
- Requirements to reduce greenhouse gas emissions by law

### Cost Impact
- Running costs are focussed
- Costs for jet fuel cause about 20% of all operating expenses of the biggest German Airline

### Supply Chain
- Typically 4 levels
- Suppliers of parts, components and systems as well as aircraft manufacturers

### Obligatory Certification
- Obligatory certification in accordance with the international EN/AS9100 standards
- Entry in the international OASIS Database of the IAGQ
- EASA type-certification

### Obligatory Quality Tests
- Automated dimensional test
- Transmission/fluoroscopy test*
- Penetration inspection*
  - Assumption analogous to the automotives

### Applications
- OEM Business
- Spare Parts Business
Benefits of Additive Manufacturing in Supply Chain

- Storage of raw material and no end parts (tools) → more available „cash“
- Local production possible (knowledge intense)
- Less waste – reduction of carbon emissions
- Mass customisation

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>Additive</th>
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<tbody>
<tr>
<td>Logistic Steps</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Land Use (m²)</td>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>294.860 Kw/h</td>
<td>60.583 Kw/h</td>
</tr>
<tr>
<td>Silicone, Wax, Water</td>
<td>5000kg</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>250 kg, 3000L</td>
<td></td>
</tr>
<tr>
<td>Local Employment</td>
<td>35%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: www.melotte.be
Agenda

Introduction
Cost Implications
Interpretation
Interpretations 1/2

• Building process costs
  • Increase of building rate most effective to decrease costs
  • Machine costs will also in the future be the major part
  • Utilisation rate needs to get improved (make vs. buy)
  • Investment costs will drop with a further spread of the technology

• Material Costs
  • Influence of material costs depends on the volume of the part and the material
  • Influence of material costs will decrease (e.g. lattice structures)
  • Material costs will drop with a further spread of the technology
Interpretations 2/2

- **Post-/Preprocessing**
  - Influence is even bigger than in the example
  - Knowledge and labor necessary
  - Better software and knowledge will help to reduce times

- **General Findings**
  - Design optimization not always the way to go (small vs. large production batches)
  - Regression effect of the optimisation regarding numbers limits the use of the topology optimisation in a major way
  - Proper design rules will help as well (saving time/ support/ post processing) → Optimisation driven design
Innovation Roadmap – What will the future bring?

Innovation Roadmap for Powder Bed Fusion - Metal

Build chamber volume (V in m³)
- 1 m³ ≤ V ≤ 2 m³
- 2 m³ < V ≤ 8 m³
- V > 8 m³

Build-up rates (B) (production speed at highest quality in cm³/h)
- 80 cm³/h ≤ B ≤ 120 cm³/h
- 120 cm³/h < B ≤ 150 cm³/h
- B > 150 cm³/h

Dimensional accuracy (average deviation in μm)
- < ± 25 μm
- ± 25-50 μm

• Main influence rates
• Increased productivity (building speed)
• Decreased material costs
• Higher utilization rates
• Increased building chamber volume and feed size
• Assumption: machine prices remain stable due to technical innovation
Ongoing Research

- Comparison of different supply chain and business models
- Detailed real part and branch analysis for different design methodologies
- Development of standardised build rate measurement
- Implementing and enhancing the current methodology in software
- Development of branch/product dependent data sets
- User-Guideline for cost efficient design

source: effectivemarketingconcepts.com
• EU – FP7 Transport
• Total Budget: 5,951,426 €
• Funding of EU: 4,276,352 €
• Project Volume UPB: 973,480 €
• Project Duration: 36 Month

• Main Objectives:
  1. Reduce repair and overhaul costs of complex spare parts
  2. Increase the automation level for spare parts production
  3. Reduce scrap and toxic chemicals in the repair process and part weight by the use AM
  4. Increase the technology readiness level (TRL) for ATT

Website: www.rep-air.eu
Thank you for your attention!

Find the Annual Report and Future Studies of the DMRC:
http://dmrc.uni-paderborn.de/downloads/

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