Additive Manufacturing potential and mechatronics development for High-Tech Systems

Gregor van Baars, TNO Technical Sciences

Wednesday 4 december 2013,
Precisiebeurs, Koningshof Veldhoven


Contents

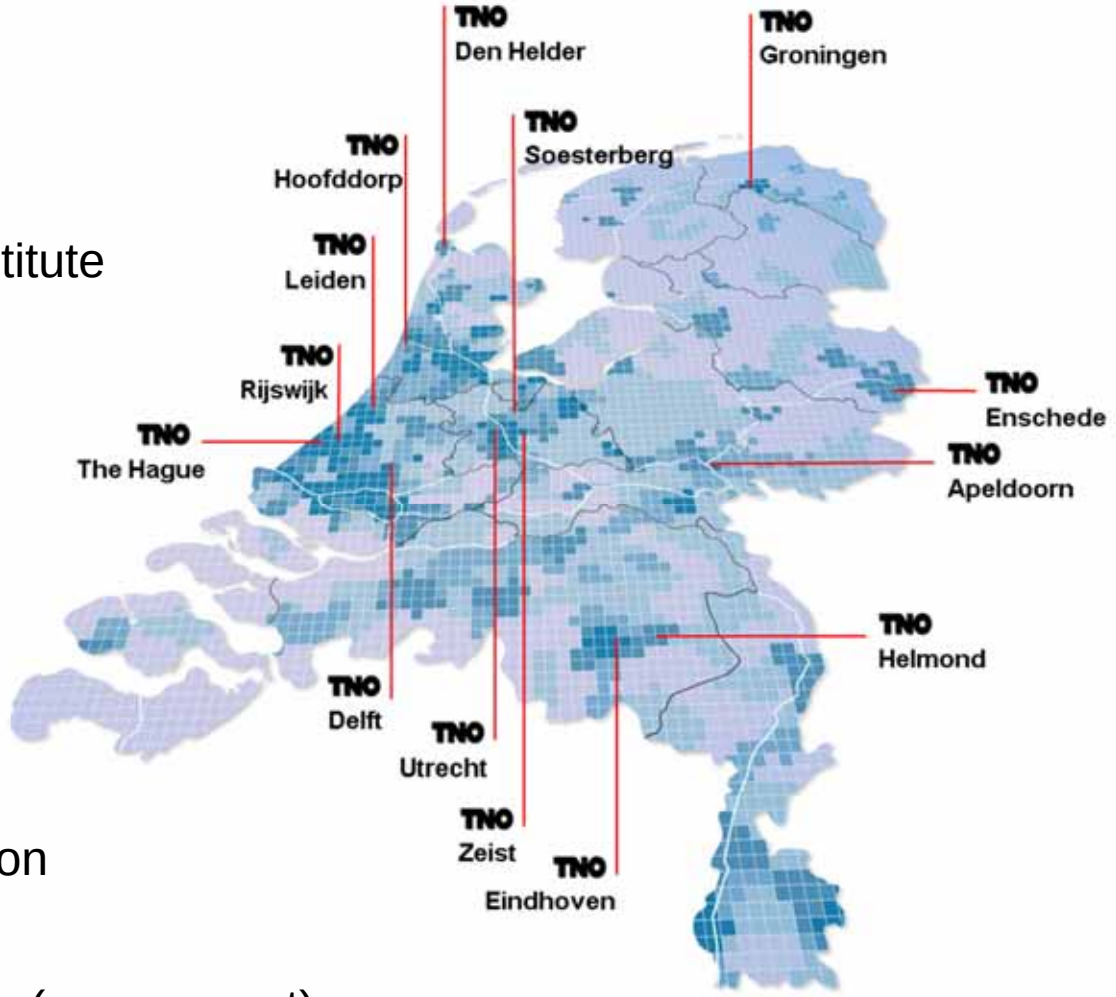
- Intro TNO
- Additive Manufacturing
  - Materials & processes
  - Cases
- AM potential for High Tech Systems
- Mechatronics development exploiting Freeform AM
- Closure

<u>Acknowledgement:</u>
Thanks to Bart van de Vorst for some really nice slides


TNO innovation for life

About TNO

- Dutch Research Institute
  - Since 1932
  - 14 locations
  - 3800 FTE
- Activities
  - Advice
  - Contract research
  - Testing / Certification
  - Licencing
  - Execute legal tasks (government)



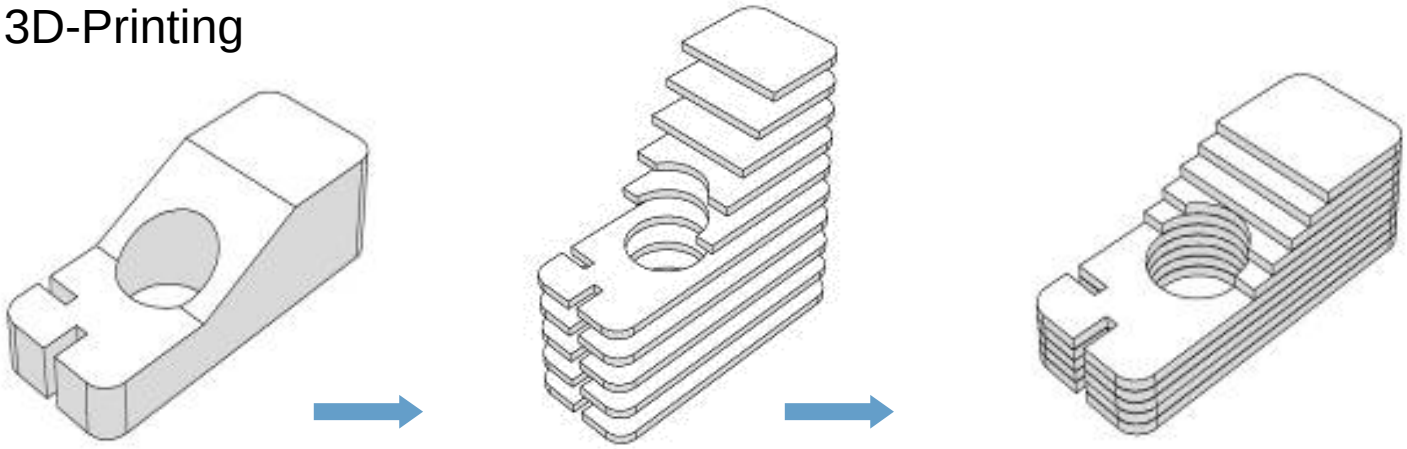
About TNO

- 7 Themes & 20 Innovation Areas.

Additive Manufacturing

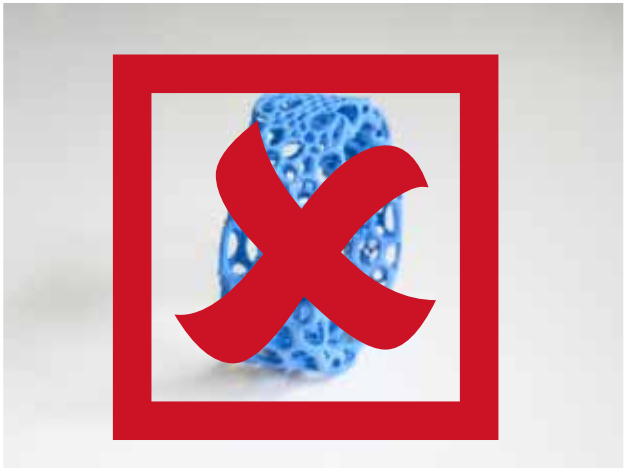
- Building of functional products by selective addition of material based on 3D CAD information

- Similar terms used:
  - Additive Manufacturing (AM)
  - Additive Fabrication (AF)
  - Digital Manufacturing
  - Direct Digital Fabrication
  - Free Form Fabrication (FFF)
  - 3D-Printing



3D Printing VS Additive Manufacturing

3D Printing



Material Extrusion - MakerBot

- Low End
- Consumer Home Printers
- Low cost
- Non qualified Materials
- Limited Support

Additive Manufacturing

Binder Jetting - ExOne

- High End
- Industrial Production Tool
- Higher cost
- Qualified Materials
- Full Service & Support

Design by: Nervous Systems


Additive Manufacturing Materials

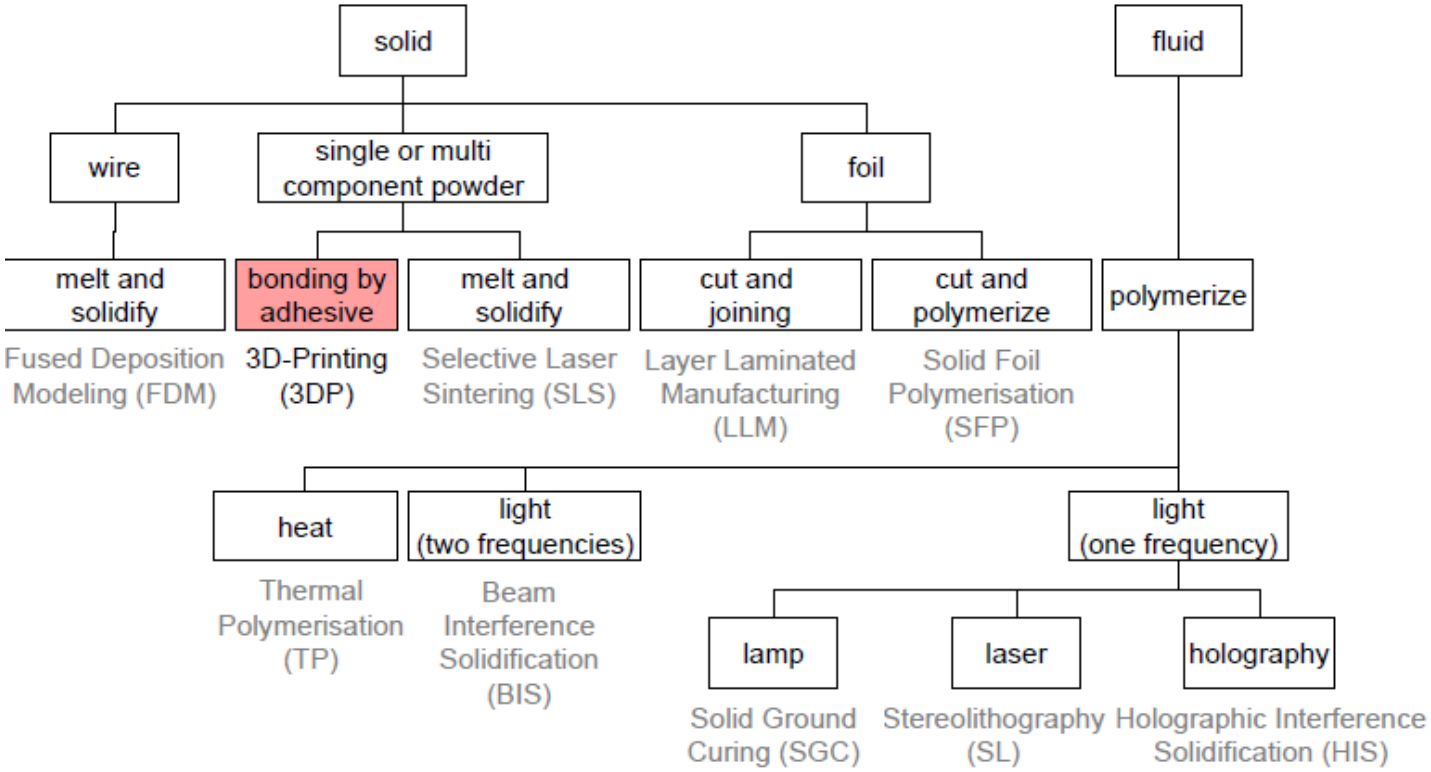
a growing number of printable materials, currently over 200 materials

Organic Materials	Ceramic Materials	Polymeric Materials	Metallic Materials
Waxes	Alumina	Poly Amide (Nylon)	Aluminium
Tissues	Zirconia	ABS	Tool Steel
Cells	Mullite	PMMA	Titanium
	Silicon Carbide	Poly Carbonate	Stainless Steel
		PEEK	Gold

Source: Wohlers Report 2013

Processes

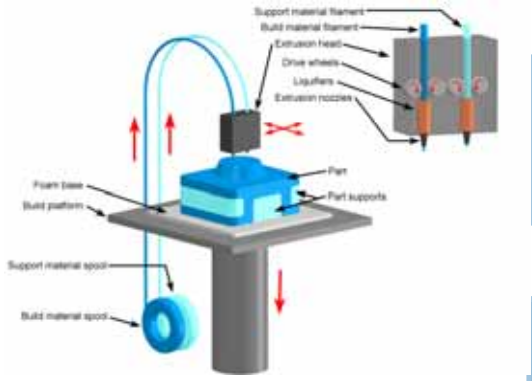
several ‘recipies’ to add material and build a product



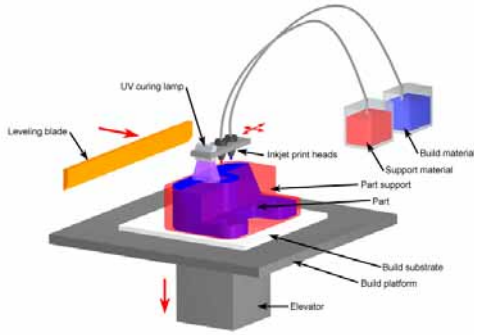
Additive Manufacturing Processes

Major processes for 3D Printing

Material Extrusion



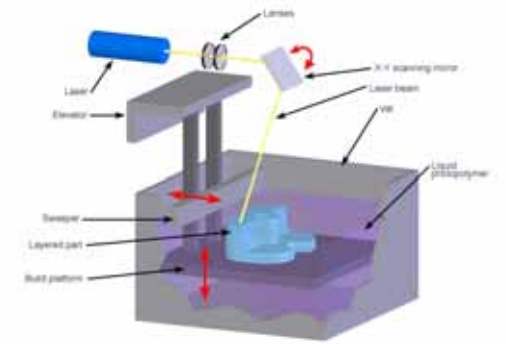
Material Jetting



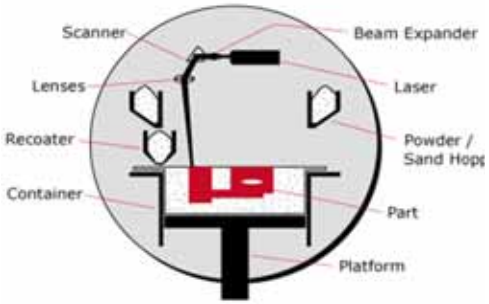
Binder Jetting

Sheet Lamination

VAT photo Polymerization



Powder Bed fusion

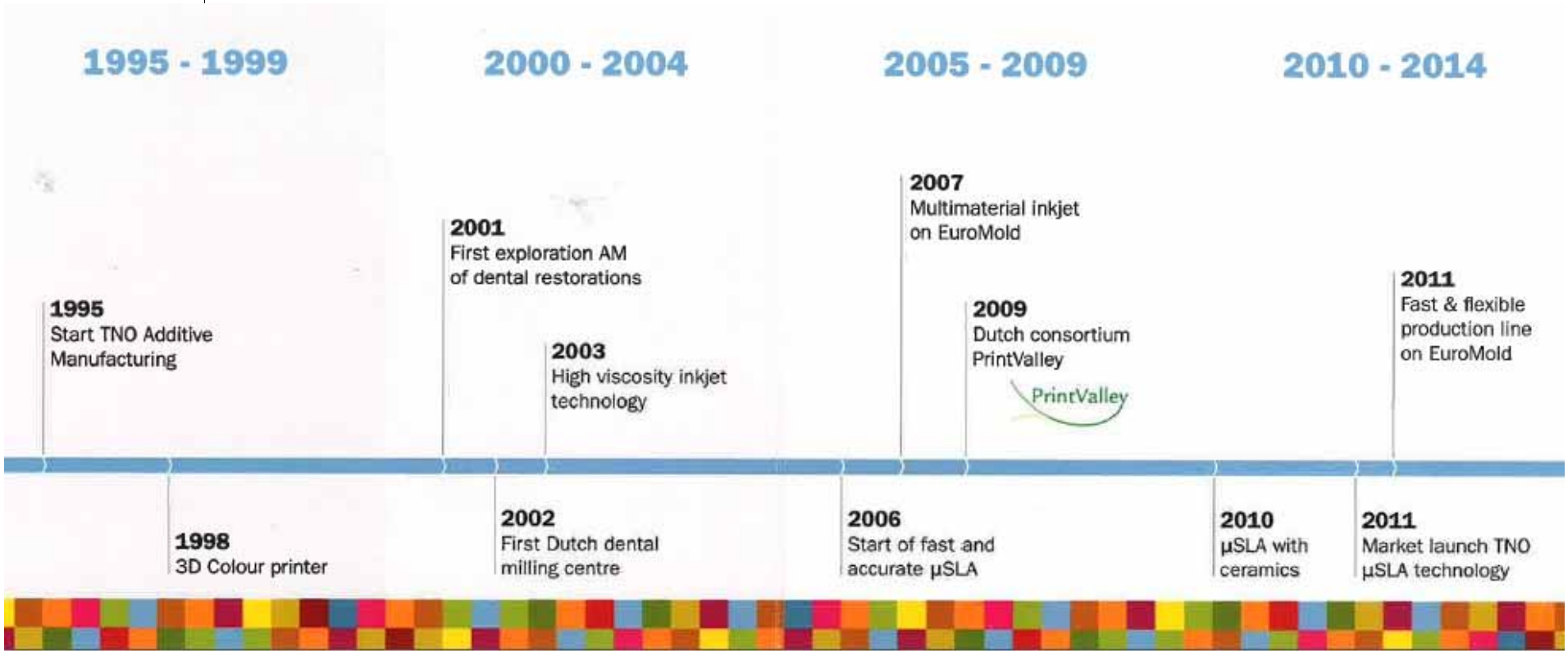


Direct Energy Deposition

Source: ASTM International Committee on Additive Manufacturing Technologies

Additive Manufacturing @ TNO

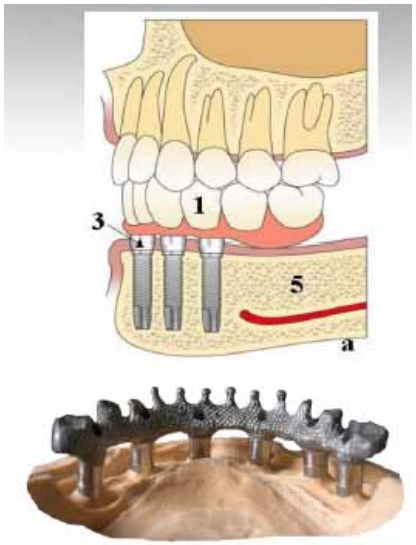
- Long history of developments and involvement from the beginning



Cases: Industrial SLM examples

- Freeform solutions for flow systems
  - Internal cooling channels for process improvement

- Personal fit from medical imaging
  - Dental implants
  - Hip implants



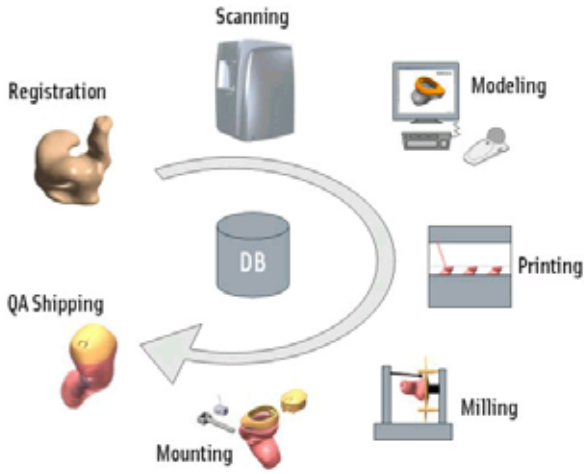
Source : Layerwise

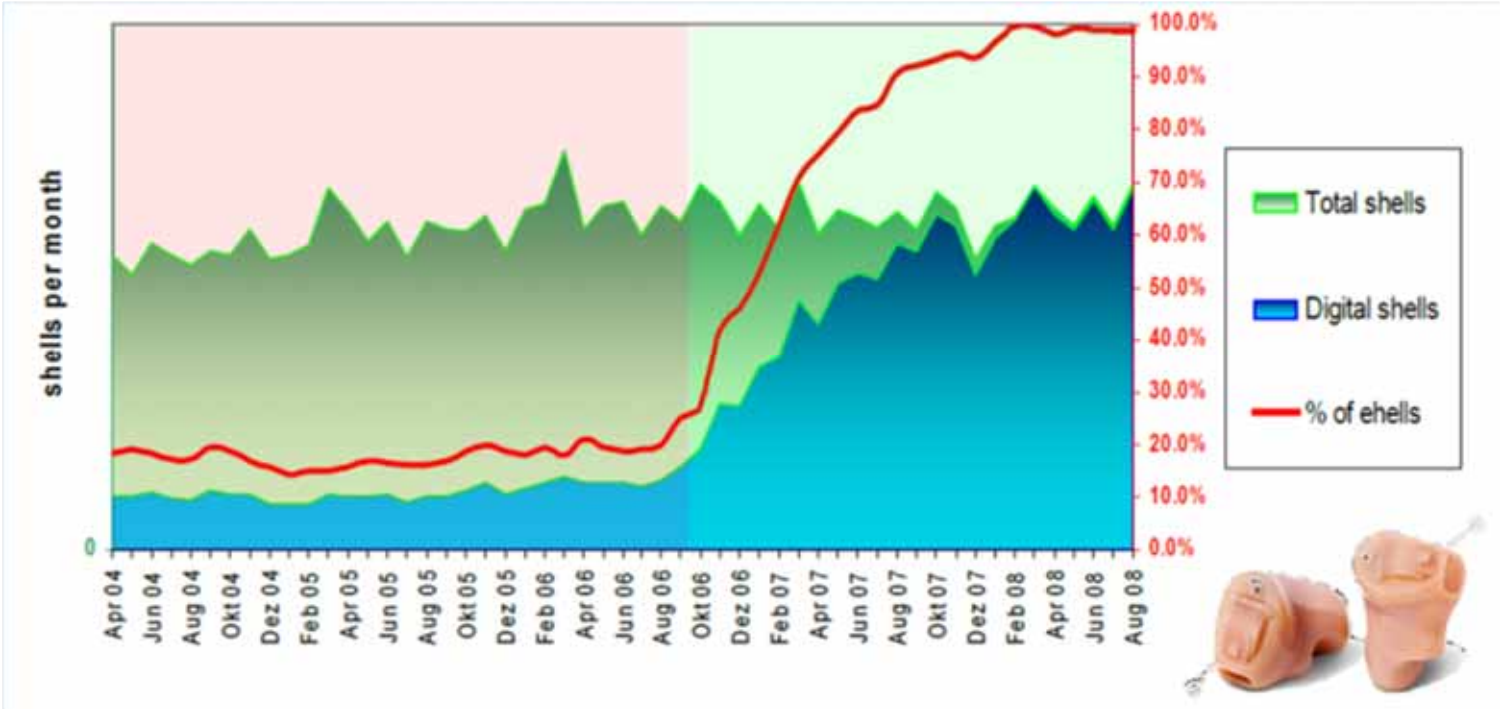

TNO innovation for life

PHONAK

Cases: Hearing Applications

- Personal fit
- In 2 years time the market changed from manual production to digital shell production.

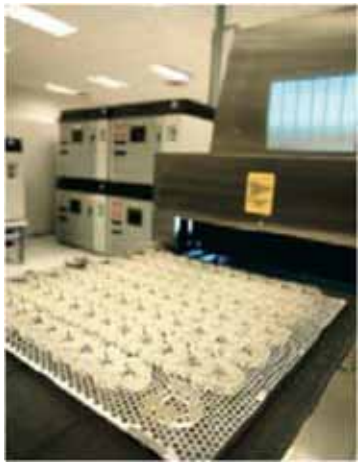




Courtesy of Phonak / Sonova

Cases: Dental Aligners

- Invisalign almost invisible aligners for dental correction
- Step by step correction: every 2 weeks a personalized new aligner
- Mass customization: every aligner is unique (no two are the same)
- 50 Print systems produce over 40.000 pieces per day



Cases: Lightweight racing horse shoes

- Hooves scanned with handheld 3D scanner
- 3D printed titanium horse shoes
- Perfect, customized fit
- Lightweight (50% off)
- Special profile for racing (grip)

=> improved racing performance

- How similar are many High Tech motion systems to racing horses?

Source: CSIRO

Additive Manufacturing potential for High Tech Systems

- Already applied in aircraft, automotive industry
- Rapid developments towards High Tech:
  - AM processes
  - High Tech materials : metals, ceramics, ..
  - Real parts and products
  - Reshoring of production

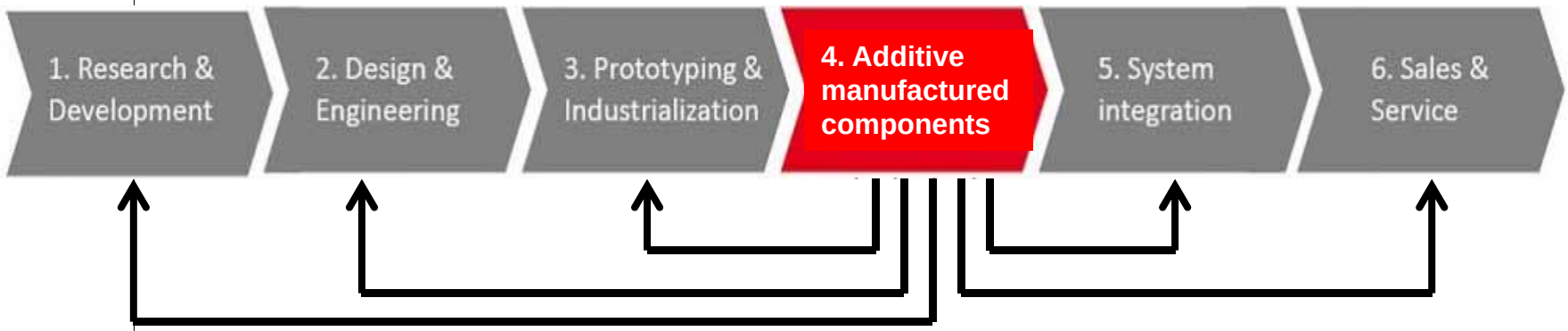
- Provides ultimate design freedom + integration
  - If you can design it, you can make it
  - Complexity or small series at no extra cost

"Manufacturing for design"
instead of
"Design for Manufacturing"

AM impacts system development chain

Traditional innovation chain

AM enabled innovation chain



- AM as a integral step in the innovation chain will have impact on every step
- and will enable a breakthrough for the whole chain

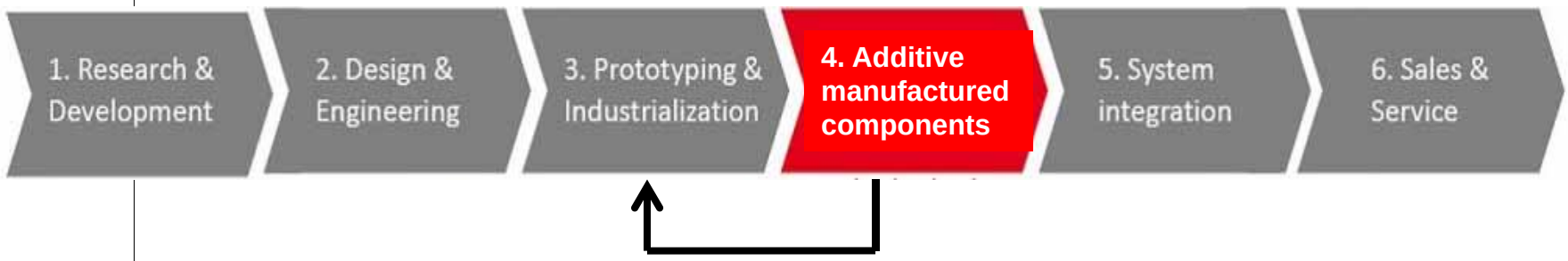
AM impacts system development chain

- Repair and maintenance
  - Fewer scrap, cost saving, faster repair
- Spare parts
  - Local production, engineering changes, end of life
- Logistics
  - fewer stock, print on demand
- Driver is cost, timing compared to existing technologies

AM impacts system development chain

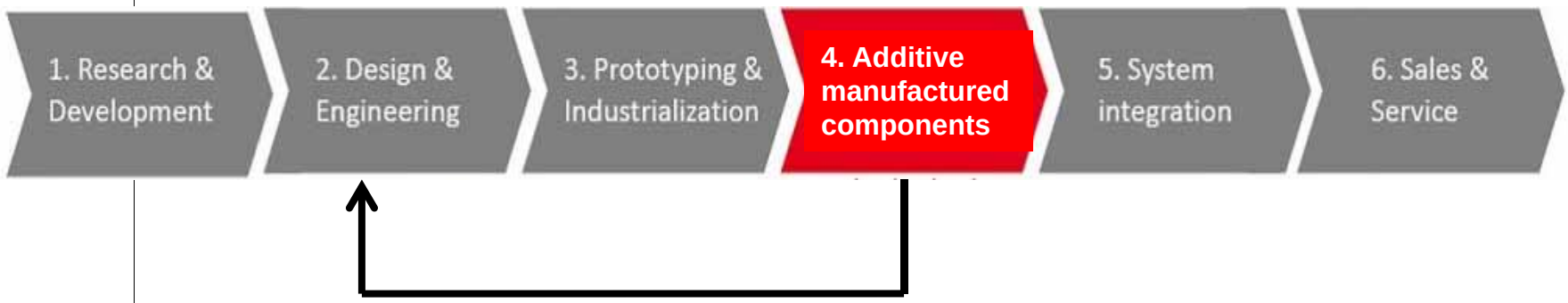
- Lower cost and shorter lead times for first production runs
- Fast design iterations in case of unforeseen behaviour
- Fewer parts to order, less assembly, less risk during build-up
- Driver is cost & timing compared to existing technologies

AM impacts system development chain



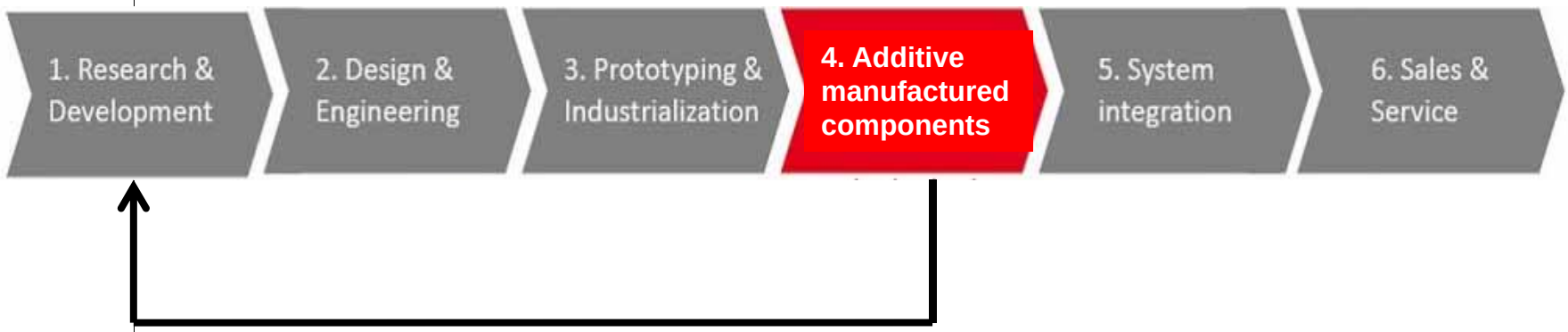
- Rapid prototyping (well known)
  - Early design verification, part testing
  - Sub-module assembly checks
  - Lower NRE for initial small series parts production
- Driver is cost, timing compared to existing technologies
- Also: risk reduction through early experimental evaluation

AM impacts system development chain



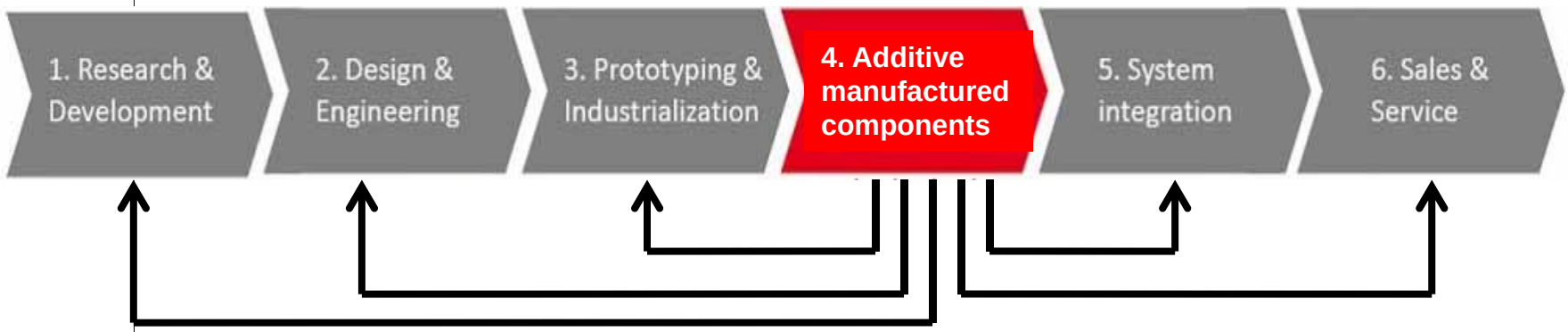
- Freeform engineering solutions:
  - Design for function without conventional manufacturing constraints
  - Integration for fewer parts, fewer connections, less assembly
- Driver is better engineering solutions, not manufacturable with existing technologies. Also: lower cost, shorter lead times

AM impacts system development chain



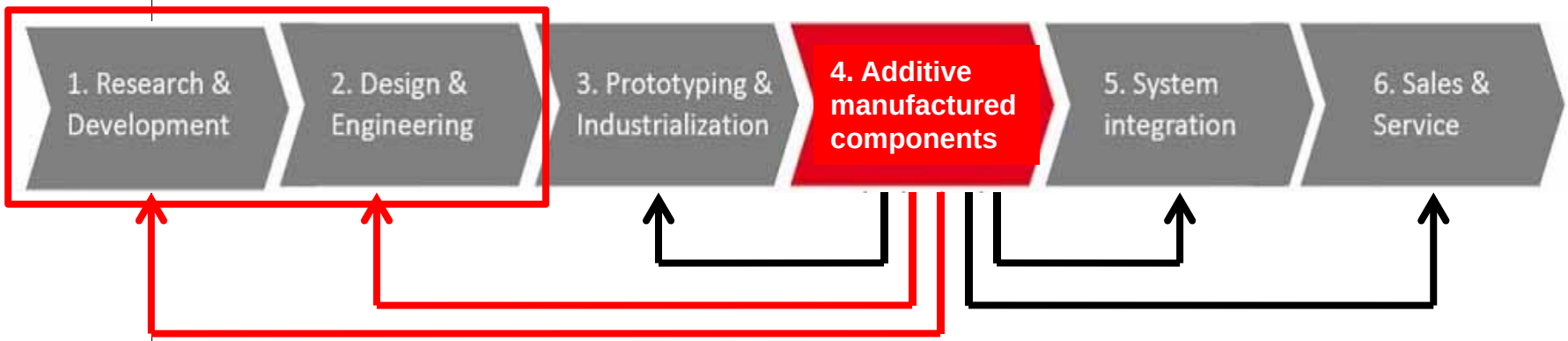
- Freeform design for system performance breakthrough
  - System architectures and module concepts achieving next performance level, not possible without AM
  - New design principles, design and analysis tools
- Driver is performance

AM impacts system development chain



- Many activities relevant for the high tech community addressing the potential AM contributions
- Across players in the eco system: OEM's, suppliers/manufacturers, knowledge institutes, universities
- In various formats: AM production facilities, shared research, strategic partnerships, EU projects, roadmap consortia, …
- Together we can be strong!

AM impacts system development chain



Focus:

- System engineering and mechatronics technologies…
- …exploiting the freeform potential of AM for performance,…
- …enabling next generation High Tech systems

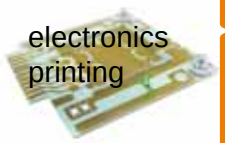
- Here: High Tech refers to high precision motion systems


semicon

solar

space

electronics printing



lighting

FPD

printing

High Tech Systems: future challenges

Primary roadmap challenges:

- Better accuracy
- Higher productivity
- Bigger substrates

Mechatronic bottlenecks:

- Internal deformation
- Mass avalanche
- Thermal behaviour
- Overall complexity

Now is the time to develop new solutions:

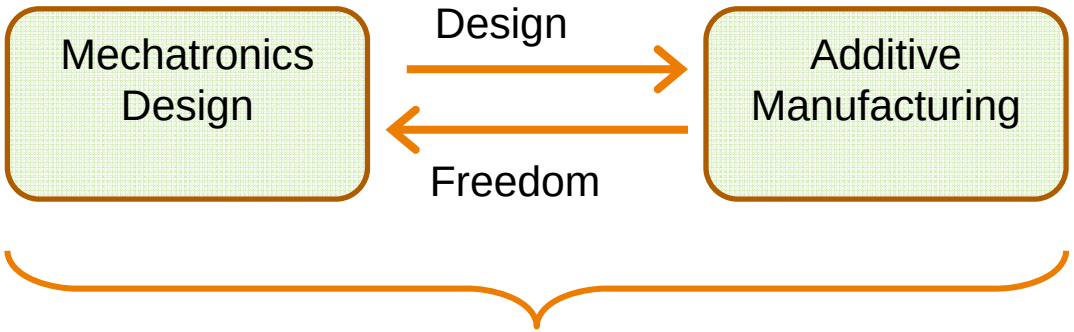
⇒ **System architectures**

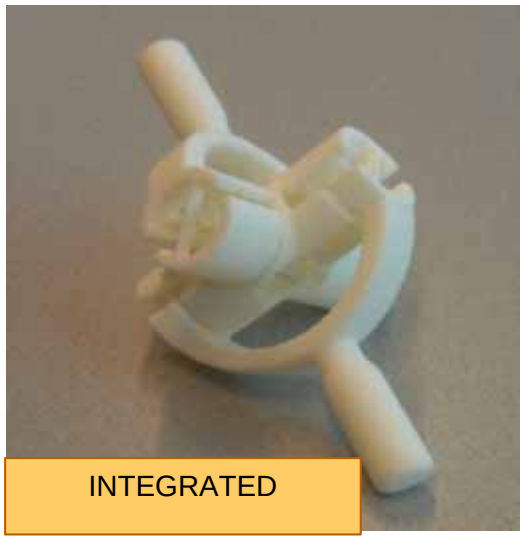
⇒ **Mechatronics technologies**

⇒ **Optimized design**

⇒ **Manufacturing technologies**

AM enables new High Tech Systems solutions





Designers should think beyond the monolith

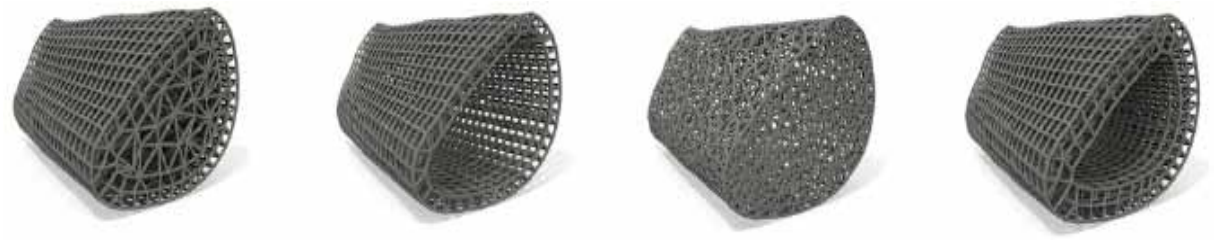
Conventional machining (drilling, milling,…)

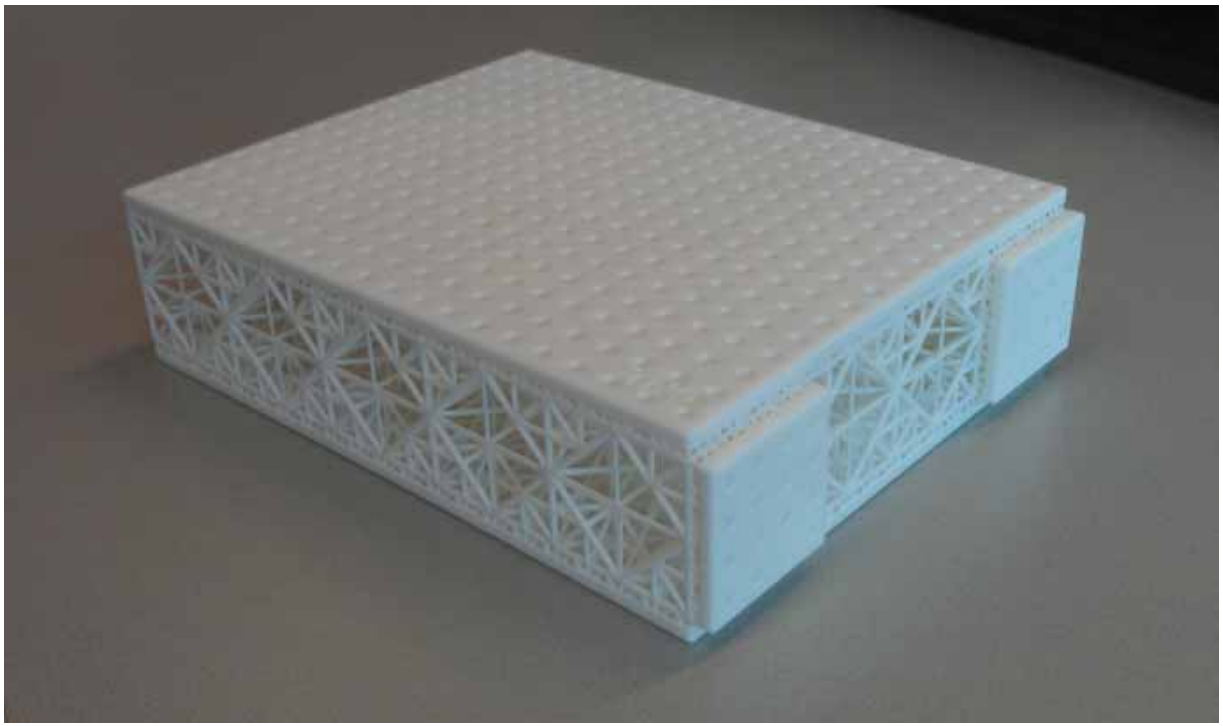
- Single material monolith
- Isotropy / uniform properties
- Obtain product by removing material
- Machining limitations to design
- Complex designs drive up cost

Additive Manufacturing

- A bit like cooking or baking a cake
- Obtain product by adding material
- Anisotropy, grading, multi-material
- Freeform designs possible
- Complex design at no extra cost

Envisioning example: lightweight






TNO innovation for life

High Tech Systems

Mechatronics innovation

Mechatronics Architecture

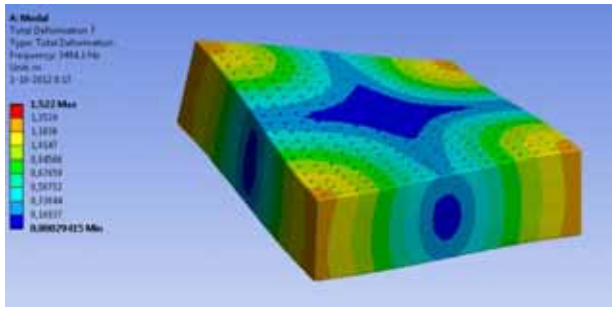
Lightweight & stiff
Integrated mechanisms

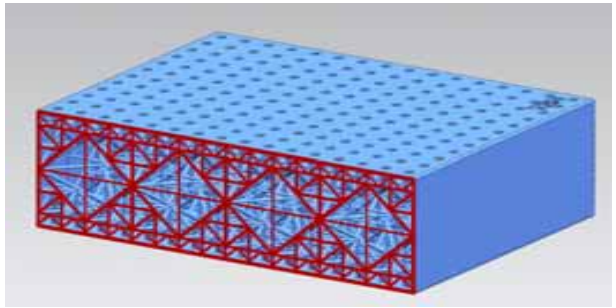
Predictive Modeling & Analysis

Multi-scale, multi-physics modeling

Design Optimization Tools

Light & stiff, isotropy
Thermal / freeform cooling
Actuators & sensors





Manufacturing innovation

Materials

Metals, ceramics, polymers
Combinations, grading

Manufacturing Process Control

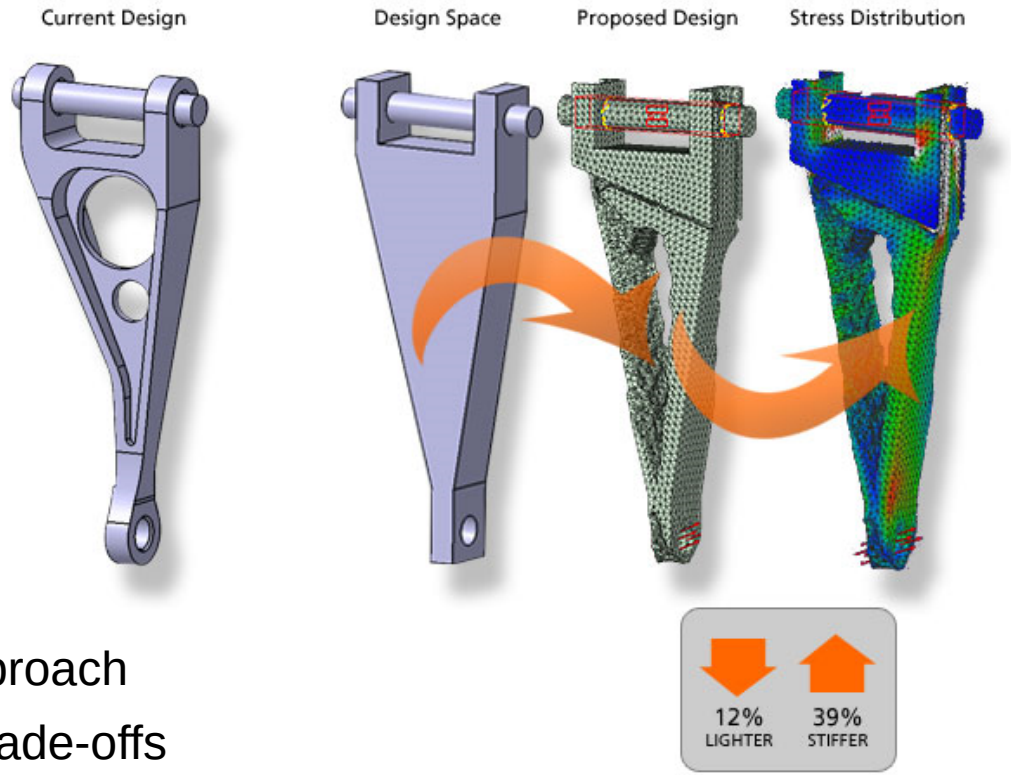
Part quality, repeatibility
Finishing

Manufacturing Equipment

Part size
Production speed / Cost
Accuracy / resolution

Design optimization: how does it work?

- Design space
- Model
- Figure of Merit
- Optimization algorithm



⇒ Model based design approach

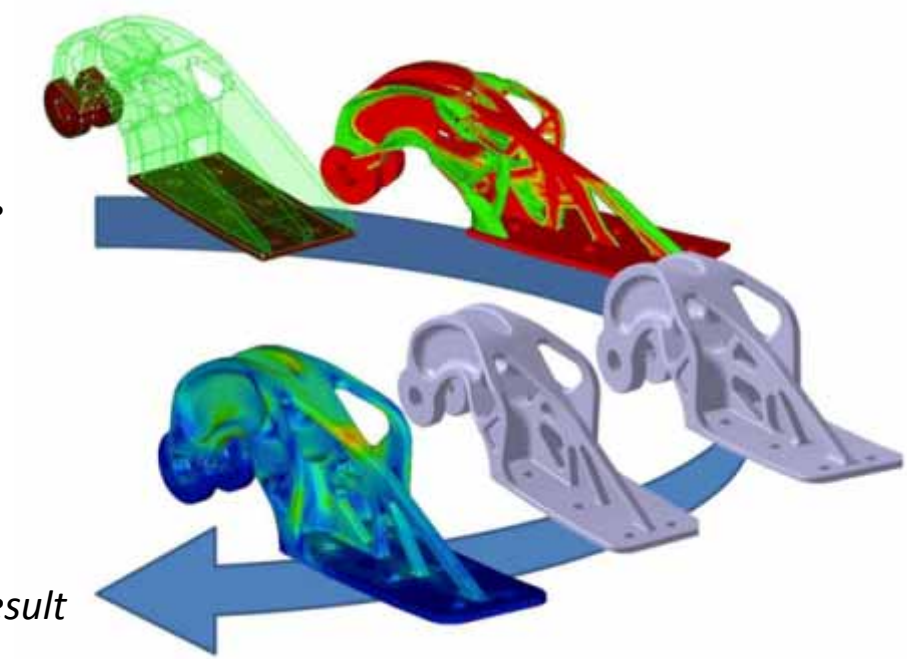
⇒ Solve complex design trade-offs

⇒ Resulting shapes to be manufactured with AM

Topology optimization: commercial SW packages

- Aerospace & Defence
  - Structural Parts
  - Topology Optimisation with Altair HyperWorks
  - Weight reduction of 60%.

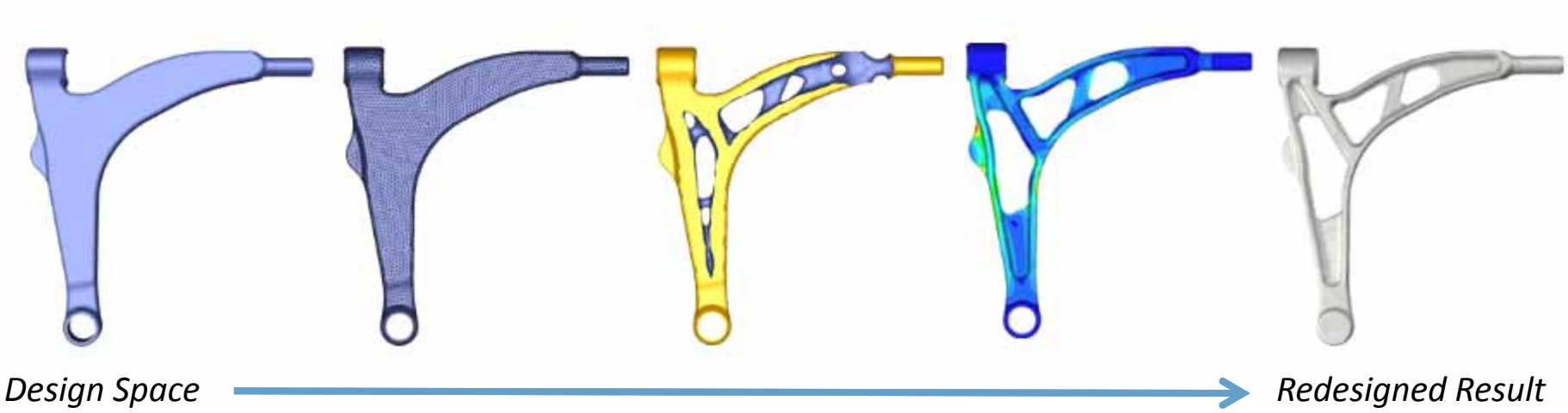
Design Space



Redesigned Result

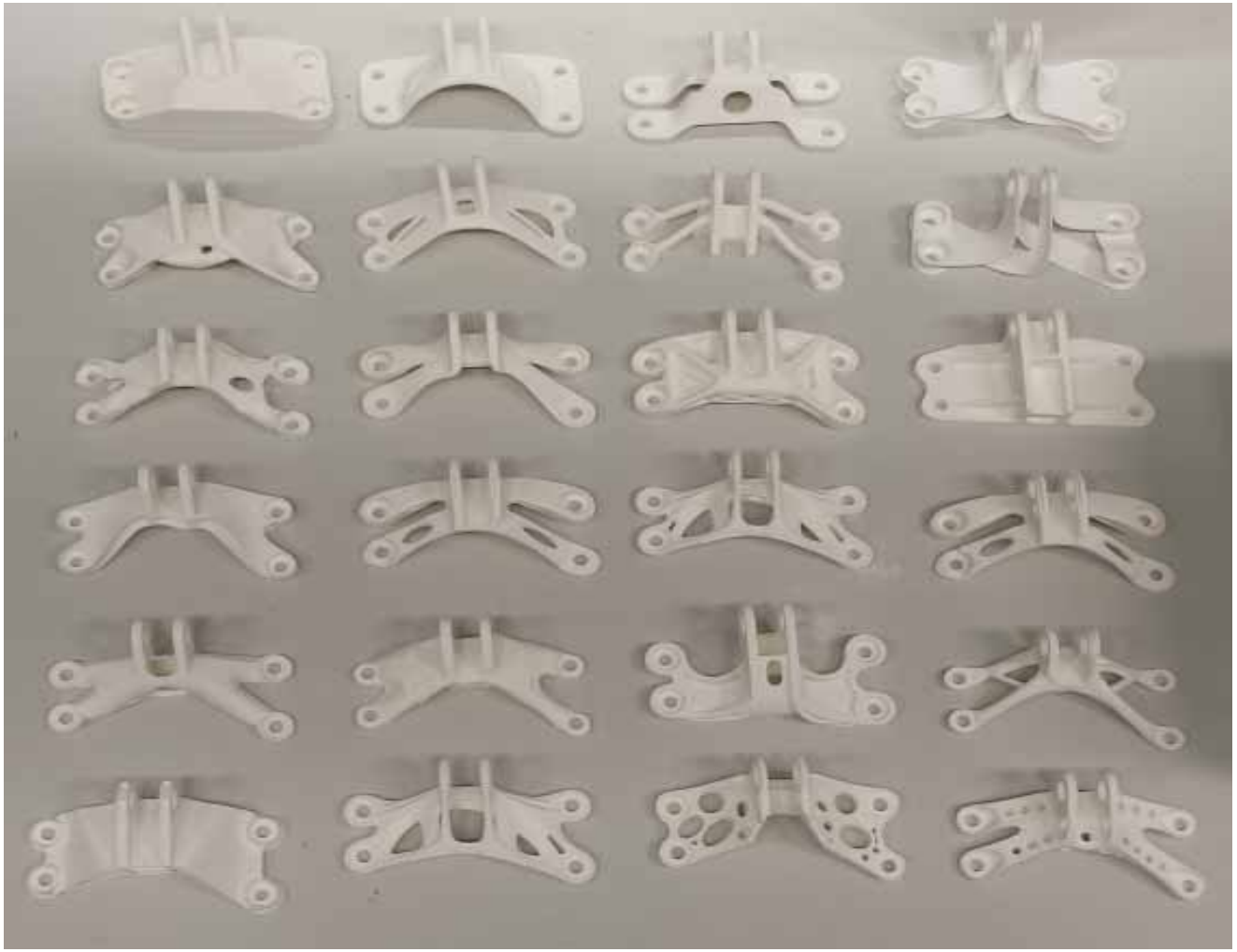
Topology Optimization: commercial SW packages

- Dassault Systemes (Catia & SolidWorks)
  - **Simulia** simulation Package
    - Abaqus
    - Including TOSCA Structure (previous FE Design)
    - Also extension for Ansys Workbench




TNO innovation for life

Design optimization: solutions are not unique…



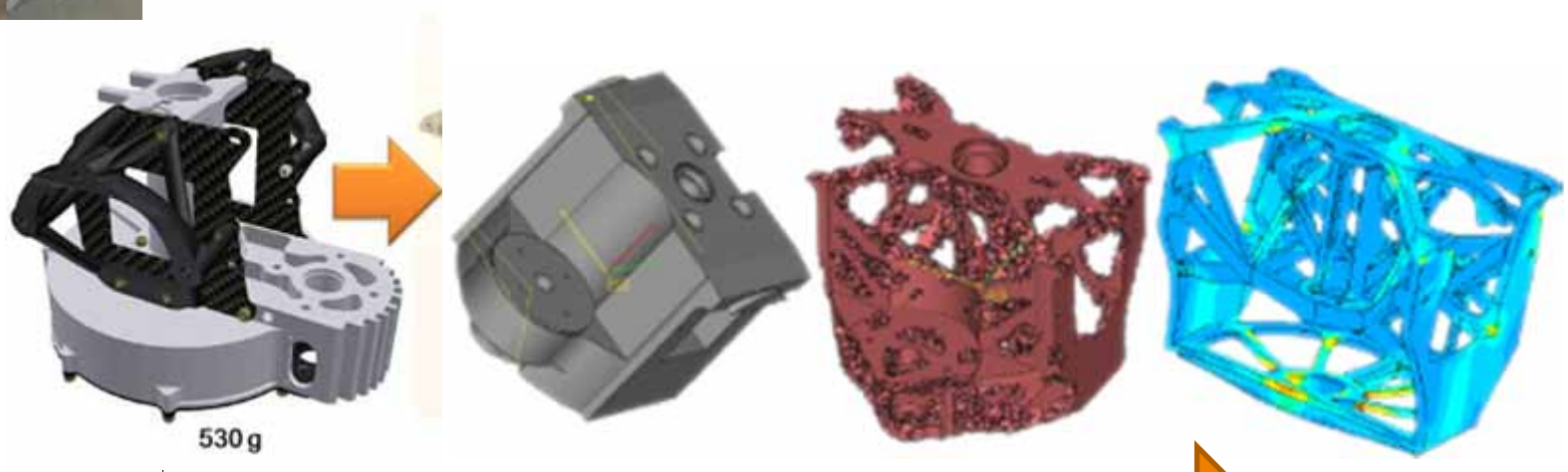
Lightweight example: flying cam

FLYING CAM

Source: compolight project

LIGHTWEIGHT

Lightweight example: flying cam

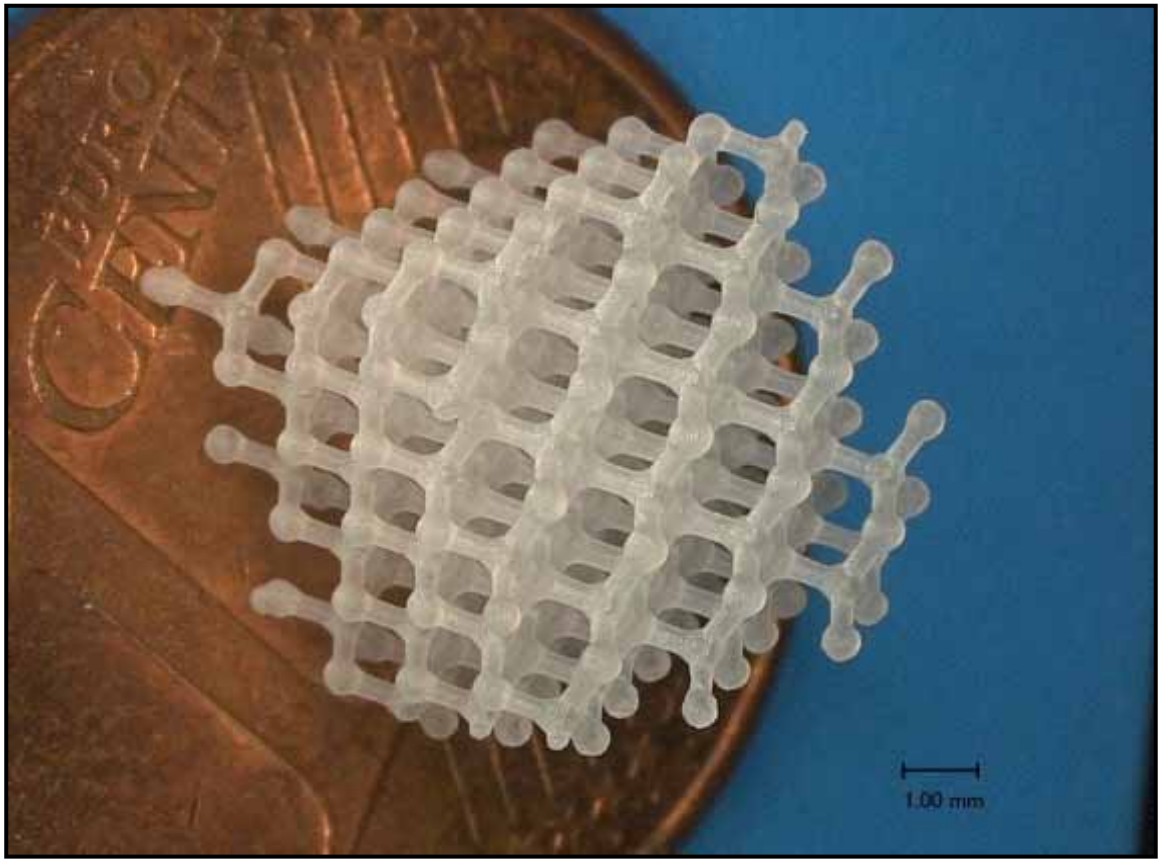


FLYING CAM

Source: compolight project

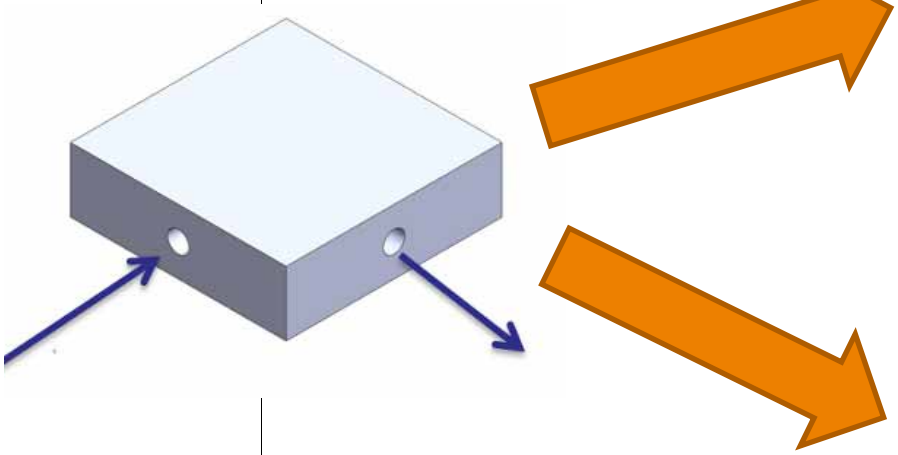
VAT photo polymerization of highly filled resins

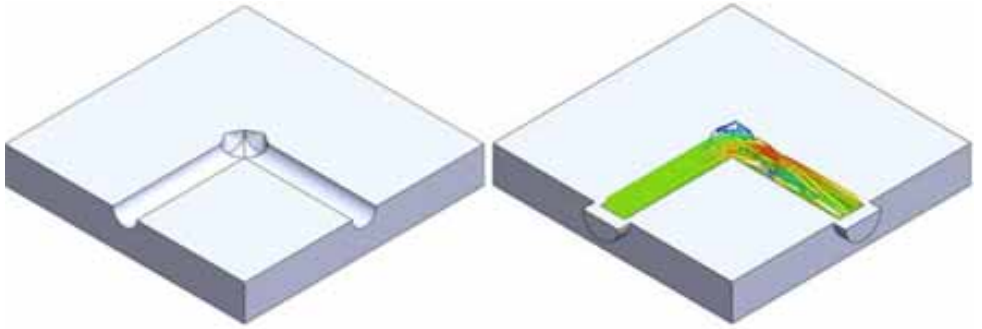
laboratory example of printing of ceramics at TNO



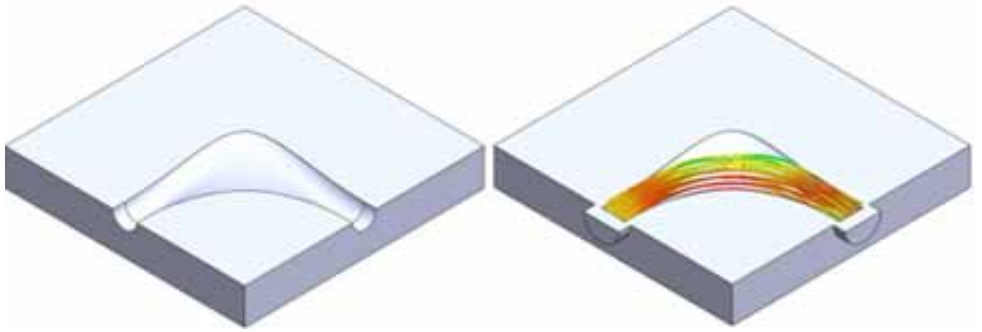
FREEFORM

Freeform example: improved flow





Design with manufacturing constraints



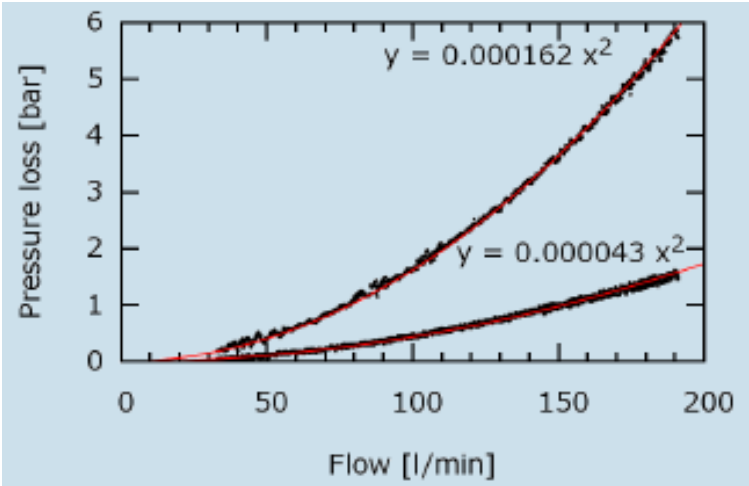
Topology optimization design and made with AM

Source: compolight project

FREEFORM

Freeform example: hydraulic crossing

- Topology optimization design and made with AM
- Improved flow : pressure loss 4x better
- Smaller volume: 23x23x5 cm3 => 8x8x5 cm3
- Lower weight: 20 kg => 1 kg.



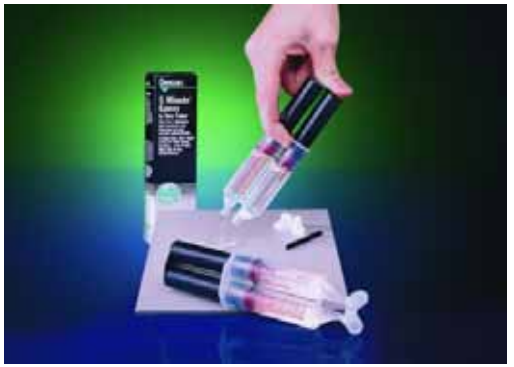
Source: compolight project


INTEGRATED

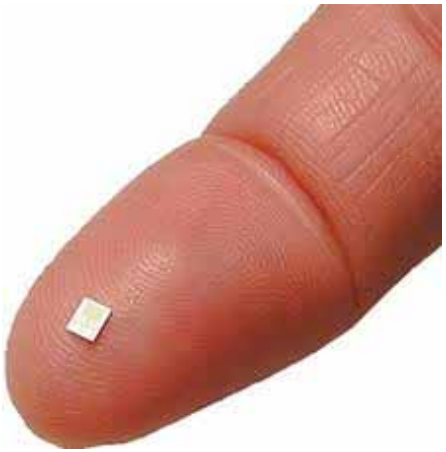
Integrated case


Integration in two ways:

- Constructions / mechanisms out of one piece
  - Reduce number of
    - Parts (# BoM items)
    - Connections
    - Assembly steps / effort
    - Reliability risk

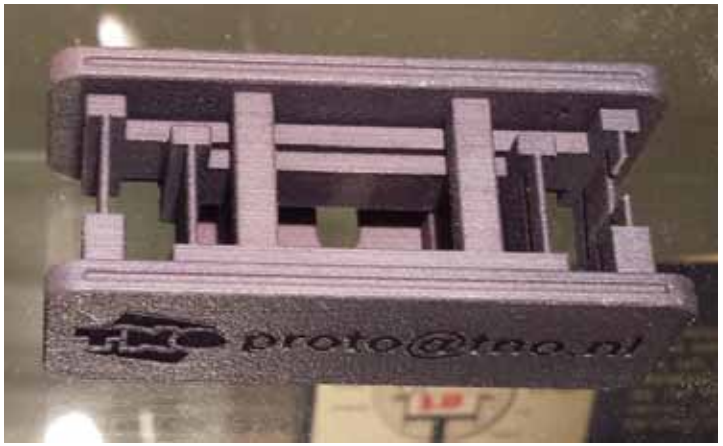



- Functionalities (rather futuristic..)
  - Add sensors, intelligence, logic, actuators to constructions during manufacturing
  - Wiring, connectivity,..

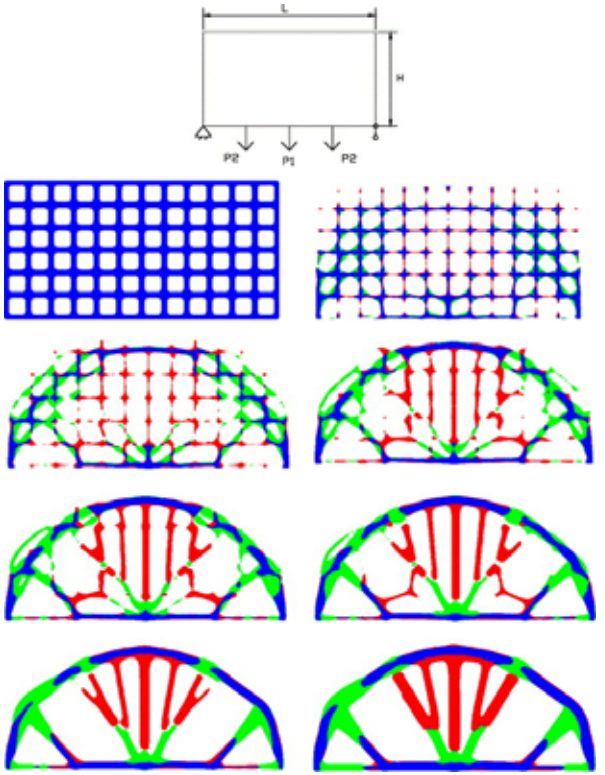


Integration examples

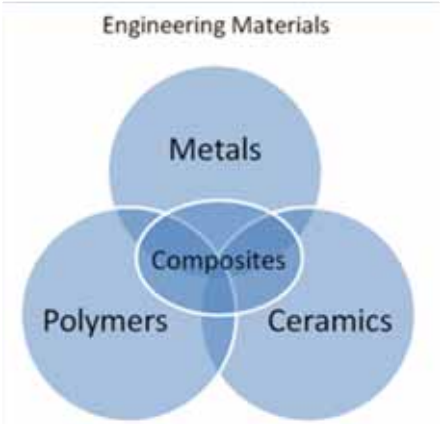
- Leaf spring flexure hinge
- Gas feedthrough
- Embedded sensors

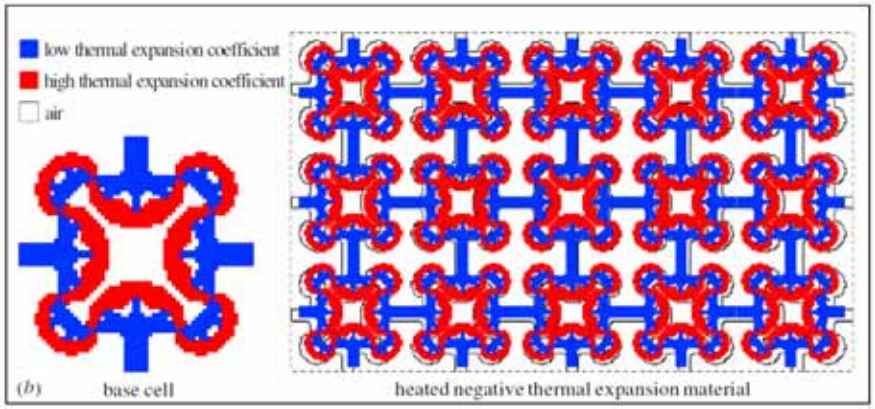


Multi-material case



- Optimal combination of materials
  - Grading
- Tailored part properties
  - Stiffness, damping
  - Thermal expansion
  - (An-)isotropy
  - …





Microstructure of 2 materials with different thermal expansion coefficients.

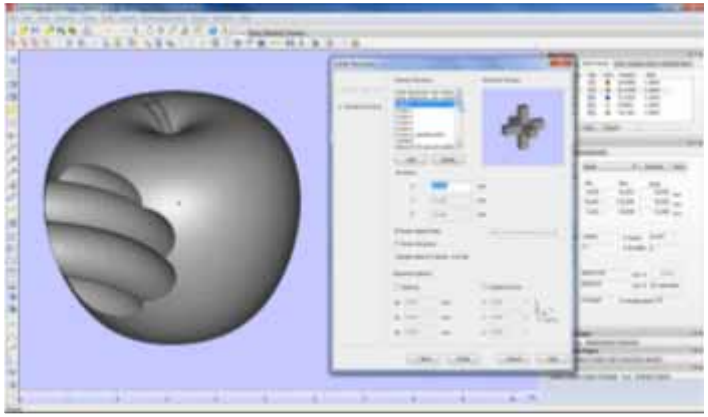
Structure *shrinks* when T increases

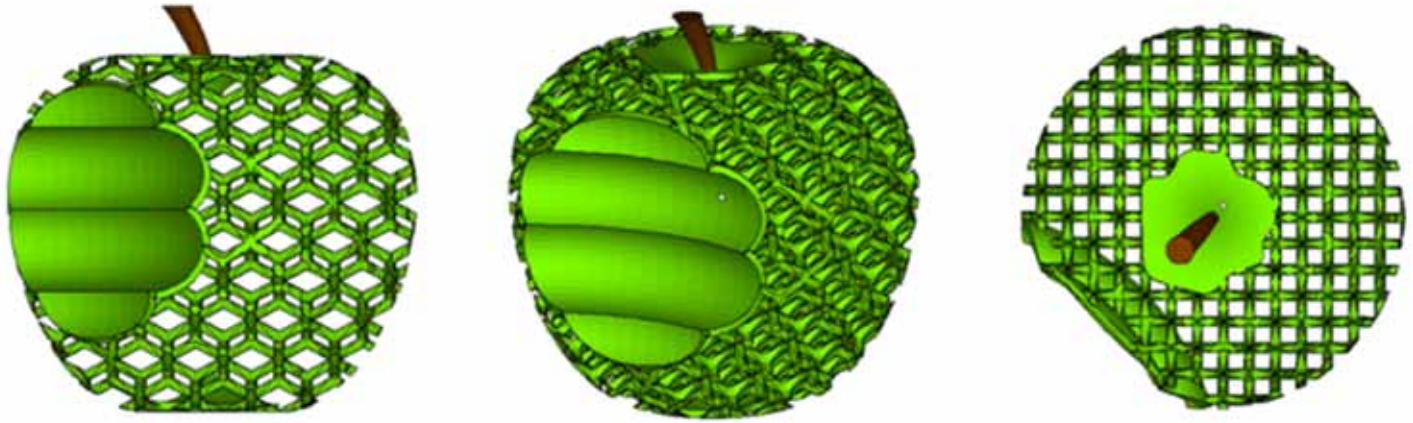
Could also be designed to have constant shape (zero thermal expansion).

Magics

Porous Structures

- Magics Structure Module

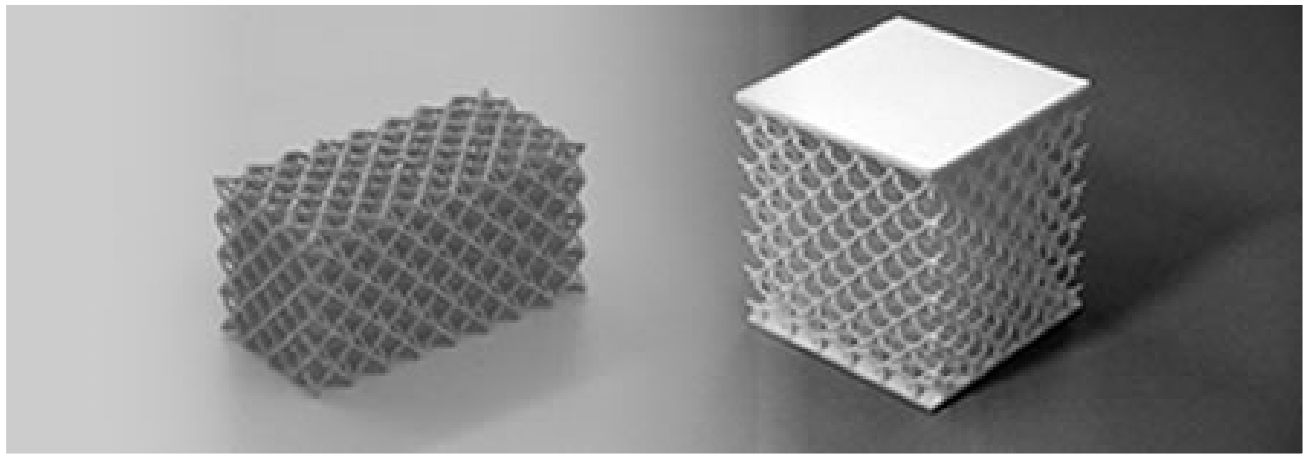




Source: www.materialise.be

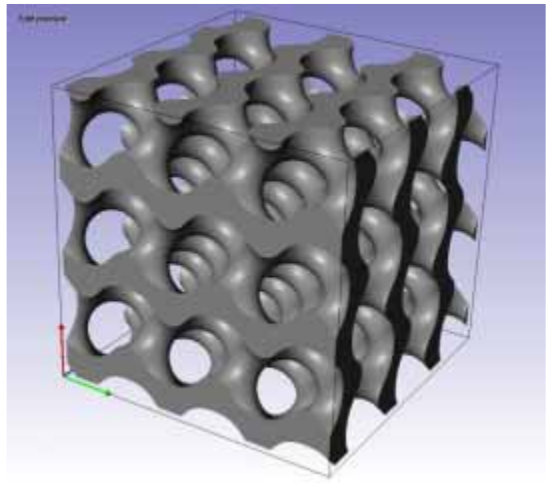
Porous Structures

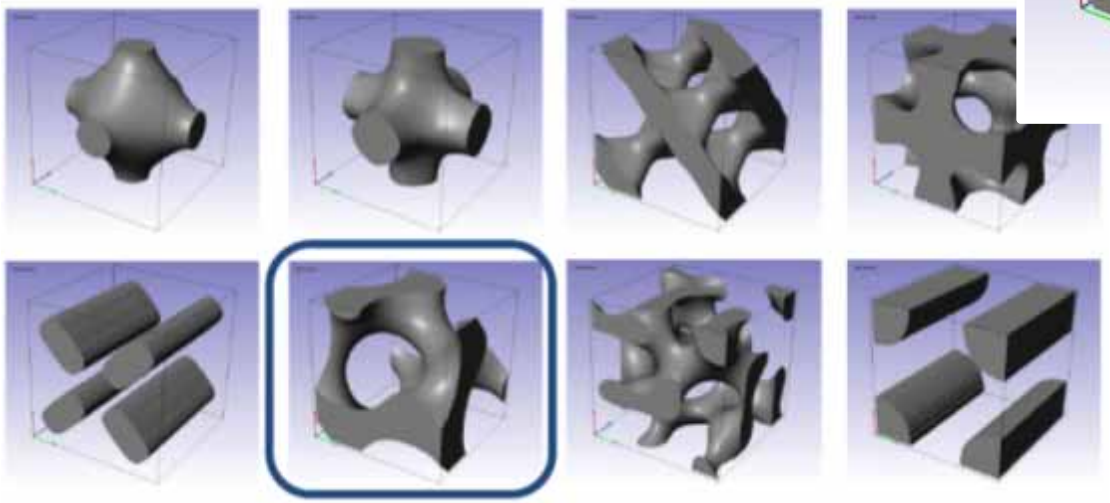
- Selective Space Structures
  - At slice level



Lattice structures by Simpleware

- Building blocks to create the structures
- Based on triply periodic implicit functions

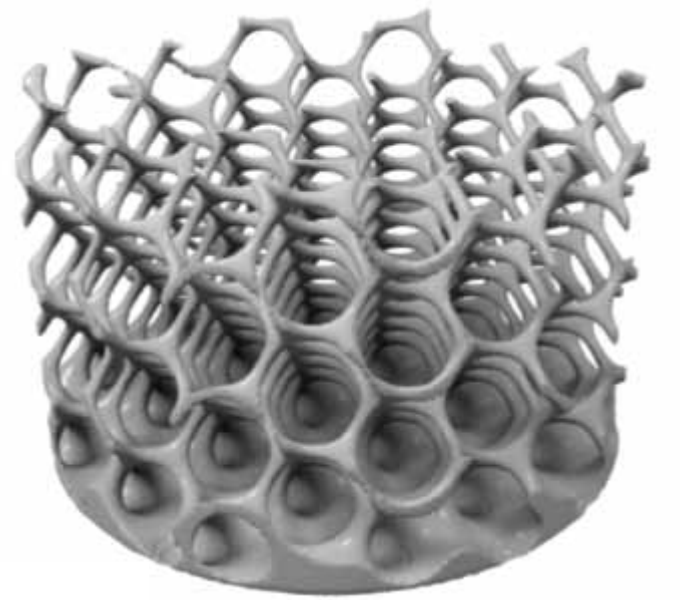


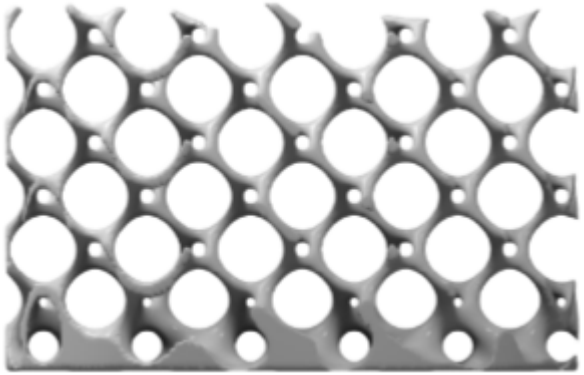


Source: Simpleware

Lattice structures

- Arbitrary Density variations

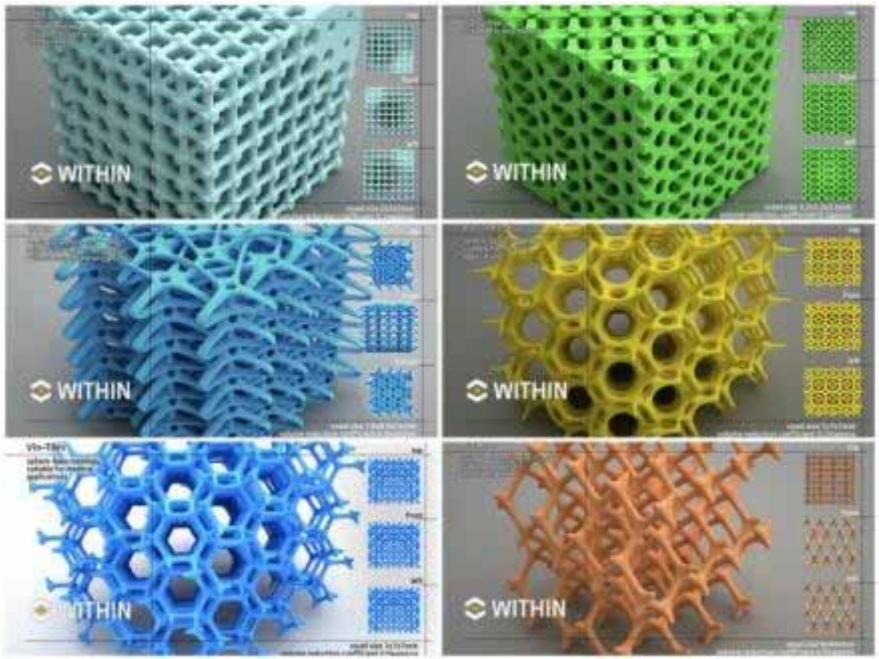




Source: Simpleware

Within Lattice Structures

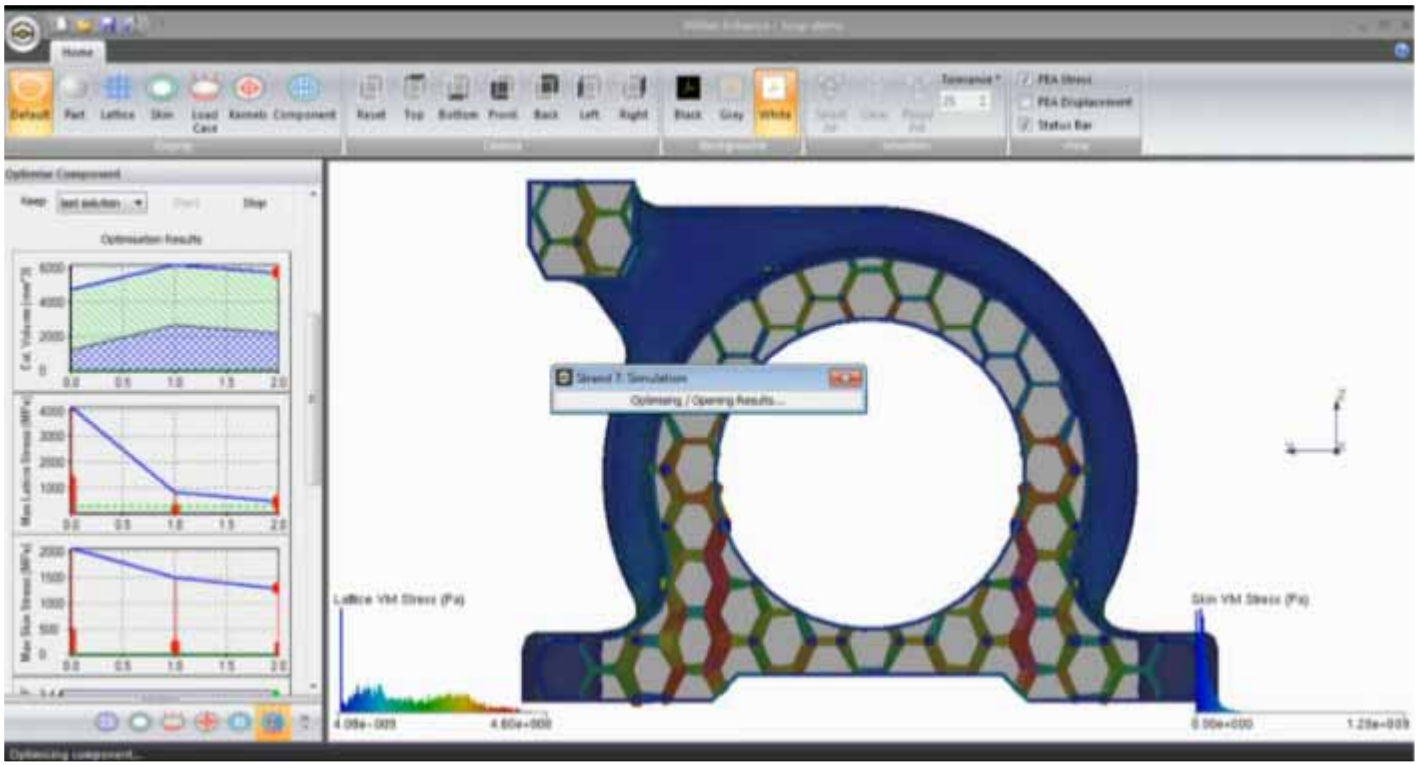
- Library with multiple unit cells
  - also graded porosity, omnidirectional and conformal



Source: Within

Within Enhance Software suite.

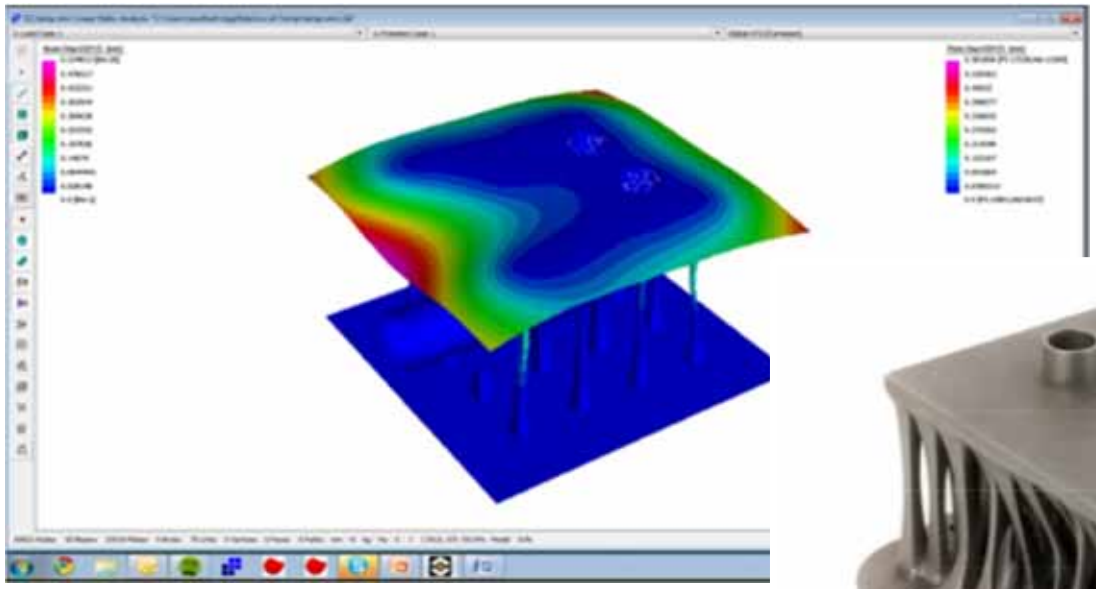
- Combination with Finite Element Analysis



Source: *Within*

Within – Enhance Lattice Structures

- In combination with Strand7 – Finite element analysis software



Source: Within


Conclusion

- Additive manufacturing rapidly developing towards High Tech
- Still many hurdles to be taken (quality, part size, speed, etc.)
- Many industrial application with specific benefits from AM
- Potential value for high tech systems clearly present
- Mechatronic design & analysis is key, but this is relatively unexplored
- Many opportunities for this high tech region to join forces!


TNO innovation for life

Thank you for your attention!

Questions?

Gregor van Baars, TNO
gregor.vanbaars@tno.nl