IVS INDUSTRIAL VALVE SUMMIT

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BERGAMO - ITALY
2ND INTERNATIONAL EXHIBITION AND CONFERENCE ON VALVE AND FLOW CONTROL TECHNOLOGIES

ENTE FIERA PROMOBERG

CONFINDUSTRIA BERGAMO

Additive Manufacturing for the Valve Industry: Opportunities, Limits, and Challenges

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The business case for AM

Lower costs
- No tooling or cheaper tooling
- Less transportation
- Less warehousing
- Less working capital required
- Fast

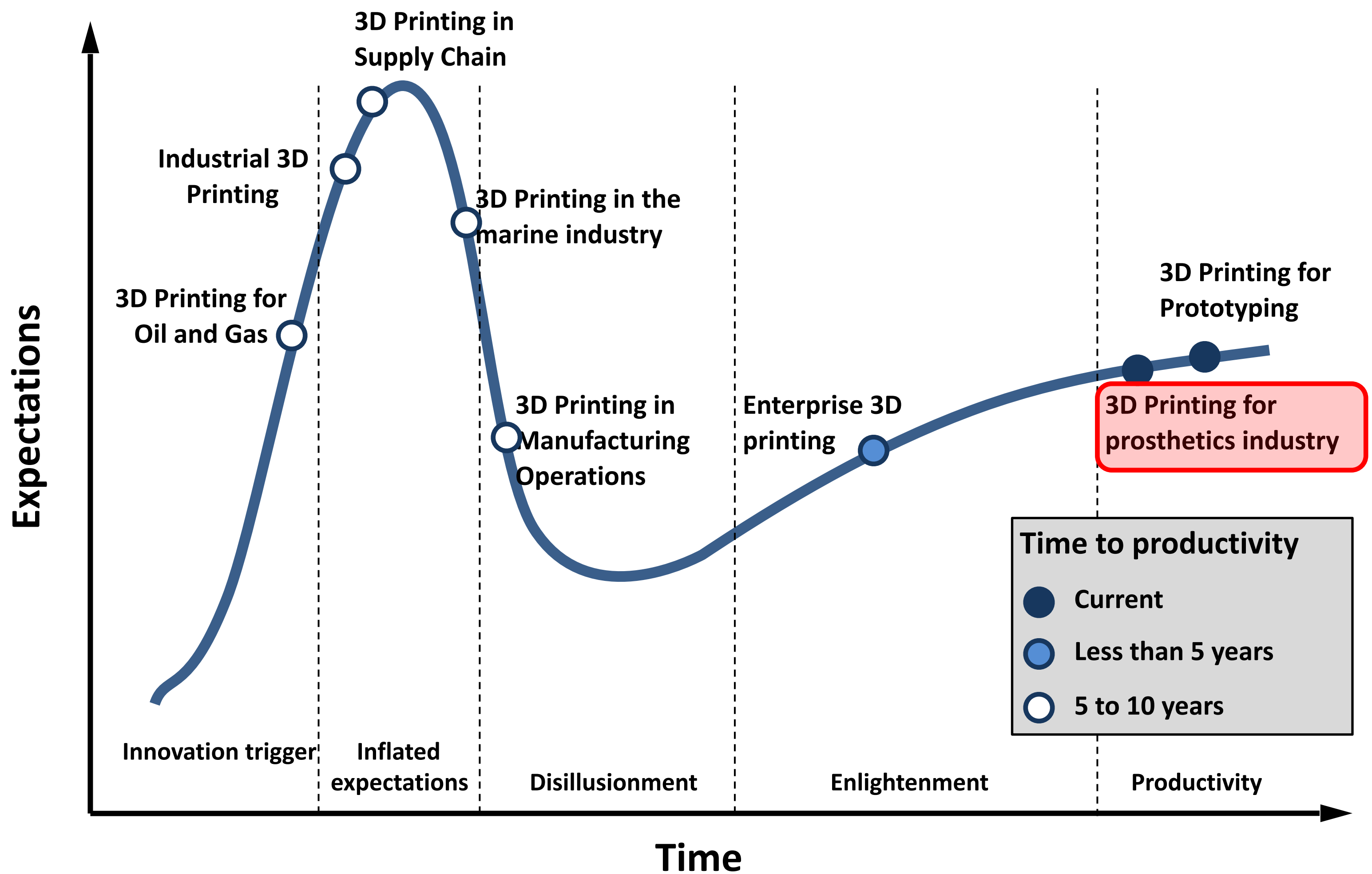
Better design
- Complexity for free
- Added features (cooling, isolation, structure, porosity, conductivity, etc)
- Hybrid materials
- Light-weight
- Less assembly by integrated design

Customisation
- Ergonomics
- Interfaces with other products
- Body contours (external and internal)
- Aesthetics
- Use specific variations

Sustainability
- Less waste
- Light weight
- Less fuel consumption
- Efficient supply chains
- Life Cycle Analysis

New business models
- Prototyping
- Shorten time-to-market
- Small series
- Supply chains (on demand, on location)
- Distributed manufacturing
- Services
- Co-creation / home creation

AM evolution



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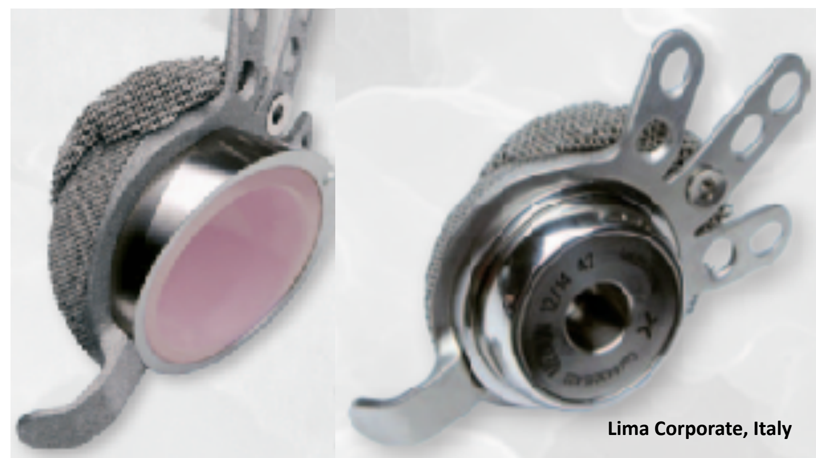
AM in the prosthetics industry

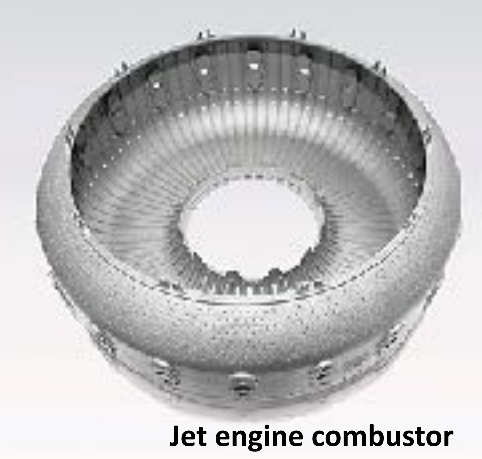
- **Prototyping**
- **Serial production of prosthetics parts with complex shapes**



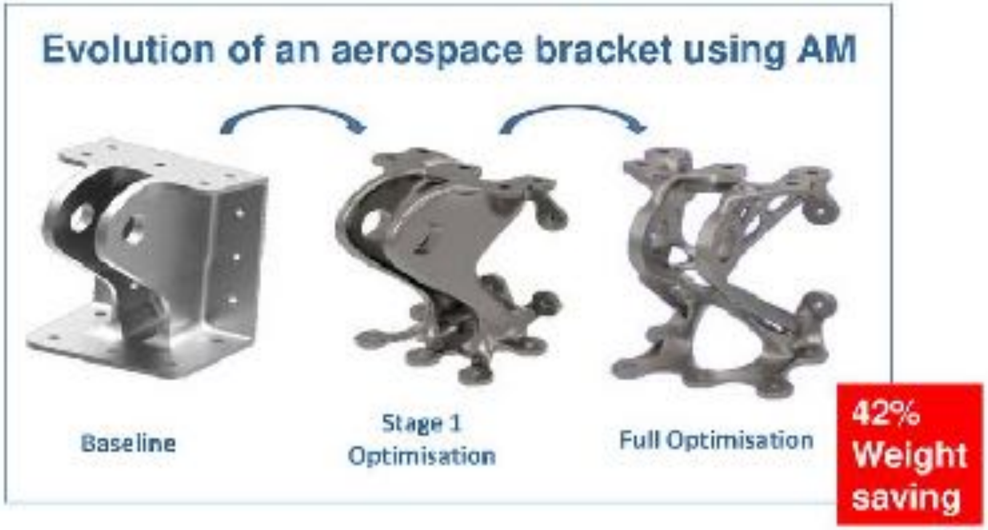
AM in the aerospace industry

- **Prototyping**
- **Production**
- **Major drivers:**
  - **Weight reduction**
  - **Lead time reduction**

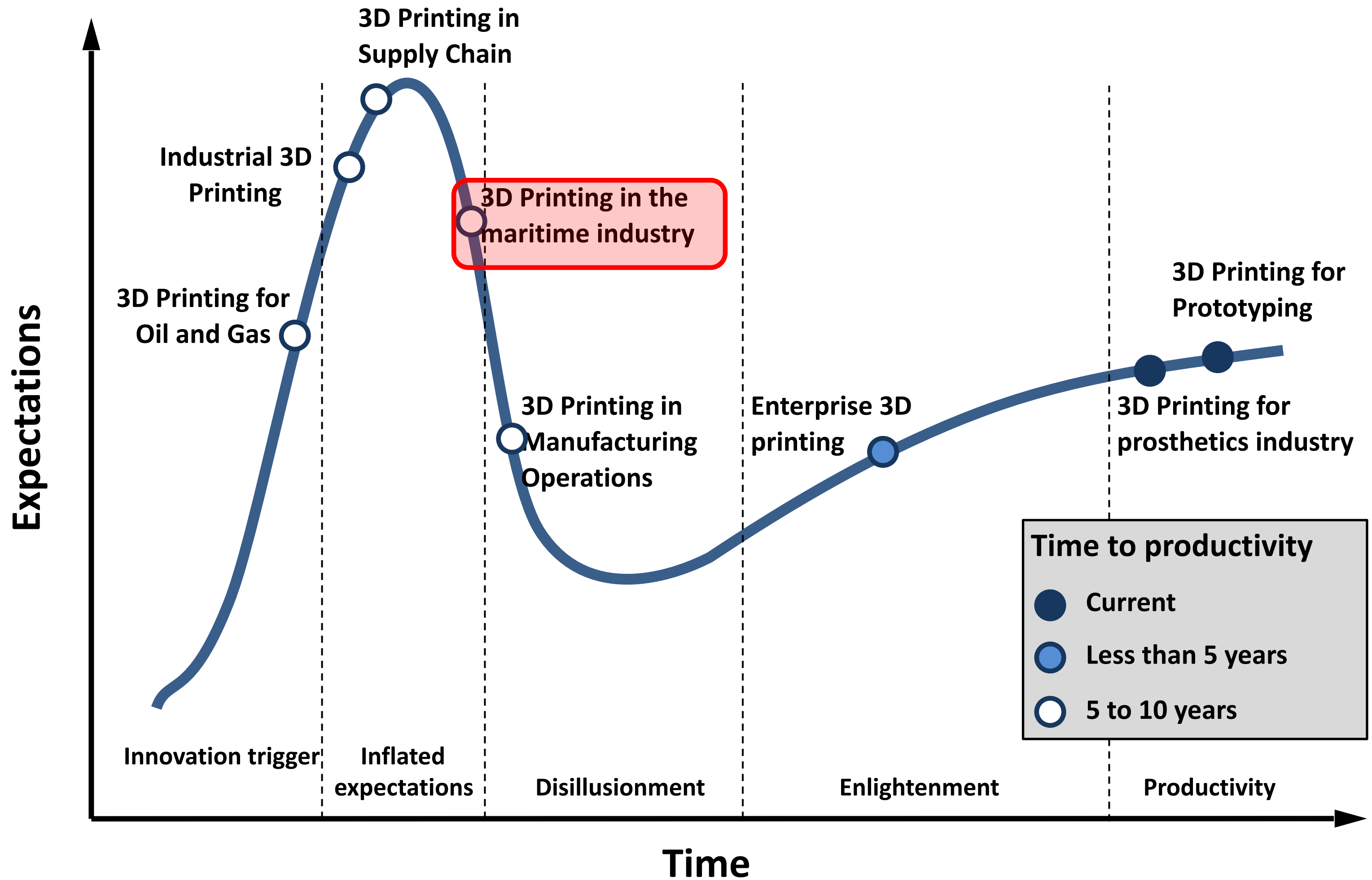
Boeing wing trim



Jet engine combustor



AM evolution



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Role of AM in the maritime industry

- **Quick availability of spare parts (on-board or in-port manufacturing capability, avoid large stock)**

- **Fast prototyping for hydrodynamic studies**

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Examples of maritime spare parts that could be produced by AM

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Which parts should be manufactured by AM?

Selection criterion: maximize AM benefits

Product design benefits

- Possibility of part consolidation
- Weight or volume reductions
- Integrated functionalities
- Less waste

Supply chain benefits

- Low volume production
- Reduced lead times
- Decreased inventory or stock levels
- Less supplier risks
- Lower location based costs

AM benefit score

#	Part	Part Consolidation	Weight/Volume Reduction	Integrated Functionality	Less waste	Low Volume	Lead Time	Inventory	Supplier Risk	Location based costs	AM Score	
1	Propeller Main [illegible]	1	1	1	1	1	1	1	1	0	8	High potential: potential for part consolidation, weight reduction, improve functionality
2	Cored valve seat [illegible]	1	0	1	0	0	1	0	0	0	3	Medium potential due to high volume production of part, complexity medium
3	Spacer ring [illegible]	0	0	0	0	1	1	1	1	1	5	High potential due to low volume part, long lead time, high cost to manufacture
4	Hinge [illegible]	1	1	1	1	1	1	1	1	0	8	High potential: Weight reduction, less waste, part optimized for AM production
5	T connector [illegible]	1	0	0	0	0	1	1	1	0	4	Medium potential; cost reduction in making of cast, surface roughness is lower
6	[illegible]	0	0	0	0	0	1	1	1	1	4	Medium potential, reduction in logistic costs only if printed locally where part is needed, long lead time
7	Hydraulic manifold [illegible]	1	1	1	0	0	0	0	1	0	4	Medium potential; weight reduction, integrated functionality
8	Neck flange	0	0	0	0	0	0	0	0	0	0	Technically and economically not challenging enough compared with conventional manufacturing
9	Swivel connector	0	0	0	0	0	0	0	0	0	0	Threaded: not technically not feasible with DMG, SCS, Ex-One and economically not challenging enough compared with conventional manufacturing
10	Wear rings (non ferro) bronze series of impeller	0	0	1	1	1	1	1	0	0	5	Medium potential; new super alloys could reduce wear and tear increase lifespan impeller
11	Mechanical seal	1	0	1	0	0	1	0	0	0	3	Medium potential; part consolidation, integrated functionality if technically feasible
12	Eccentric reducer	1	0	1	0	0	1	1	1	0	5	Medium potential, depending on size (large size, low volume production)
13	Worm wheel (bronze)	0	0	0	0	0	0	0	0	0	0	Threaded: not technically not feasible with DMG, SCS, Ex-One and economically not challenging enough compared with conventional manufacturing
14	Worm shaft (alloy steel)	0	0	0	0	0	0	0	0	0	0	Threaded: not technically not feasible with DMG, SCS, Ex-One and economically not challenging enough compared with conventional manufacturing
15	Piston for air compressor (non ferro)	0	0	0	0	0	1	0	0	0	1	Technically feasible, economically not challenging enough compared with conventional manufacturing
16	Structural fastener	0	0	0	0	0	0	0	0	0	0	Technically and economically not challenging enough compared with conventional manufacturing
17	Bearing shell [illegible] metal)	0	0	1	0	0	0	0	1	1	3	Potential for laser cladding different materials on base material, cost of conventional production probably cheaper
18	[illegible] heat exchanger	1	1	1	1	1	1	1	0	0	7	High potential: Part consolidation, weight reduction etc. proven benefits in other markets for instance formula 1
19	Screw pin shackle	0	0	0	0	0	1	1	1	0	3	Medium potential, depending on size (large size, low volume)
20	Open spelter socket	0	0	0	0	0	1	1	1	0	3	Medium potential, depending on size (large size, low volume)
21	Wire rope cable sheave	1	1	1	0	0	1	0	0	0	4	Medium potential, part consolidation, integrate functionality such as hardness of material to reduce wear and tear
22	Twist lock pin	0	0	0	0	0	0	0	0	0	0	Technically and economically not challenging enough compared with conventional manufacturing
23	Alum / Steel transition joint	1	0	0	0	1	1	0	1	0	4	Medium potential, part consolidation low volume production part, few suppliers. Technically feasible to be determined
24	Hydraulic hose end fitting	0	0	0	0	0	0	0	0	0	0	Threaded: not technically not feasible with DMG, SCS, Ex-One and economically not challenging enough compared with conventional manufacturing
25	Eyebolt	0	0	0	0	0	0	0	0	0	0	Threaded: not technically not feasible with DMG, SCS, Ex-One and economically not challenging enough compared with conventional manufacturing
26	Exhaust gas manifold	1	1	1	1	1	1	1	1	1	9	High potential, depending on complexity of the manifold, potential weight reduction, production volume
27	Weldolet	1	0	1	0	0	0	1	0	0	3	Medium potential: potential to consolidate parts/improve functionality, however surface finish important factor to take into consideration
28	Turbocharger nozzle ring	1	1	1	1	1	1	1	1	1	9	High potential: improve heat and corrosion resistance, reduce long lead times, see for instance [illegible] Singapore example
29	Turbocharger gas inlet/outlet casing	1	1	1	1	1	1	1	0	0	7	High potential: potential for part consolidation, weight reduction, improve functionality
30	Valve [illegible] parts (valve disk)	0	0	1	0	0	1	0	0	0	2	Technically and economically not challenging enough compared with conventional manufacturing

Raising interest for AM in maritime applications

Port of Rotterdam

RDM MAKERSPACE

Innovation Quarter

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Raising interest for AM in the Valve Manufacturing Industry

VALVE MAGAZINE
THE OFFICIAL MAGAZINE OF THE VALVE MANUFACTURERS ASSOCIATION OF AMERICA

FEATURES

Additive Manufacturing: Will It Change the Valve Industry?

VALVE MAGAZINE
THE OFFICIAL MAGAZINE OF THE VALVE MANUFACTURERS ASSOCIATION OF AMERICA

3D Printing: A New Era for Valve Manufacturing?

05 Jul 2015 Written by Kate Kunkel

VMA VALVE MANUFACTURERS ASSOCIATION OF AMERICA

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EMERSON OPENS SECOND ADDITIVE MANUFACTURING CENTER

Monday, March 27, 2017

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3D PRINTING FOR VALVE MANUFACTURERS

ADDITIVE MANUFACTURING REVOLUTIONIZES VALVE PRODUCTION

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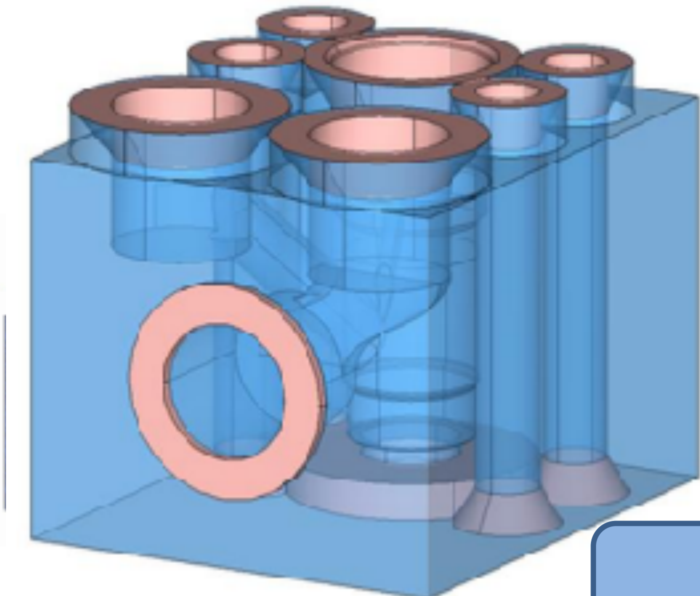
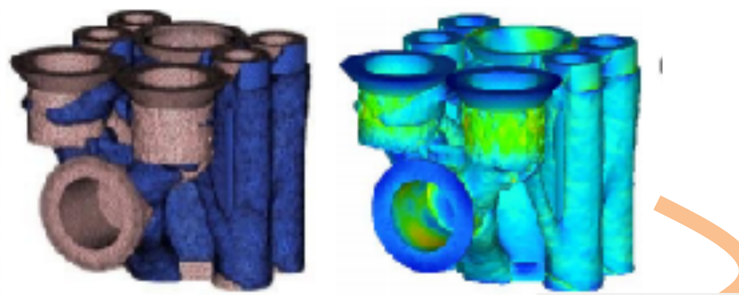
AM in the VM industry
The opportunty for better design

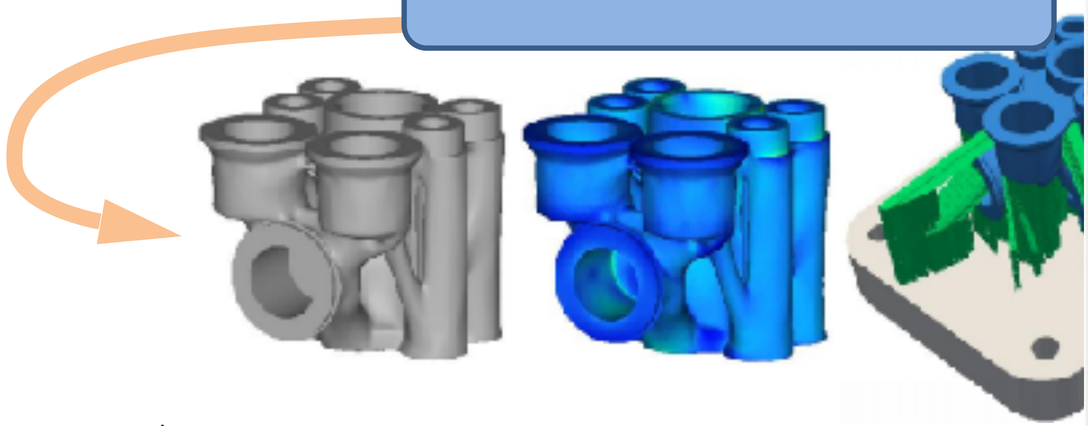
Hydraulic Valve Block Re-Design

(VTT Finland)





76% mass reduction



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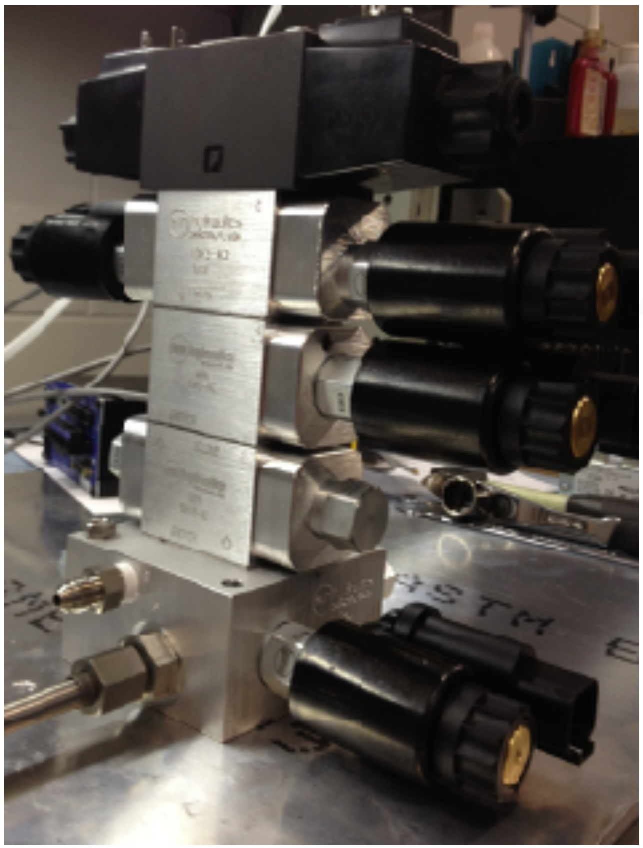
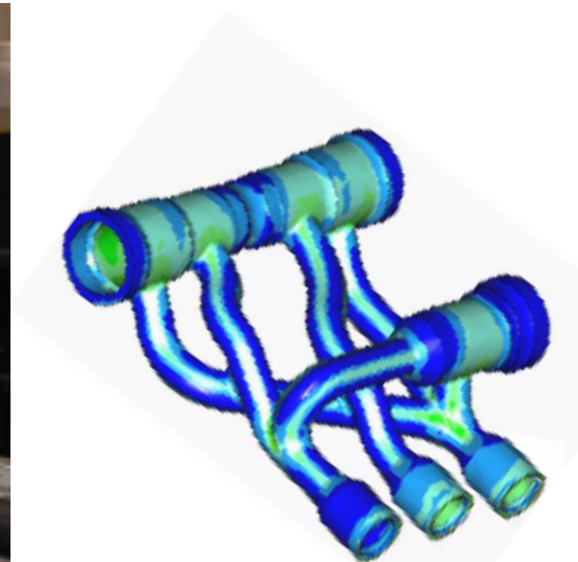
AM in the VM industry
The opportunty for better design

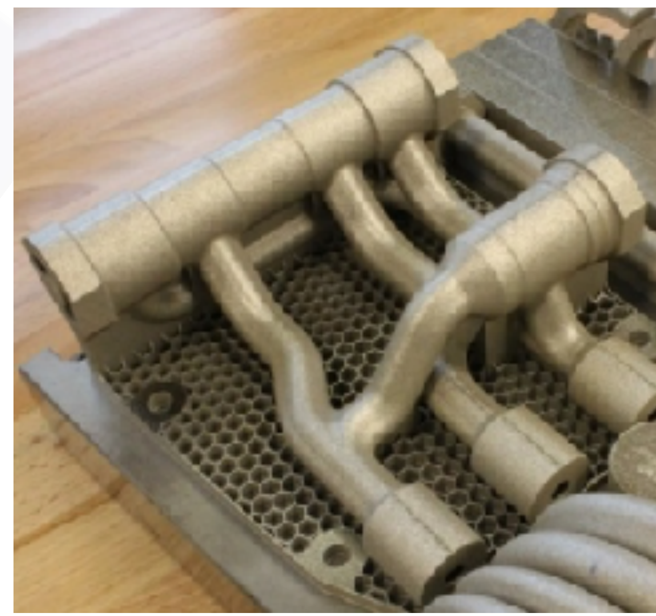
Hydraulic Manyfold Re-Design

J. Mech. Design 137, 111404-1 (2015)





60% weight reduction
53% max heigth reduction



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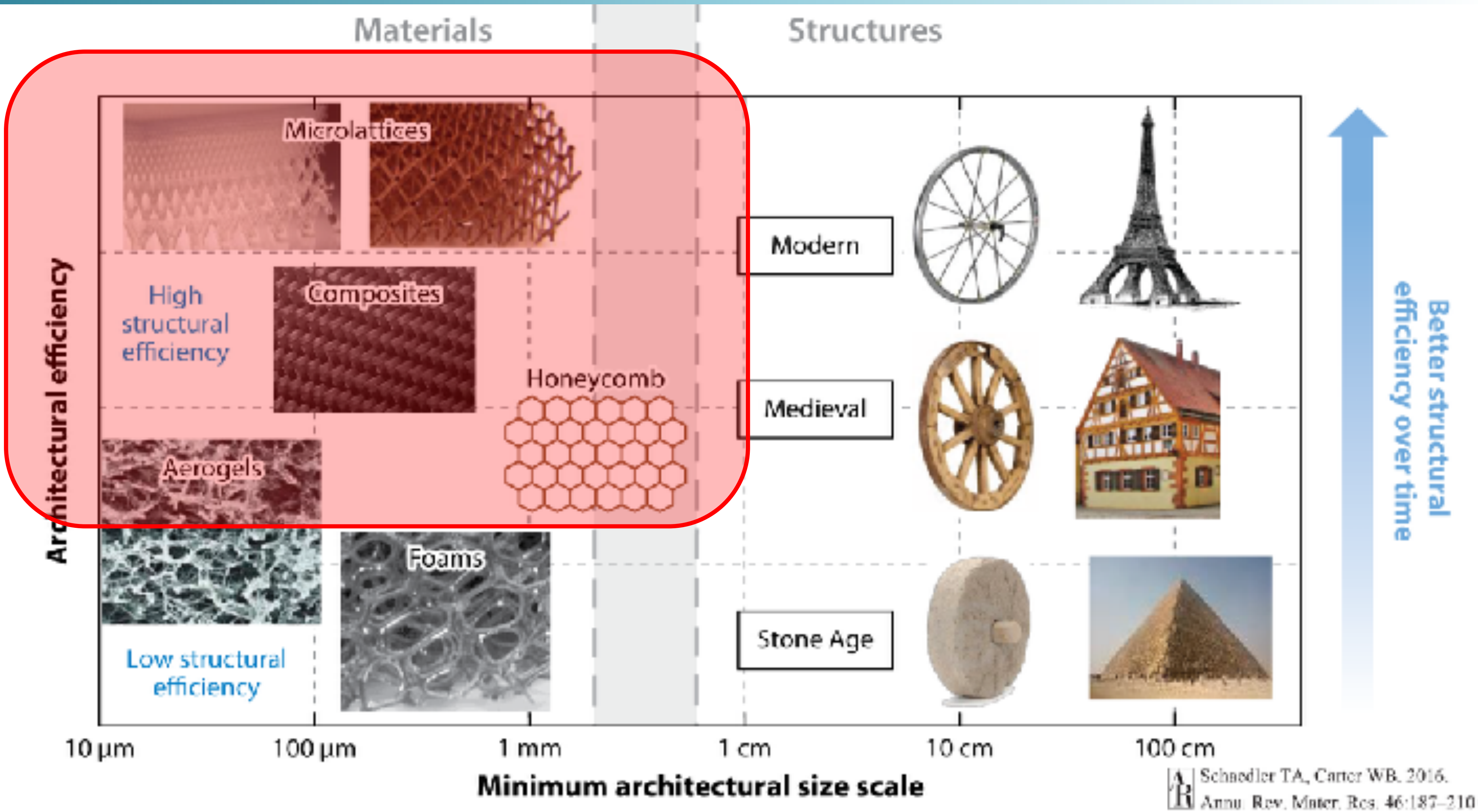
Better desing with Architected materials

- AM as an opportunity for high architectural efficiency and function integration -



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AM: Limits and Challenges

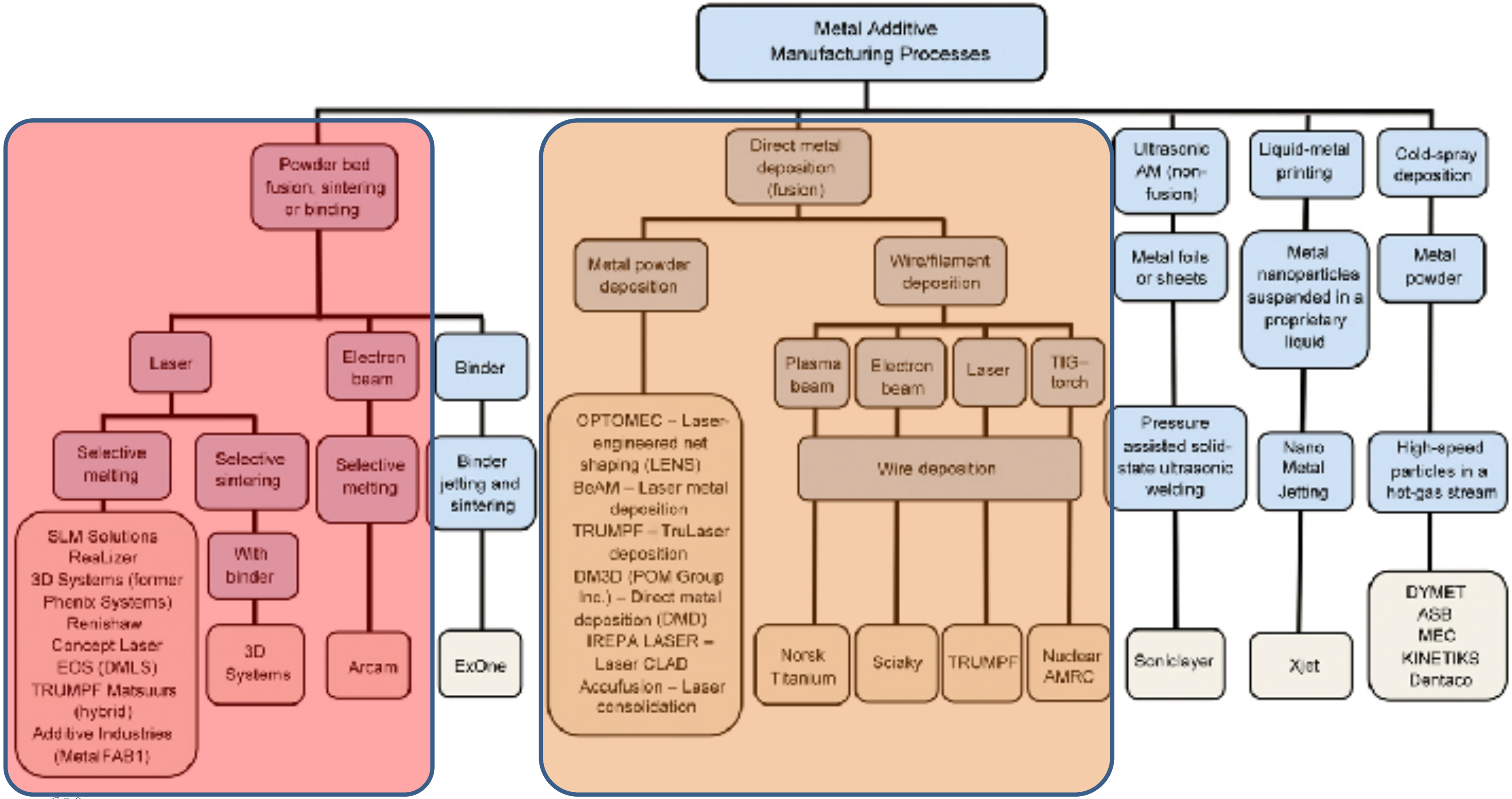
- Size
- Cost (capital, materials)
- Surface finish
- Maturity of design engineers
- Intellectual Property and Liability
- Materials
- Qualification and Certification

"The single biggest obstacle to widespread use of AM parts for structurally critical components are the cost and time associated with qualification and certification"

- William E. Frazier, US Naval Air Systems Command -

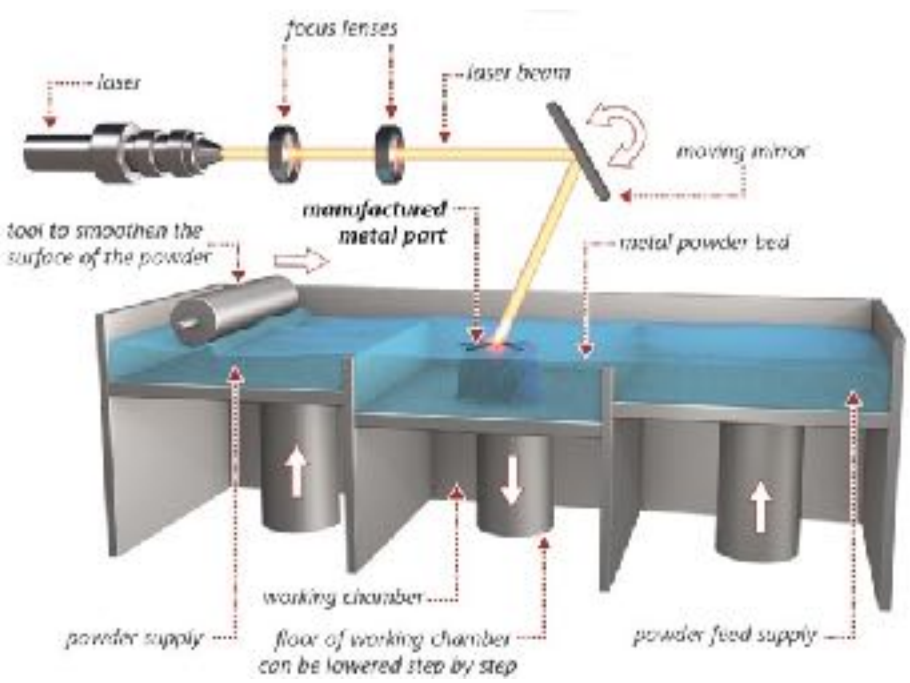
Materials Issues

Wide range of AM processes

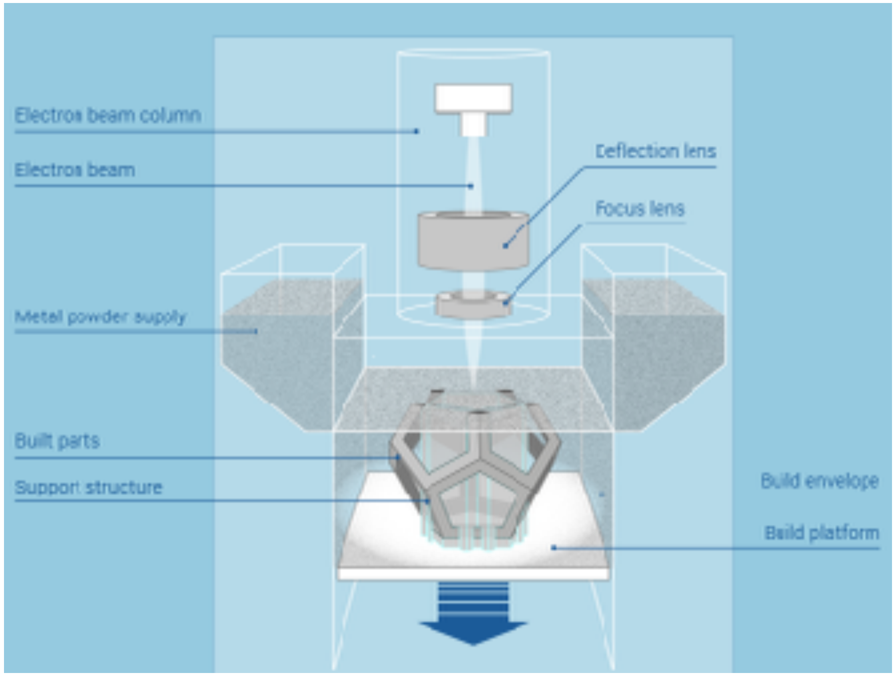


Most promising processes for the Valve Manufacturing Industry

Selective Laser Melting



Electron Beam Melting



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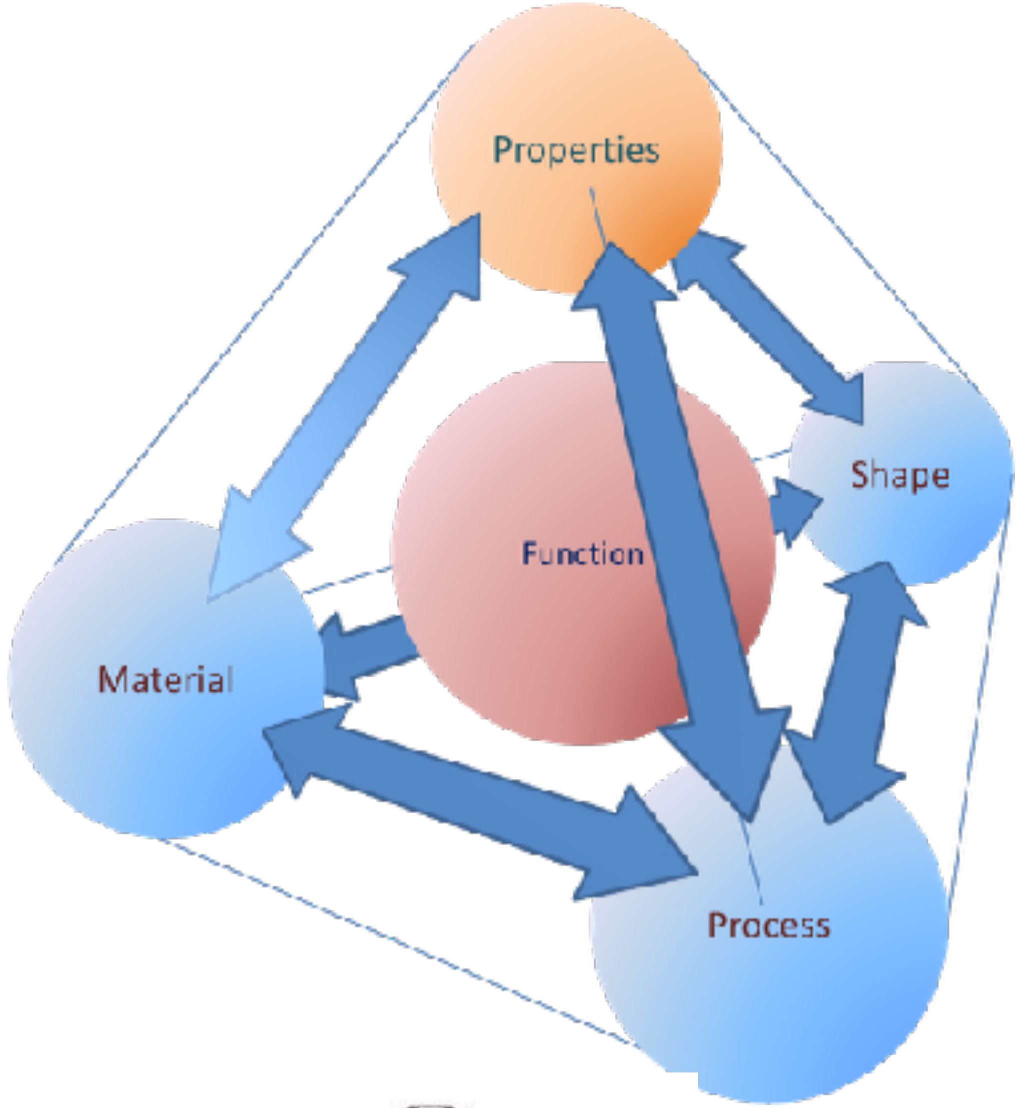
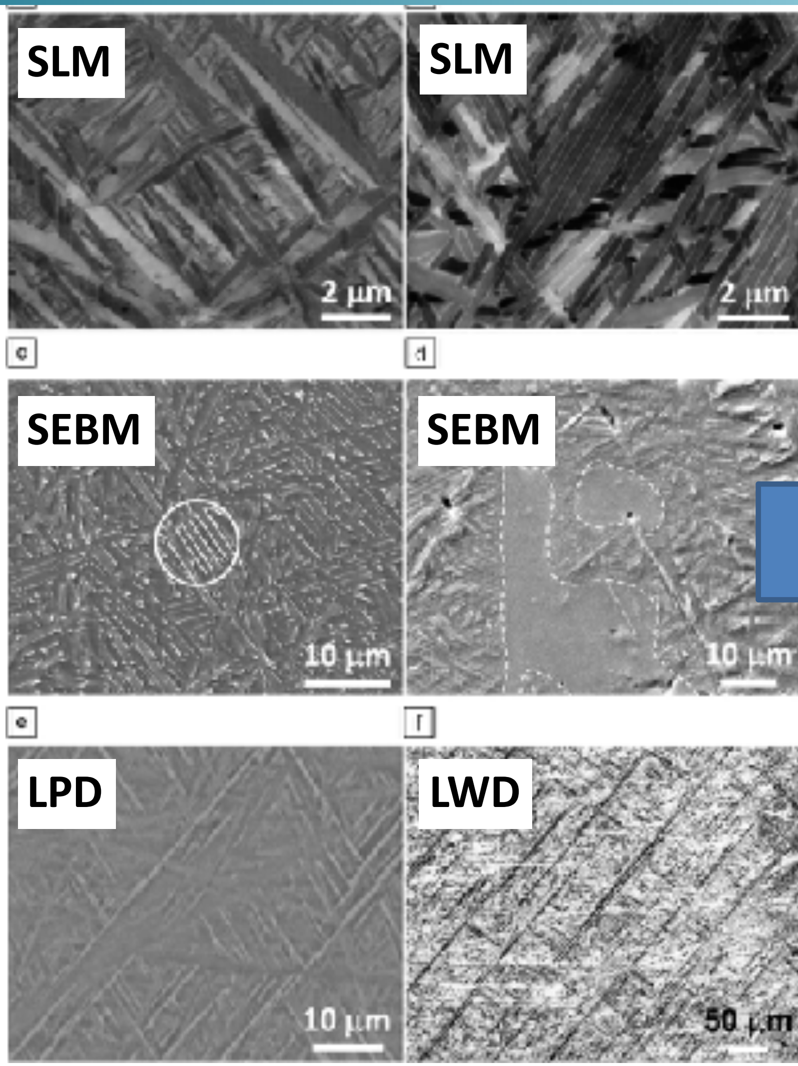
Wide range of materials for AM

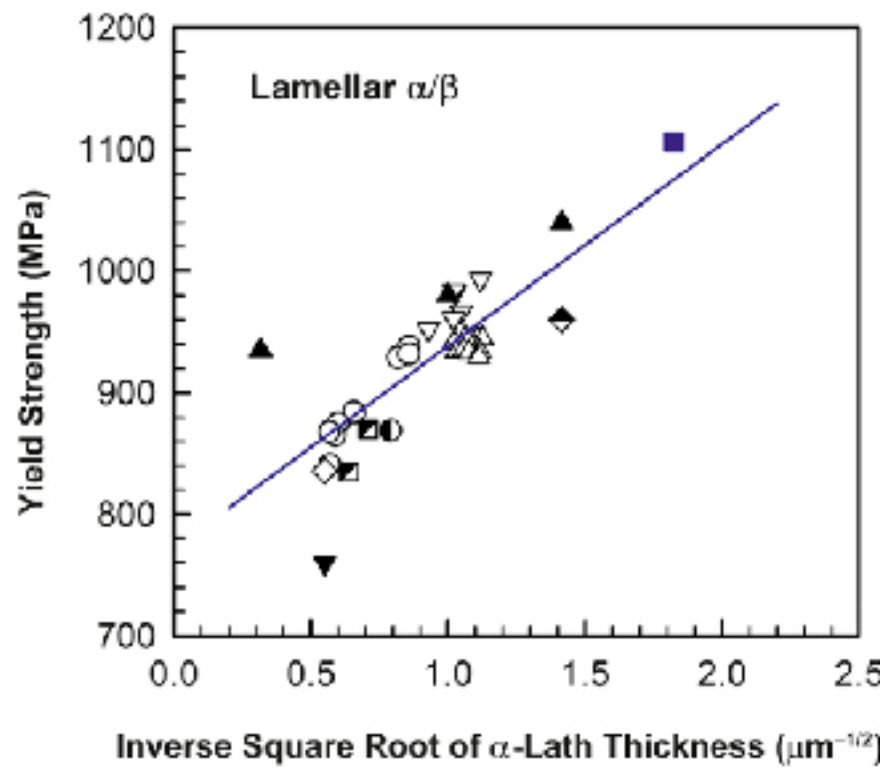
- Titanium (pure, Al-V alloy, …)
- Steels (including stainless)
- Ni-Cr alloys (e.g. Inconel)
- Aluminum and aluminum alloys
- Cobalt-chrome alloys
- Copper and bronze
- Iron
- Precious metals

Materials, process, structure, geometry



AM Process → Microstructure → Properties





C.Qiu et al., J. Alloys Compd. 629, 351 (2015)
E.Brandl et al., Mater. Des. 32, 4665 (2011)
W.Xu, Acta Mater. 85, 74 (2015)
S.L.Lu, Acta Mater. 104, 303 (2016)

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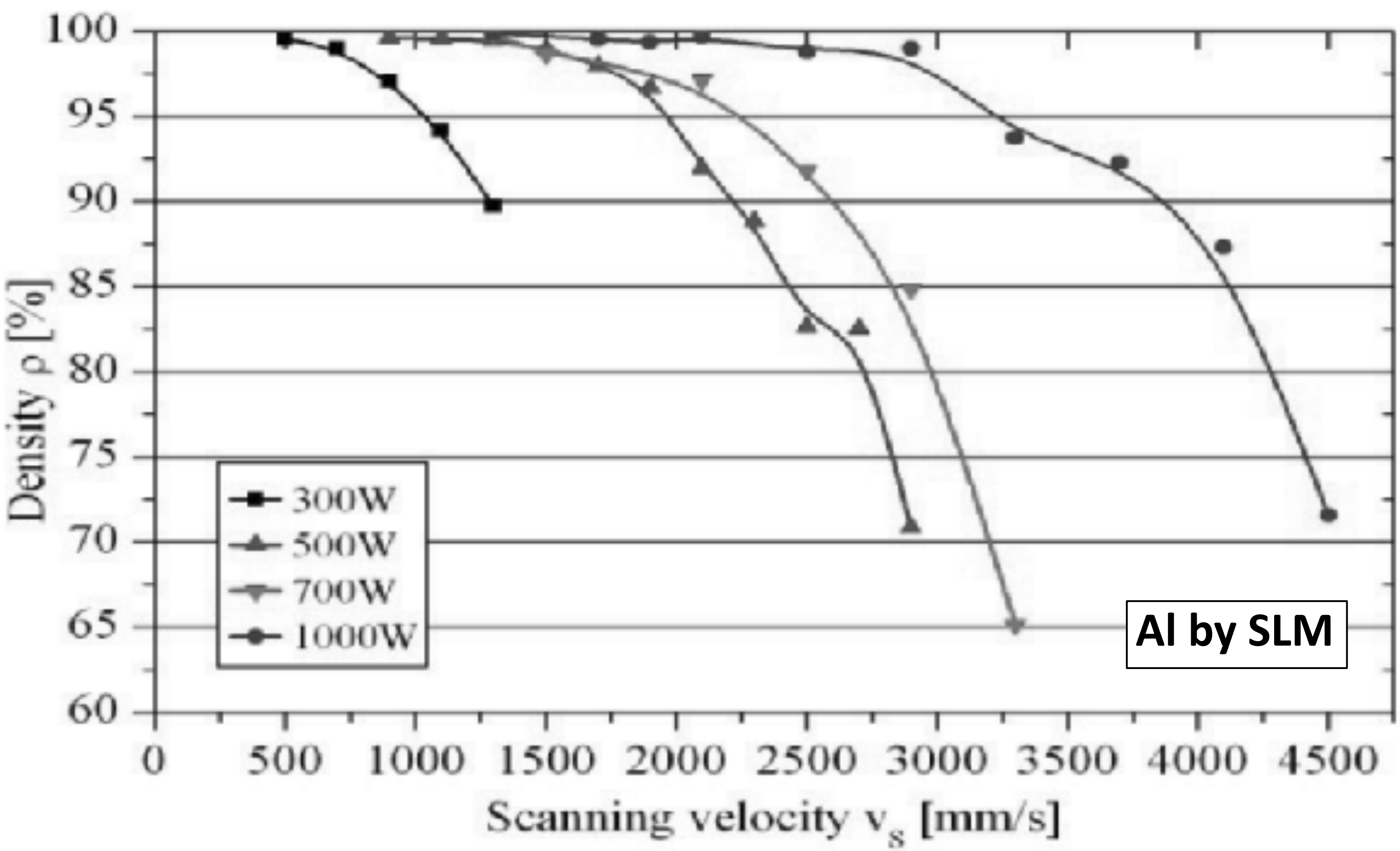
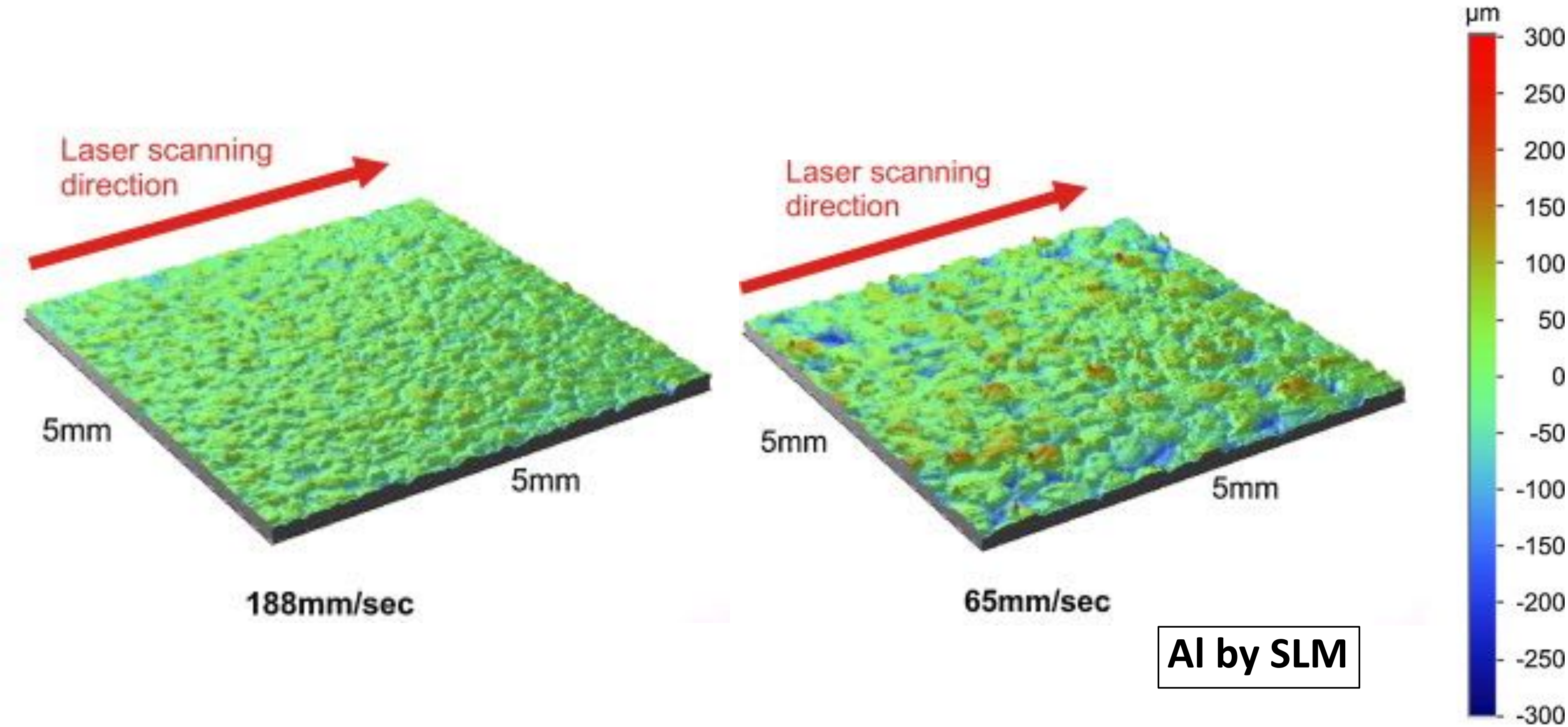
AM Process → Microstructure → Properties
- learning control: porosity -



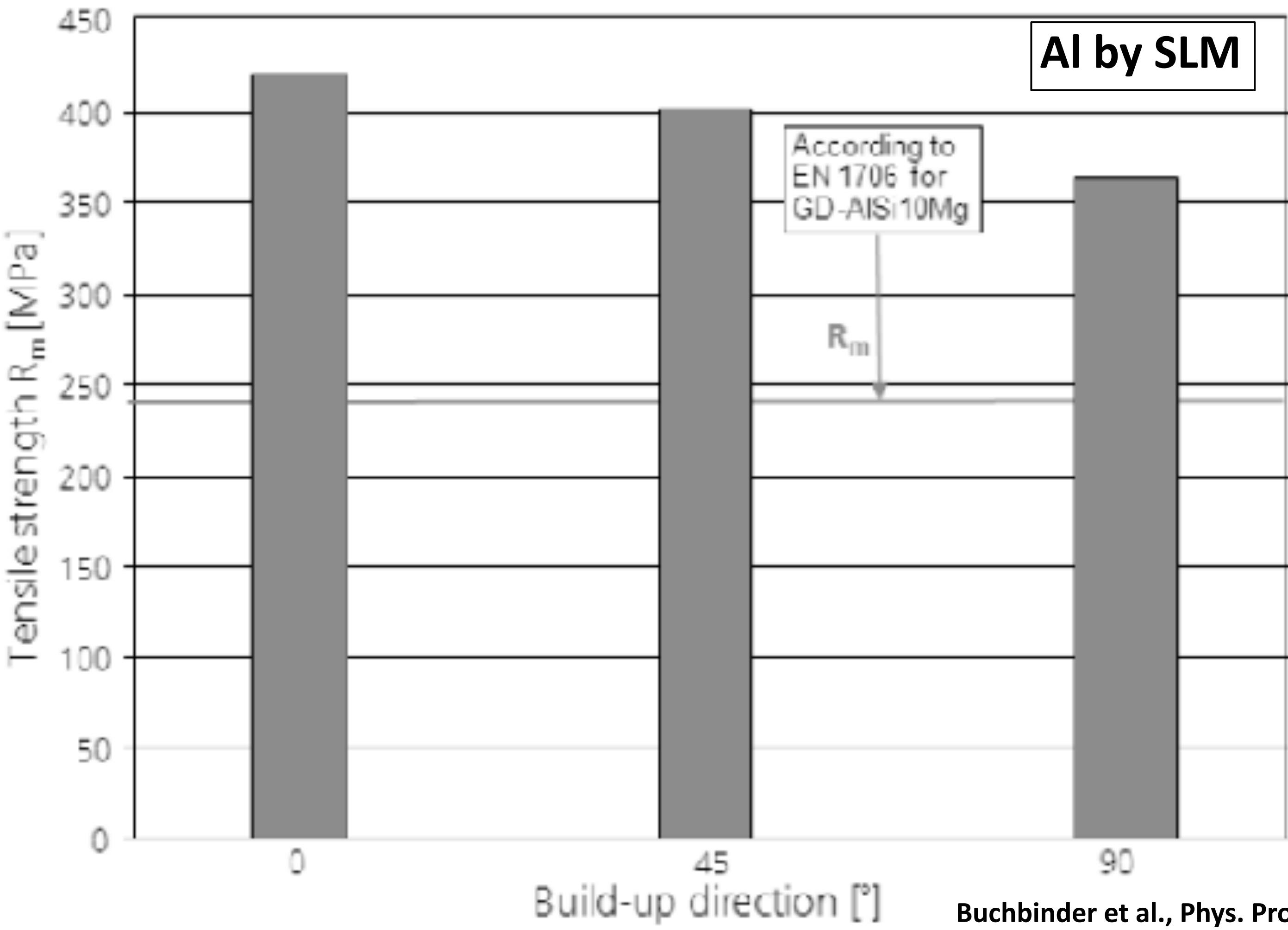
Buchbinder et al., Phys. Proc. 12 (2011) 271

AM Process → Microstructure → Properties
- learning control: surface finish -



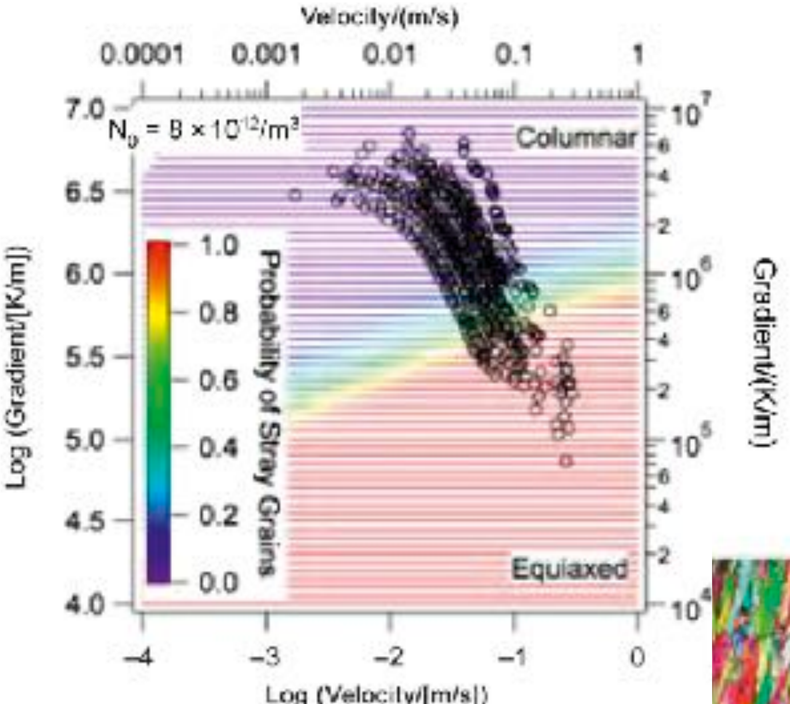
Louvis et al., J Materials Processing Tech. 211 (2011) p275

AM Process → Microstructure → Properties
- learning control: strength -



Buchbinder et al., Phys. Proc. 12 (2011) 271

AM Process → Microstructure → Properties
- learning control: predicting the microstructure -

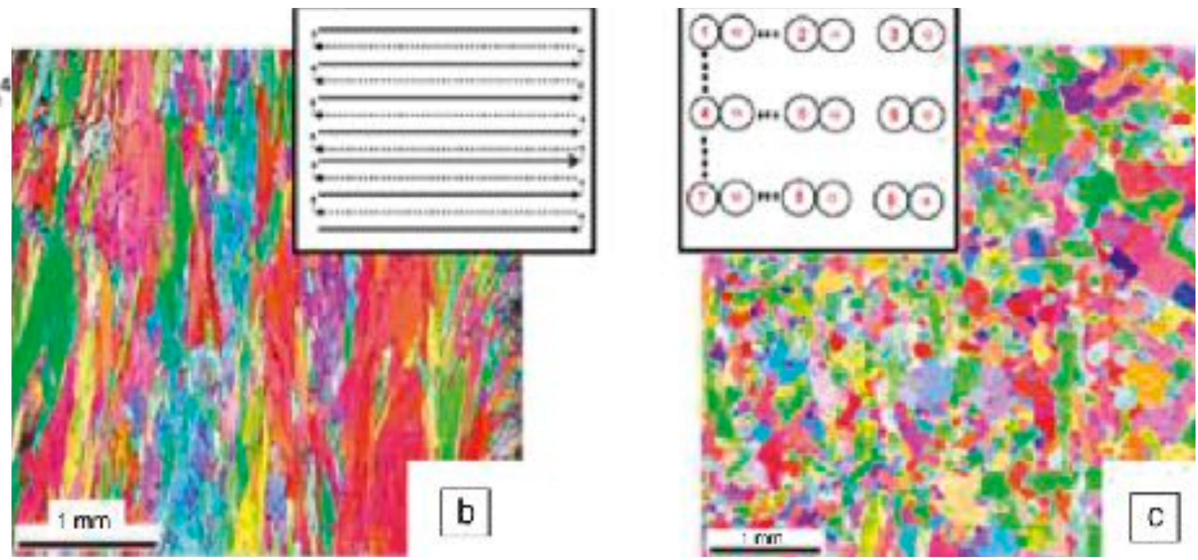


R.R.Dehoff et al., Mater. Sci. Technol. 31, 931 (2015)

Ni superalloy by EBM

<u>**Modeling-driven process design**</u> **(no trial-and-error):**

Temperature gradient and liquid interface velocity control the microstructure in a predictable way



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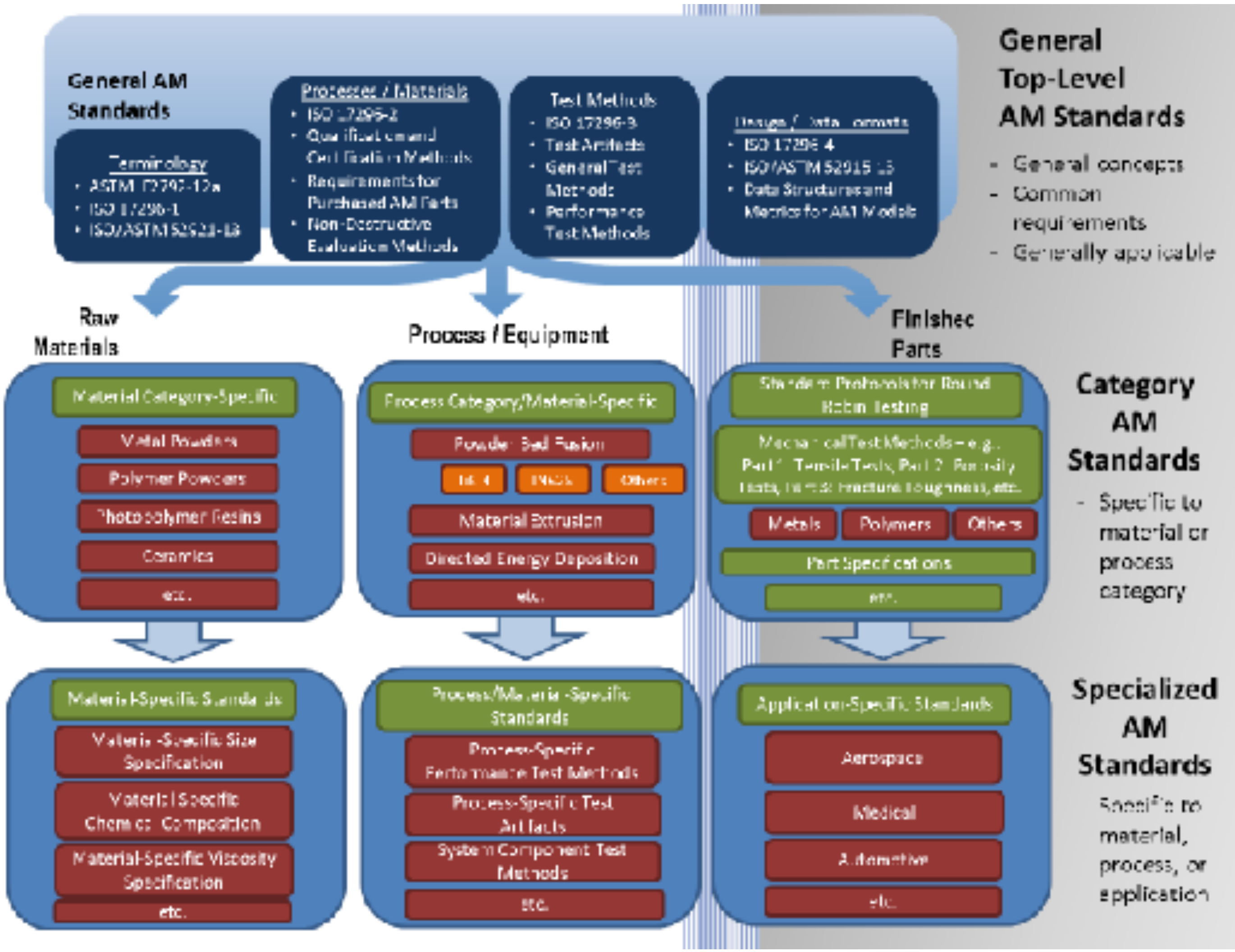
Qualification Issues

Process qualification – development of standards



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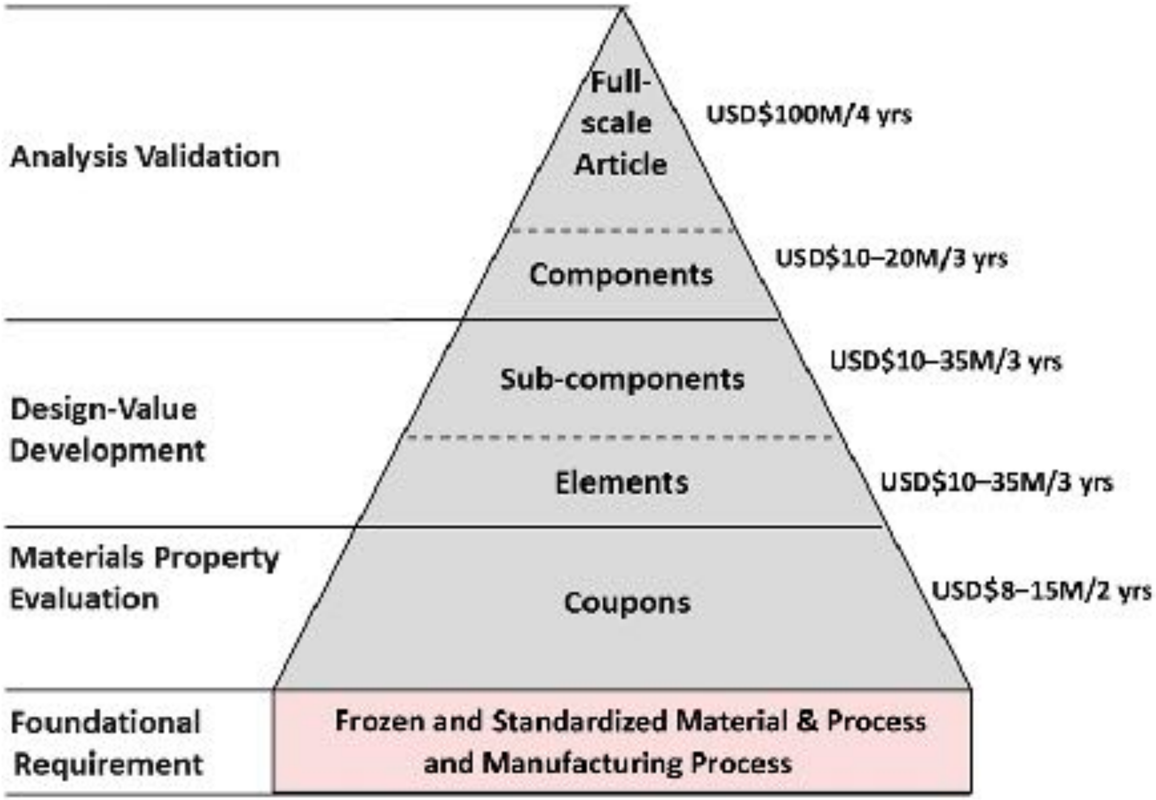
Process qualification



Linear approach to qualification is unfit forAM

Need a paradigm shift towards Integrated Computational Materials Engineering

Process qualification

- **Detailed logging and analysis of parameters during manufacturing**
- **In-situ monitoring of layers (optical and thermal imaging)**
- **Modelling of process and material: identify the tendency to defect formation or microstructural heterogeneity**
- **Sacrificial samples for testing (US, X-ray or neutron CAT, residual stress distribution, …)**

Table 2 - Excerpt from ISO 17296-3:2014

		Suggested ISO standard for Metal Testing	
Surface Requirements	Appearance	16348	
	Surface Texture	1302 /4288	
	Colour	11664-i	[i = 1 - 5]
Geometric Requirements	Size,length and angle dimensions, dimensional tolerances	129-1, 286-1, 14405-1, 1938-1c, 2786-1	
	Geometrical tolerancing (deviations in shape and position)	1101, 2786-2	
Mechanical Requirements	Hardness	6507	
	Tensile strength	6892-1*	
	Impact Strength	148-j	j = 1,2(charpy)*
	Compressive Strength	4506	
	Flexural Strength	3327	
	Fatigue Strength	1099, 1143	
	Creep	204	
	Ageing	Not relevant	
	Frictional coefficient	No ISO specified	
	Shear Resistance	148-1	
	Crack Extension	2889	
Build Material Requirements	Density	3369	
	Physical and physico-chemical properties	5579	
		3452-k	k = [1,2]
		61625	nb. IEC not ISO
Additional	Microstructure (DT)	9934-1	

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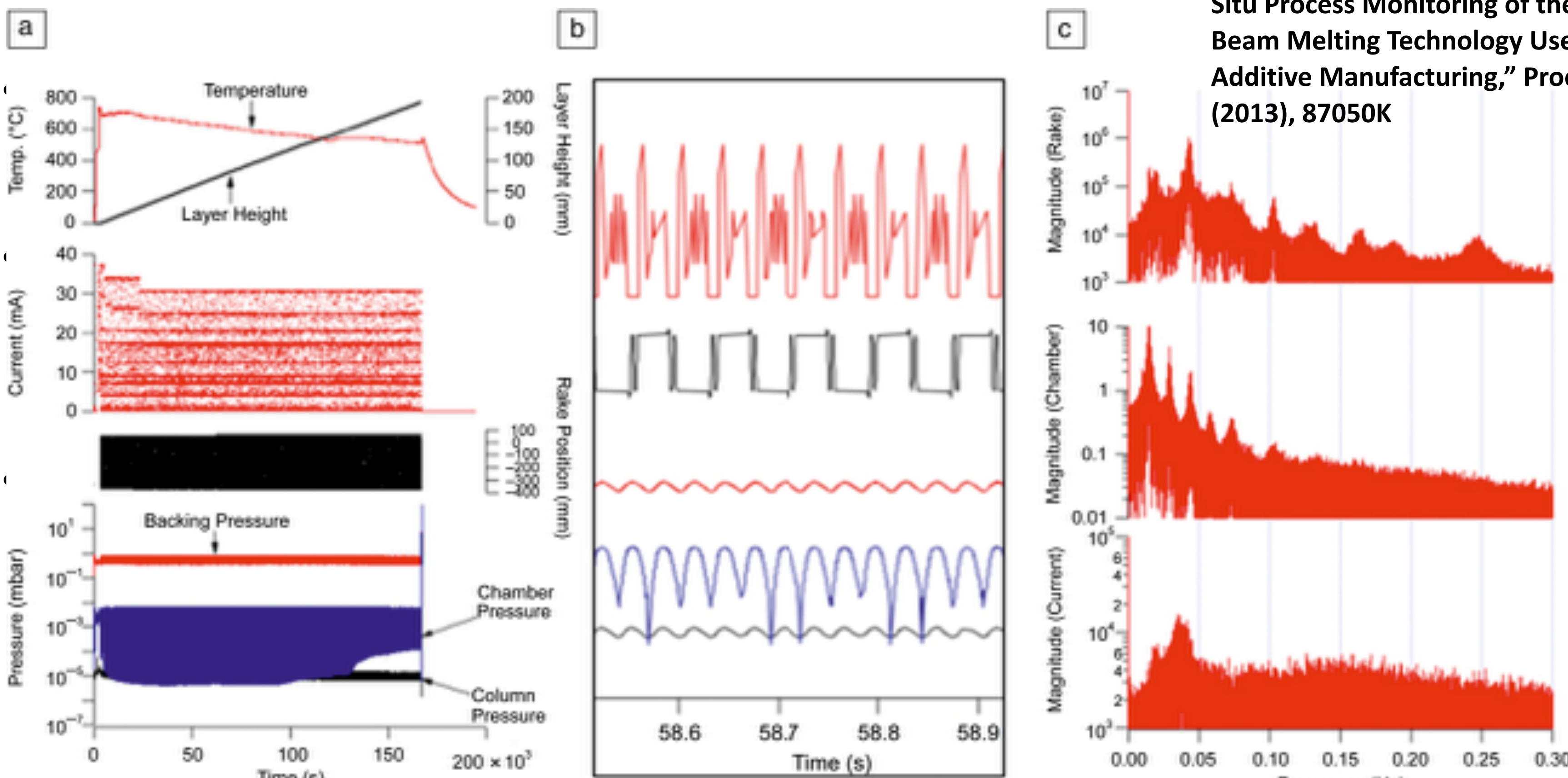
Process qualification

- Detailed logging and analysis of parameters during manufacturing

R.B.Dinwiddie et al., "Thermographic In Situ Process Monitoring of the Electron-Beam Melting Technology Used in Additive Manufacturing," Proc. SPIE 8705 (2013), 87050K



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Process qualification

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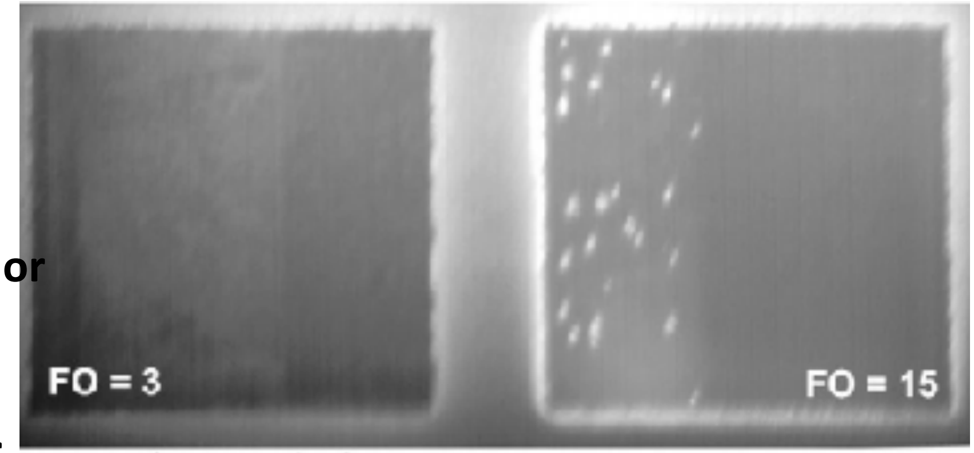
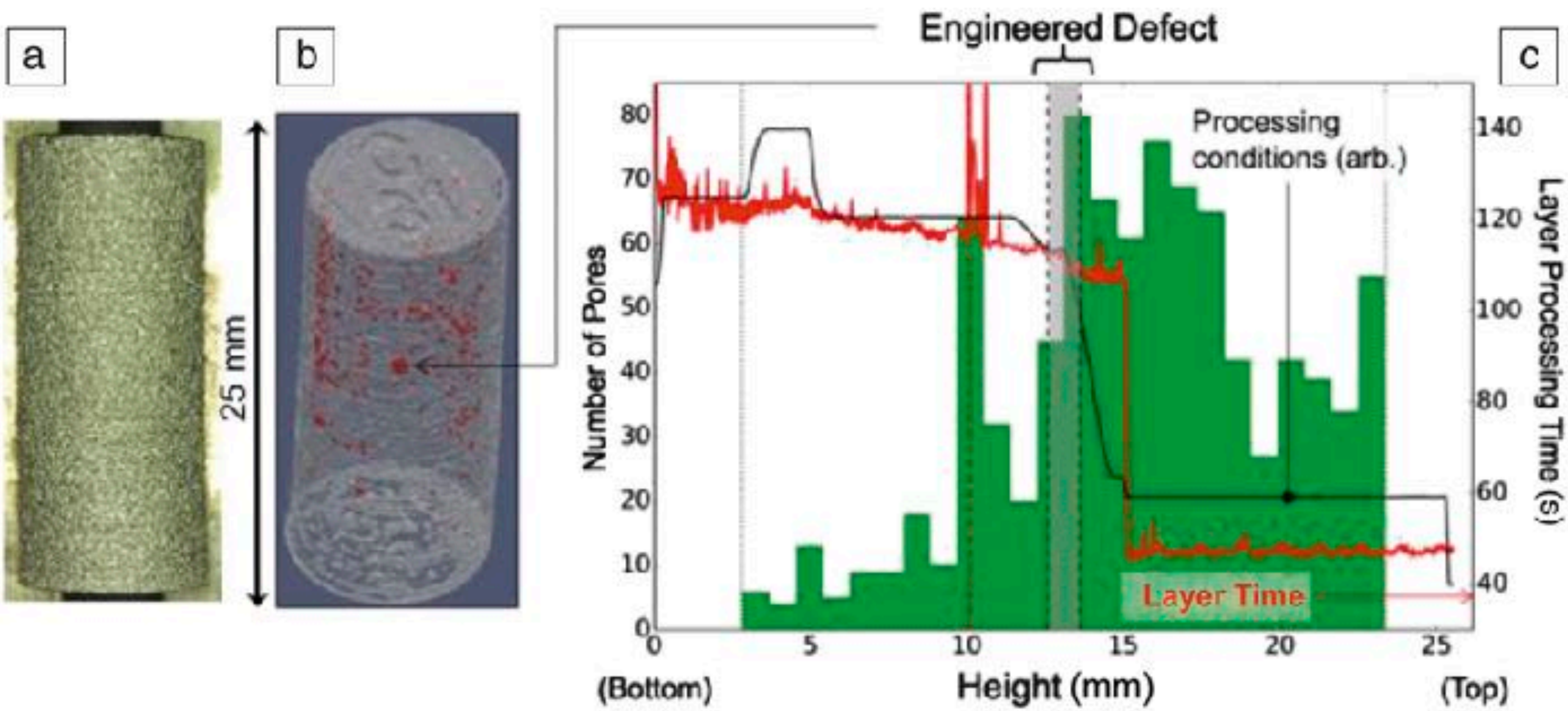
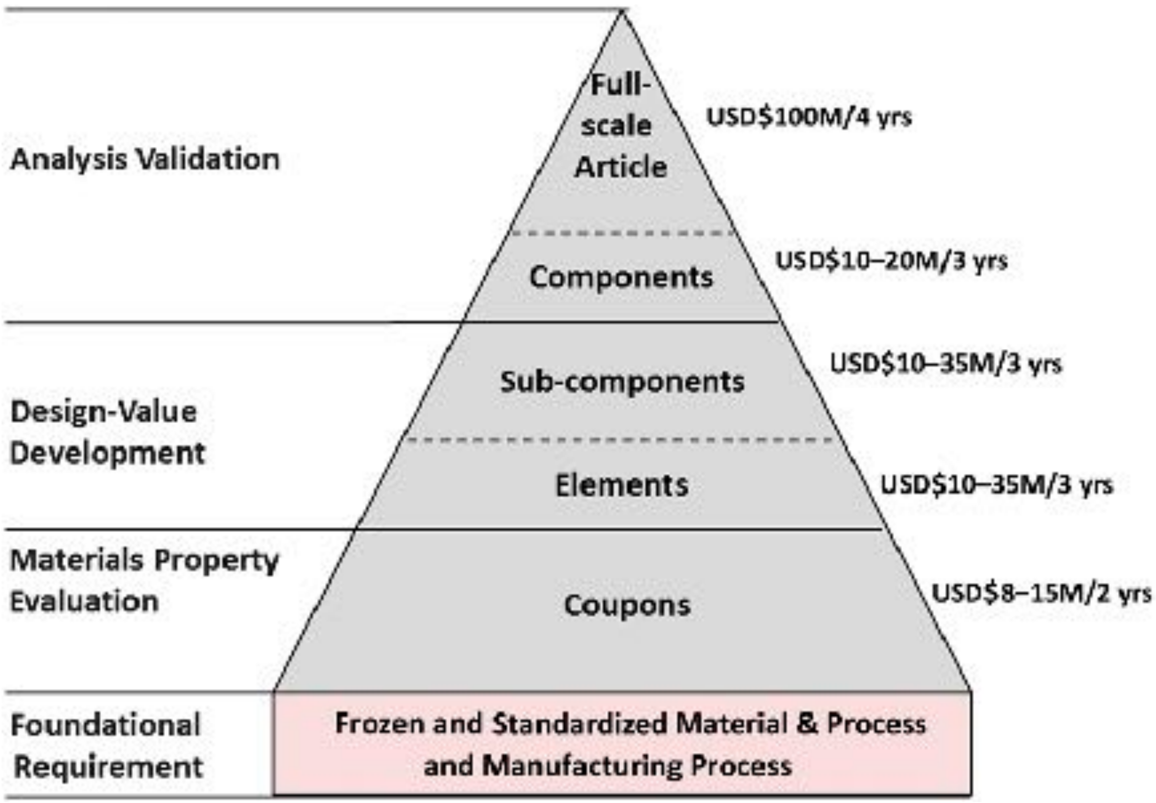


Process qualification



E.Schwalbach , M.Groeber , "Multi-Model Data Collection and Integration for Metallic Additive Manufacturing," AAAS Annual Meeting: Symposium on Integrated Computational Materials Engineering Principles for Additive Manufacturing, San Jose, CA (2015)

Process qualification

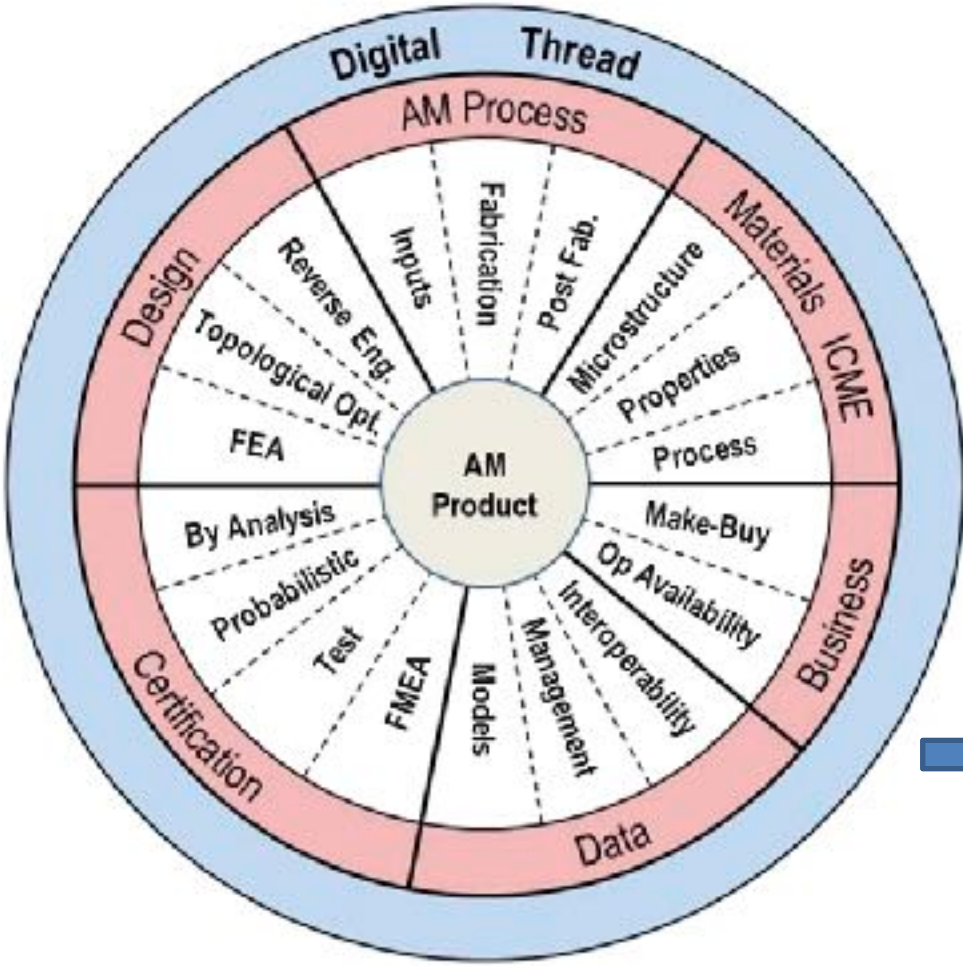


Linear approach to qualification is unfit forAM

Need a paradigm shift towards Integrated Computational Materials Engineering

ICME

Integrated Computational Materials Engineering



ICME-informed qualification leverages an integrated system of:

- **Design tools**
- **Data management and analysis**
- **Materials (multiscale modeling)**
- **Business modeling**
- **Manufacturing process**

A process "quality envelope" is defined

Sensors and controls are needed to maintain the process within the quality envelope

Concluding remarks

- Comparison of AM with traditional manufacturing requires an integral, lifetime analysis

- Traditional manufacturing is cheaper in most cases
- Other benefits should be factored in (e.g. faster production)
- Capital cost can hardly be recovered; using AM providers might be a better business case

- Once a satisfactory technological level is reached (predictability and qualification):
  - AM allows for faster production
  - AM requires less tooling, less investments, less working capital
  - AM allows for optimization of design: synergic effects

- Standardization, classification, quality control, validation of design and product, are needed at both the technological and regulatory level

- Need more focus on the materials aspects:
  - Develop a larger portfolio
  - More work about the relationship material-process-microstructure-properties

VM-specific concluding remarks

- AM in the VM industry is at an embrional stage →
  important not to force the technology (avoid «rebound effects», disillusionment)

- Expected adoption timeline in the VM industry
- Short term → Prototyping
- Medium term → Production of small valve components, small batches

- Recommendation: Definition of a set of selection criteria for candidate parts for AM