Buchbinder*, Damien; Schilling**, Gregor; Meiners*, Wilhelm; Pirch*,Norbert; Wissenbach*, Konrad
*Fraunhofer Institut für Lasertechnik (ILT), Aachen
**Lehrstuhl für Lasertechnik, RWTH Aachen University

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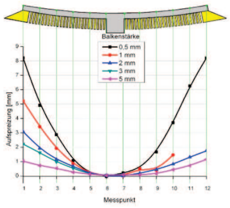


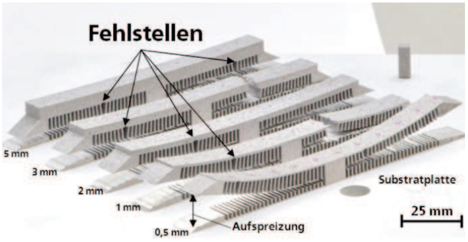
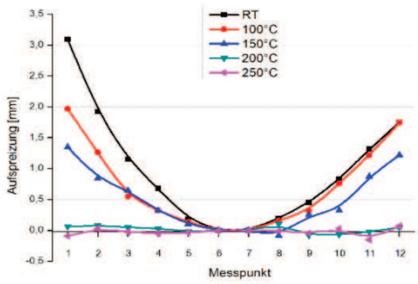


Bild 7 : Aufspreizungen und Fehlstellen an Twincantilevern in verschiedenen Balkenstärken mit



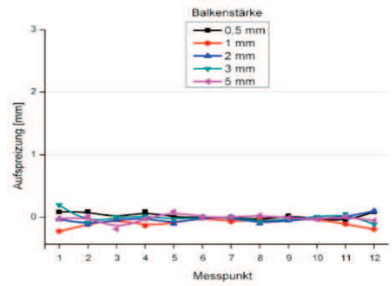


Bild 11: Aufspreizung der Twincantilever in Abhängigkeit von Balkenstärke und Messpunkt T_V = 250°C

T. Hoeling, L. Zimmermann, K. Wegener

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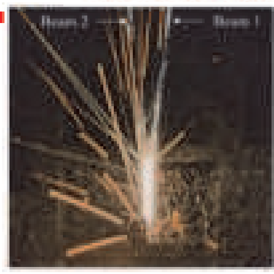
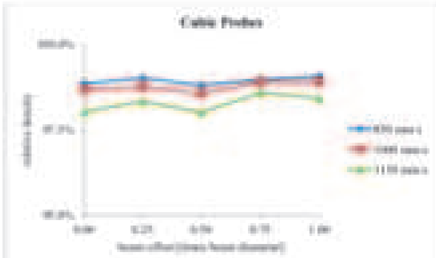
Table 2: Experimental setting for cubic probe experiments

	Power 1 [W]	Power 2 [W]	Scan Speed [mm/s]	Offset [beam diameter]
Reference	200	0	850	
	200	0	1000	
	200	0	1150	
Offset Strategy	150	50	850	0.25, 0.50, 0.75, 1.00
	150	50	1000	0.25, 0.50, 0.75, 1.00
	150	50	1150	0.25, 0.50, 0.75, 1.00





IWF
Institut für Werkzeugmaschinen und Fertigung
Institute of Machine Tools and Manufacturing
ETH

Repair Mono Crystal Blades

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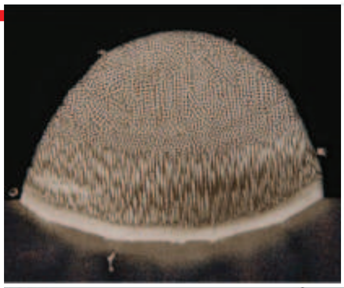
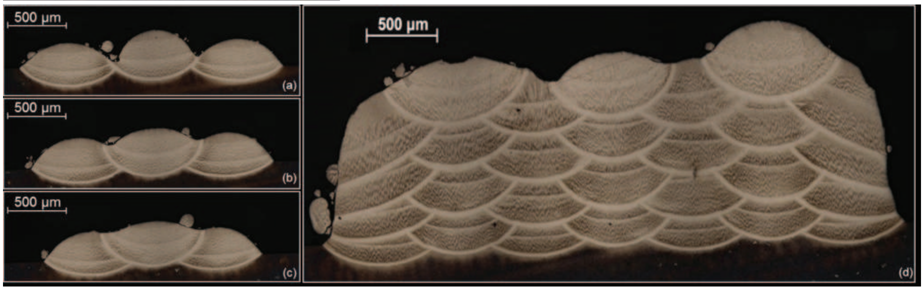


CIRP Journal of Manufacturing Science and Technology
Volume 19, November 2017, Pages 196-199

Single-crystal turbine blade tip repair by laser cladding and remelting

Stefan Kaierle[(3)a], Ludger Overmeyer[(2)a, b], Irene Alfred[a], Boris Rottwinkel[a], Jörg Hermsdorf[a], Volker Wesling[a], Nils Weidlich[c]



Tracks with a spacing of (a) 1.7 mm, (b) 1.5 mm, (c) 1.3 mm and (d) a multilayer - 4 clad

technology Boris Rottwinkel*, Christian Nölke, Stefan Kaierle, Volker Wesling (Procedia CIRP 22 (2014) 263 – 267)

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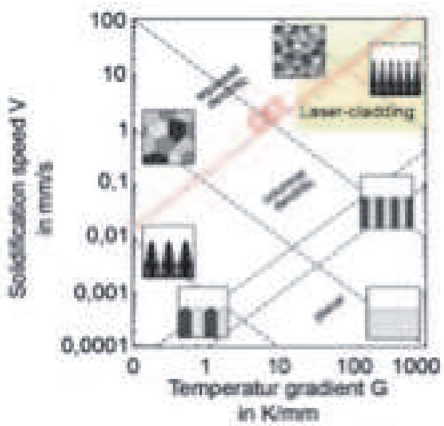

Fig, 2: CET - columnar to equiaxed transition [2]

[2] Kurz, E.; Bezenvon, C. & Gaeumann, M. (2001) Columnar to equiaxed transition in solidification processing. Science and Technology of Advanced Materials, Volume 2, Pages 185-191

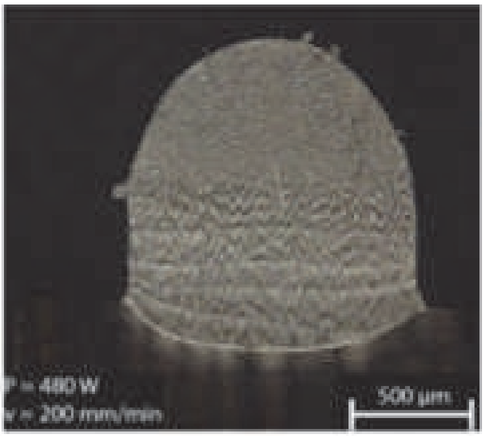

Fig. 6: Cross section of laser cladded CMSX-4 sample (single-track per layer)

AM Multi- Materials Variants (Michael Ott) TU Munich 2012 (ISBN 978-3-8316-4201-4)

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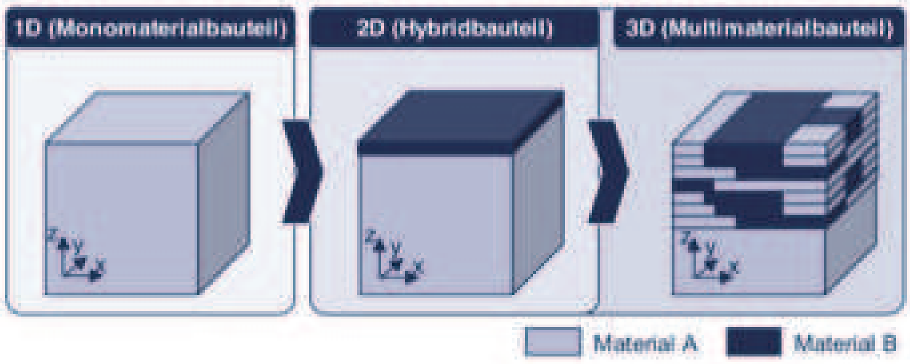
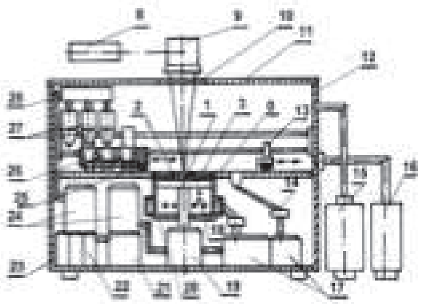


Multi-material processing in additive blasting and powder bed based production

(19) United States
(12) **Patent Application Publication** (10) **Pub. No.: US 2016/0339639 A1**
CHIVEL (43) **Pub. Date: Nov. 24, 2016**

(54) METHOD FOR PRODUCING THREE-DIMENSIONAL OBJECTS FROM POWDERS AND DEVICE FOR IMPLEMENTING SAME

B23K 26/064 (2006.01)
B33Y 10/00 (2006.01)
B23K 26/144 (2006.01)
(52) U.S. Cl.



ABSTRACT

The invention is a method and device for producing three-dimensional objects, having a gradient of properties and multi-material objects, from powders. A method involves the

Gradual Materials Directed Energy Deposition

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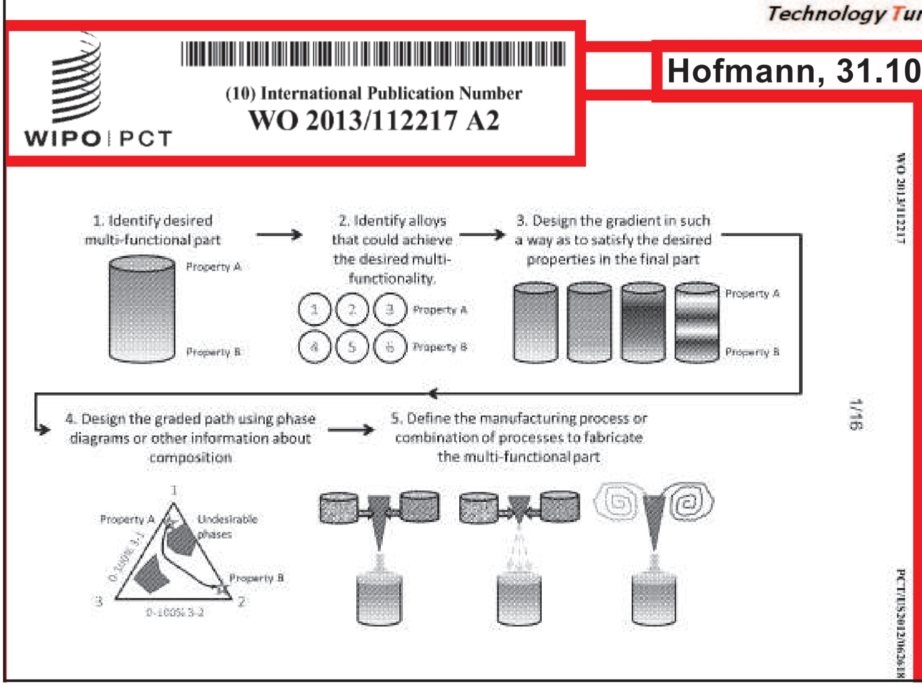

Hofmann, 31.10.2011

INDUSTRY

Gradient Materials

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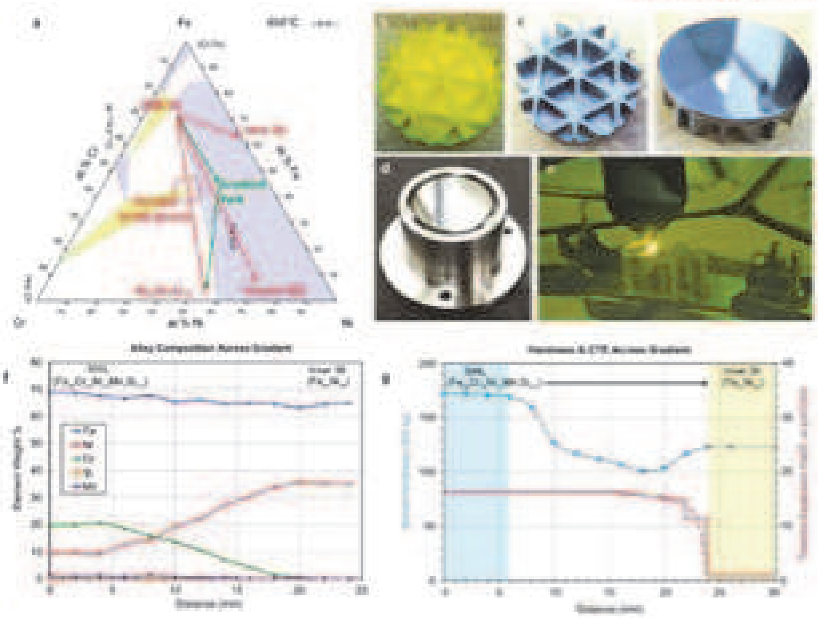

MICHAEL MOLITCH-HOU, The Fusing of Industries at the

Multi-Material Builds & Custom Alloys

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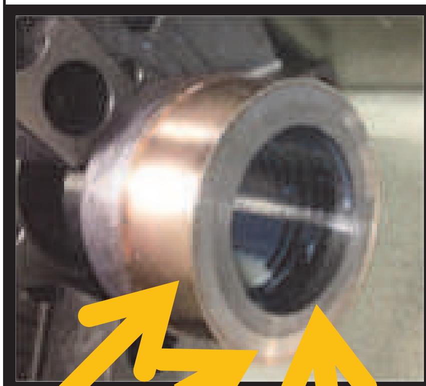
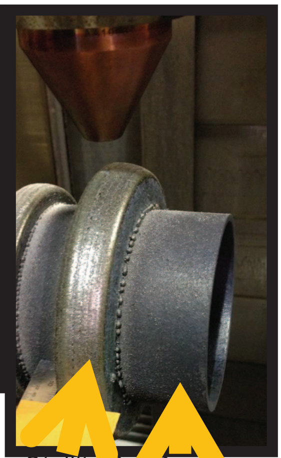


Copper – Inco 718 1045 Steel



Stellite o Copp r

Multi-material

Gradient material

"DIY" Alloy

Cold Spray (Ballistic deposition) Multi material

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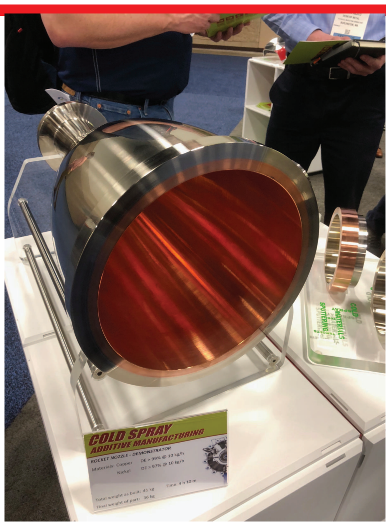

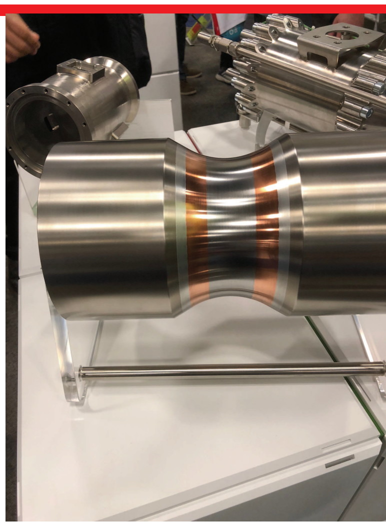

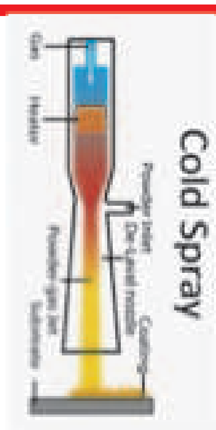

No-Tool, Carbon-fibre-reinforced PA12 SLS parts

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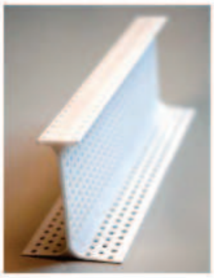
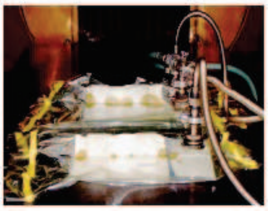
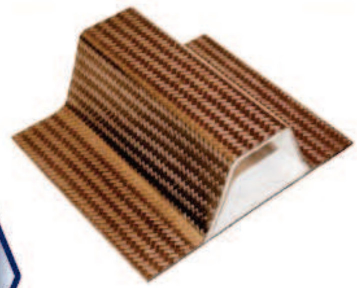
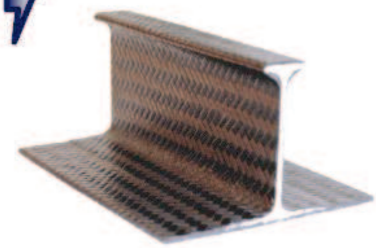
SLS PA12 made core



Vacuum bagging







ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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Technology Turn Around

1. Introduction
2. Process
   - Laser vs Non-Laser
   - Voxelization
   - Size and Productivity
3. Material for Processes
4. AM work flow
   - Dataflow Design Simulation
   - In situ control
   - Automation
5. Economical and Functional justifications
6. Already in Manufacturing
7. Complexity challenges ahead
   - Standards
   - IP
8. Conclusions

Geometrical Features

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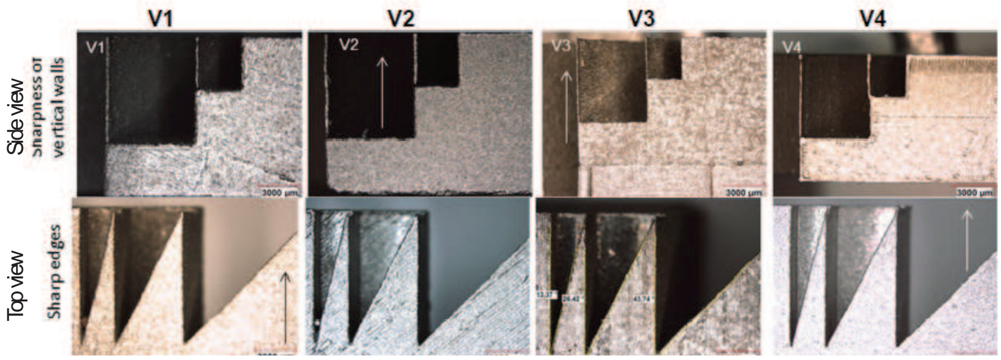

- V1 and V3 could manufacture the sharp edges best despite different build directions

Geometrical Features

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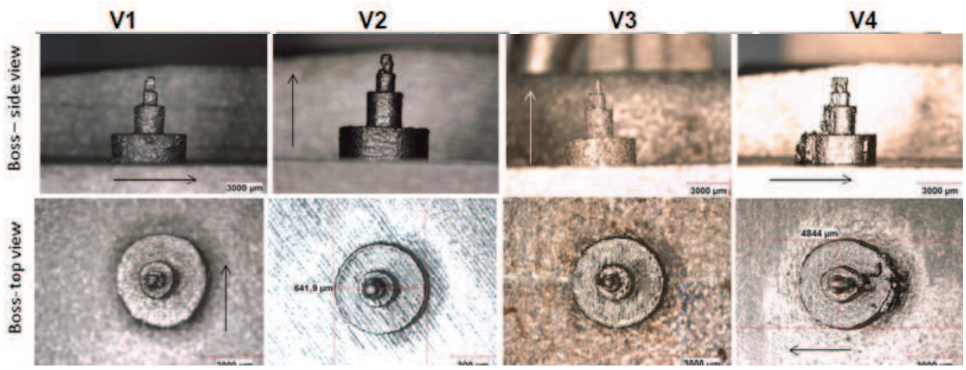

- Boss – cylinder tower with nominal diameters of 5, 2, 1 and 0.5 mm
- 0.5 mm cylinder was only built by V3 with an accuracy of 20 µm
- V1 and V4 – unacceptable
- V2 surface quality and sharpness best

"First Time Right" with to "Virtual Manufacturing"

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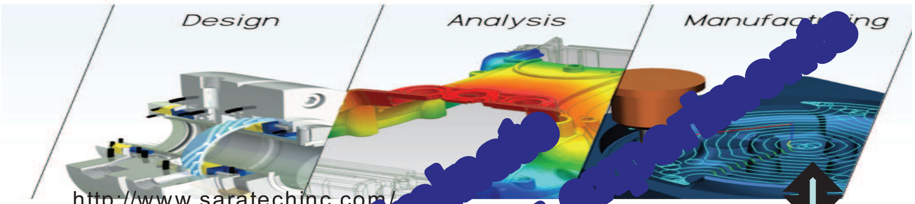

http://www.saratechinc.com/

Virtual Manufactu

In situ Monitoring

QA

- Optimal functional desi
- Optimal supports d
- Geometrical a y and surface finish
- Thermal s and deformation minimization
- Metall al grain size direction alloying chemical composition
- Density and minimal porosity
- Best quality

From Design to Part

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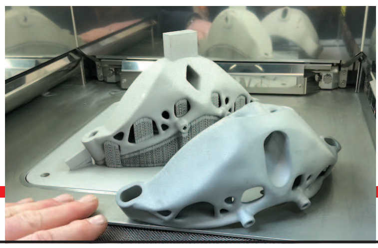
Technology Turn Around

- Design
- Topology Optimization
- Lattice Structures
- Part Mechanical Simulation
- Orientation evaluation
- Supports
- Process Simulation



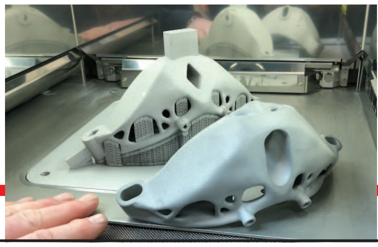
- Build in Machine
- In Situ Process Control
- (Adaptive Process Control)

- Postprocessing
- Thermal treatment
- Support Removal
- Machining
- Quality Inspection (QA)

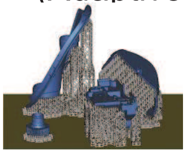
From Design to Part

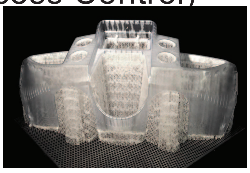
TTA
Technology Turn Around

- Design
- Topology Optimization
- Lattice Structures
- Part Mechanical Simulation
- Orientation evaluation
- Supports
- Process Simulation



- Build in Machine
- In Situ Process Control
- (Adaptive Process Control)





- Postprocessing
- Thermal treatment
- Support Removal
- Machining
- Quality Inspection (QA)

https://wohlersassociates.com/

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WOHLERS ASSOCIATES

Multi Physics-CAD (MP-CAD) Tools are in due

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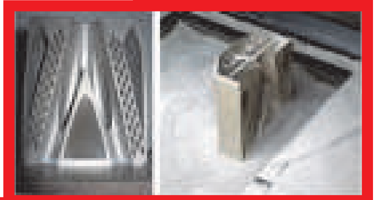
- Light weight
  - *Ecological design*
  - *Topological optimization*
- Flow
  - *Minimal parts(Diffusor)*
  - *Static mixer*
  - *Aeronautics*
- Heat transfer
- Local physical properties
  - *Digital materials*
  - *Alloyed materials*
- Medical
  - *Biological design*
  - Engineered surfaces
  - *Scaffolds*
- Life Style



Minimal manifolds revisited - shedding more material & boosting performance

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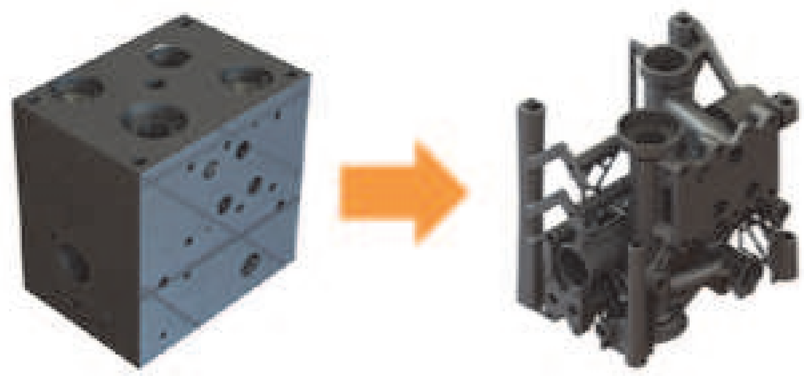

Marc Saunders
Director - Global Solutions Centres at Renishaw, accelerating adoption of additive manufacturing (metal 3D printing) (2016)

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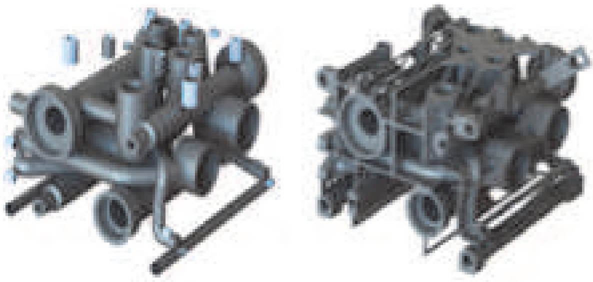

The first design iteration yielded a part with a 52% reduction in part volume and a 60% increase in flow efficiency:

	[illegible]	[illegible]	[illegible]
Material	AlSi10Mg	AlSi10Mg	S316L
Volume (cm3)	9,600	4,550	2,049
Mass (kg)	25.6	12.3	16.3

Simulation and verification

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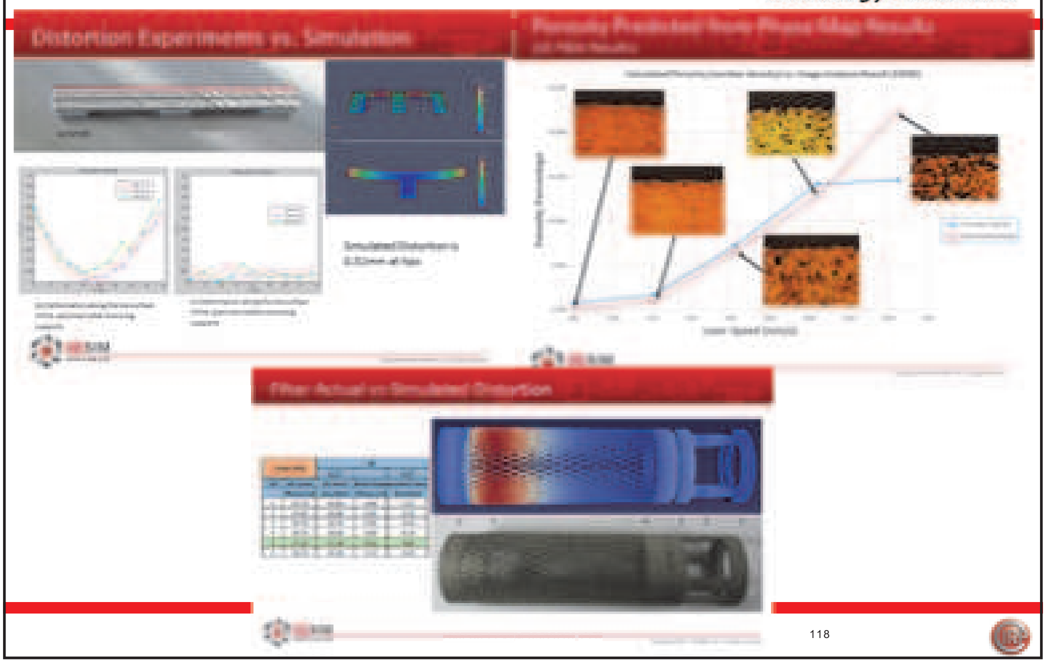

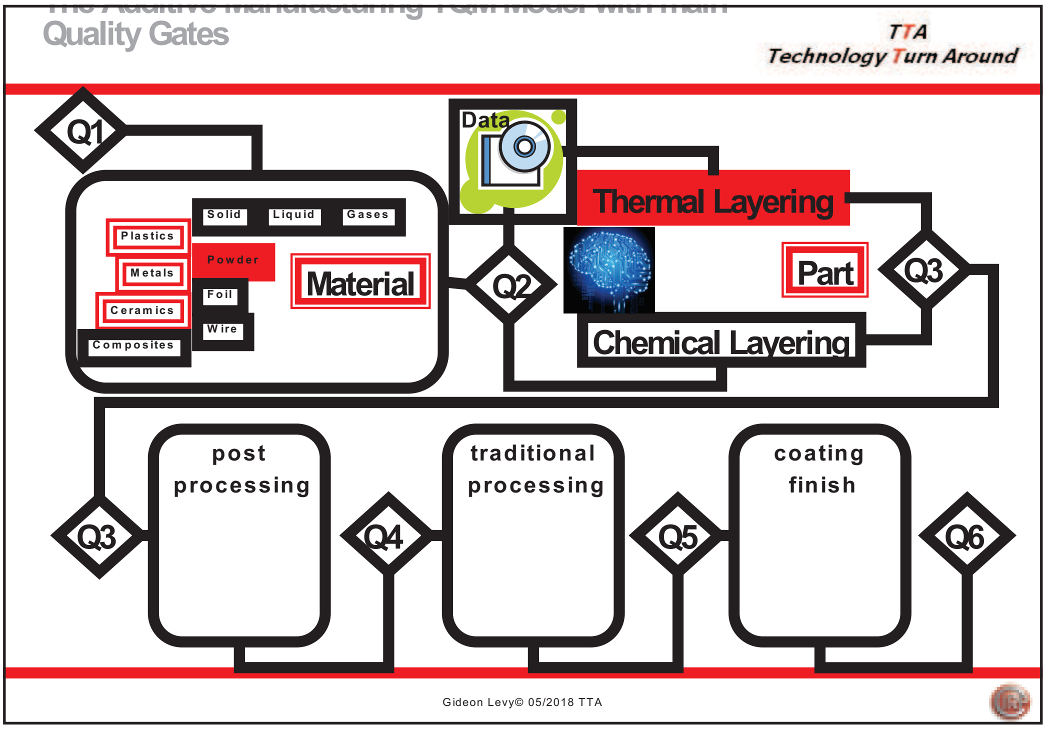

Quality Gates
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Q1
Data
Thermal Layering
Solid
Liquid
Gases
Plastics
Metals
Ceramics
Composites
Powder
Foil
Wire
Material
Q2
Part
Q3
Chemical Layering
post processing
traditional processing
coating finish
Q3
Q4
Q5
Q6
Gideon Levy© 05/2018 TTA

Powder Characterization
GRANU TOOLS
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GRANU
GRANU
GRANU
GRANU
GRANU
❑ New powder as delivered
❑ Used and sifted
❑ Mixed used /new (ratio?)
Camera
Avalanche Angle
(a) Granular sugar
(b) Powdered sugar
Figure 1: granular and powdered sugar in rotation in the Granudrum's cell
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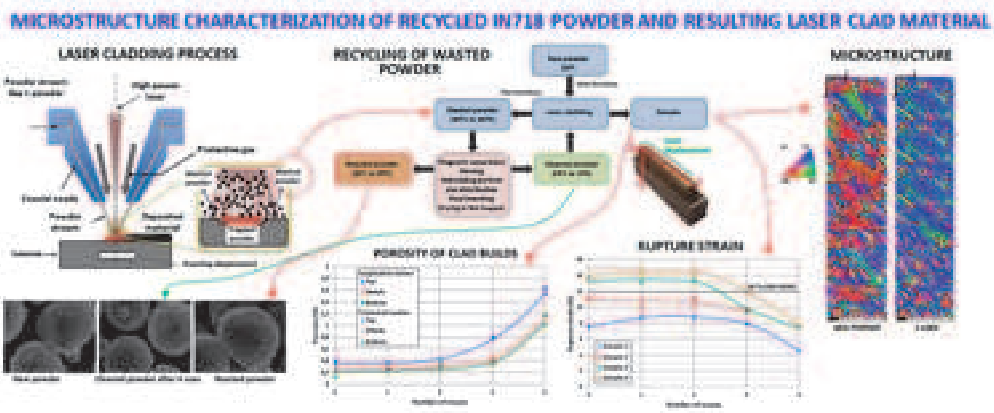
Mercury Scientific Inc

http://www.mercuryscientific.com/

DMD - RECYCLED IN718 POWDER



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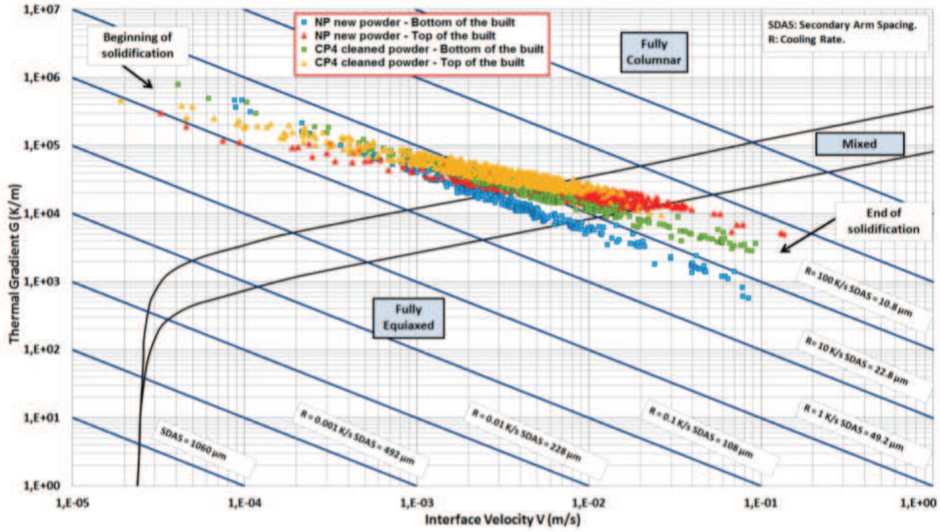

Effect of IN718 recycled powder reuse on properties of parts manufactured by means of Selective Laser Melting – LANE 2014

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L. C. Ardilaa, F. Garciandiaa, J. B. González-Díaza, P. Álvareza, A. Echeverriaa, M.M. Petitea, R. Deffleyb, and J. Ochoaa,* aIK4

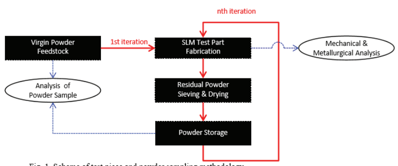
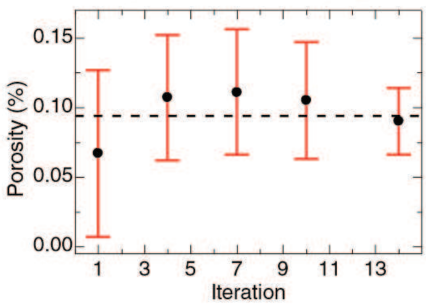
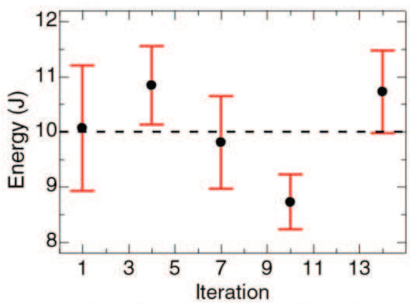


Fig. 1. Scheme of test piece and powder sampling methodology.





Feedback control of Selective Laser Melting

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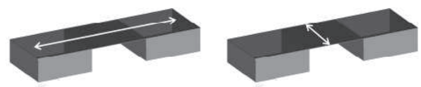
P. Mercelis, J.P. Kruth, J. Van Vaerenbergh
Department of Mechanical Engineering, University of Leuven, Celestijnenlaan 300B, Leuven, Belgium



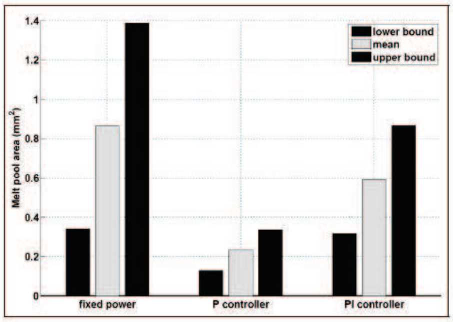


Figure 13: Mean melt pool area and +/- σ bounds in case of fixed parameters (left), proportional control (middle) and proportional-integrative control (right).

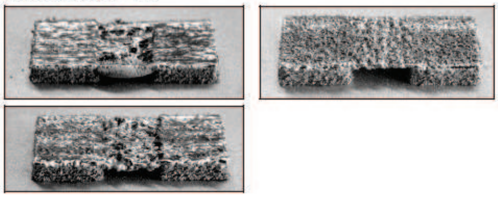


Figure 14: Resulting overhang geometry in case of fixed laser power (top left) versus P (top right) and PI (bottom left) feedback control.

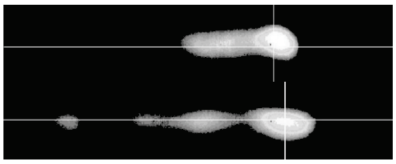


Figure 4: Comparison of melt pool images at 45W laser power and 16 mm/s (top) versus 50 mm/s (bottom) scanning velocity.

In situ monitoring

Fraunhofer IWU

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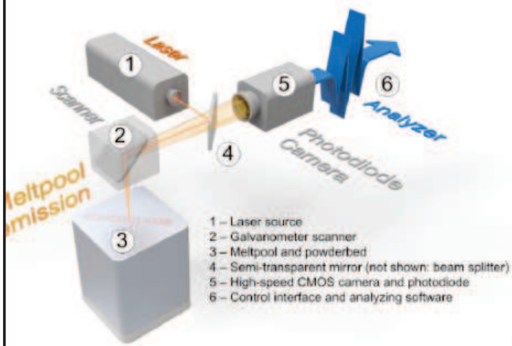
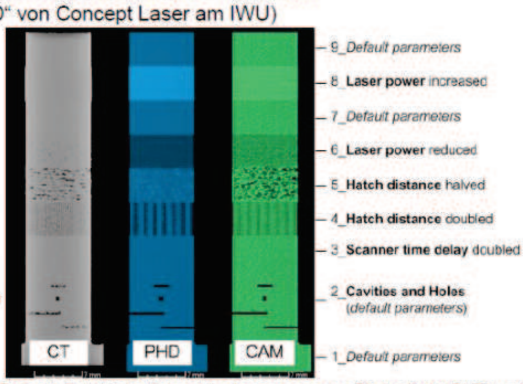
- Vorarbeiten zum Prozessmonitoring der Schmelzbademissionen vorhanden (kommerzielles System „QM Meltpool 3D" von Concept Laser am IWU)



Prozessmonitoring-System QM Meltpool 3D
(Quelle: Concept Laser GmbH)

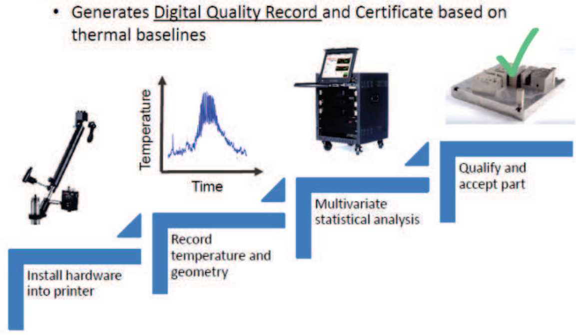


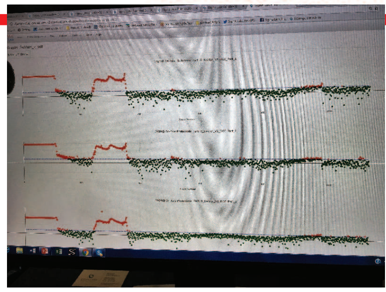
Beispiel: Detektierte Schmelzbademissionen von Phototdiode (PHD) und Kamera (CAM) im Vergleich zu CT-Daten
(Quelle: T. Toeppel et al.: *3D Analysis in Laser Beam Melting Based on Real-time Process Monitoring*, MS&T2016, Symposium "Additive Manufacturing: In-situ Process Monitoring, Defect Detection and Control", Salt Lake City, Oktober 2016, Paper/Vortrag angenommen)

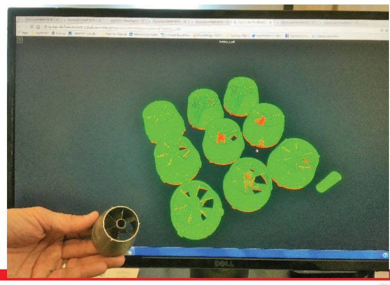
CONCEPTLASER

SIGMA LABS
Quality Beyond Inspection™

- In-process Inspection of Metallurgical Properties
  - Generates Digital Quality Record and Certificate based on thermal baselines







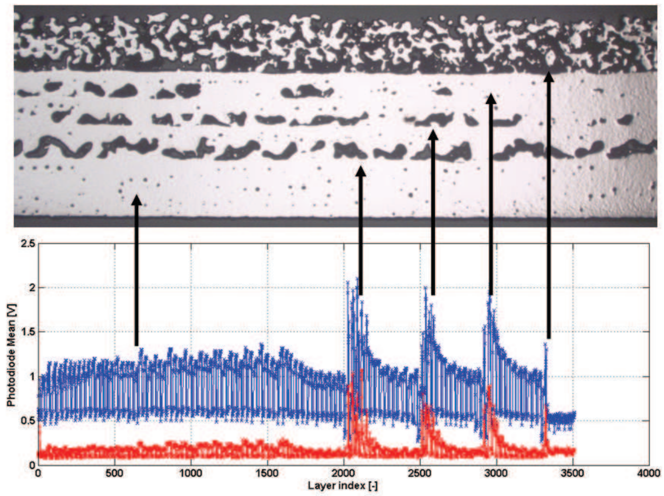
Application example: Layer thickness

Varying layer thickness
on research machine

→ variation of heat transfer to molten layers underneath

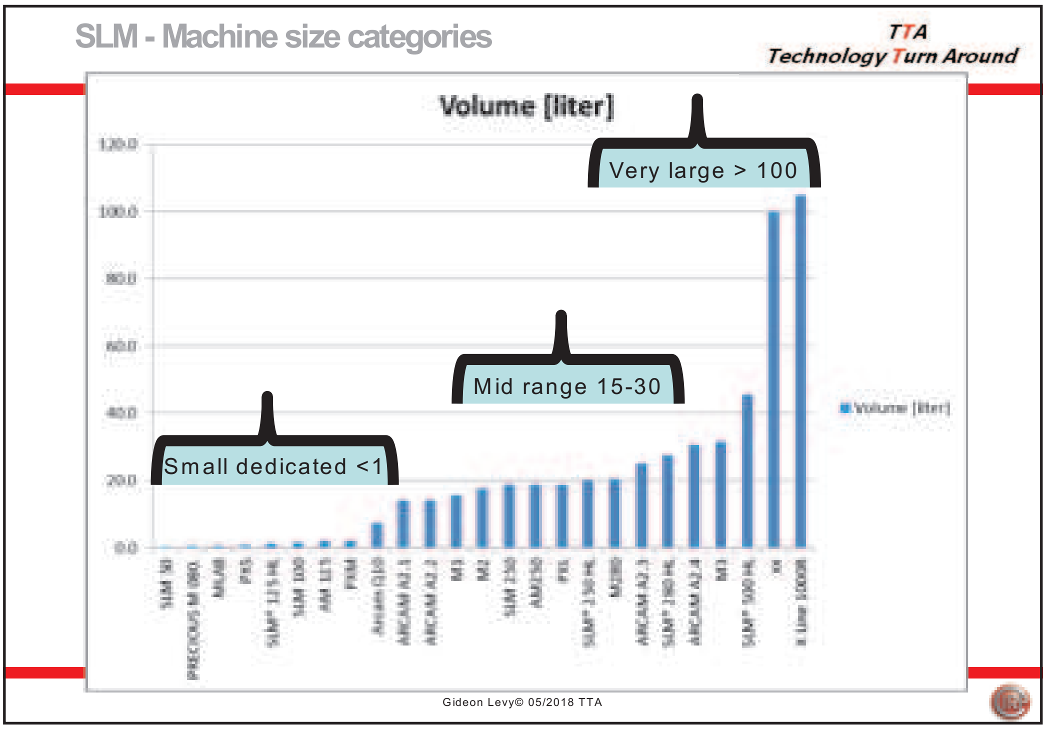
→ Enlargement of melt pool

→ Increase of melt pool emission



SIGMA LABS

Source: KU Leuven



SLM - Machine size categories
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Volume [liter]
Very large > 100
Mid range 15-30
Small dedicated <1
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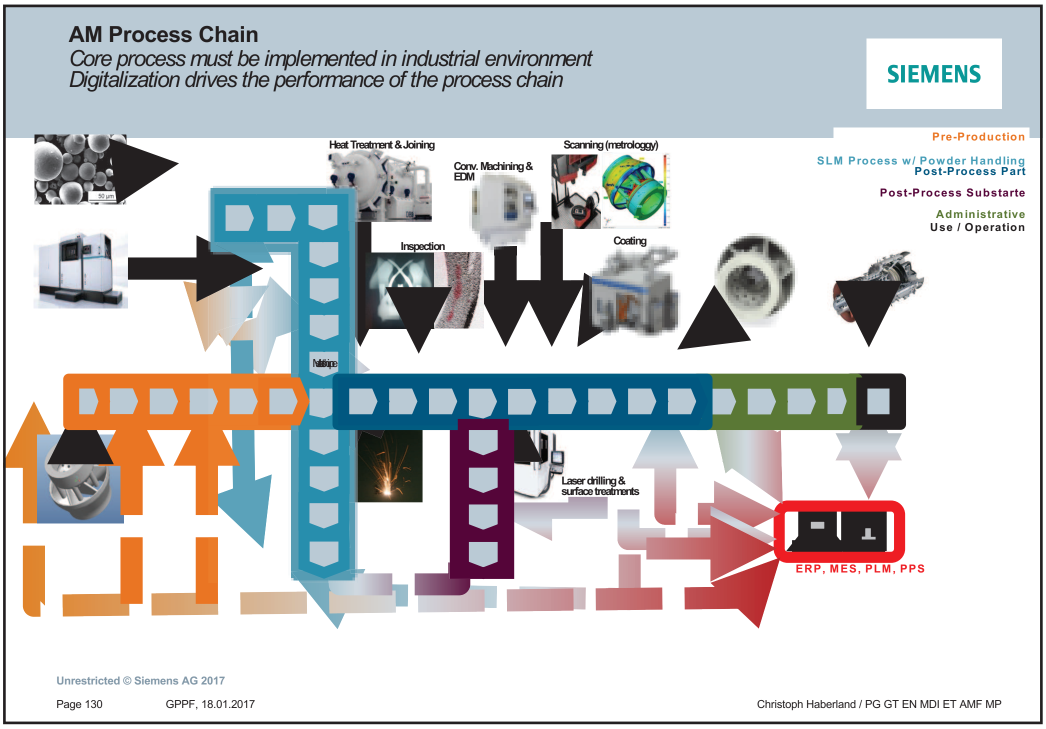

AM Process Chain
Core process must be implemented in industrial environment
Digitalization drives the performance of the process chain
SIEMENS
Heat Treatment & Joining
Conv. Machining & EDM
Scanning (metrology)
Inspection
Coating
Laser drilling & surface treatments
Pre-Production
SLM Process w/ Powder Handling
Post-Process Part
Post-Process Substarte
Administrative
Use / Operation
ERP, MES, PLM, PPS
Unrestricted © Siemens AG 2017
Page 130
GPPF, 18.01.2017
Christoph Haberland / PG GT EN MDI ET AMF MP

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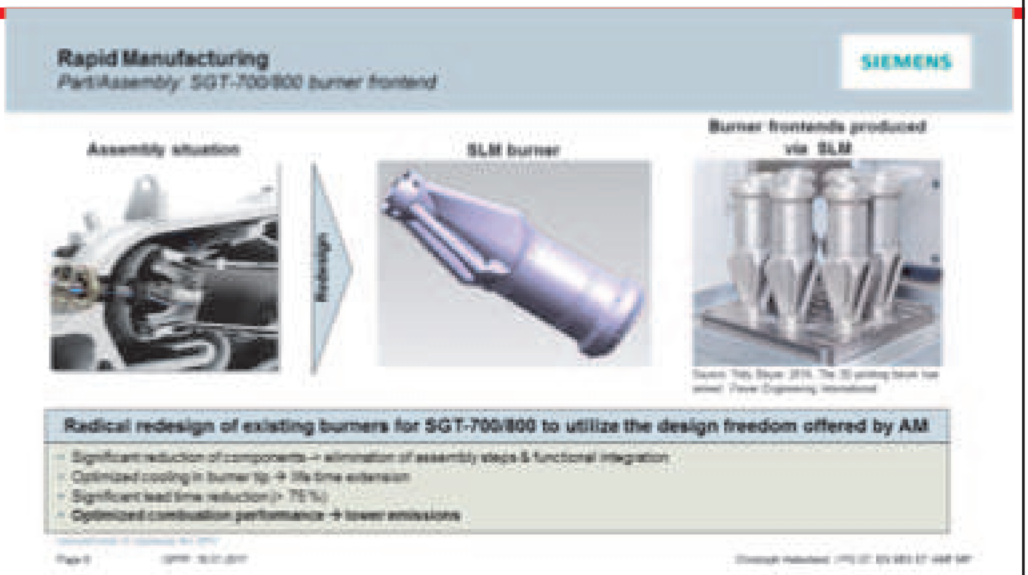

AM Automated Production Cell

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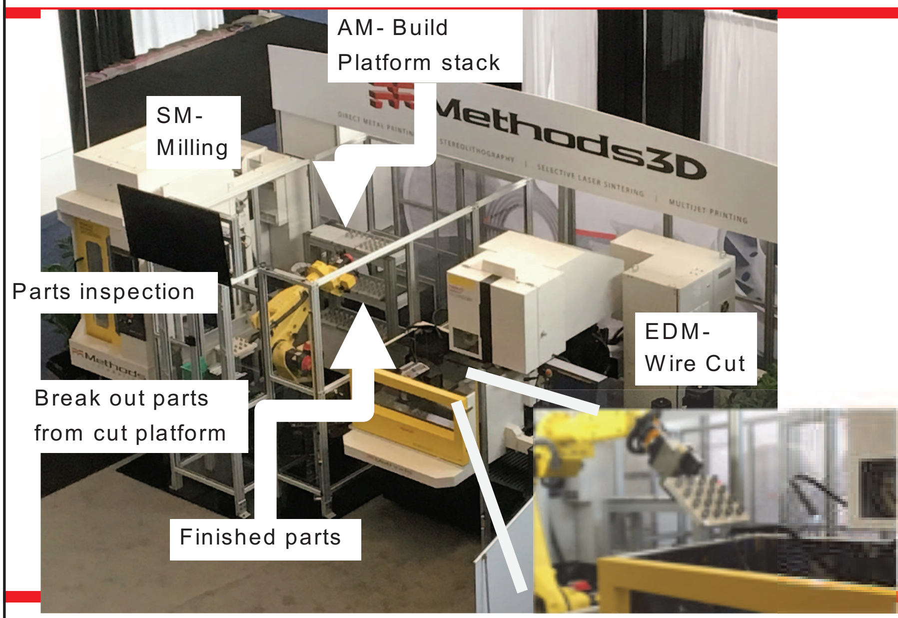

New 2018 Product Removal Module

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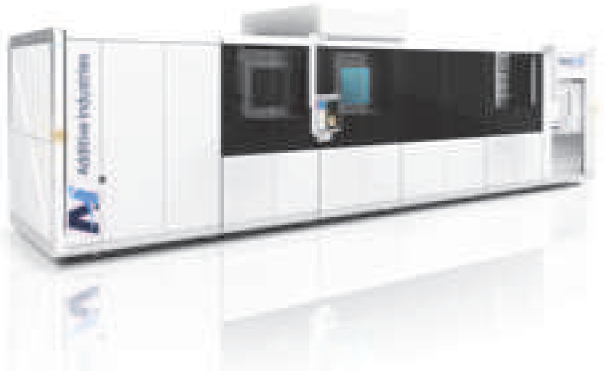

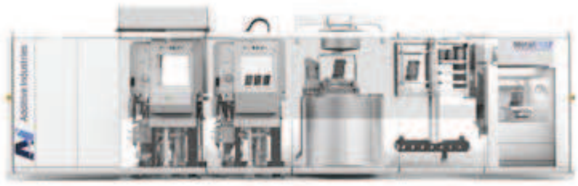

Product Removal Module
Allows integrated removal of printed parts from the build plate, after the heat treatment, also provides resurfacing of the build plate without any operator intervention.

The module consists of the following sub-modules

- Trapped powder removal (in supports or channels)
- Product removal with band-saw technology
- Surface milling with integrated tool changer
- Products collected in separate bin for safe transport
- Atex grade vacuum cleaner

09.05.2015 Pittsburg

rapid + tct

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Manufacturing paradigms

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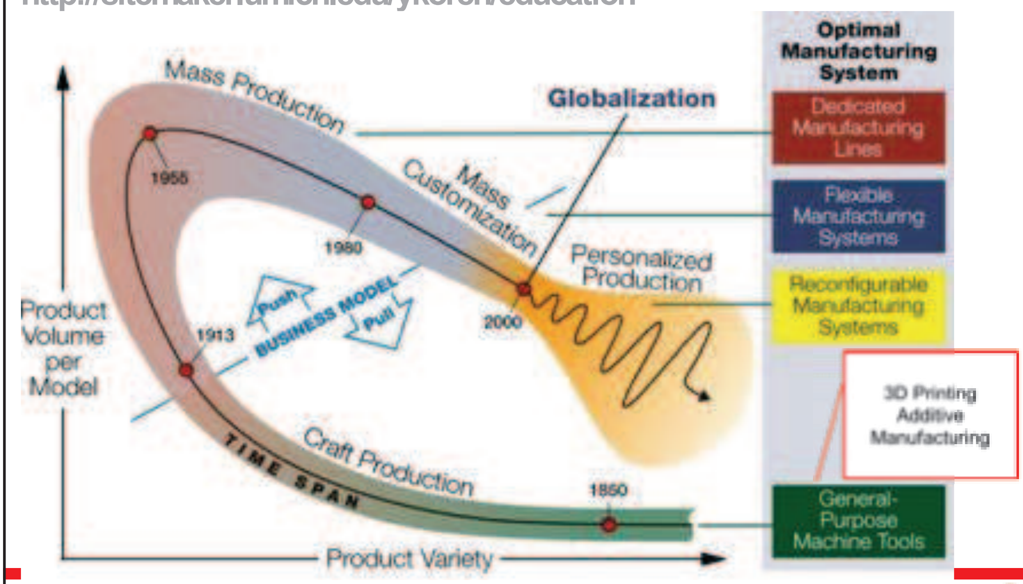
http://sitemaker.umich.edu/ykoren/education



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Over 50% of high end plastic products are coated

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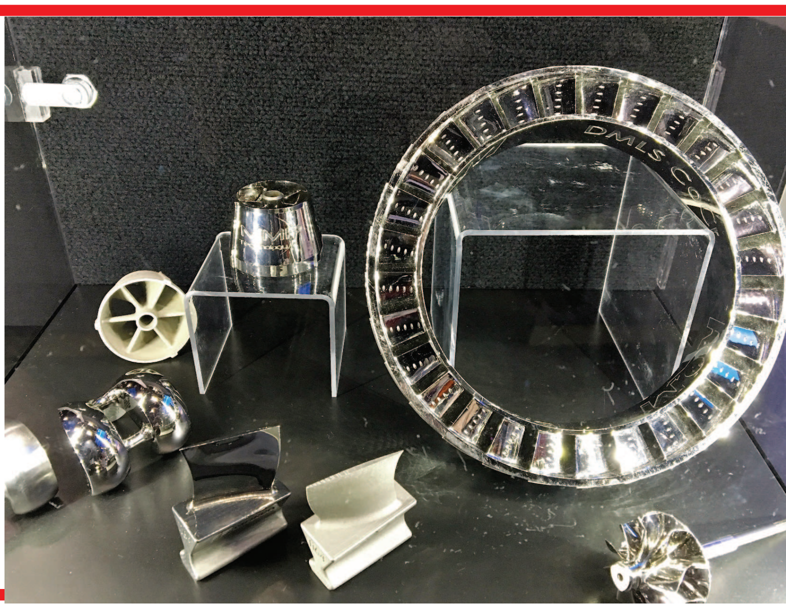

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1. Introduction
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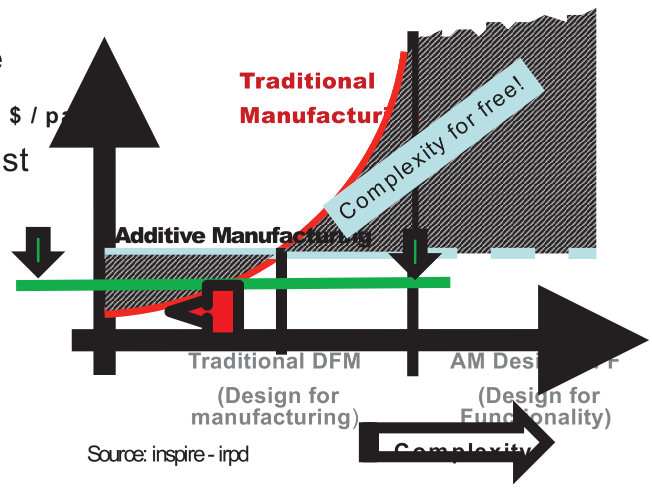
   - Automation
5. Economical and Functional justifications
6. Already in Manufacturing
7. Complexity challenges ahead
   - Standards
   - IP
8. Conclusions

- Higher productivity
- Lower machine price
- No Laser
- Reduced material cost
- Competition
- Functinality
- DFAM



Source: inspire - irpd

Additive Manufacturing government funding (2014)

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World gov. funding		5`561 Mio €	Mio €
Singapore	500 Mio SGD	293 Mio €	293
China	2 Billion USD	1466 Mio €	1466
UK	60 Mio GBP	74 Mio €	74
European Union (approx.)	2 Billion EUR	2000 Mio €	2000
Russia	2 Billion USD	1466 Mio €	1466
Australia AMCRC	250 Mio AUD	171 Mio €	171
Australia AM machines	17.5 Mio AUD	12 Mio €	12
US (NAMII)	30 Mio USD	22 Mio €	22
US America Makes	9 Mio USD	7 Mio €	7
New Zeland			50
Taiwan			
South Africa			
South America			
Mexico			
		Mio €	5'561

into specific business cases

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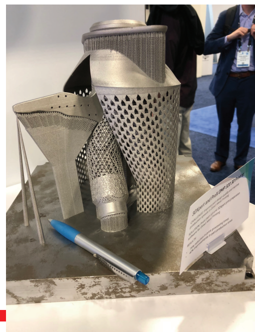
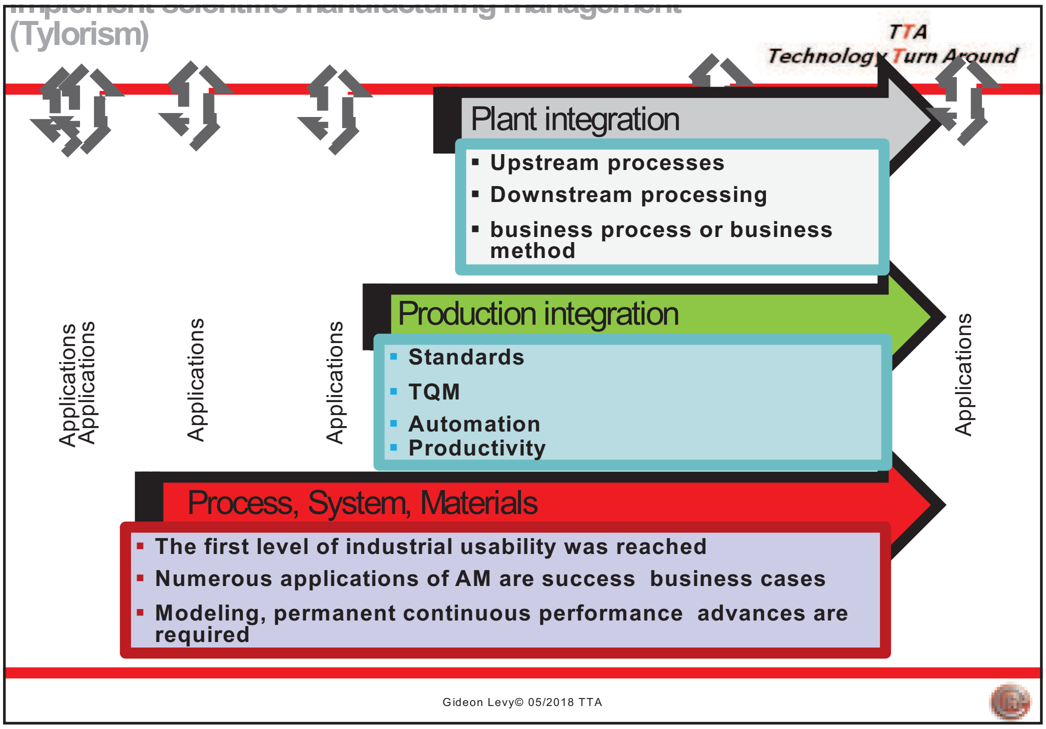
- ✓ Freedom of Design
- ✓ Lightweight structures (hollow)
- ✓ No-Tool production
- ✓ Assemblies, integrated design
- ✓ Anatomical personalized
- ✓ Ergonometric design
- ✓ individualization
- ✓ Conformal coolingCustomization
- ✓ Gradual materials (on the way)
- ✓ Medical scaffolds (on the way)

Application driven innovation!





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Dental: orthodontics , crowns bridges implants

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Data → AM → User

3DP
SLA
SLS
SLM

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Production of SLA Thermoforming Tooling for orthodontic use

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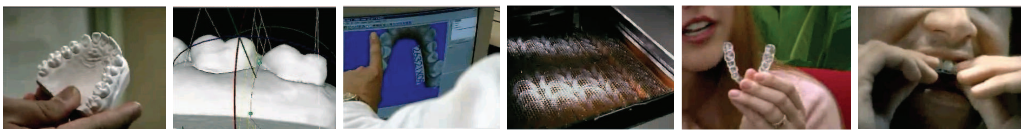

a → b → c → d → e → f

Individual set manufacturing process chain for each patient: a) dental impression, b) digitised data elaboration, c) STL forming tool data, d) tooling sets on SLA 7000 system, e) thermoformed biocompatible transparent plastic bridge, f) bridge use in mouth (Source: Align Company)

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adidas

carbon3D

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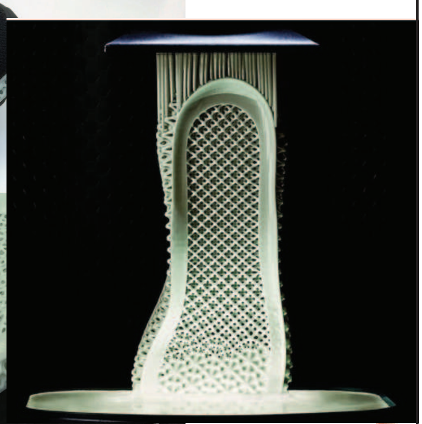

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HP Multi Jrt Fusion AM Sysm

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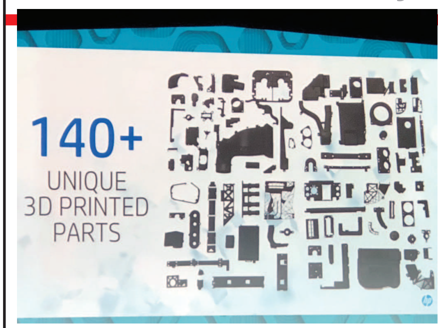

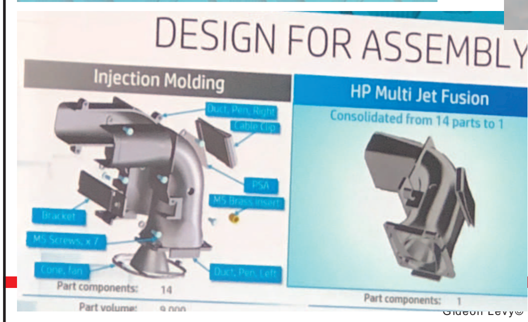

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Design for Assembly (DfAM)

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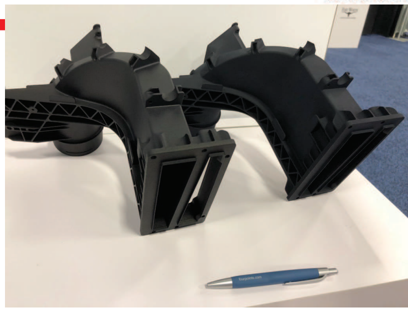

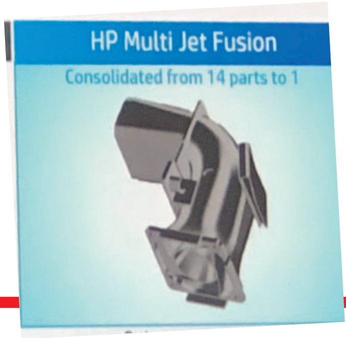

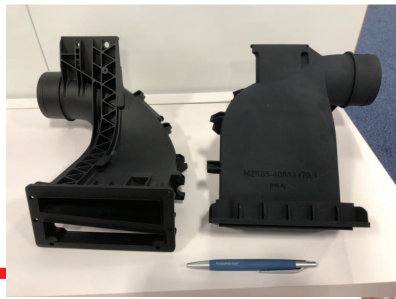

SIEMENS

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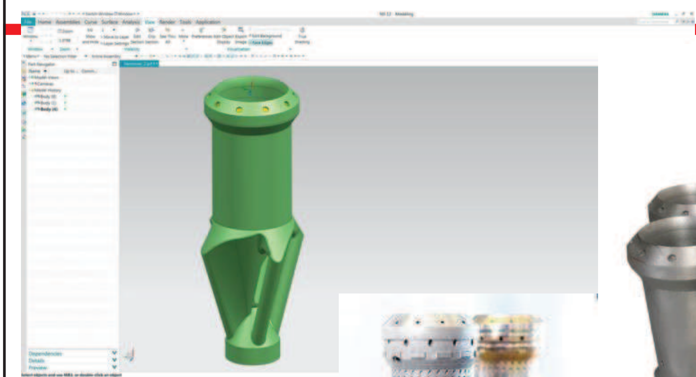

Impressive results in Advanced AM designed Turbo Prop aircraft Engine

GE Additive

AM a green technology

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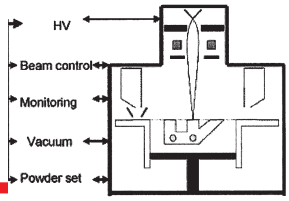
Avio Aero
A GE Aviation Business



ARCAM - EBM AM technology

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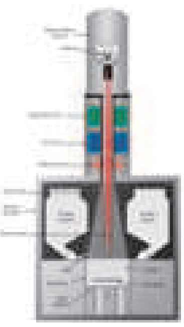

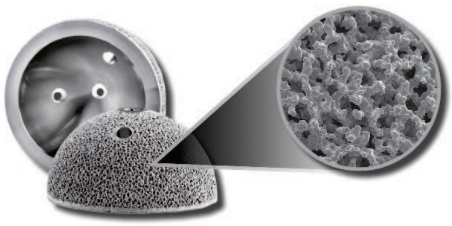

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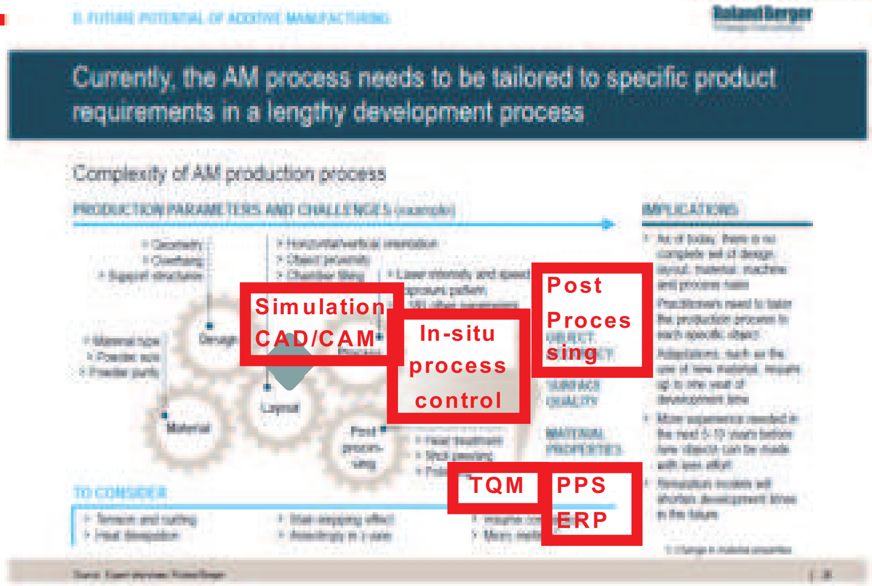

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Overview of the international activities known so far

The figure below illustrates the agreed-upon common structure of AM standards.

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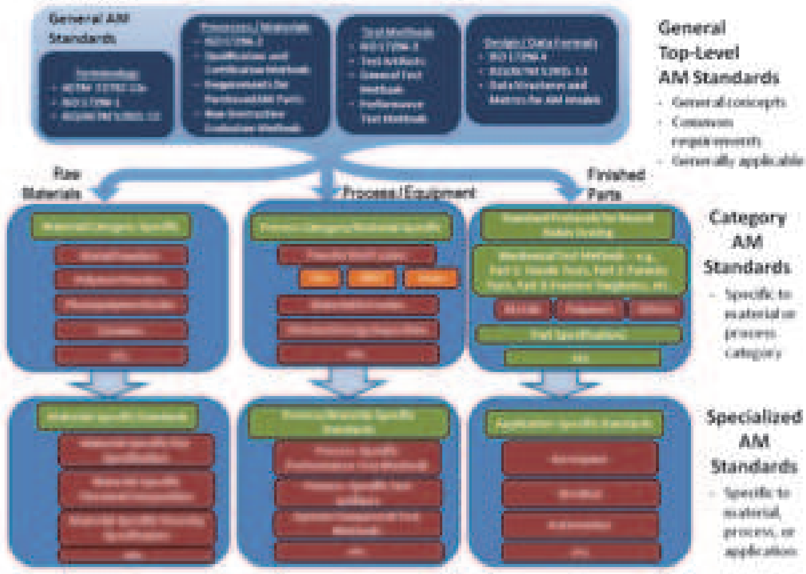
Structure of AM Standards



US Patents on RP/AM in steady state trend- maturity ?

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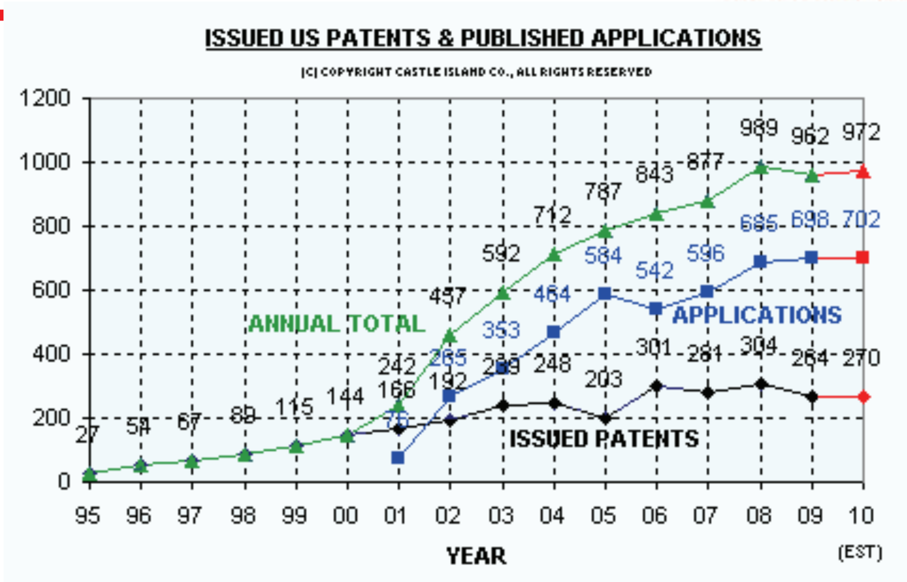

Source: www.additive3d.com/home.htm

manufacturing January 26, 2015

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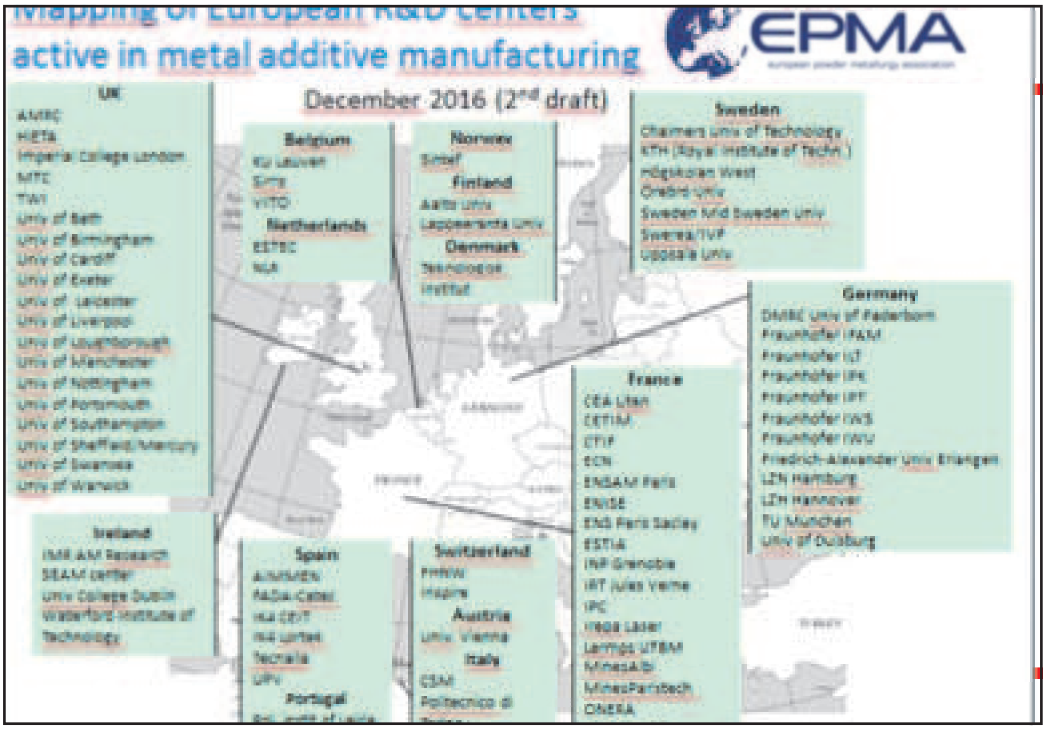
the CPC (Cooperative Patent Classification)

B33Y	ADDITIVE MANUFACTURING, i.e. MANUFACTURING OF THREE-DIMENSIONAL [3-D] OBJECTS BY ADDITIVE DEPOSITION, ADDITIVE AGGLOMERATION OR ADDITIVE LAYERING, e.g. BY 3-D PRINTING, STEREOLITHOGRAPHY OR SELECTIVE LASER SINTERING
B33Y10/00	Processes of additive manufacturing
B33Y30/00	Apparatus for additive manufacturing; Details thereof or accessories therefor
B33Y40/00	Auxiliary operations or equipment, e.g. for material handling
B33Y50/00	Data acquisition or data processing for additive manufacturing
B33Y70/00	Materials specially adapted for additive manufacturing
B33Y80/00	Products made by additive manufacturing
B33Y99/00	Subject matter not provided for in other groups of this subclass



devices

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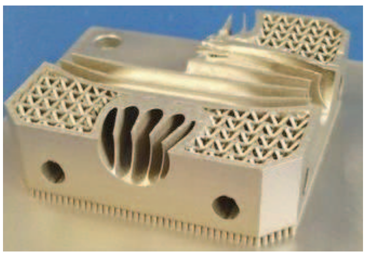
exchange based on "fish gill"

thanks to 3D printing

3D SYSTEMS

sirris



Design by: Julien Rouillac

https://www.sirris.be/

AM made - (no supports) Heat exchanger

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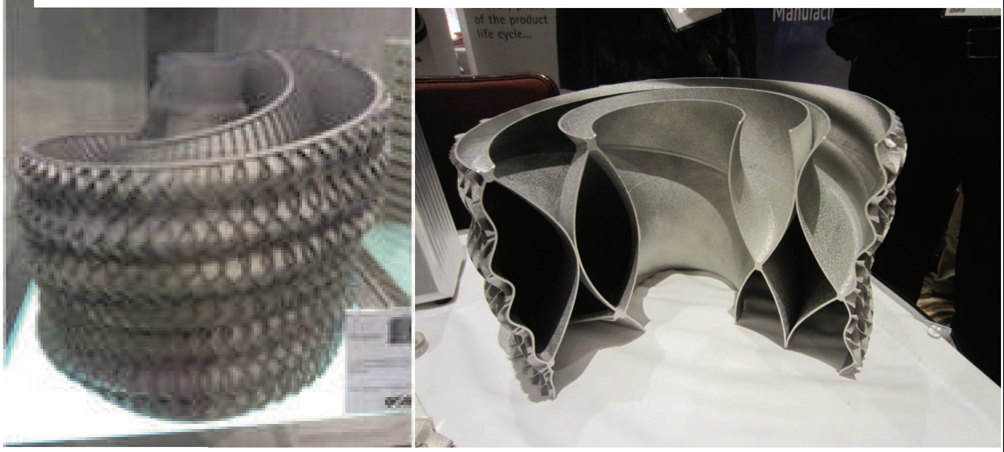
Heat exchanger 450x4050x500 mm



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SPACEX LAUNCHES 3D-PRINTED PART TO SPACE, CREATES PRINTED ENGINE CHAMBER

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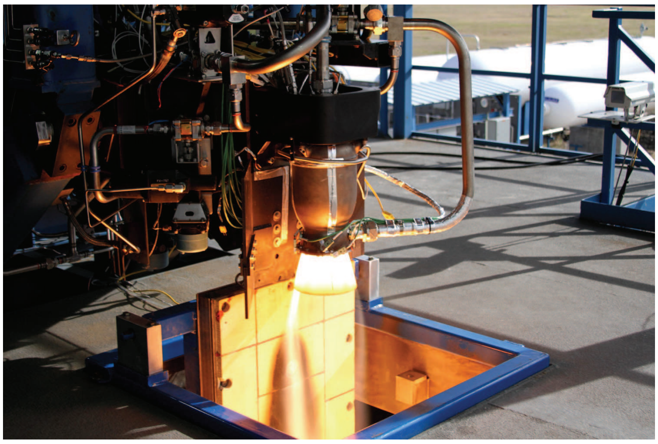
Dragon Version 2 vehicle

JULY 31, 2014



The chamber is regeneratively cooled and printed in Inconel, a high performance superalloy. Printing the chamber resulted in an order of magnitude reduction in lead-time compared with traditional machining – the path from the initial concept to the first hotfire was just over three months.

Object made from 100% meteorite dust.

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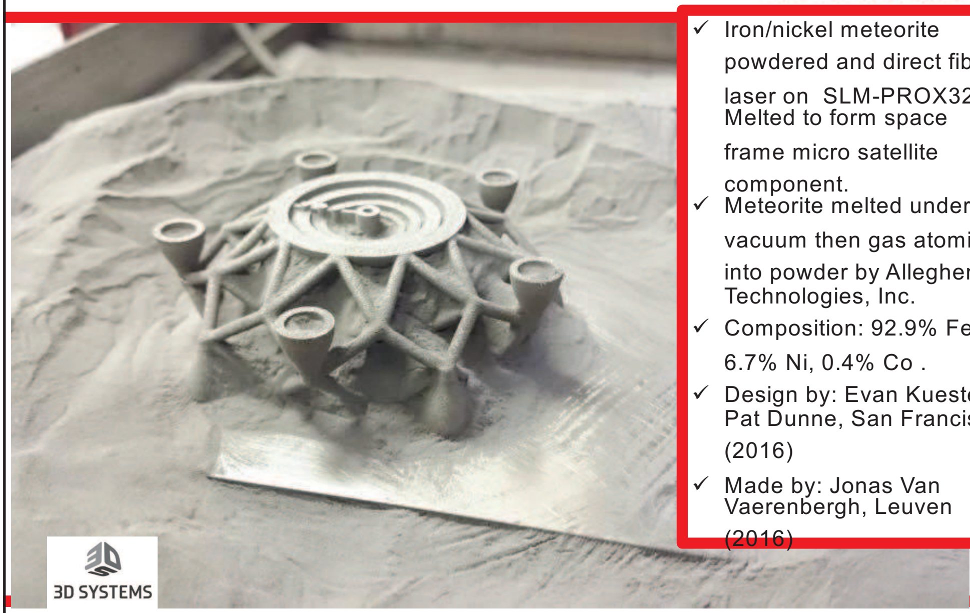

- ✓ Iron/nickel meteorite powdered and direct fiber laser on SLM-PROX320 Melted to form space frame micro satellite component.
- ✓ Meteorite melted under vacuum then gas atomized into powder by Allegheny Technologies, Inc.
- ✓ Composition: 92.9% Fe, 6.7% Ni, 0.4% Co .
- ✓ Design by: Evan Kuester & Pat Dunne, San Francisco (2016)
- ✓ Made by: Jonas Van Vaerenbergh, Leuven (2016)

Michelin unveils airless, 3D printed concept tire

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https://www.youtube.com/watch?v=D_QVKpPTiQU&feature=youtu.be

MICHELIN

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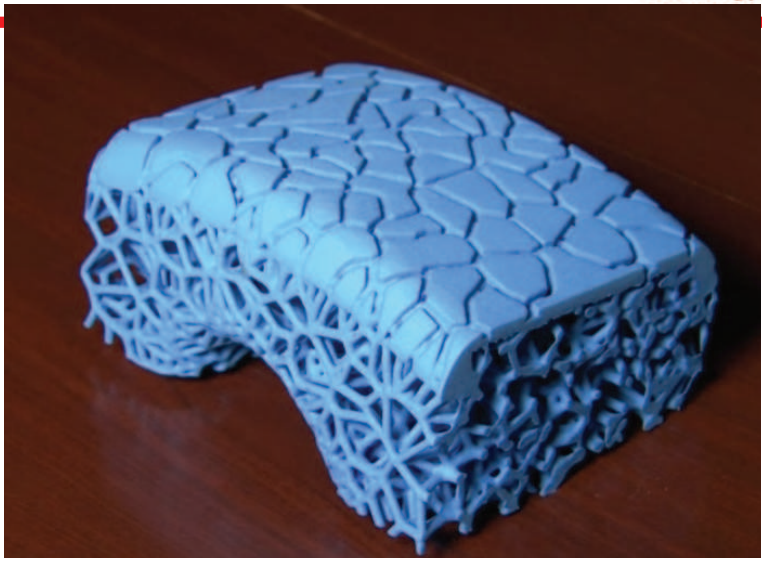

https://www.youtube.com/watch?v=D_QVKpPTiQU&feature=youtu.be

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I will NOT deal with

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- sustainability,
- democratization of design
- democratization of manufacturing,
- product liability
- warranty and
- copyright
- intellectual property (IP)
- .
- .
- and some more aspects.

The AM Field and Research Opportunities and Efforts

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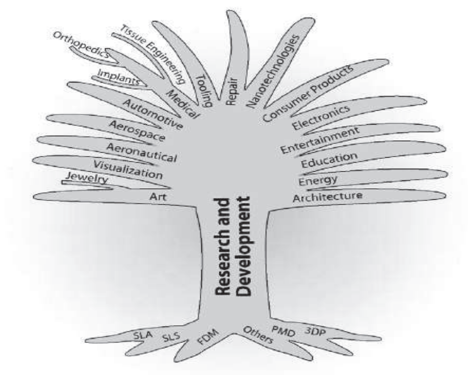
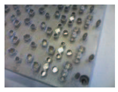


Source Road Map ALM 2009 D. Bourell et al.

Part type have different primary requirements and standards!	
Decorative surface structure	 
Functional accuracy	 
Structural properties	 
Medical biocompatible	 

The wide ranging applications and requirement is a great challenge for manufacturing.
Can a universal systems cover it?

View Points

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- ✓ Additive Manufacturing - The Revolutionary Enabling Technological Innovation Space in our Century.
- ✓ Variety of Process, Materials and Applications in commodities, mobility over aviation space, medicine and healthcare.
- ✓ Additive Manufacturing revolutionize the way we design and manufacture almost everything,
- ✓ Additive Manufacturing the economic driver for the well-being of society.

70 years ago…

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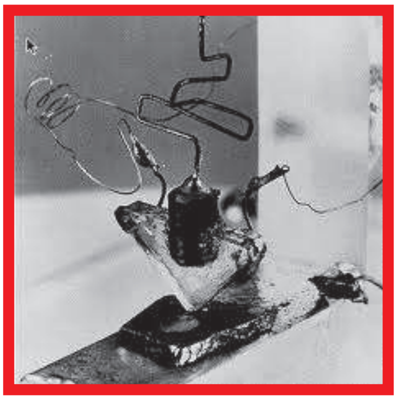
The First Transistor was Invented, November 17-December 23, 1947



John Bardeen William Shockley and Walter Brattain at Bell Laboratories

CIRP - General Nicolau Award recipient 2014

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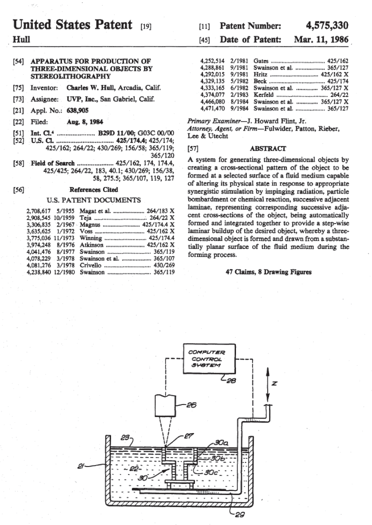

United States Patent [19]
Hull

[11] Patent Number: 4,575,330
[45] Date of Patent: Mar. 11, 1986

[54] APPARATUS FOR PRODUCTION OF THREE-DIMENSIONAL OBJECTS BY STEREOLITHOGRAPHY
[75] Inventor: Charles W. Hull, Arcadia, Calif.
[73] Assignee: UVP, Inc., San Gabriel, Calif.
[21] Appl. No.: 638,905
[22] Filed: Aug. 8, 1984
[51] Int. Cl.4 .... B29D 11/00; G03C 00/00
[52] U.S. Cl. 425/174.4; 425/174; 425/162; 264/22; 430/269; 156/58; 365/119; 365/120
[58] Field of Search 425/162, 174, 174.4, 425/425; 264/22, 183, 40.1; 430/269; 156/38, 58, 275.5; 365/107, 119, 127

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Primary Examiner—J. Howard Flint, Jr.
Attorney, Agent, or Firm—Fulwider, Patton, Rieber, Lee & Utecht

[57] ABSTRACT

A system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed at a selected surface of a fluid medium capable of altering its physical state in response to appropriate synergistic stimulation by impinging radiation, particle bombardment or chemical reaction, successive adjacent laminae, representing corresponding successive adjacent cross-sections of the object, being automatically formed and integrated together to provide a step-wise laminar buildup of the desired object, whereby a three-dimensional object is formed and drawn from a substantially planar surface of the fluid medium during the forming process.

47 Claims, 8 Drawing Figures

08.08.1984

Dr. Charles W. Hull; born May 12, 1939, is the co-founder, board member, executive vice president and chief technology officer of **3D Systems Inc.**(the biggest 3DP OEM). He is the inventor of the **Stereolithography;** he holds more than 60 U.S. patents
Dr. Chuck Hull is recognized as **"the father"** of the worldwide upcoming **3D Printing** or **Additive Manufacturing** technologies.

We are on the right track

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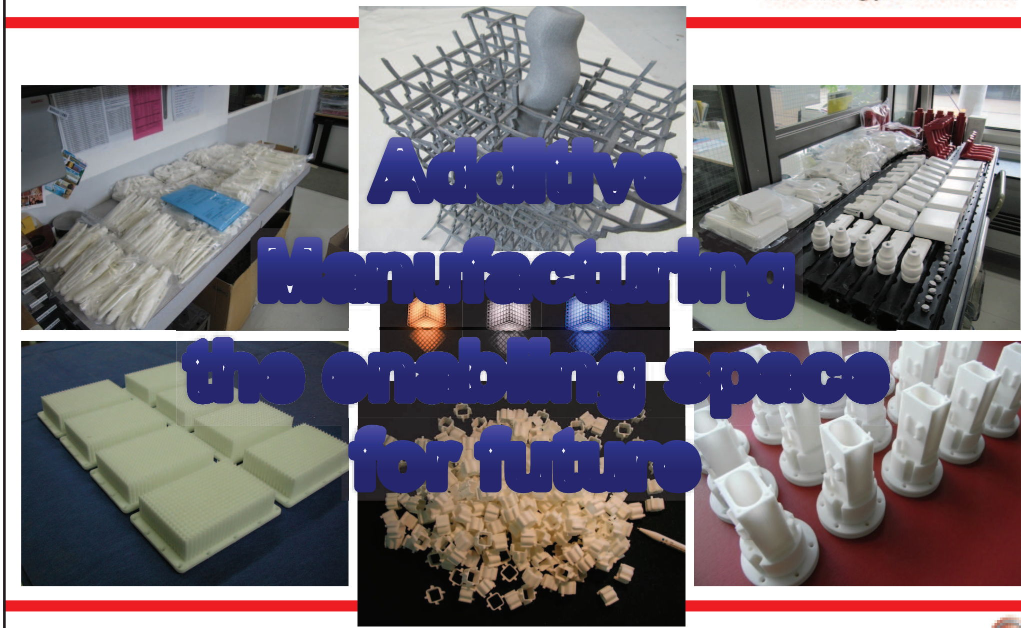

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AM will play also a great role in sustainability!

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Thank you for your attention!

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International Recognitions and publications

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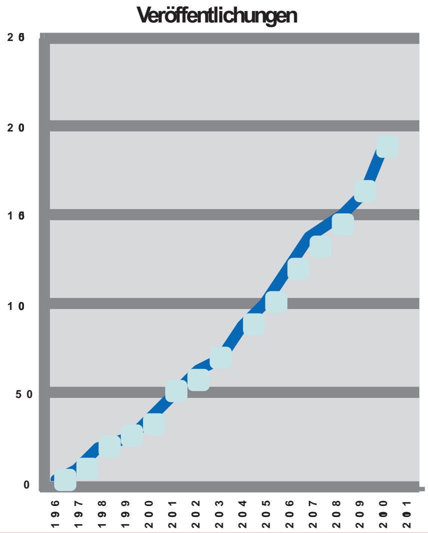

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