3D-Drucker/Generative Fertigung – Wie sich die Produktion verändert und die Logistik vor neue Herausforderungen stellt

Logistiktag 2014, Kassel, Germany, June 25, 2014

Adj. Prof. (RMIT) Vis. Prof. (NUAA) Akad. Oberrat Dr.-Ing. Ingomar Kelbassa

Dr.-Ing. Andres Gasser

Dr.-Ing. Dipl.-Phys. Wilhelm Meiners

Dipl.-Phys. Christian Hinke

Dipl.-Ing. Gerhard Backes

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Content

- Motivation
- Process basics
- Developments & Applications
- Digital Photonic Production

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Mega Trends

Political Conflicts

Change of Work

Globalization

Health

Demographic Change

Climate Change

Knowledge Society

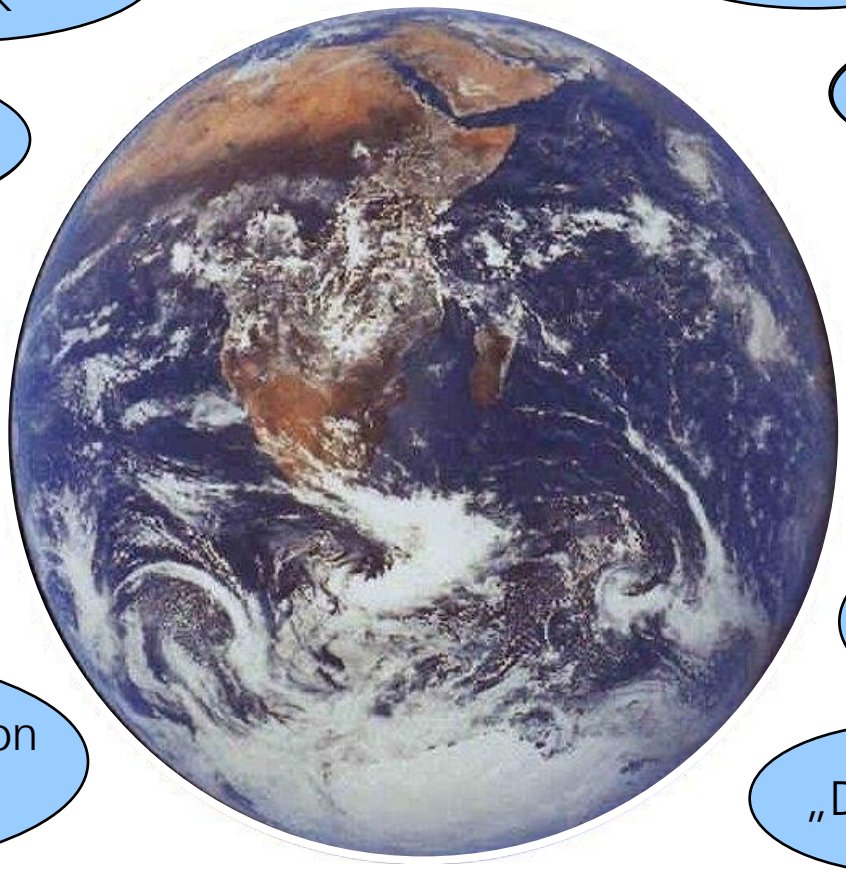
Value Change

Mobility and Transport

New Production

Energy Consumption and Resources

„Dynaxity“



„Fraunhofer Gesellschaft Z punkt.-Lebenswelten 2015 plus“, „Siemens-Horizons 2020“

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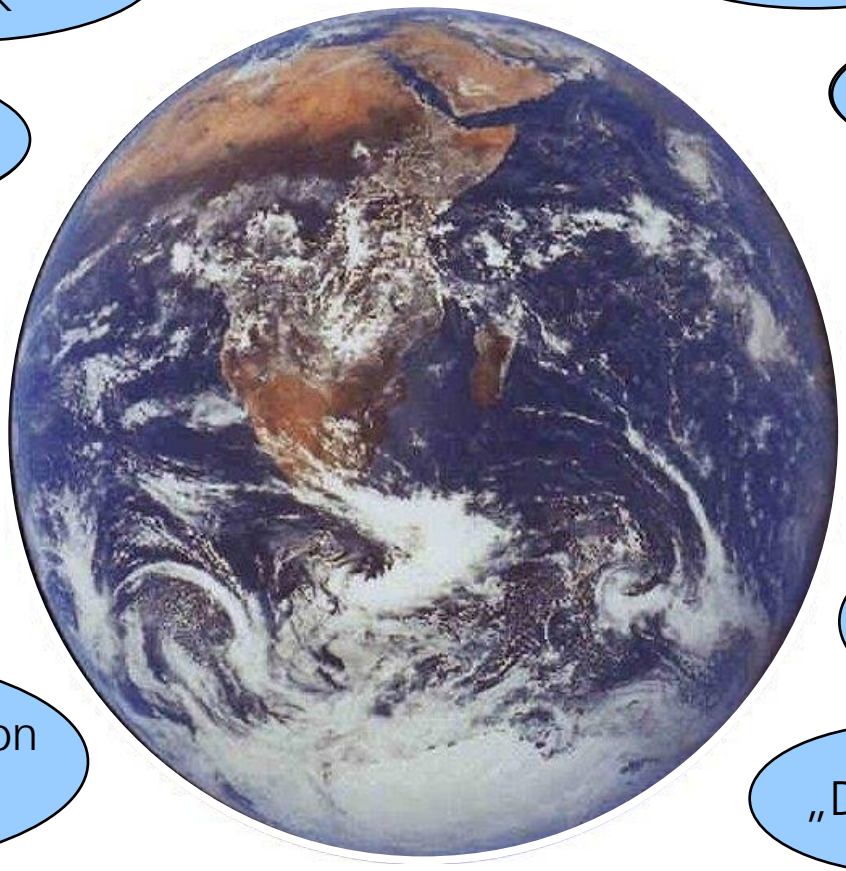
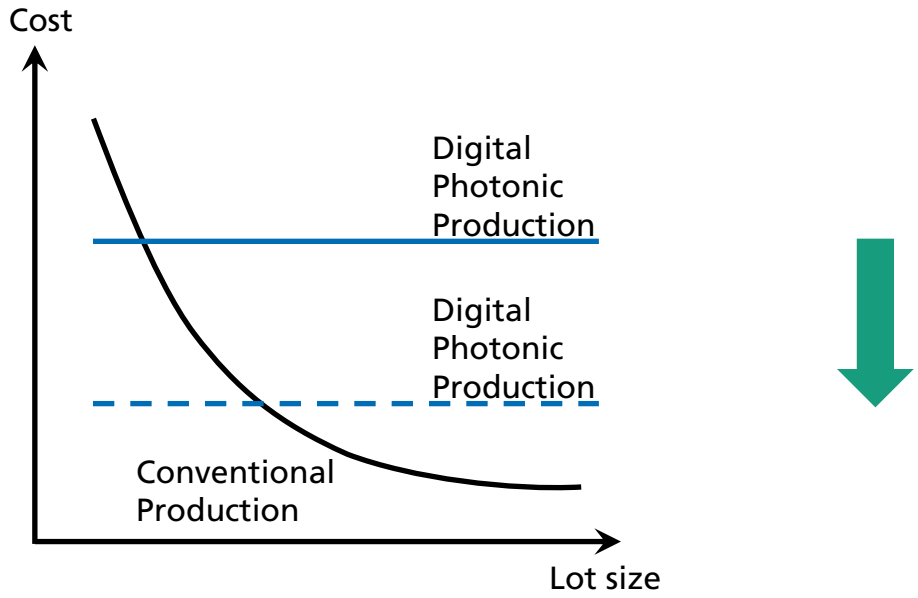


„Fraunhofer Gesellschaft Z punkt.-Lebenswelten 2015 plus“, „Siemens-Horizons 2020“

Direct Photonic Production



Increase in deposition rate = Decrease in cost!
„Time is money“

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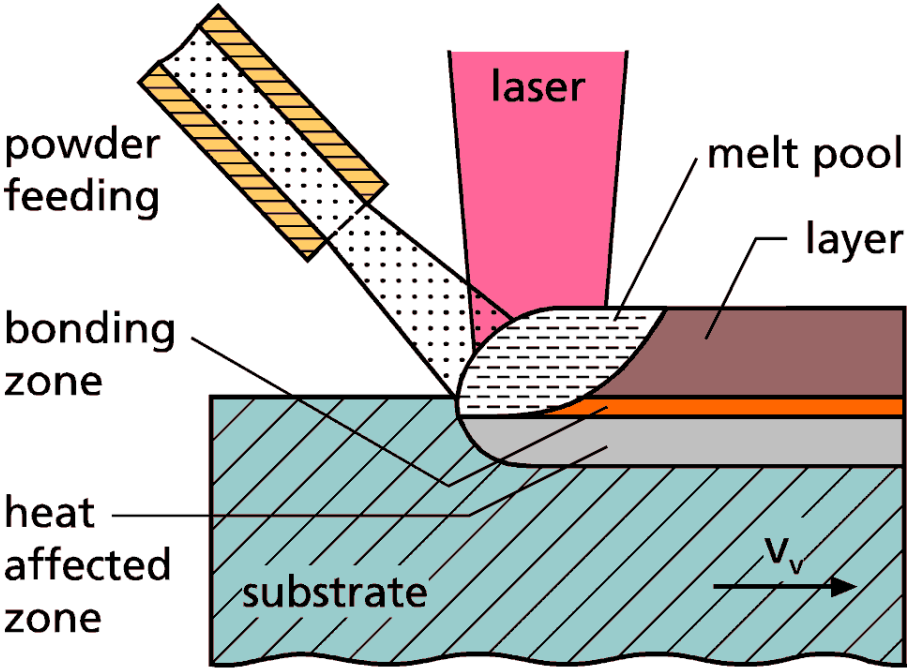
Laser Material Deposition LMD
>> 1 step process <<

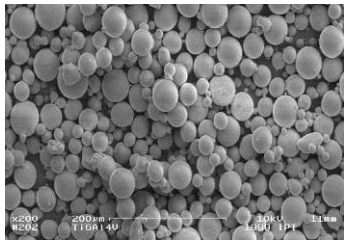


b:\a23\2006\zusatzwerkstoffe\230331067E-LMD.png

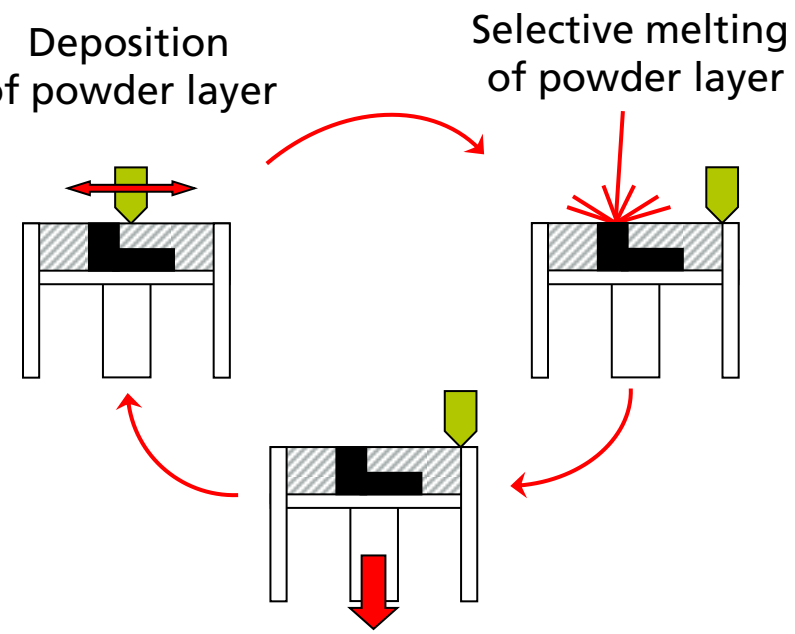
Selective Laser Melting SLM
>> 2 step process <<

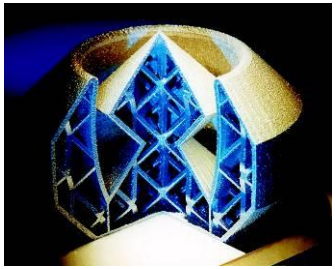
3D CAD model, sliced into layers

+



Metal powder





Metal part made from serial material

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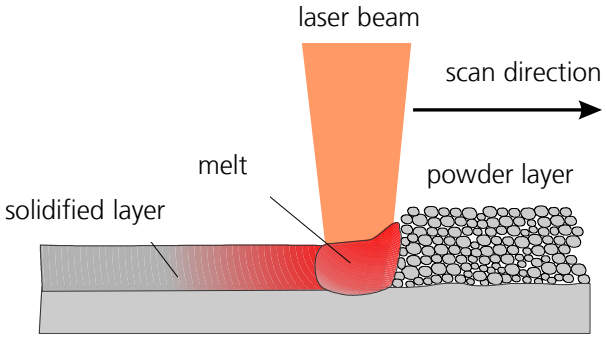
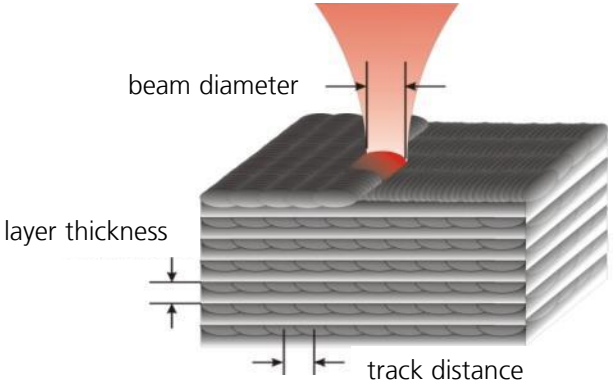
Selective Laser Melting SLM – Basic Principle

- use of serial material
- complete melting of the powder particles
- part density of 100%
- preheating device enables processing of a wide range of materials:
  - Titanium alloys
  - Aluminum alloys
  - Steel
  - CoCr alloys
  - Nickel alloys





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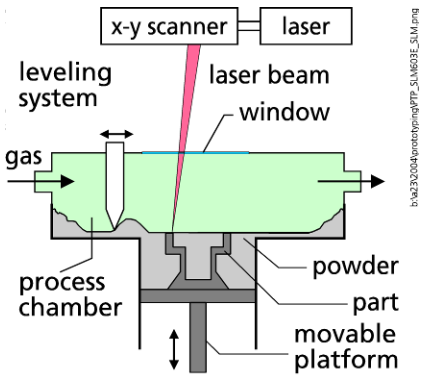
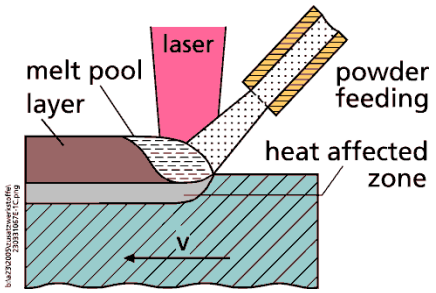
Comparison of the characteristics SLM / LMD

Selective Laser Melting (SLM)



Laser Metal Deposition (LMD)



characteristics	LMD	SLM
materials	large materials diversity	• limited and lower experience in comparison to LMD
part dimensions	limited by the handling system	limited by the process chamber (ø : 250 mm, height : 160 mm)
part complexity	limited	nearly unlimited
dimensional accuracy	≥ 0.1 mm	≥ 0.1 mm
deposition rate	3 – 10 mm^3/s	1 – 3 mm^3/s
build-up on	• 3D-surface • on existing parts	• flat surface • flat preforms
roughness R_z	60 – 100 µm	30 – 50 µm
layer thickness	≥ 0.03 - 1 mm	≥ 0.03 - 0.1 mm

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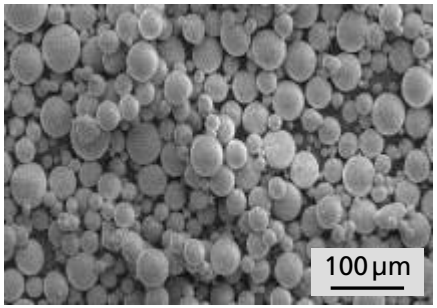
Fields of expertise for process development

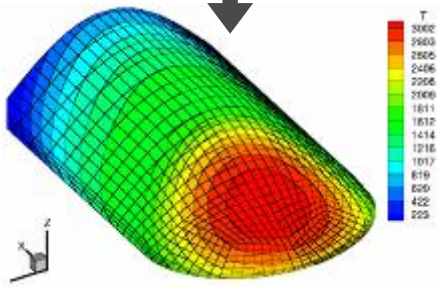
Systems engineering

Process layout

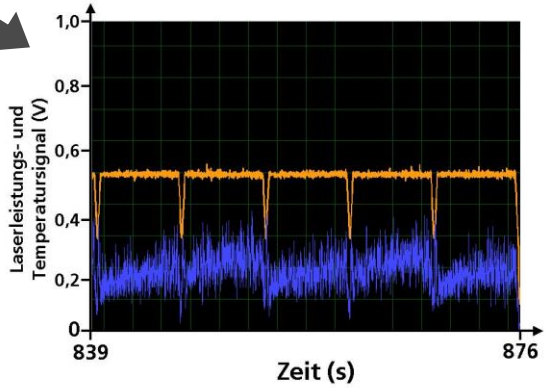
Materials



Beam source(s)

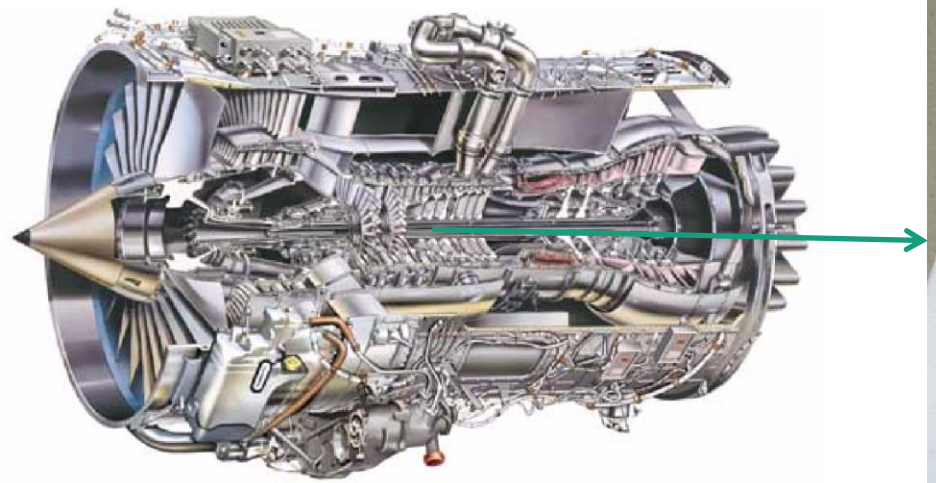


Process fundamentals



Process monitoring

BLISK – BLade Integrated DiSK or BLaded DISK



Source: Rolls-Royce Deutschland Ltd & Co KG

Compared with conventional parts:

Pro: Lower weight (- 30 %)

Pro: Higher pressure ratio / stage

Pro: Smaller moment of inertia

→ Higher specific efficiency

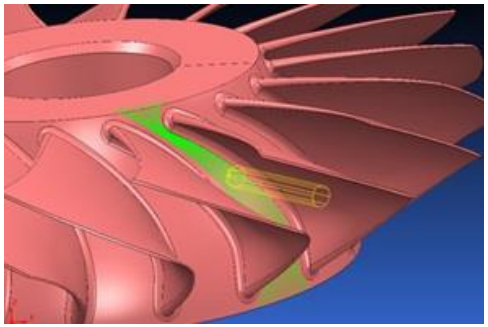
→ Saving of resources

Con: High manufacture / repair costs

BLISK manufacture today and tomorrow

From material removal (Stone Age thrugh today)…

…to additive manufacture (tomorrow)



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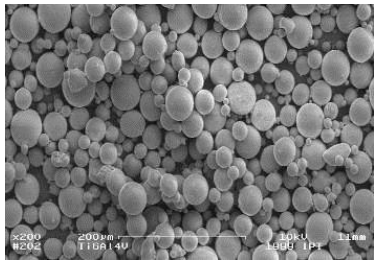

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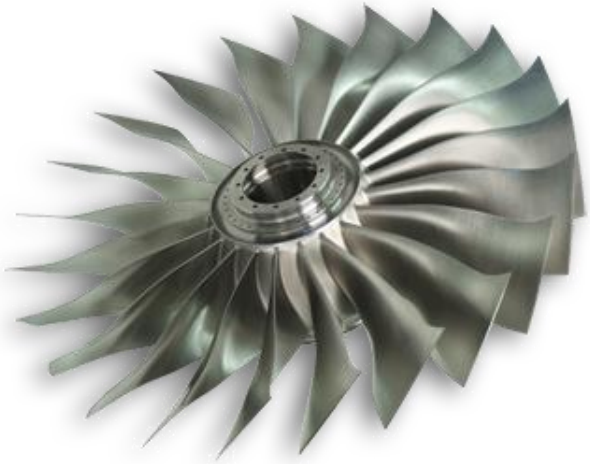

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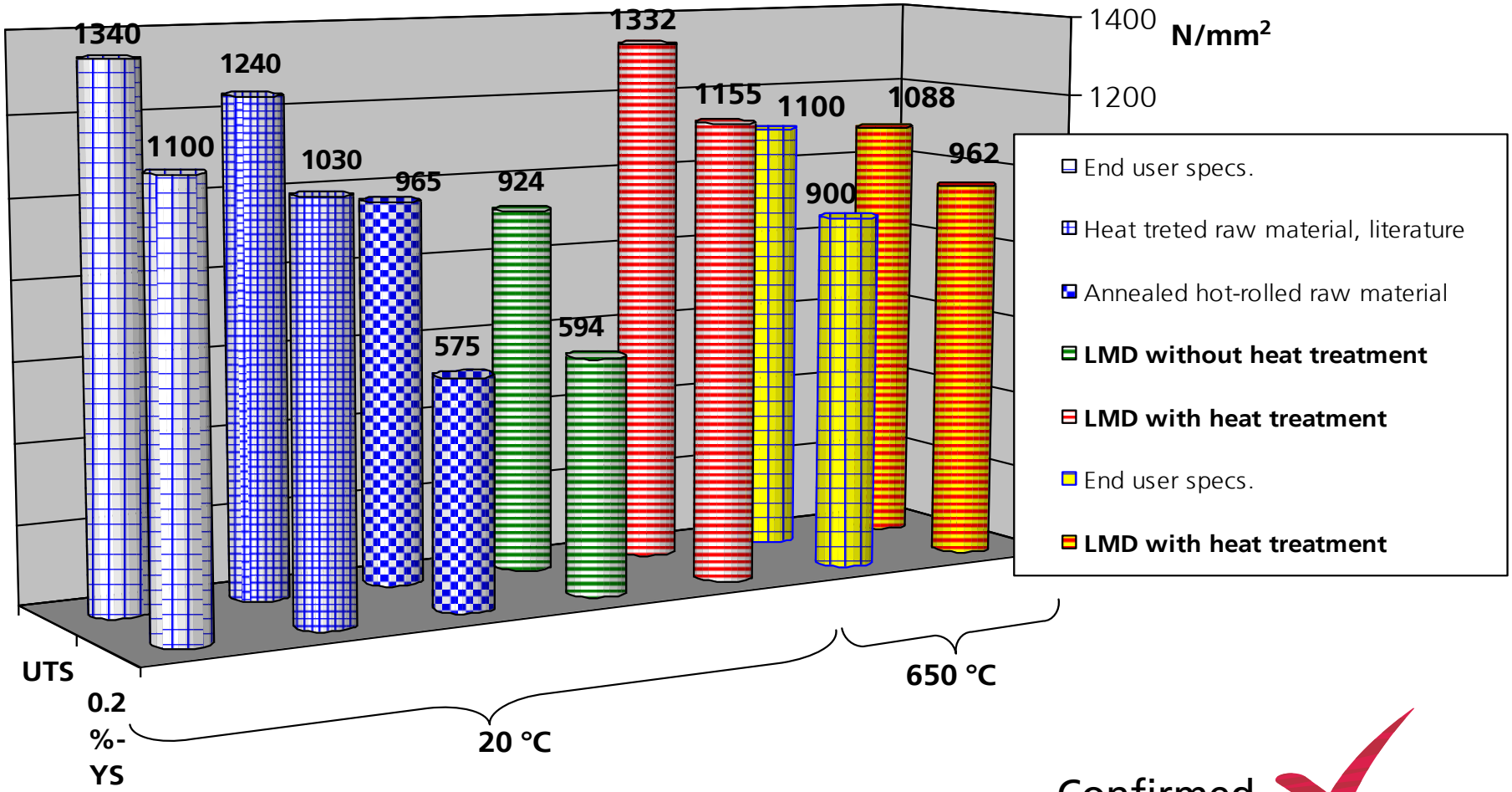
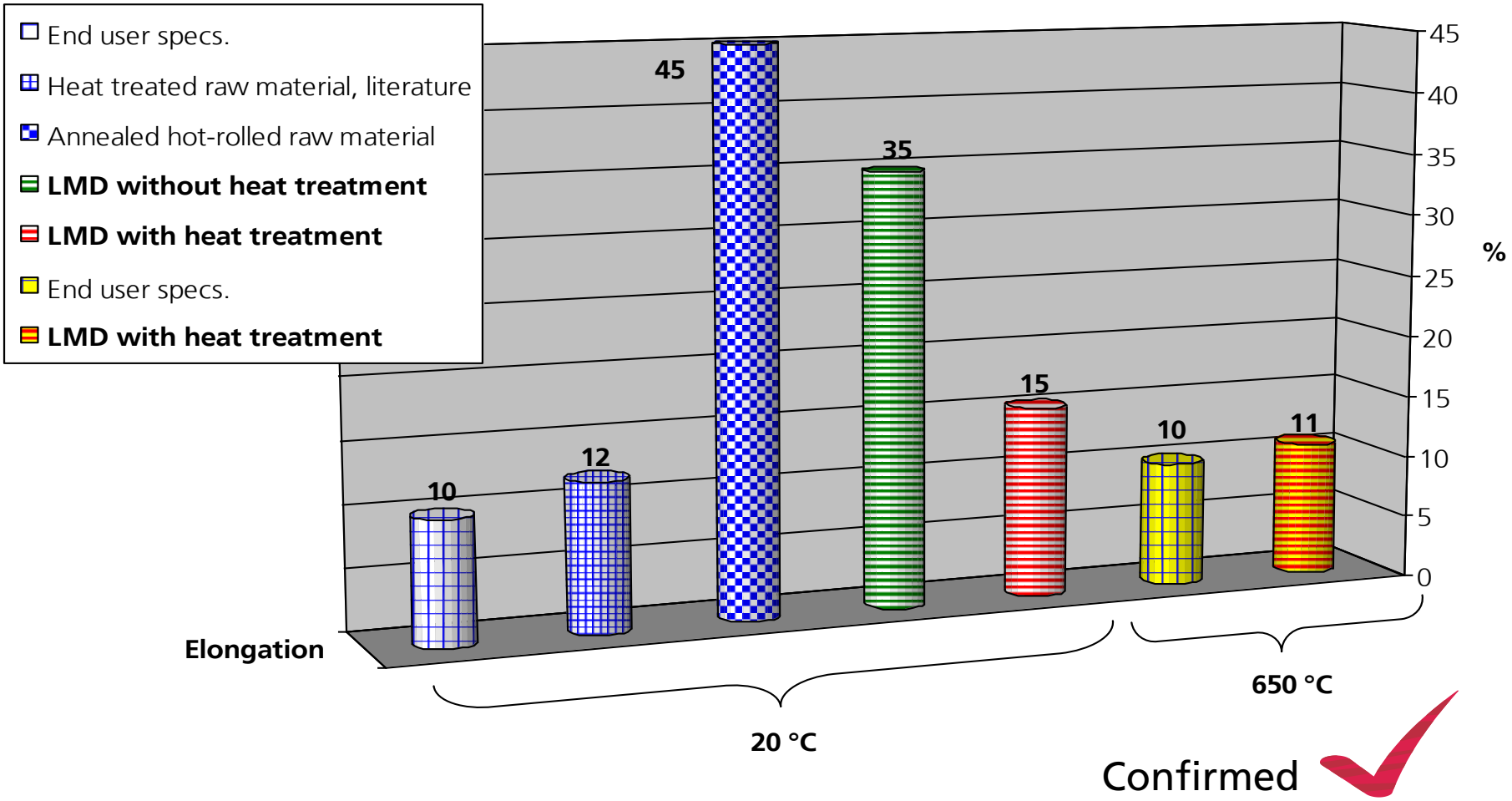
Static mechanical properties I



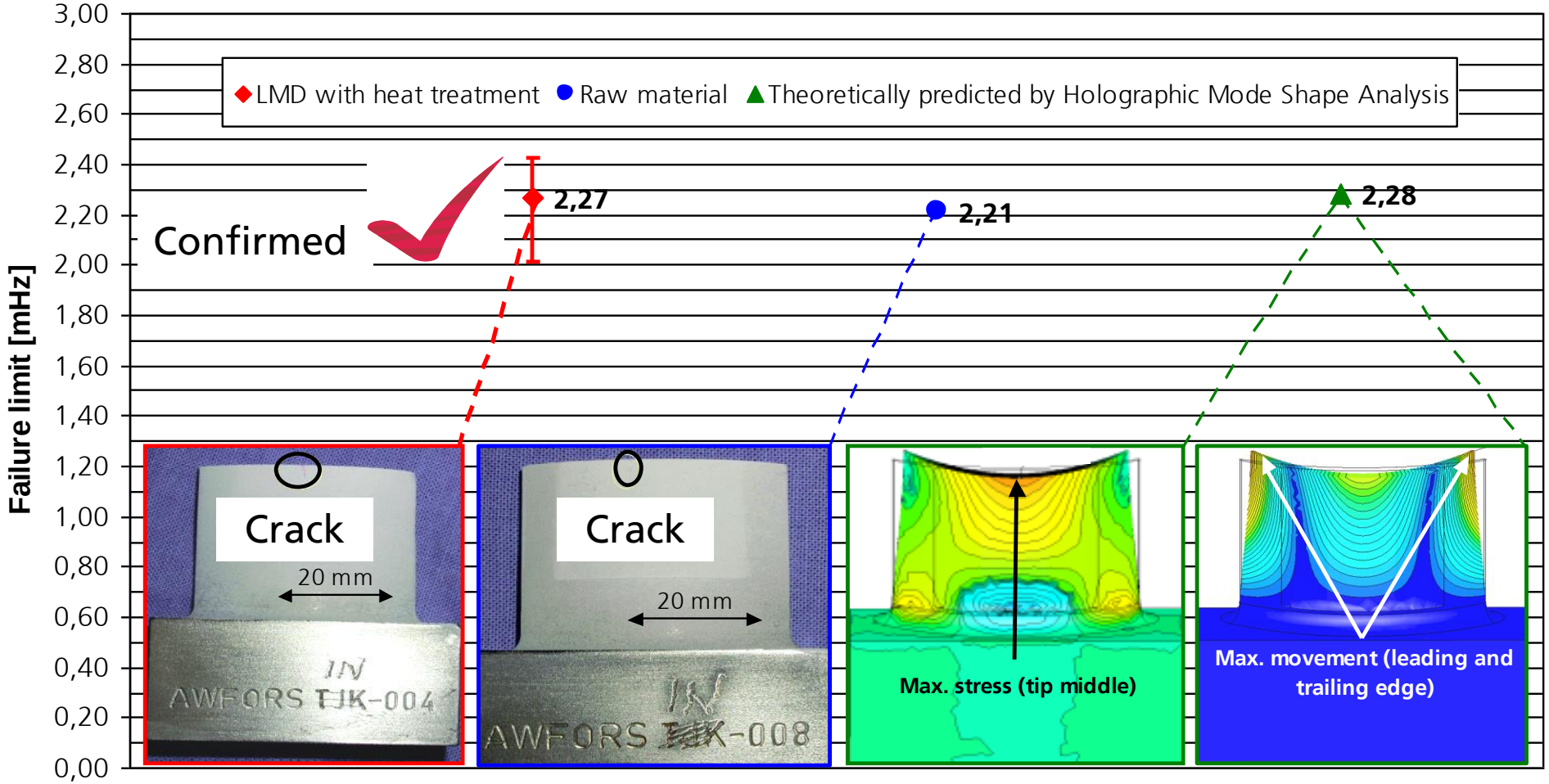
Confirmed

Static mechanical properties II



Confirmed

Dynamic mechanical properties (HCF, 1C mode)



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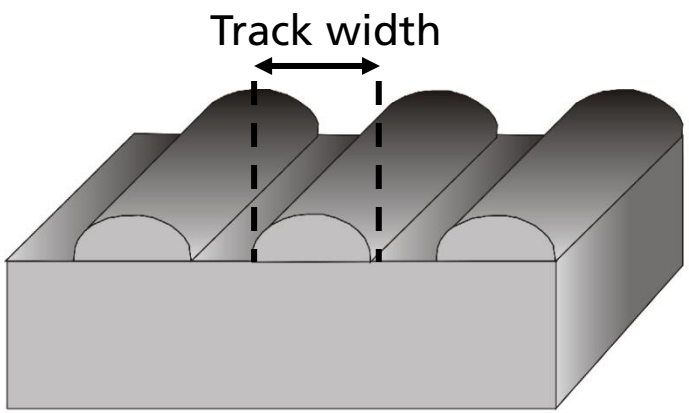
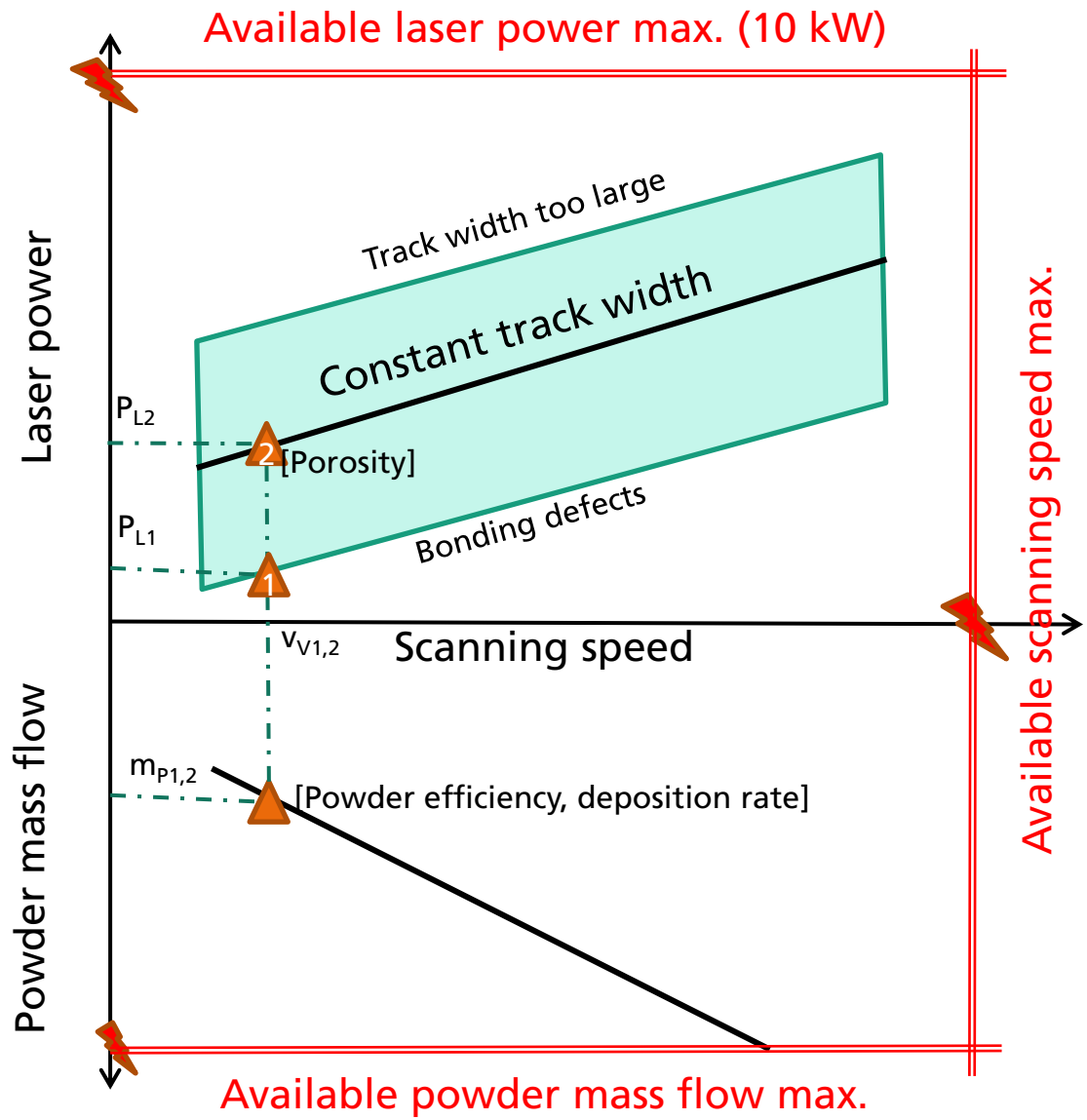
LMD diagram

- Depiction of appropriate process windows for a constant track width
- Information regarding porosity
- Information regarding powder efficiency





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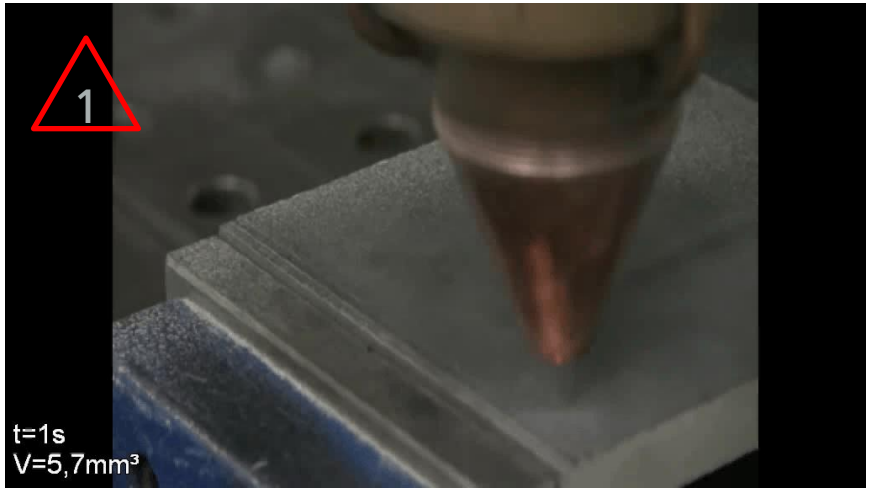
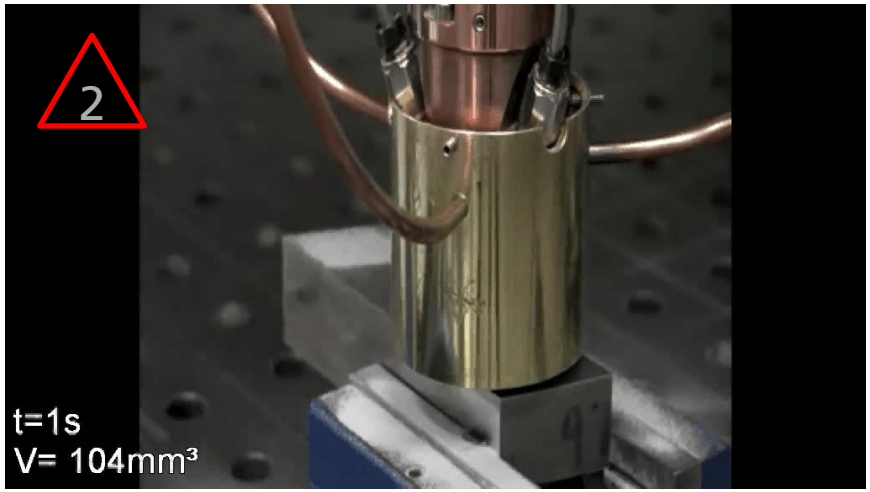
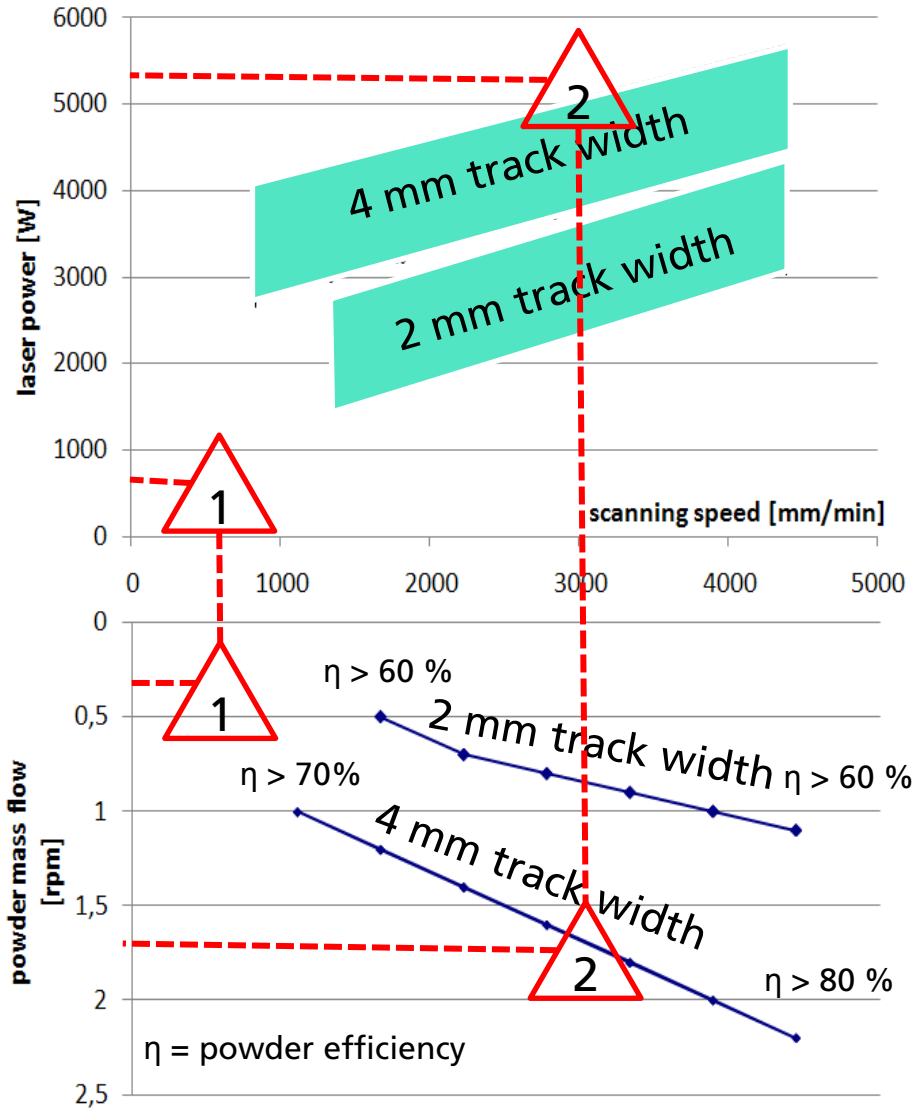
LMD of cuboids







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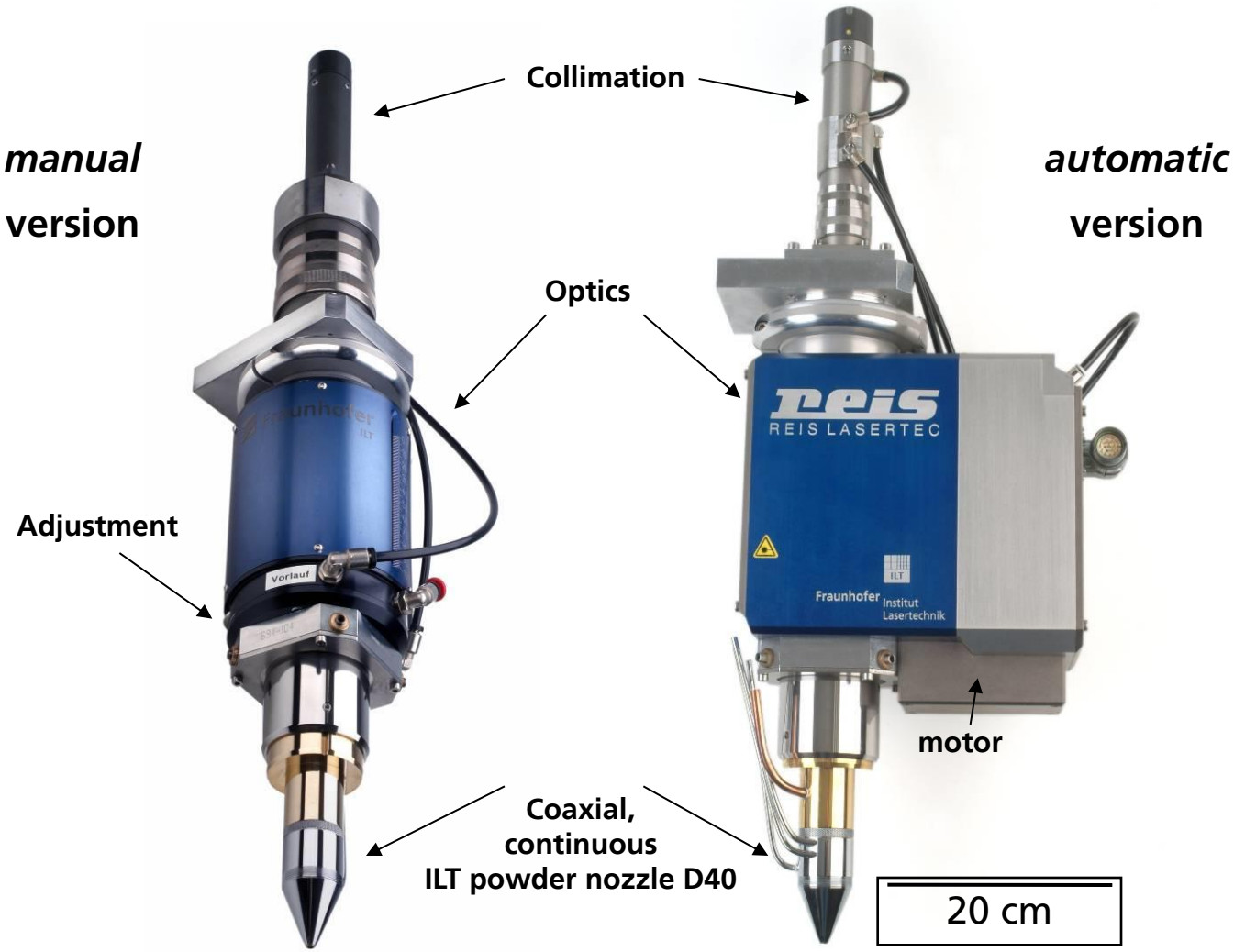
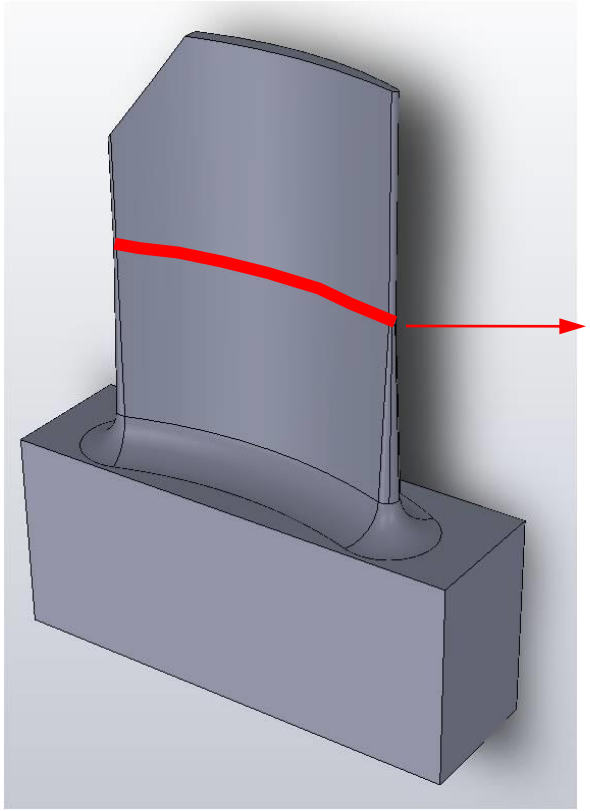
Zoom optics for on-line variation of laser beam diameter

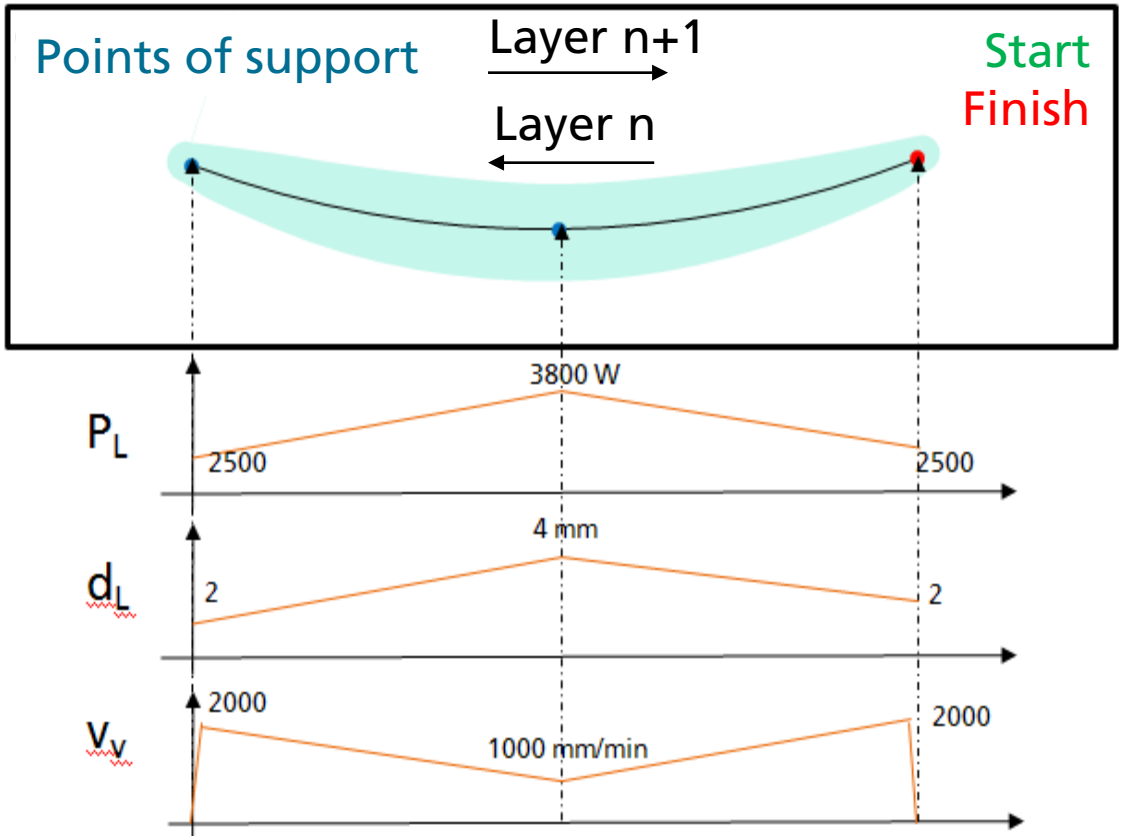


Near-net-shape build-up of BLISK blade mock-ups



HPC FRONT DRUM HCF TEST SPECIMEN
(Source: Rolls-Royce Deutschland Ltd & Co KG)

Process strategy for blade build-up



Near-net-shape build-up of BLISK blade mock-ups

Additive manufacture of one BLISK blade in t < 2 min. (near-net-shape)

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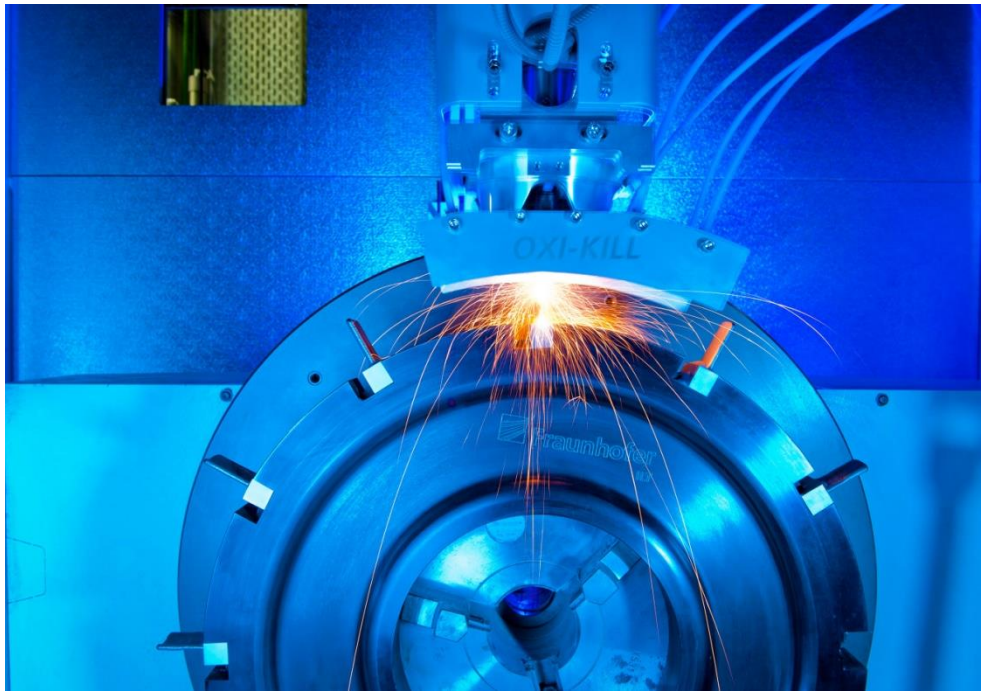
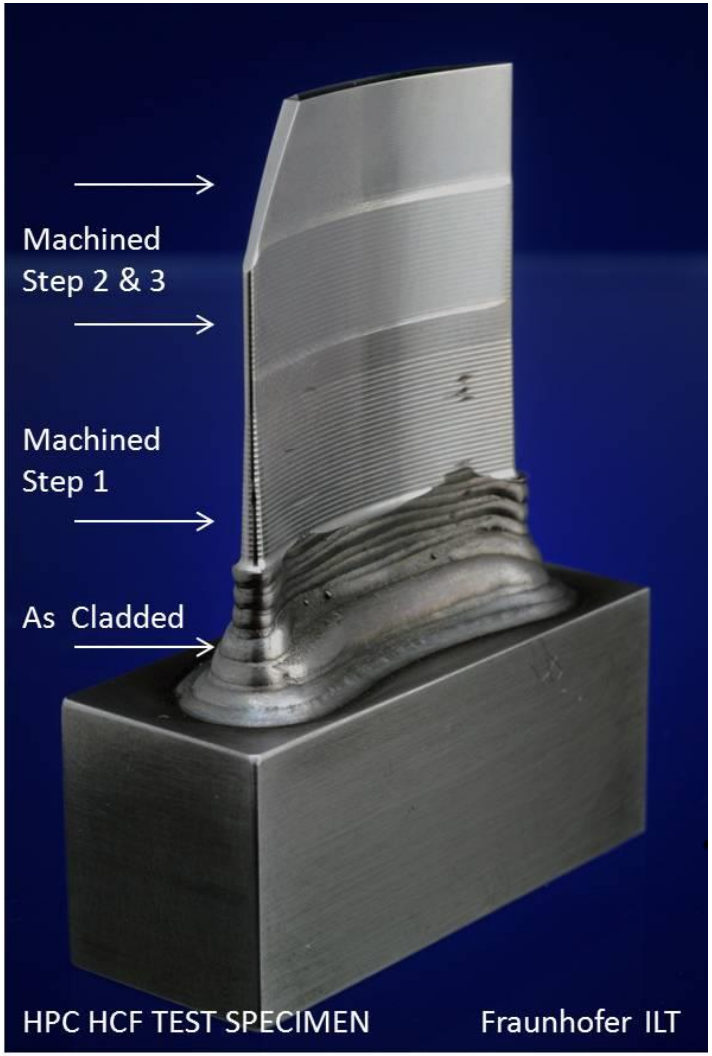
Laser Metal Deposition LMD



Process



BLISK Blade additively manufactured by LMD

Hannover Trade Fair
April 04, 2011

Ferchau Innovation Award 2011
Additive BLISK Manufacture by
Laser Material Deposition LMD

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Washington, D.C.
March 07, 2012

Innovation Challenge Award (Aviation Week) in the Category "Power and Propulsion"
Additive BLISK Manufacture by Laser Material Deposition LMD

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TurPro

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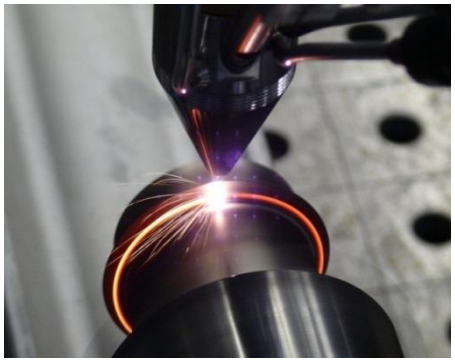
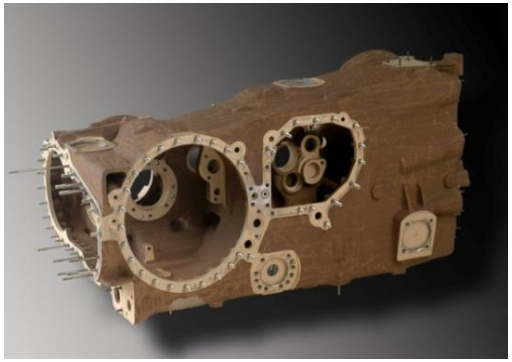
Ultra high-speed LMD

Classification of LMD processes by process velocity/ feed rate:

- Pulsed LMD → v_v = 0 mm/min
- Low-speed LMD → v_v = > 0 – 200 mm/min
- Standard LMD → v_v = 200 – 2,000 mm/min
- High-speed LMD → v_v = 2,000 – 20,000 mm/min
- Ultra high-speed LMD → v_v = 20,000 – > 100,000 mm/min





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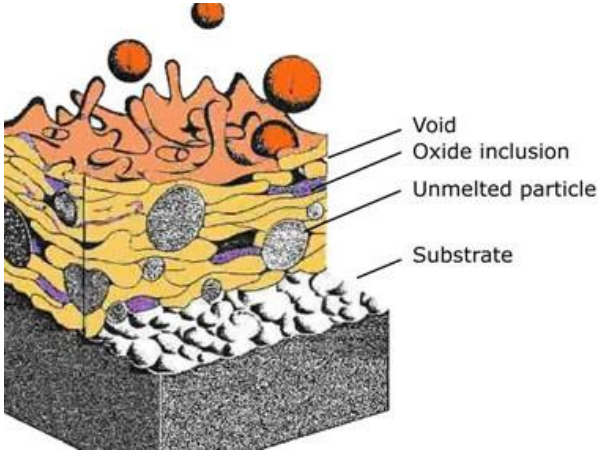
Ultra high-speed LMD

Replacement of

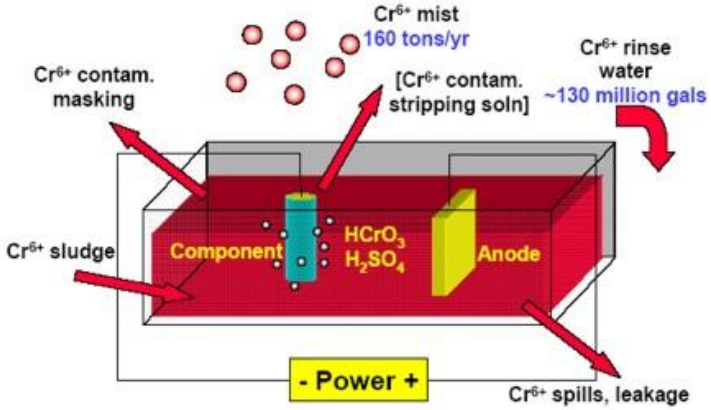
- Thermal spraying (APS, VPS, HVOF etc.)
- Chromium plating

by *LMD (thin layers between 25 and 200 µm)* due to process specific advantages such as

- Metallurgical bond
- Factor of min. 10 higher process speed compared to conventional LMD
- Smoother surface finish



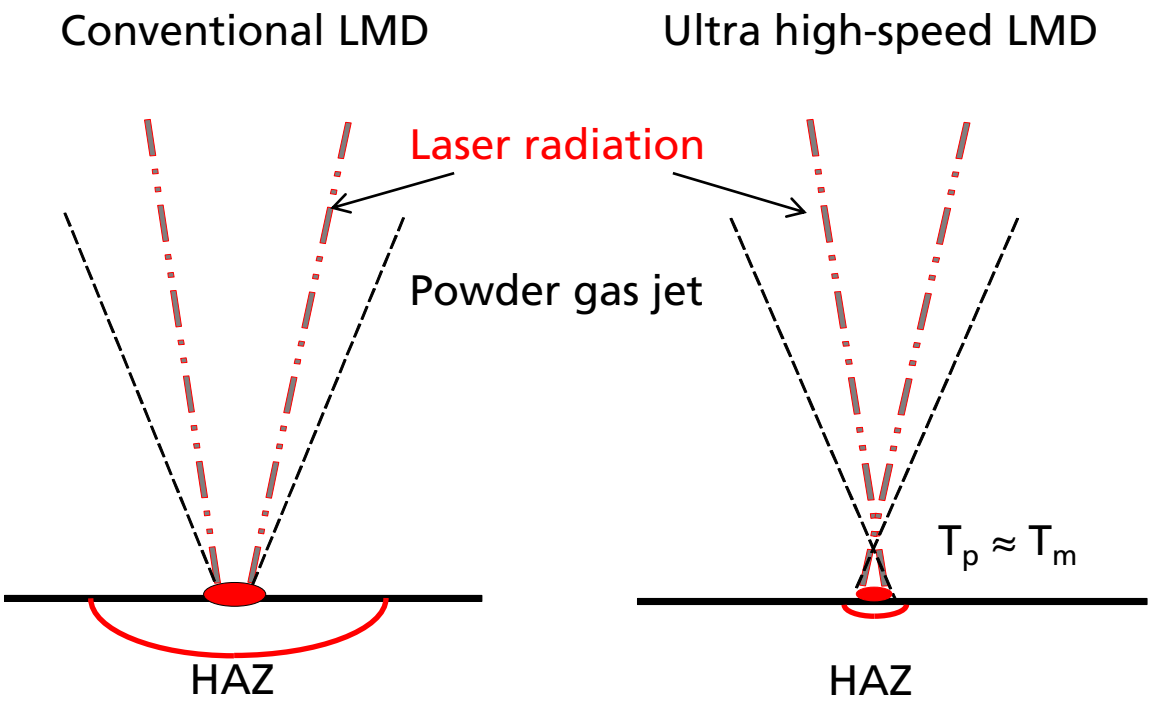
http://www.advanced-coating.com/english/spraying.htm



http://www.hazmat-alternatives.com/Alt_tech-Chrome.php

Ultra high-speed LMD

Principle

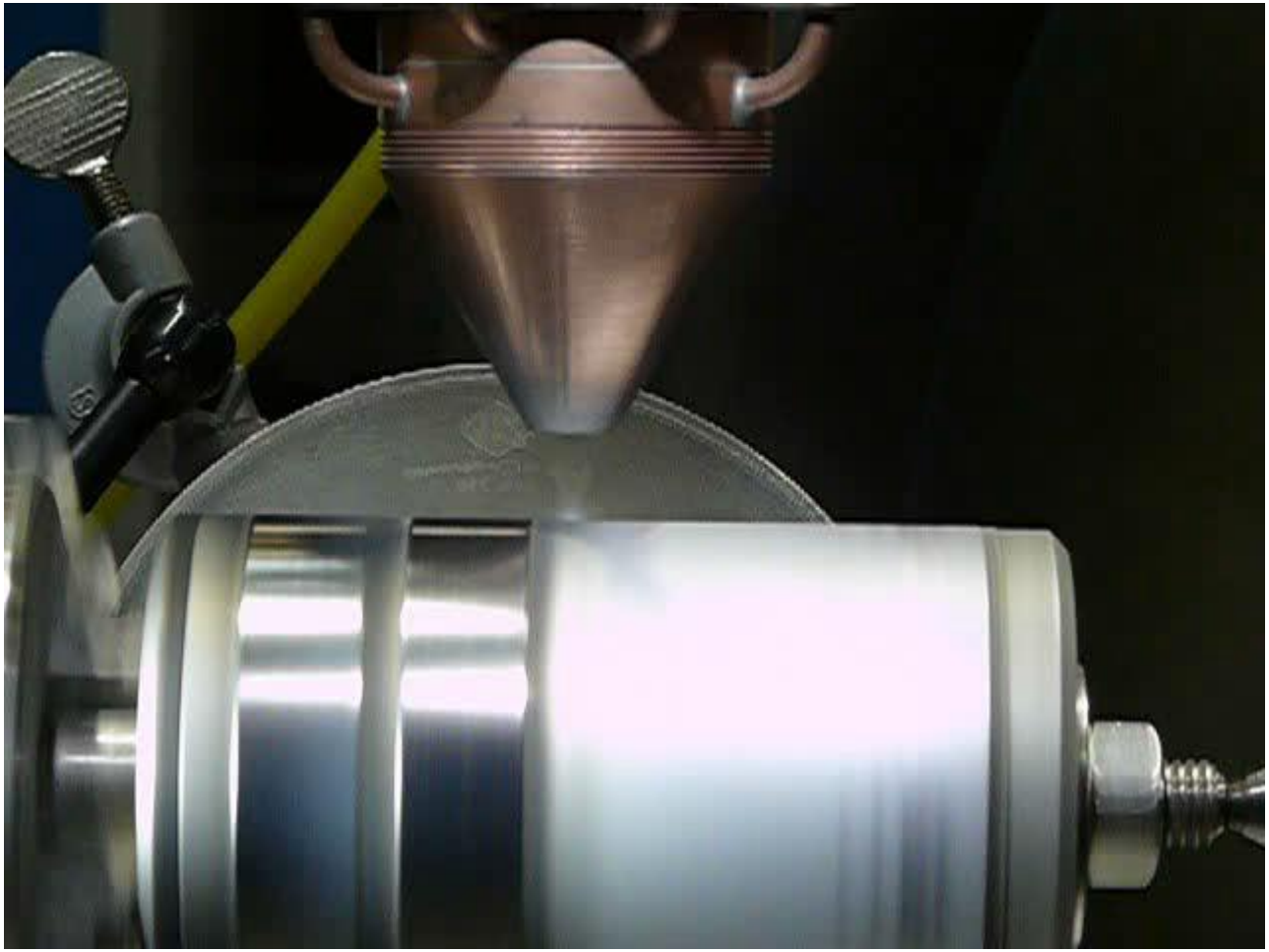


A_p = 20 – 30 %
v_v = 1,000 – 2,000 mm/min

A_p = 80 – 90 %
v_v = 100,000 – 500,000 mm/min

Ultra high-speed LMD

Process velocity v_v = 200,000 mm/min



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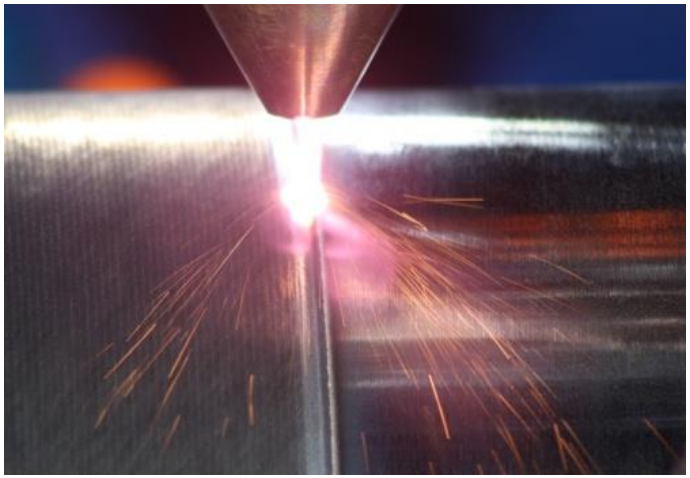
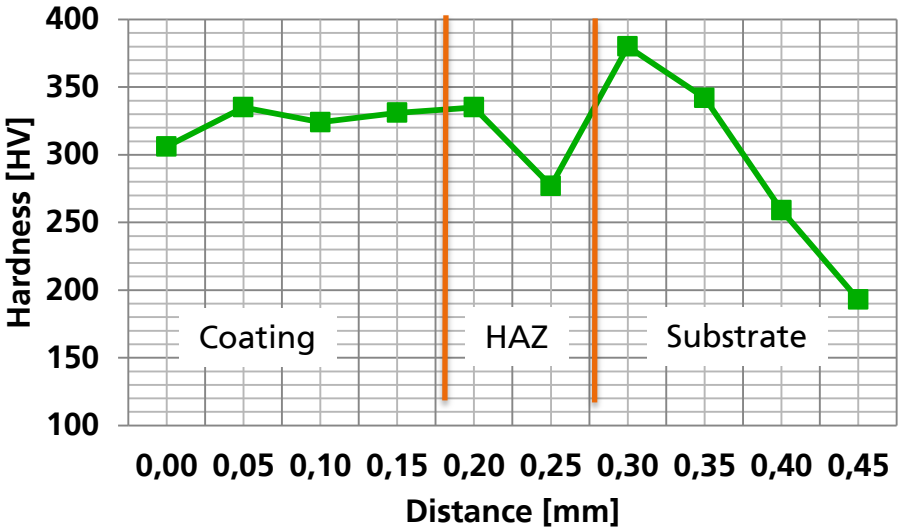
Ultra high-speed LMD

Inconel 625





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Ultra high-speed LMD

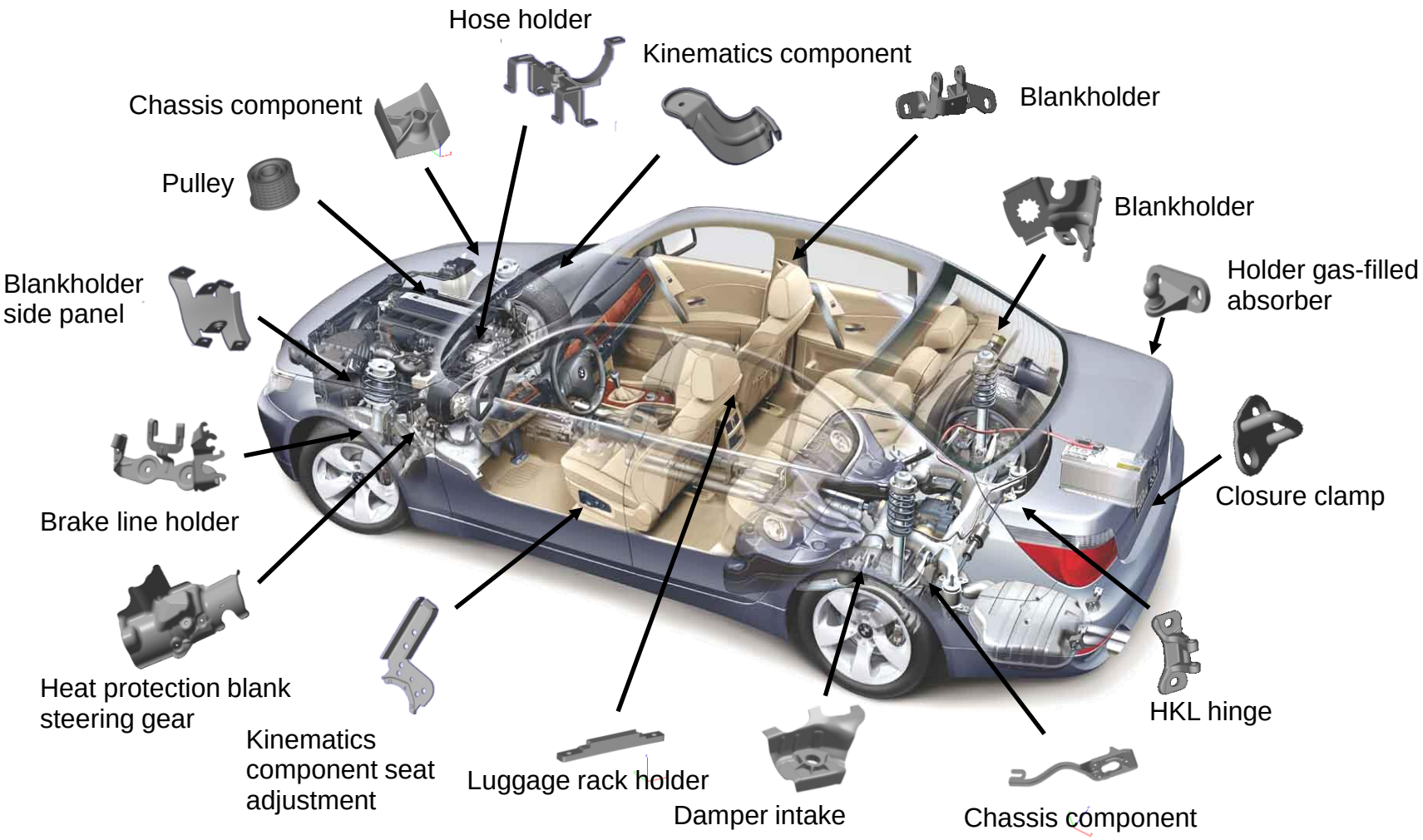
LMD of a shaft used in off-shore apps.

Weight of shaft: 1000 kg

Process velocity v_v up to 50,000 mm/min

Laser power 4000 W

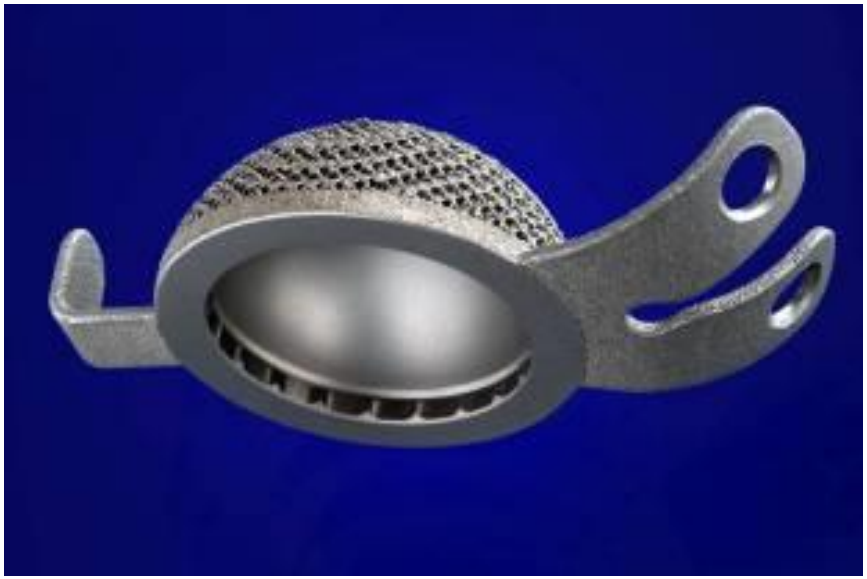
Laser Additive Manufacturing – Automotive Applications



Source: N. Skrynecki, Kundenorientierte Optimierung des generativen Strahlschmelzprozesses, 2010

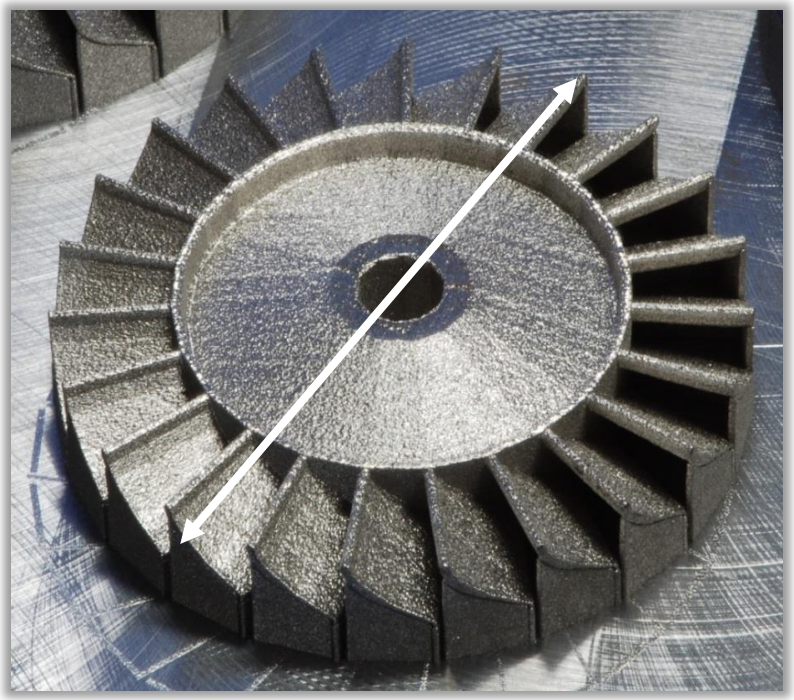
First SLM Hip Cup

- Bone substitute implants
  with mesh structure made from TiAl6V4
- Conventional manufacturing not possible
- Improvement of bone-implant interaction

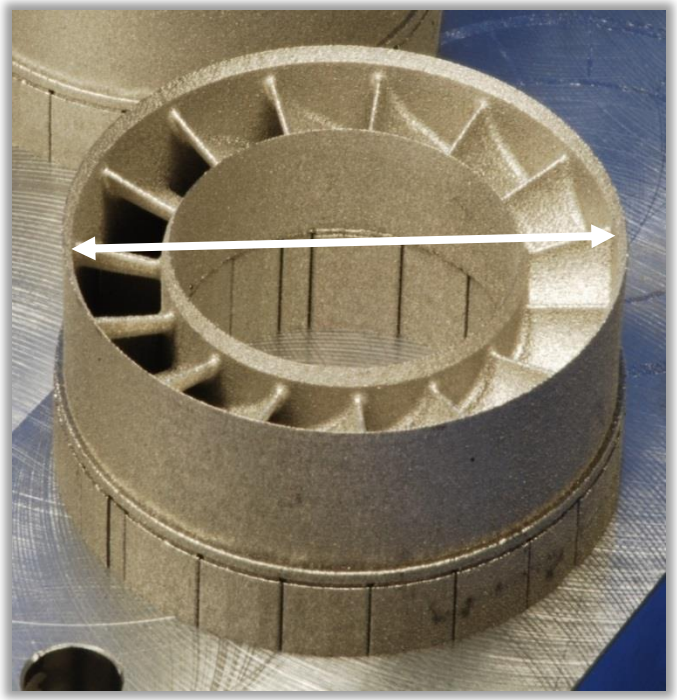


- Hip cup manufactured at ILT
  implanted in January 2008

Actual Reseach Topics/ Precision: Dimensional Accuracy



Target: 64,00 mm
Actual: 63,98 mm



Target: 64,40 mm
Actual: 63,36 mm

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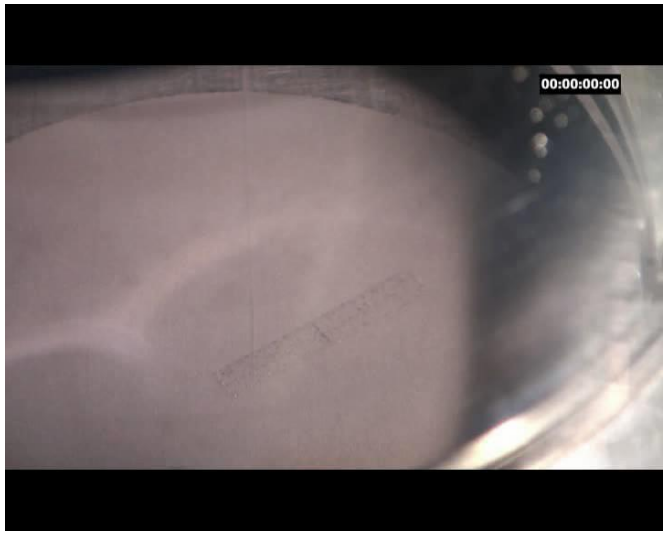
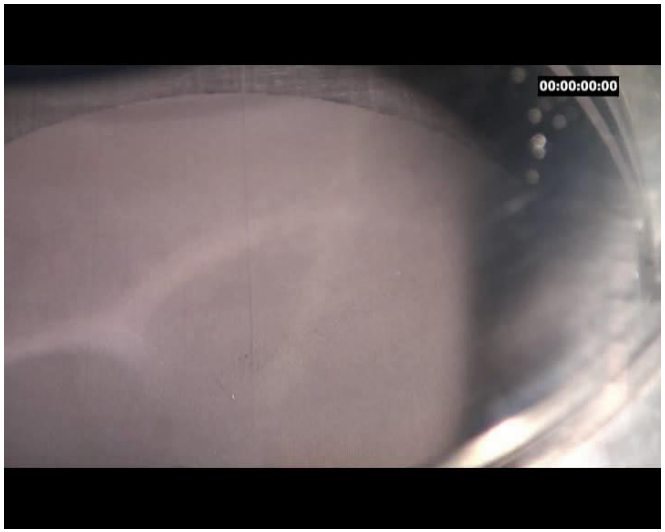
High power SLM for Aluminum

Material: AlSi10Mg
P_L: 200 W
Beam diameter: 200 µm
Scan speed: 800 mm/s



Material: AlSi10Mg
P_L: 1000 W
Beam diameter: 200 µm
Scan speed: 2000 mm/s

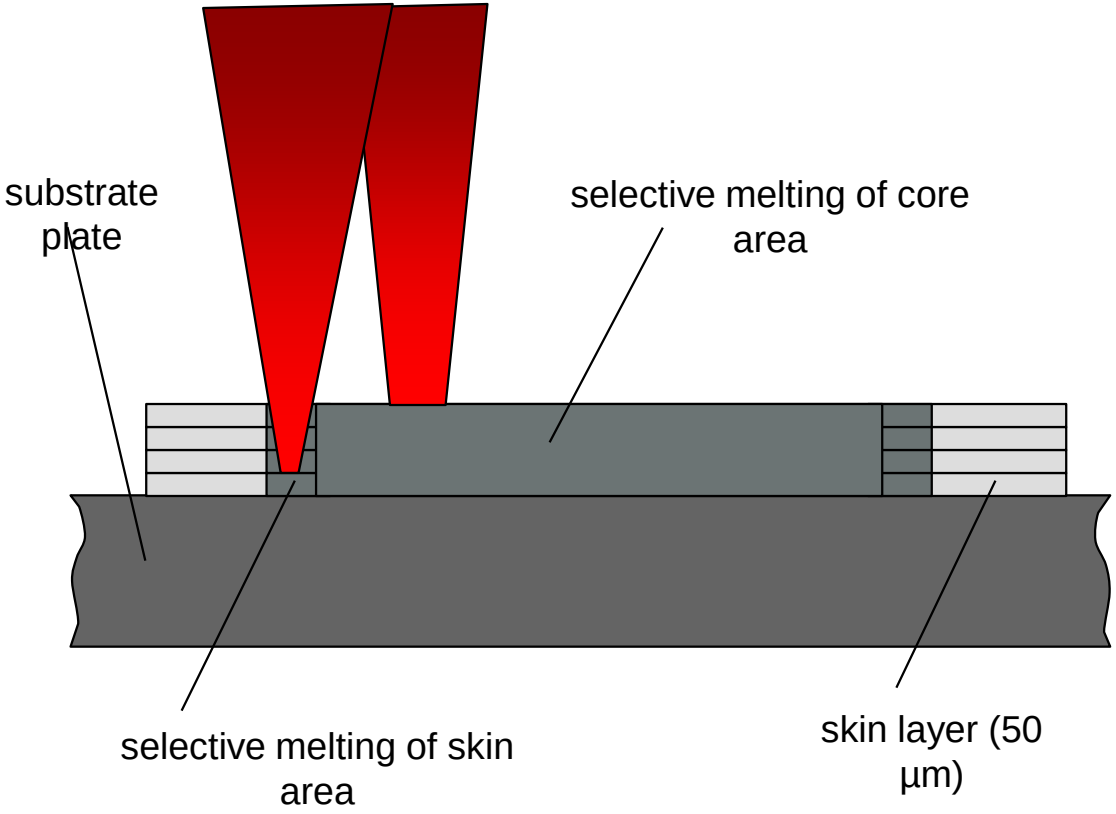


© Fraunhofer ILT

Skin-Core Strategy

Procedure

- Deposition of “skin layer” (50 µm)
- SLM of skin area
- Re-iteration until core layer thickness is reached (e.g. 4 times if core layer thickness is up to 200 µm)
- SLM of core area
- Repetition of steps 1 - 4



Skin-Core Strategy

Material: Stainless steel

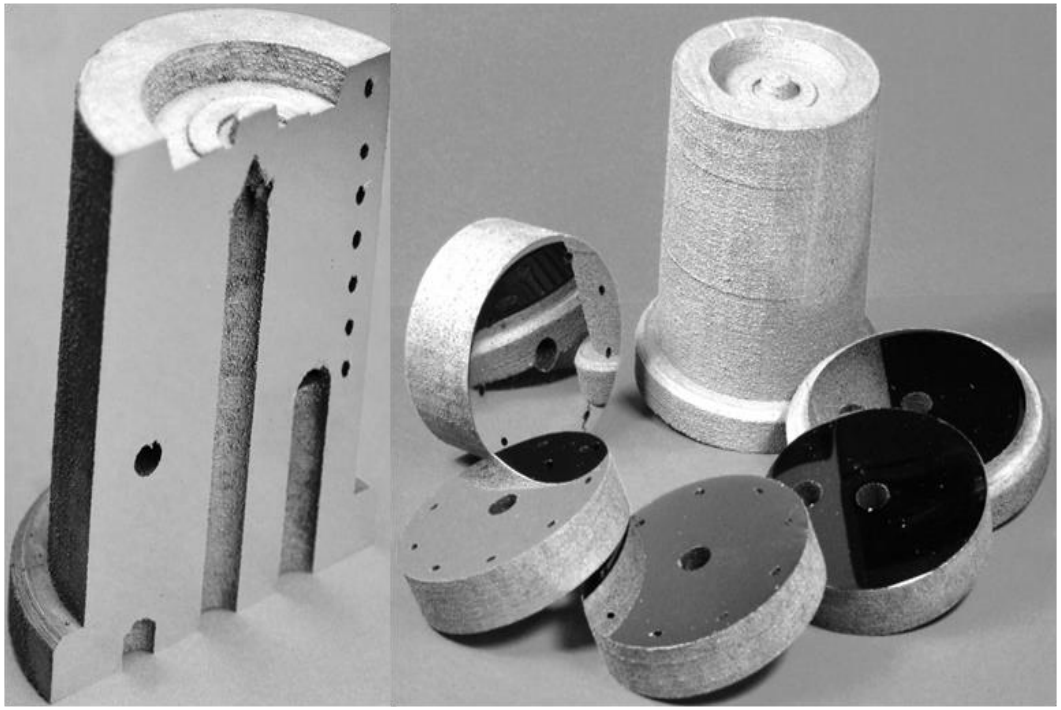
Skin
P_L: 350 W
Beam diameter: 200 µm
Layer thickness: 50 µm

Core
P_L: 1000 W
Beam diameter: 1000 µm
Layer thickness: 200 µm

© Fraunhofer ILT

Additive Manufacture of skin-core demonstrator

- Tool insert for injection mold
- Conformal cooling channels
- Layer thickness ratio of 1:4
- Skin core overlap 0.75 mm
- Density ~ 100%
- Core dep. rate: 16.8 mm^3/s
- Skin dep. rate: 3 mm^3/s
- Average dep. rate: 10.2 mm^3/s



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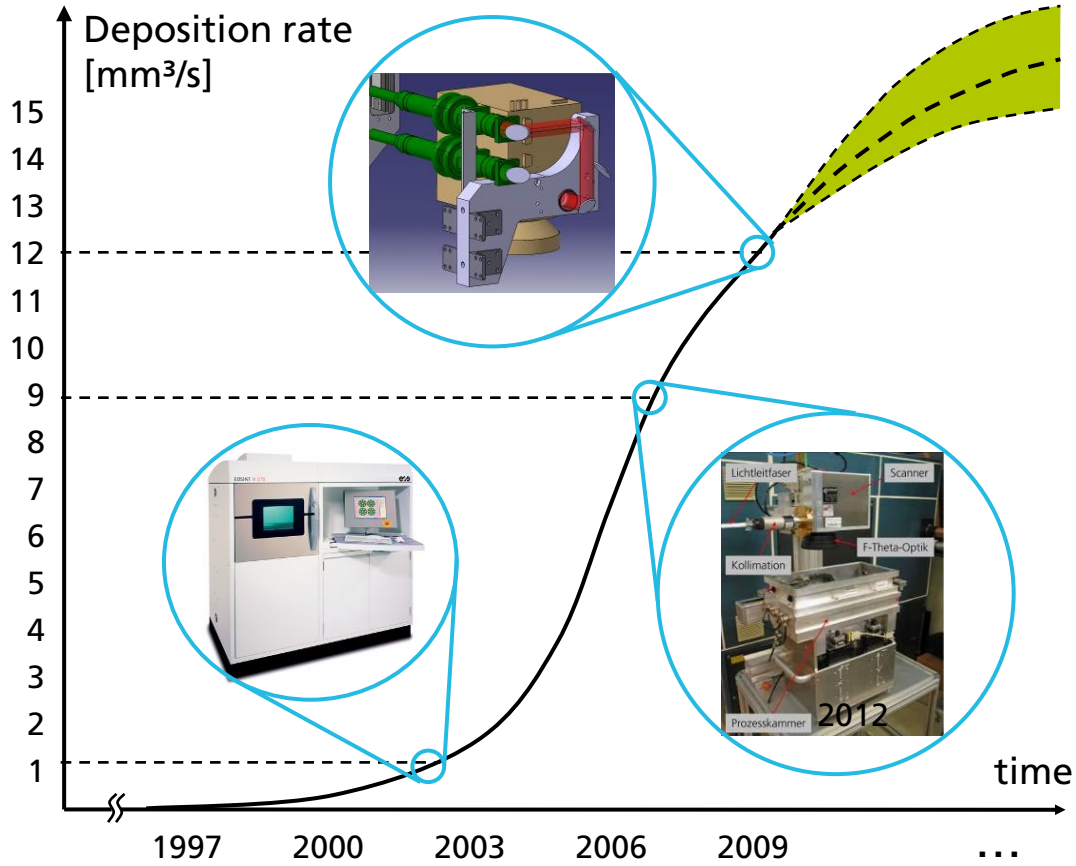
Commercial machine with 1kW laser system

Actual Research Topics/ Productivity: Process speed

Deposition rate

- Since 2003 :
  Industrial state-of-the-art unchanged at approx. 1.2 mm³/s
- Since beginning 2007:
  Increase in deposition rate up to approx. 9 mm³/s (experimental set-up)
- 2008:
  Installation of demonstration machine
- 2009:
  Further increase of deposition rate up to min. 12 mm³/s by using higher laser power (up to 1kW)



Selective Laser Melting SLM

SLM Machine

Process

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Fraunhofer ILT

Duesseldorf
November 14, 2011

Innovation Award of the federal state of North Rhine Westphalia 2011
Additive Manufacture by Selective Laser Melting SLM

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Content

- Motivation
- Process basics
- Developments & Applications
- Digital Photonic Production

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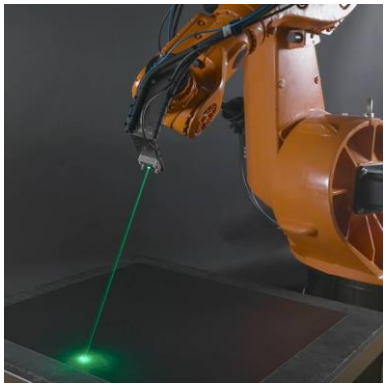
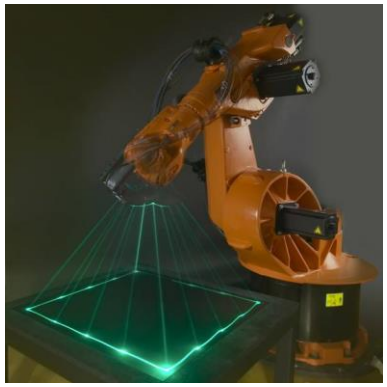
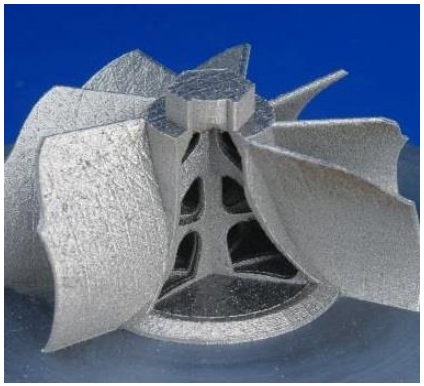
Digital Photonic Production
“From Bits to Photons to Atoms”

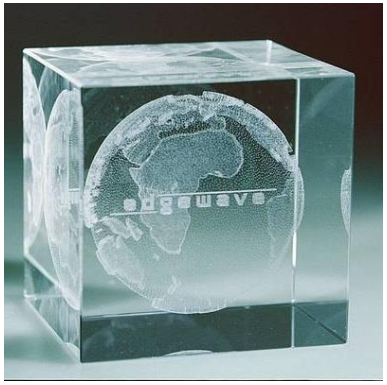
Light is unique due to…

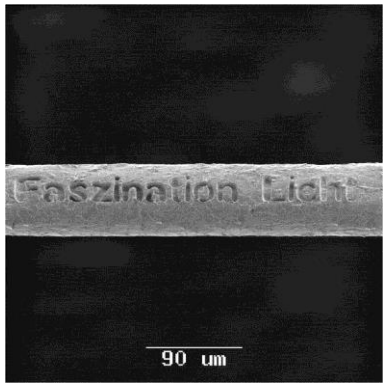
- highest energy density
- shortest pulses
- highest speeds
- massless, forceless and contactless
- best controllability (CAD>Product)



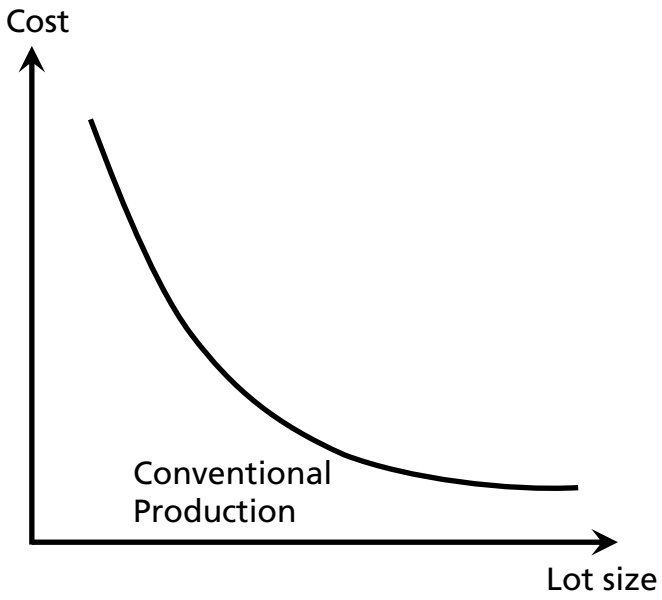


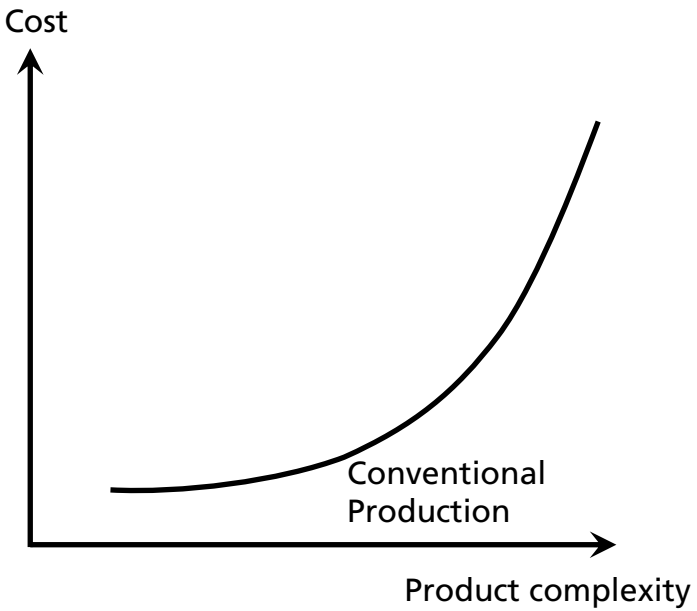






Digital Photonic Production – “Production 2.0”





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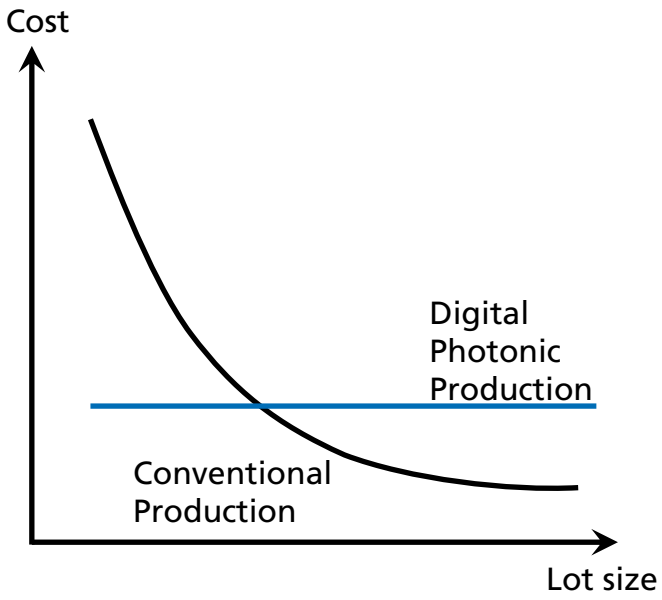
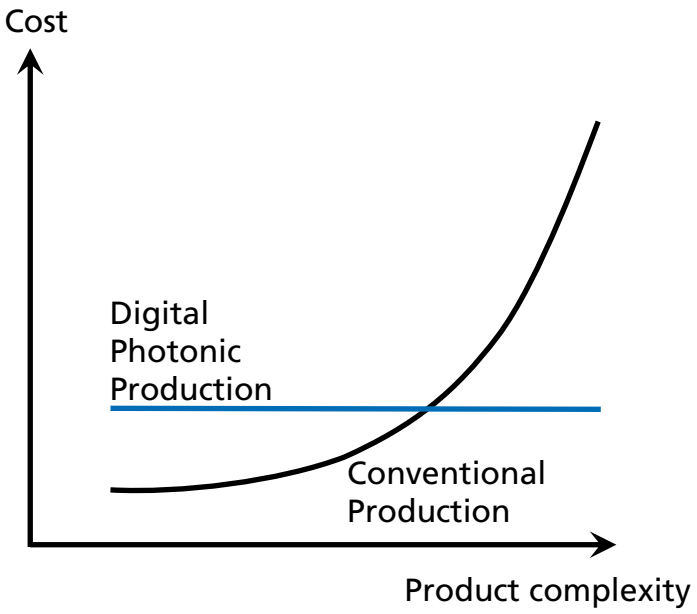
Digital Photonic Production – “Production 2.0”





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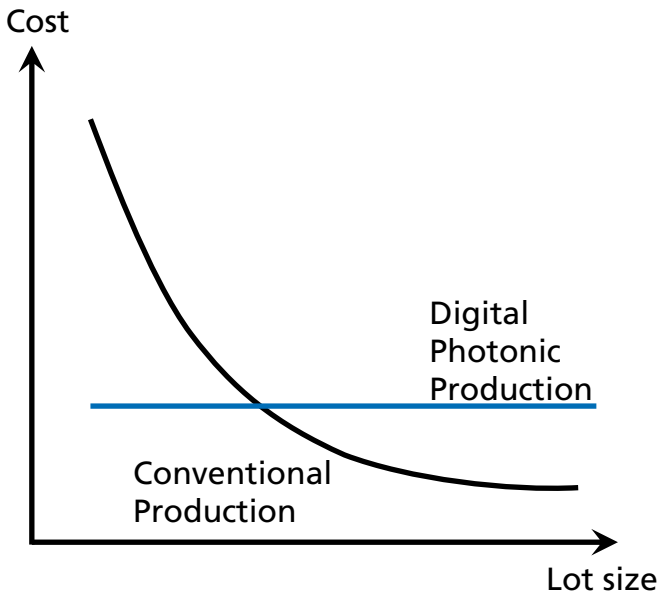
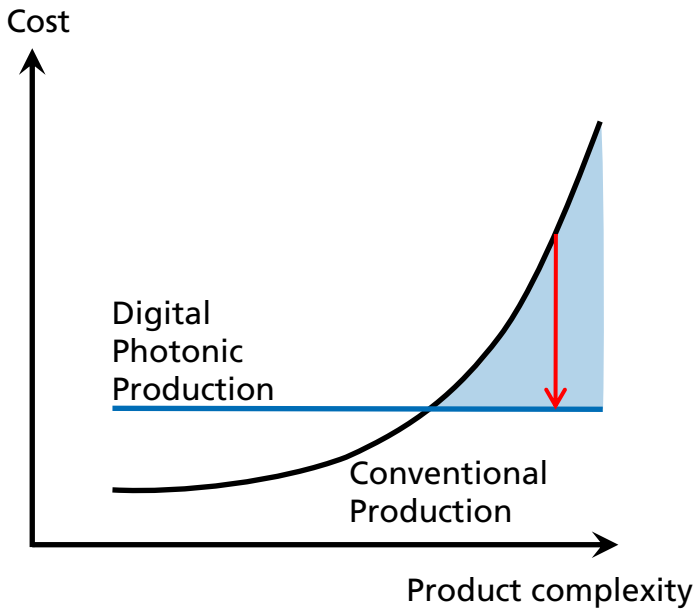
Digital Photonic Production – “Production 2.0”



Complexity for free



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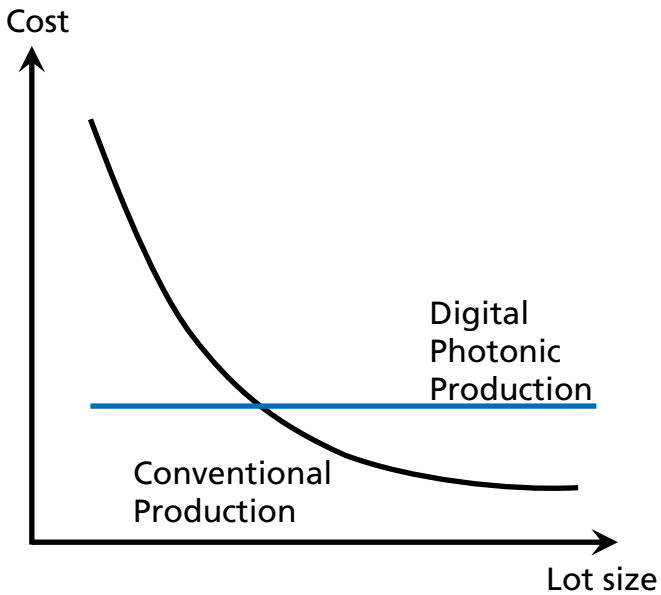
Digital Photonic Production – “Production 2.0”



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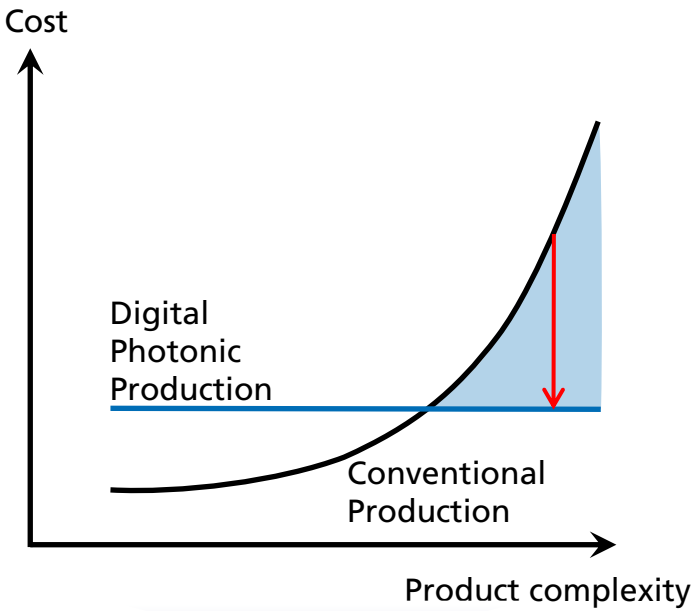
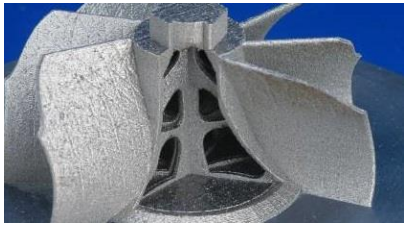
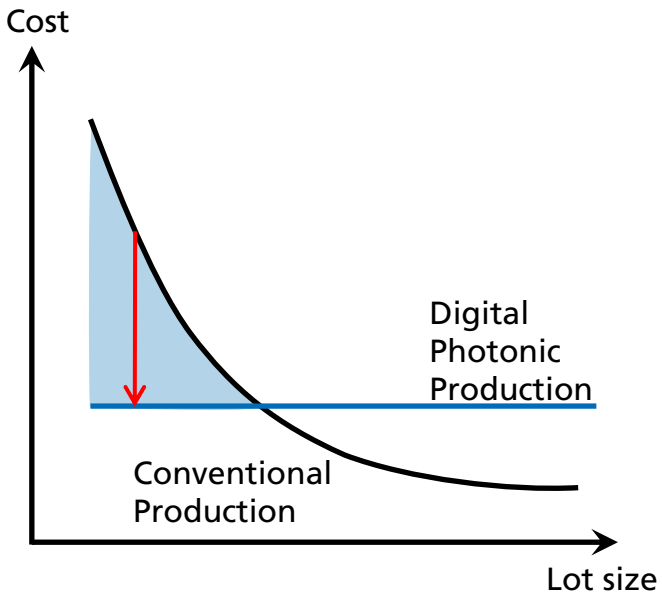




Innovative products

Digital Photonic Production – “Production 2.0”

Individualisation for free



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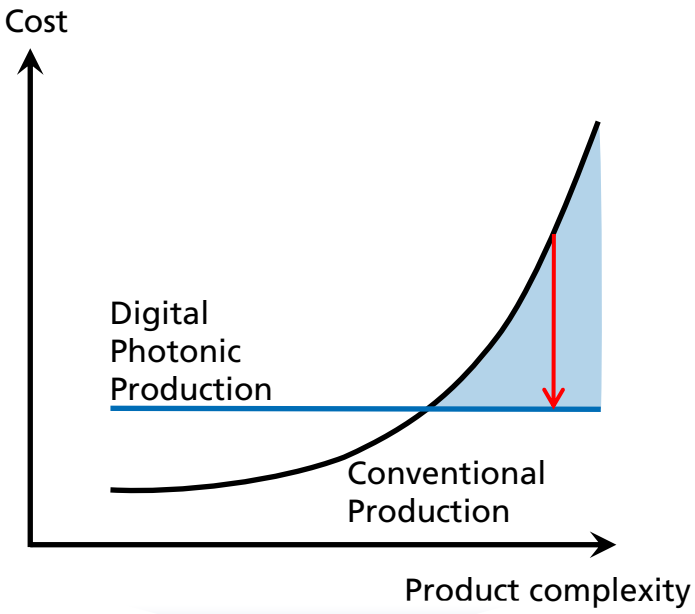

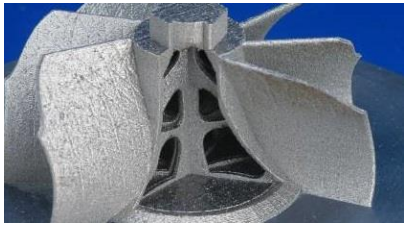

Innovative products

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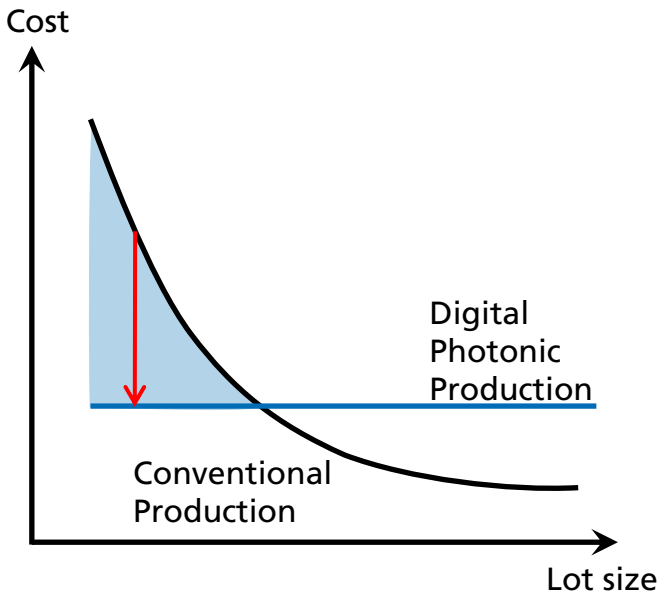
Digital Photonic Production – “Production 2.0”

Individualisation for free



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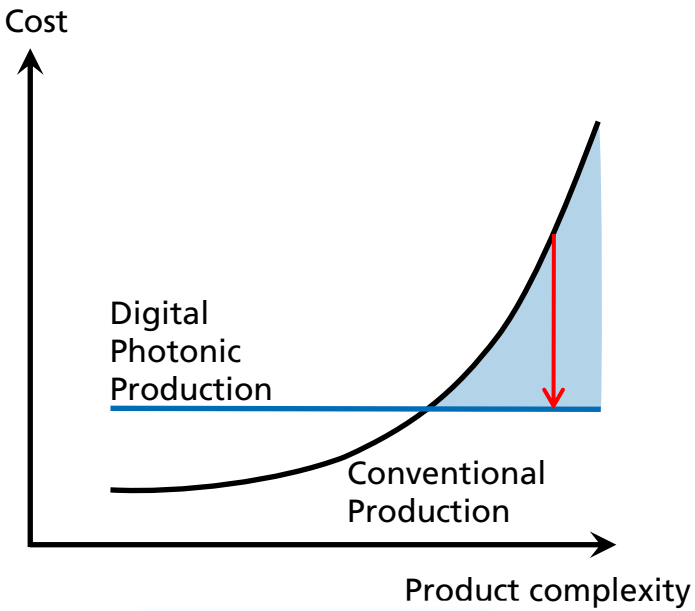
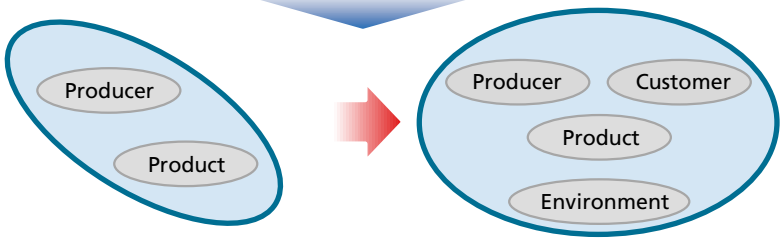
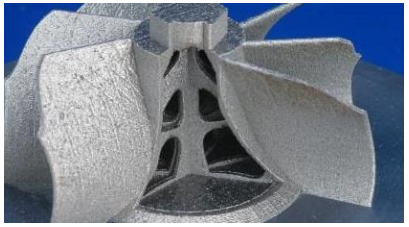




Providing-Value

Value-Co-Creation



Innovative business models

Innovative products

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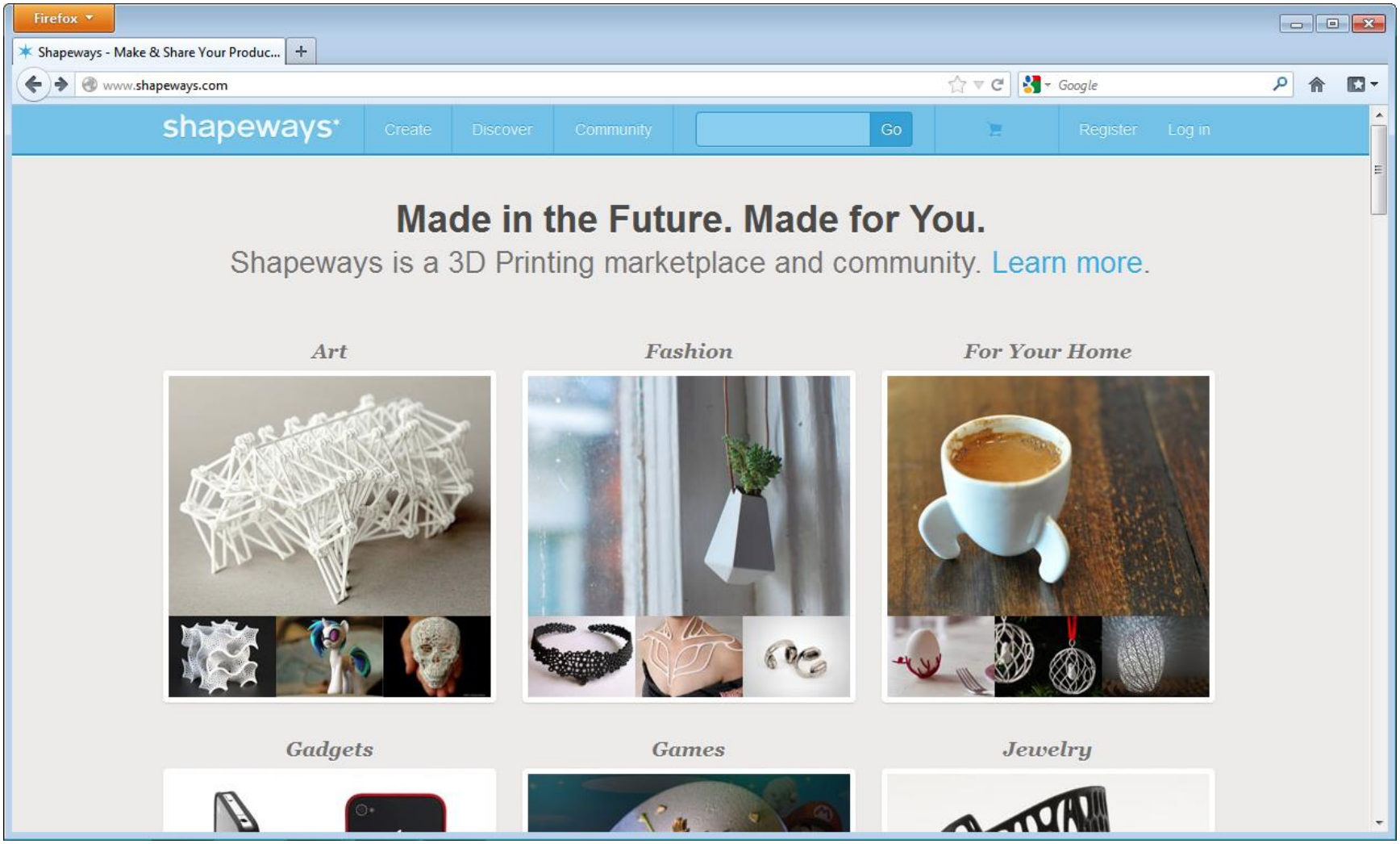
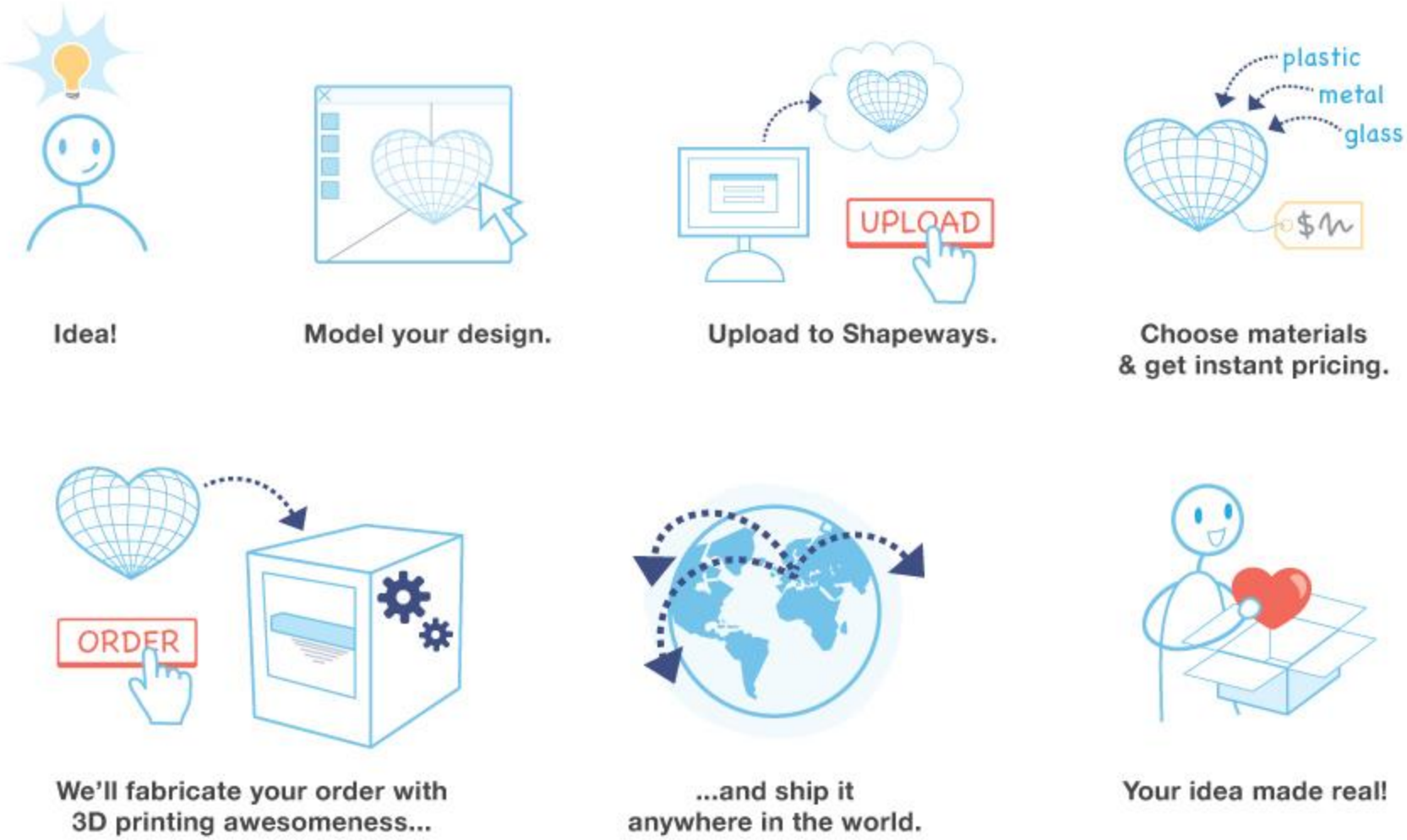
Individualization for free – Shapeways



Source: Shapeways

Shapeways – new kind of production community



Source: Shapeways

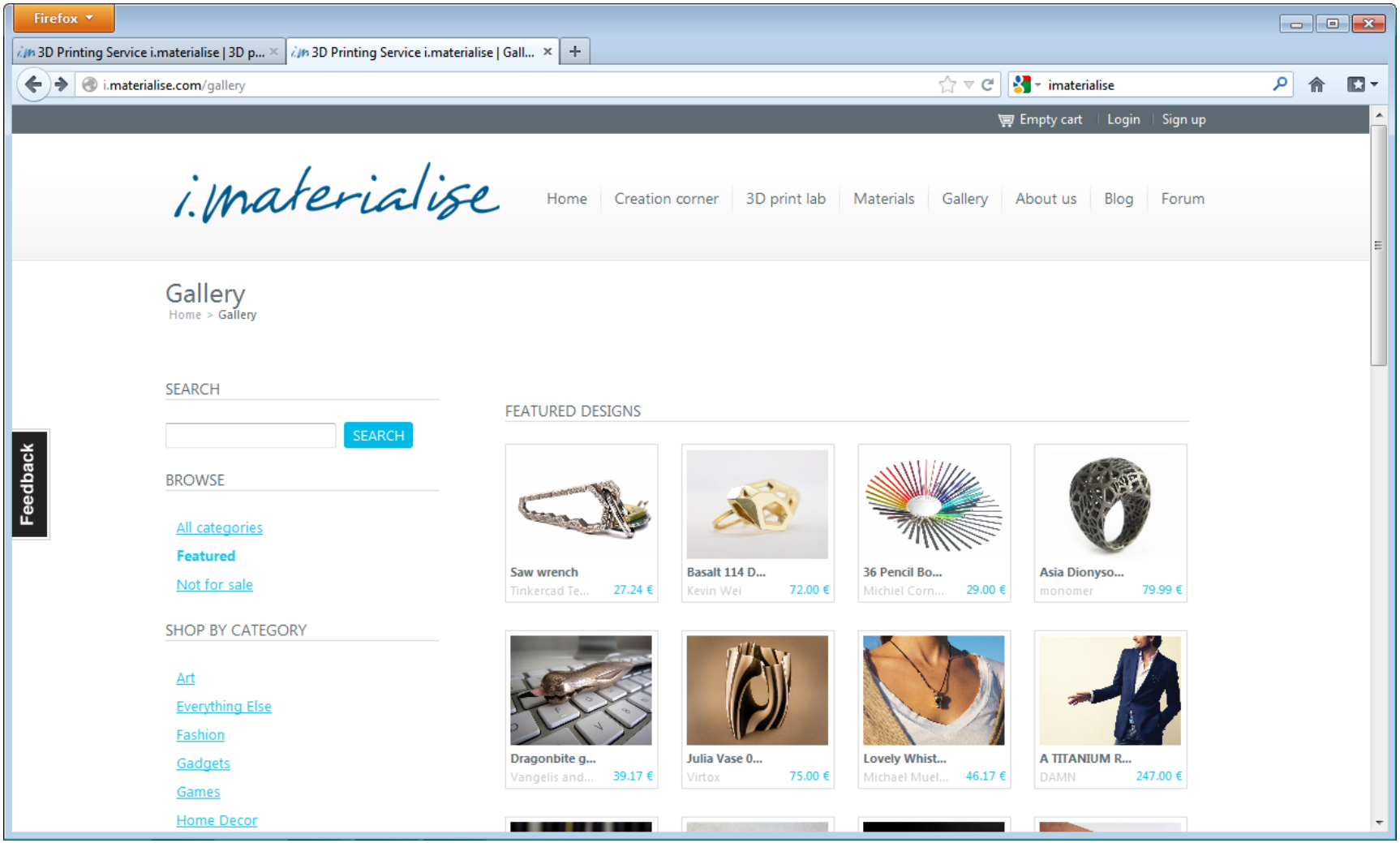
Shapeways – huge momentum for 3D printing in 2012

- 1,000,000 3D printed products in 2012
- over 10,000 uploads per week
- 8000+ Shapeways Shops
- shop owners earned $500,000 in 2012
- 230,000+ Community Members in over 130 countries

- new factory opened in New York
  to 3D print 3 to 5 million unique products per year

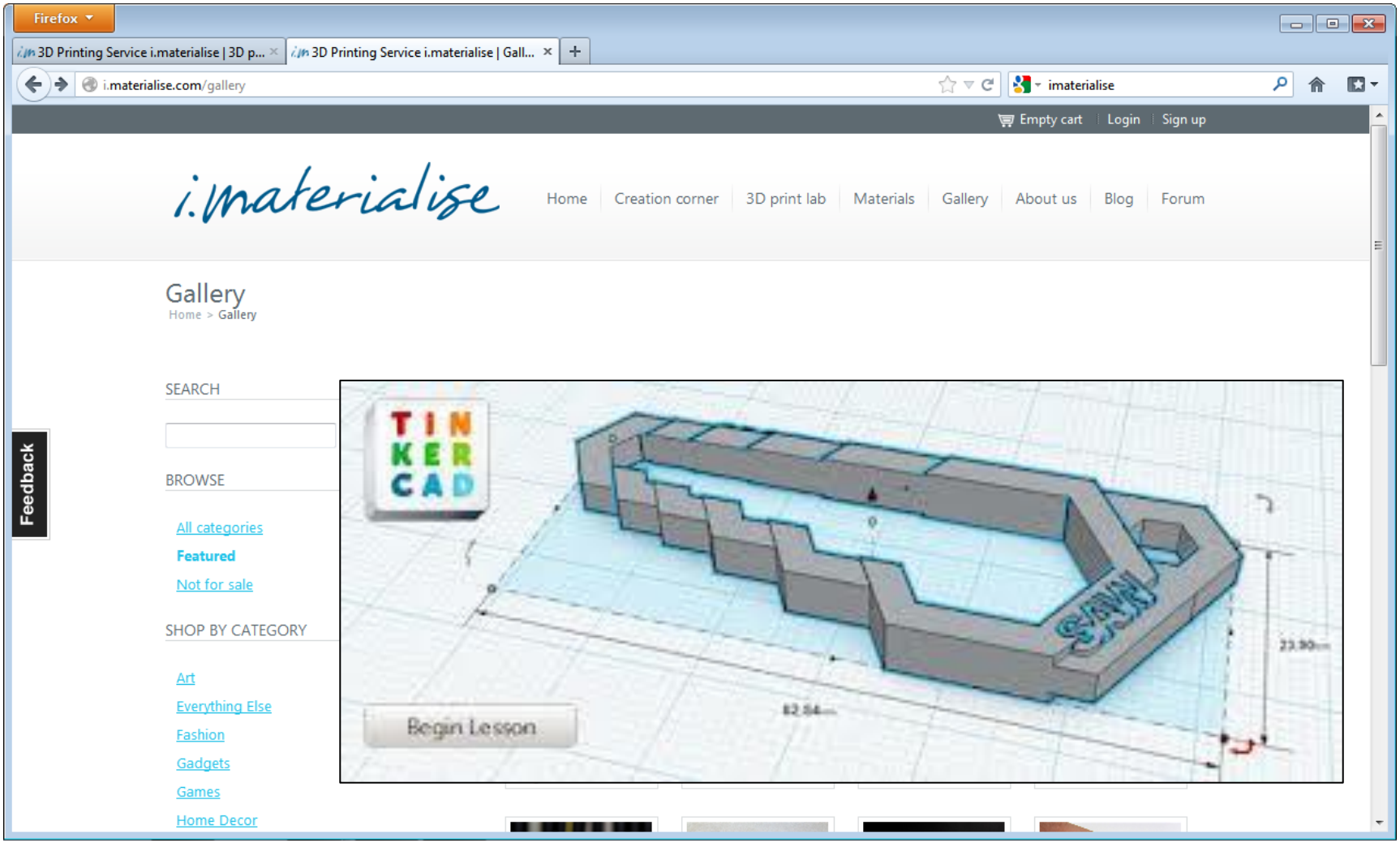
Source: Shapeways

Production Communities – i.materialise, Ponoko, Sculpteo



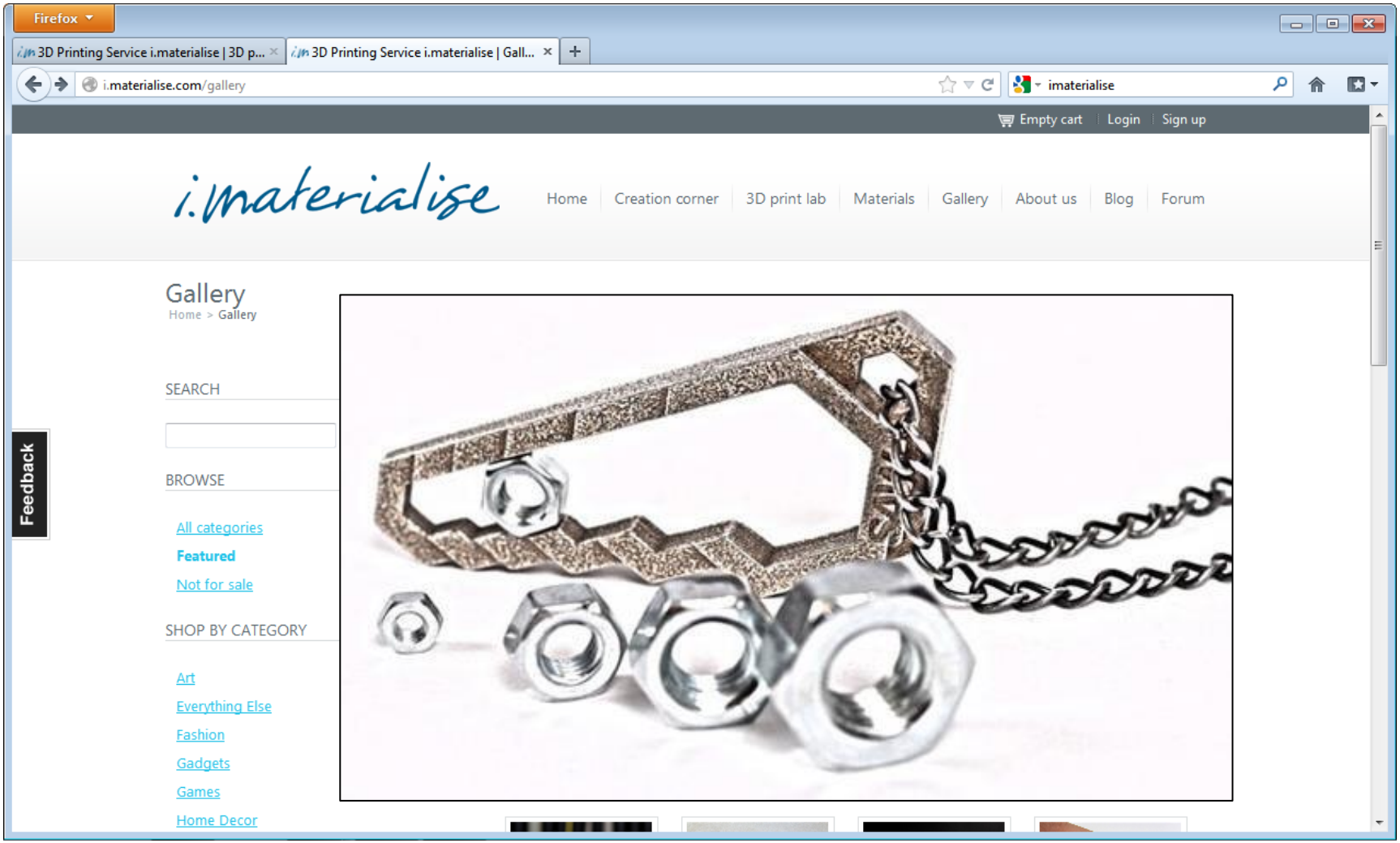
Source: Materialise

Tinkercad – browser based solid modeller



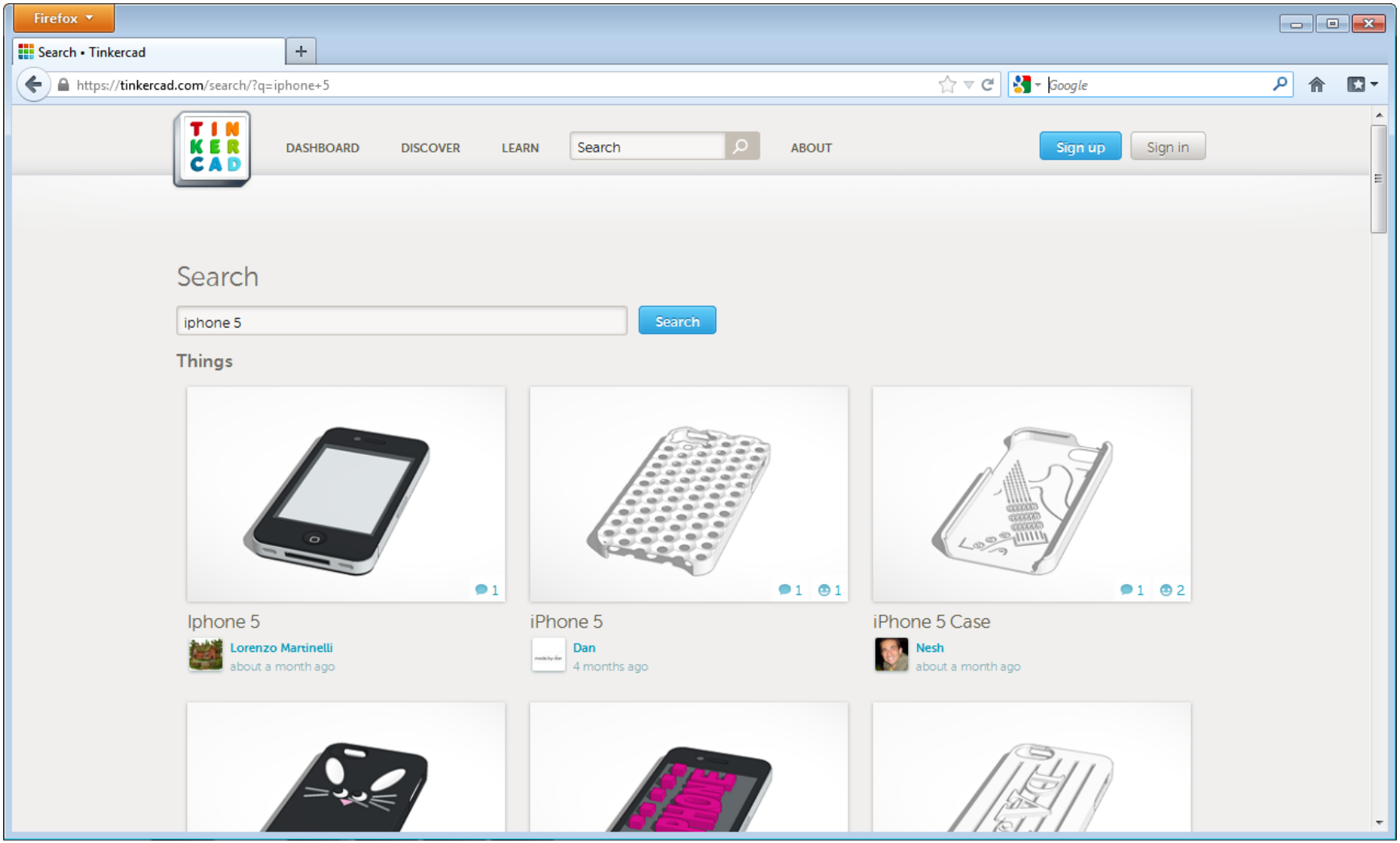
Source: Materialise, Tinkercad

… with direct connection to Shapeways, i.materialise, …



Source: Materialise, Tinkercad

… and a growing community for 3D design data



Source: Tinkercad

Nokia Lumia 820 3D printing community project – First major label released 3D Development Kit (3DK)

Source: Nokia

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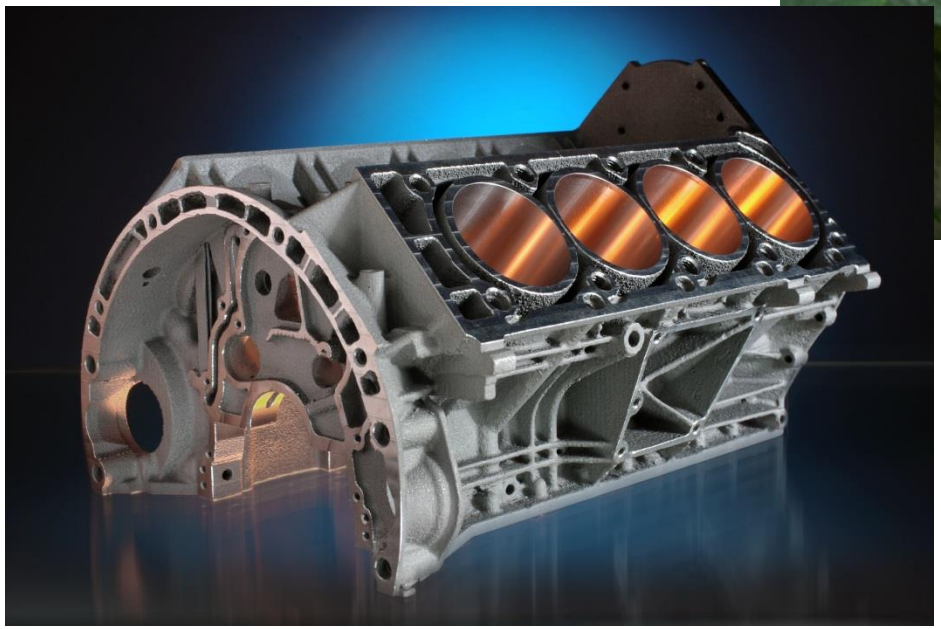
Direct Photonic Production
LAM – A Paradigm Shift in Manufacture

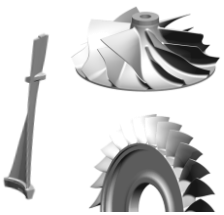
Topology optimized axle stub with hollow structures – additively manufactured by Selective Laser Melting SLM



Engine block – additively manufactured (‚printed out‘) by Selective Laser Melting SLM

© Fraunhofer ILT

Additive Manufacturing – Process Chain



Design/ Function

Raw material e.g. powder

Shaping

Additive manufacture

Adaptive Automated Machining

Turning | Roughing | Finishing

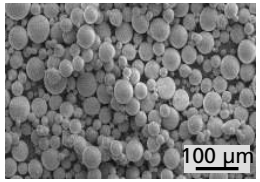
Clamping | Measuring | CAx

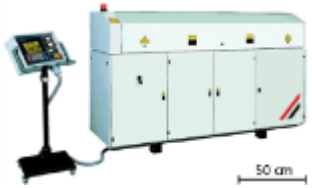
Continuity/ Integration

Systems engineering

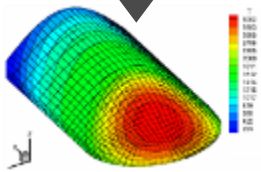
Process layout

Materials

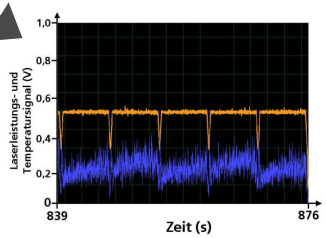




Beam source(s)



Process fundamentals



Process monitoring

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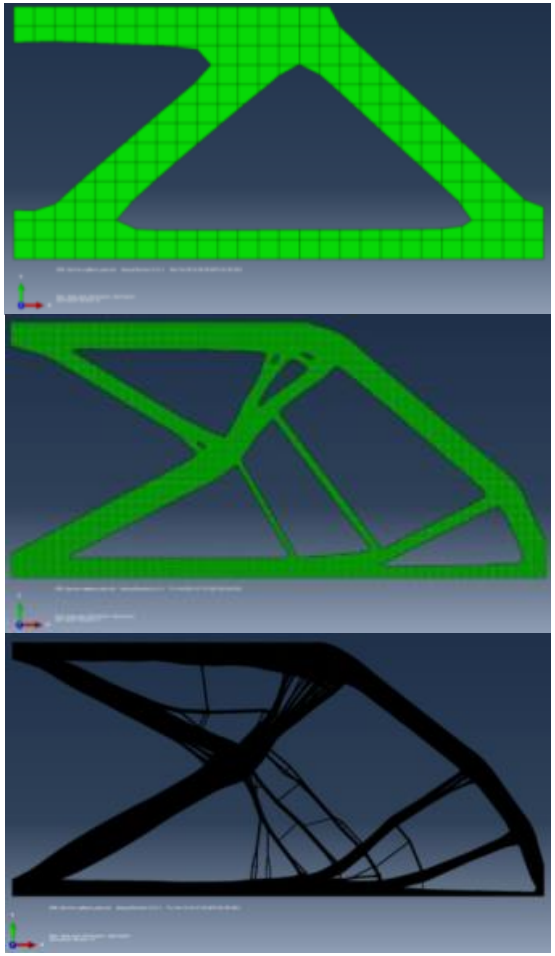
Opportunities and challenges in part design & simulation

Bionic design

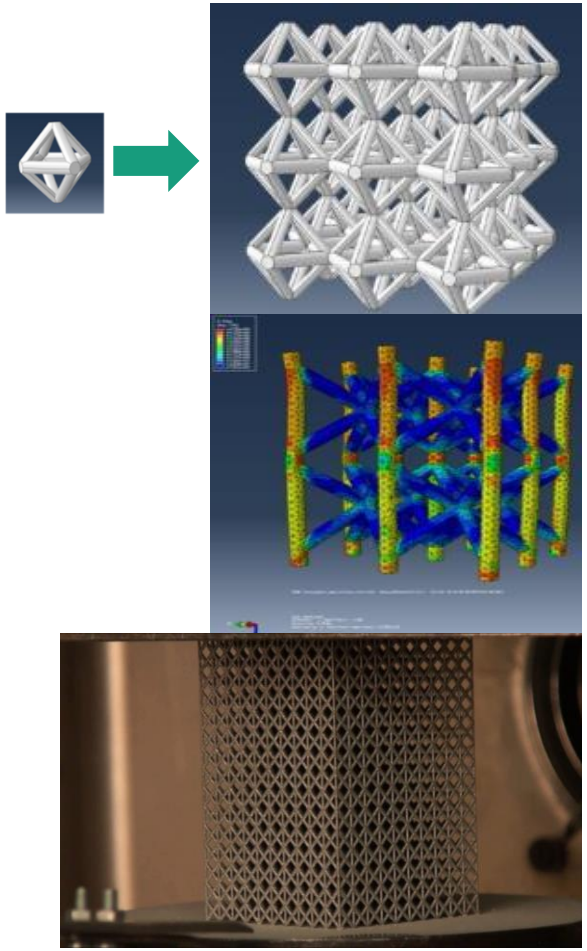
Material: AlSi10Mg
Weight saving: ca. 30 %

Topology optimization



Top: 338 elements
13 min 13 s
Center: 21,000 elements
41 min 47 s
Bottom: 2,100,000 elements
ca. 48 h

Lattice structures



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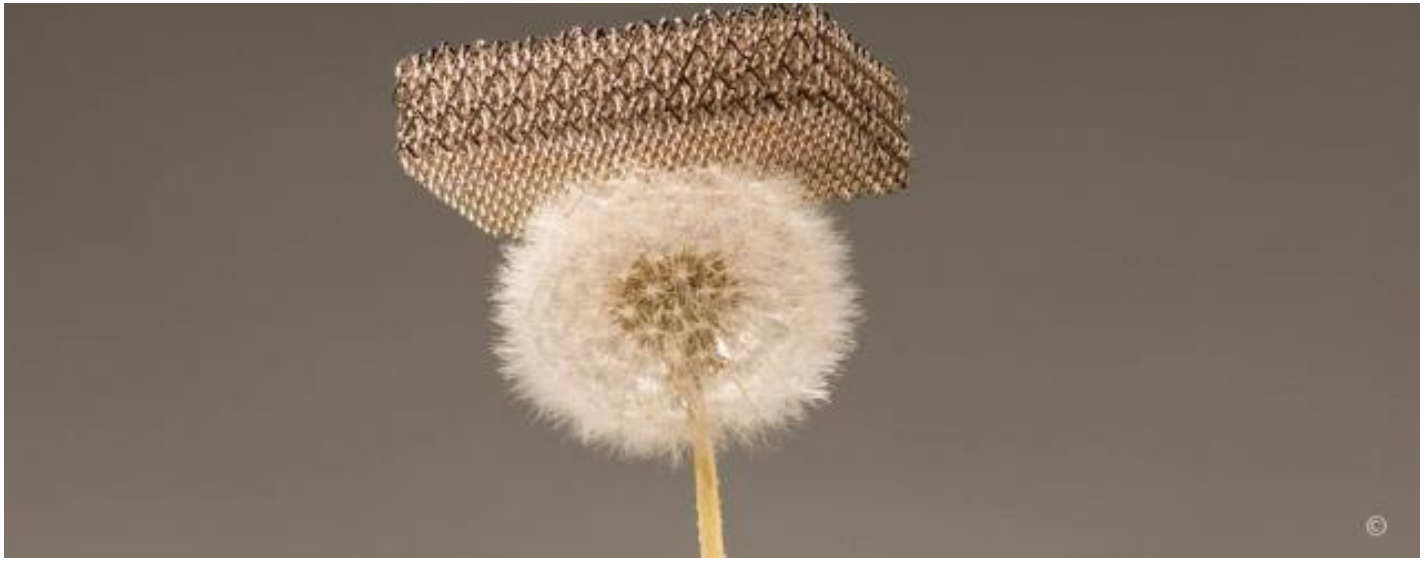
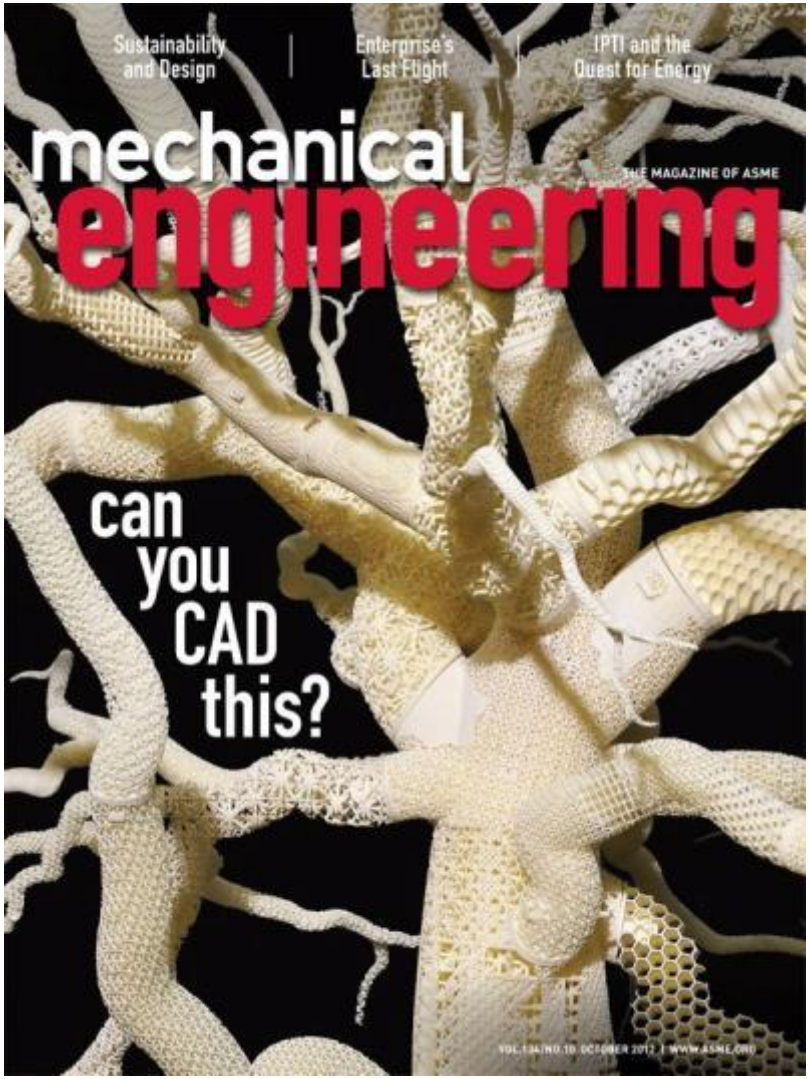
Vision – Lightest material of the world



- Density: 0,9 mg/cm³
- 99,99 % air
- 100 times lighter than foamed polystyrene
- 1000 times thinner than human hair

Source: Nature, University of California Irvine

Opportunities and challenges in part design & simulation



Individualized parts

- Design tools
  - patient specific
  - part specific
- Solution-Space-Design
- Real time simulation

Functional parts

- Design and simulation tools for
  - filigree structures
  - multi scale structures
  - multi material systems

Vision I: *Tailored* part *design* (designed for function, only)

Source: ASME Mechanical Engineering Magazine, Netfab

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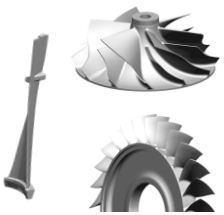
Additive Manufacturing – Process Chain



Design/ Function

Raw material e.g. powder

Shaping

Additive manufacture

Adaptive Automated Machining

Turning | Roughing | Finishing

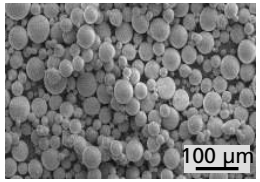
Clamping | Measuring | CAx

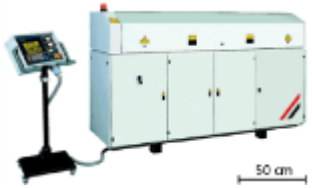
Continuity/ Integration

Systems engineering

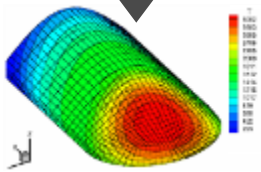
Process layout

Materials

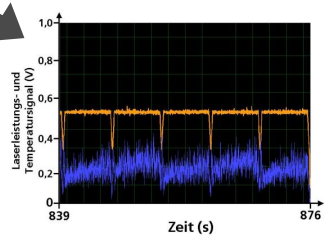




Beam source(s)



Process fundamentals



Process monitoring

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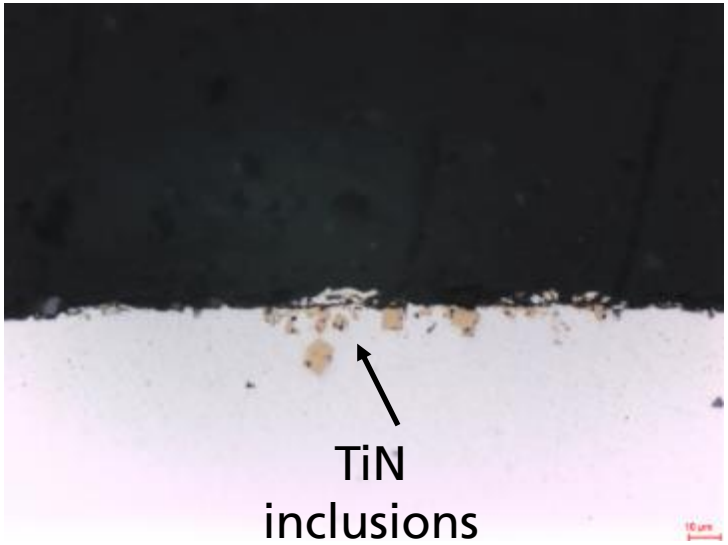
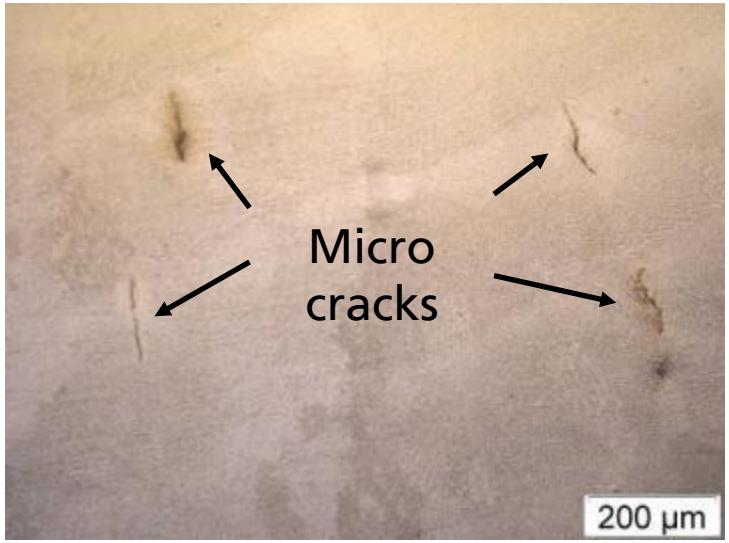
Material development: *Powder additives* (Inconel 718)





Powder	O	N	Porosity	Cracking	Inclusions (TiN)
AMDRY	0.010	0.020	High	Low	Low
Nistelle	0.035	0.110	mid	High	High
TLS	0.013	0.009	Low	Low	Low

Now: Designed for APS, VPS, HVOF → Thermal Spraying

Future: Tailored for AM

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Material development: *Graded* & *3D multi-materials*

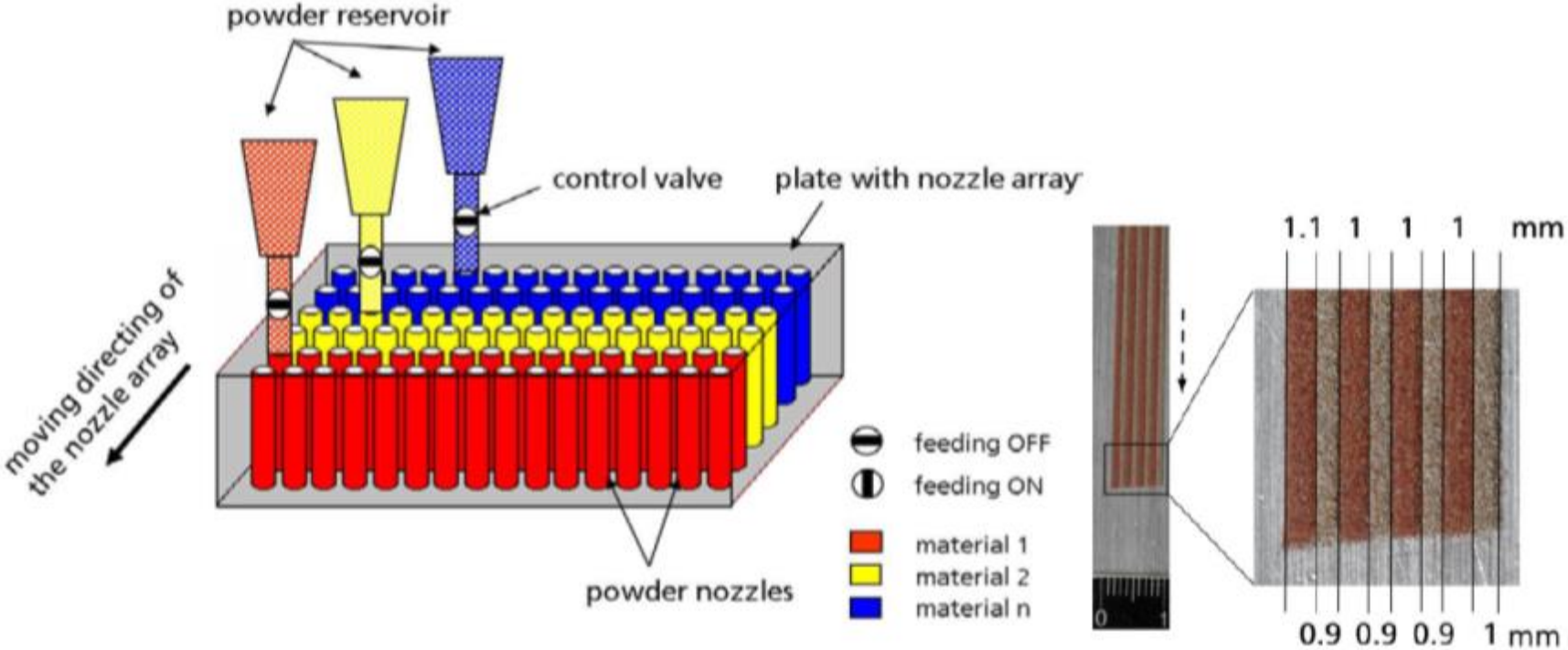
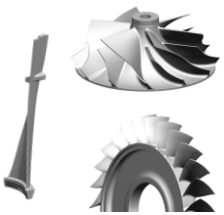


Fig 1: Concept of multi-material SLM (left) and deposited multi-material combination (right)

Vision II: *Tailored materials*
(inorganic & organic)

Additive Manufacturing – Process Chain



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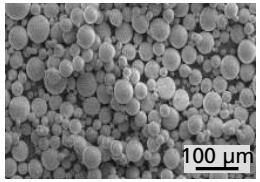

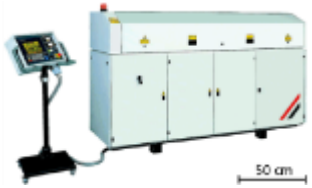

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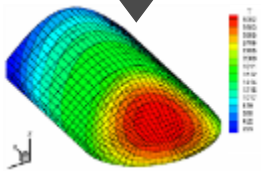
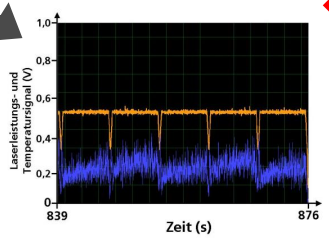


Process fundamentals



Process monitoring

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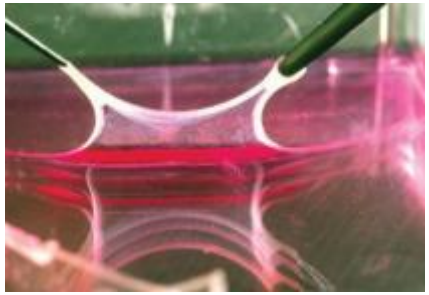
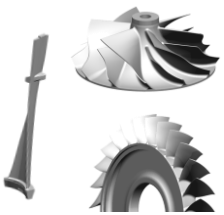
Process qualification for new material(s) combinations

- For laser and non-laser based processes such as SLM, LMD, STL, FDM, EBM (ARCAM), LIFT (organic materials) etc.
- For non powder-based processes (wire, liquids, slurry etc.)
- Below 10 μm^3 resolution (voxel) with materials:
  - *Industrial polymers* (p-T-t cycles; e.g. via pressurized process chamber)
  - *Hybrid* materials → e.g. switchable properties through switchable materials (metal-polymer, MMCs, CMCs, particle reinforced,…)
  - *Organic* materials such as *biopolymers* → Aim: Tissue engineering & Printable organs (approach: LIFT processes)

Vision III: *Tailored processes* (inorganic & organic)



Additive Manufacturing – Process Chain



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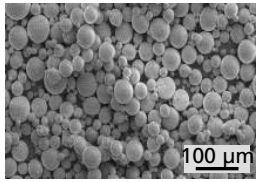

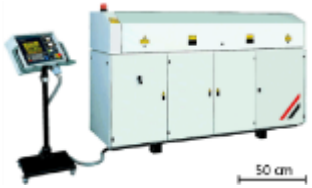

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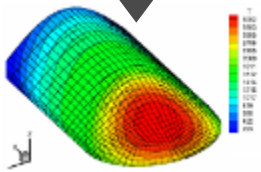
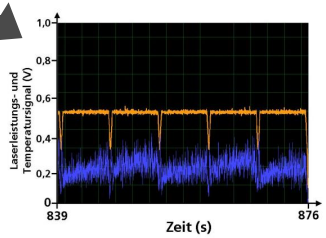


Process fundamentals



Process monitoring

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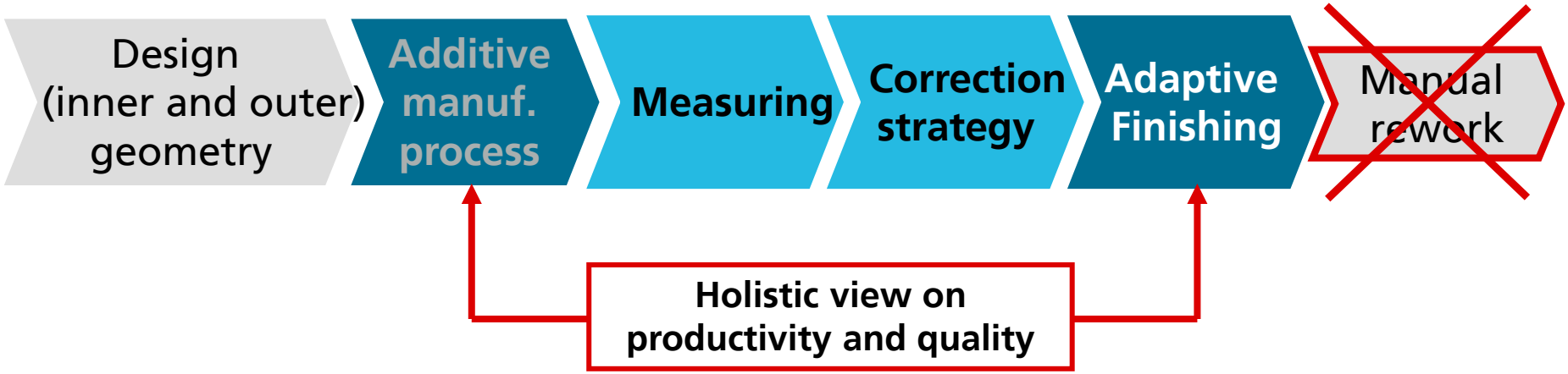
Holistic view to ensure productivity and part quality



Efficiency

- Higher efficiency of additive manufacturing process
- Parameters focusing on optimum of total process chain

Vision IV: *Tailored process and CAx chain(s)* (holistically adapted)

Accuracy

- Adaptive finishing step provides high part precision
- Elimination of manual rework reduces failure sources

Source: Fraunhofer IPT

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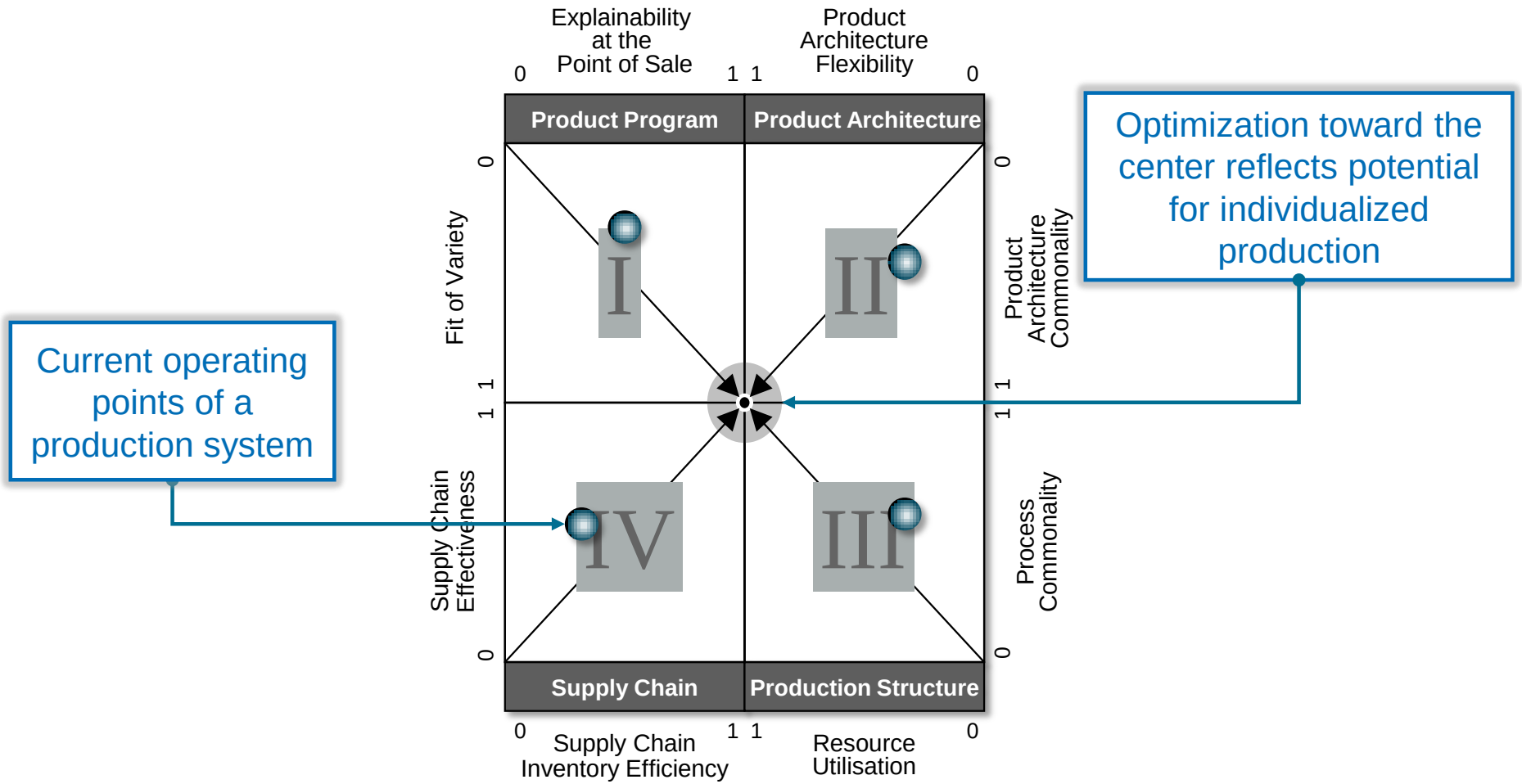
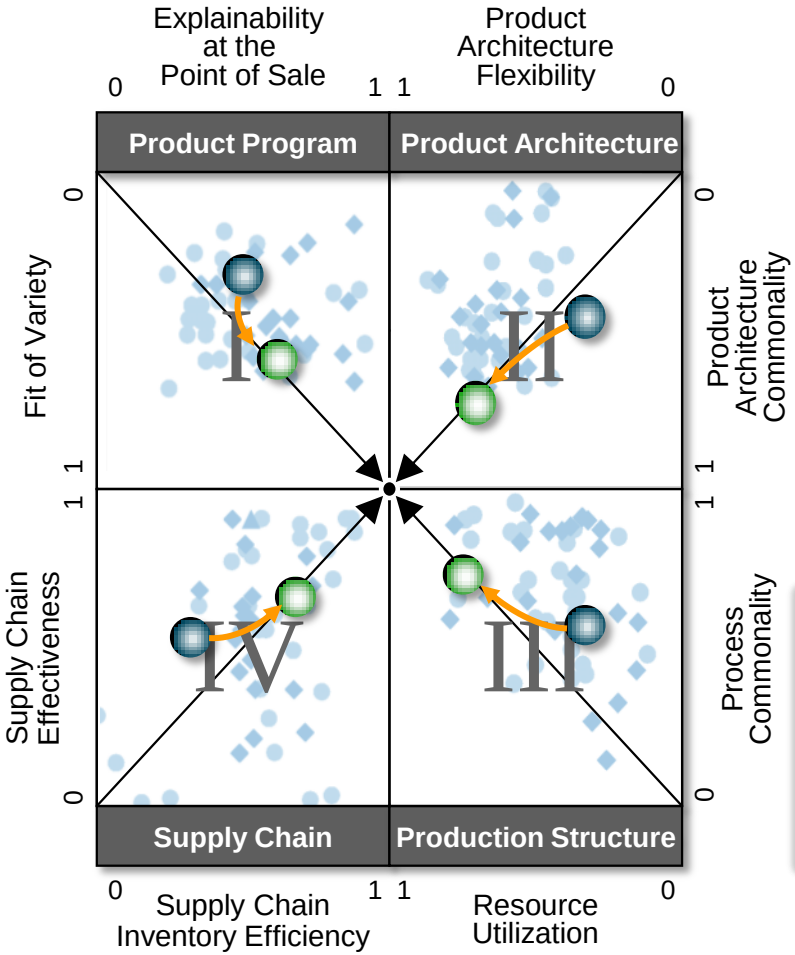
Holistic view to ensure productivity and part quality

	External Perspective	Internal Perspective
Product Perspective	**Product Program** Product range I	**Product Architecture** Inner structure of the products II
Production Perspective	Logistic interface to the customer IV **Supply Chain**	Resources and processes III **Production Structure**

Holistic view to ensure productivity and part quality



Holistic view to ensure productivity and part quality



Only the integrative configuration within all areas exploits the full potential of DPP

Mission statement

"Advanced Manufacturing is the use of innovative technology to improve products *or* processes." (http://en.wikipedia.org/wiki/Advanced_manufacturing as of November 22, 2013)

"Advanced Manufacturing is the use of innovative technology to improve products *and* processes."

"Advanced Manufacturing is manufacture for design instead of design for manufacture."

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Questions?

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