Karlsruhe Institute of Technology

KIT – The Research University in the Helmholtz Association

Steffen G. Scholz

Figures and Facts

Karlsruhe Institute of Technology

5 Campuses – **200** ha area

18 Spinoffs and startups

355 Professors and executive scientists

471 Trainees

300 Buildings with a usable area of **430,000** m²

25,000 Students

KIT budget
EUR 860 million

3,000 Doctoral students

59 Patent applications

9,300 Employees

1,000 International scientists

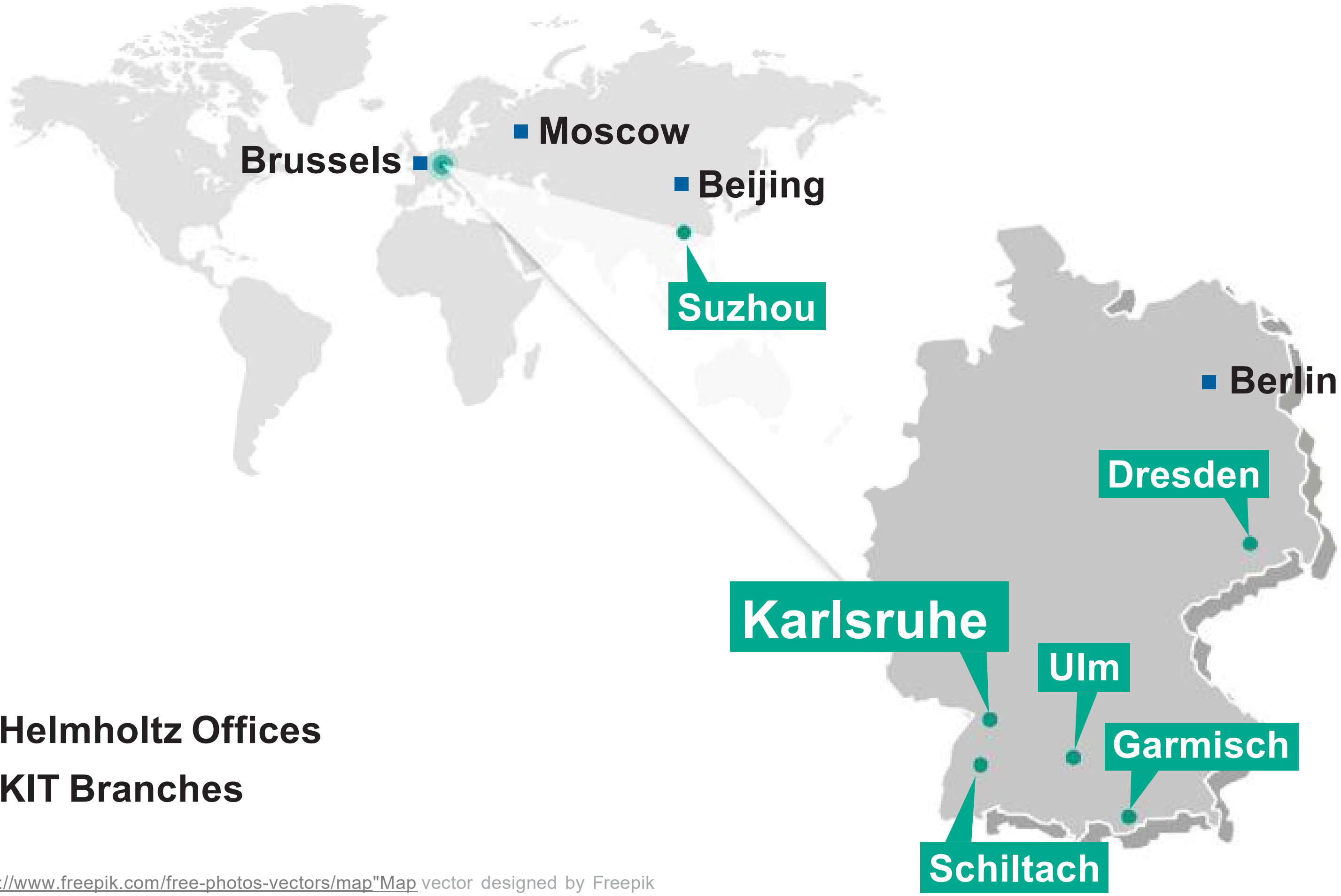
Status: 2015

KIT - „established 2010“

Campus North:
Forschungszentrum
Karlsruhe

Campus South:
Former University of Karlsruhe

Branch Offices



■ Helmholtz Offices

● KIT Branches

http://www.freepik.com/free-photos-vectors/map"Map vector designed by Freepik

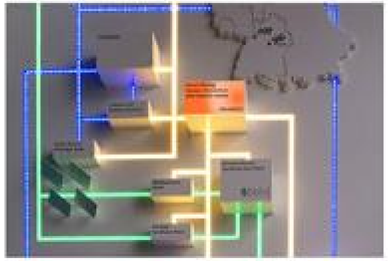
Big Research Infrastructures at KIT

Karlsruhe Institute of Technology

Acoustic Four-wheel Roller Dynamometer

ANKA Synchrotron Radiation Facility

Biomass to Liquid (bioliq®)



EnergyLab 2.0

European Zebrafish Resource Center

High-perfomance Computer for Research

Grid Computing Centre Karlsruhe (GridKa)

Karlsruhe Nano Micro Facility (KNMF)

Karlsruhe Tritium Neutrino Experiment

Theodor Rehbock River Engineering Laboratory

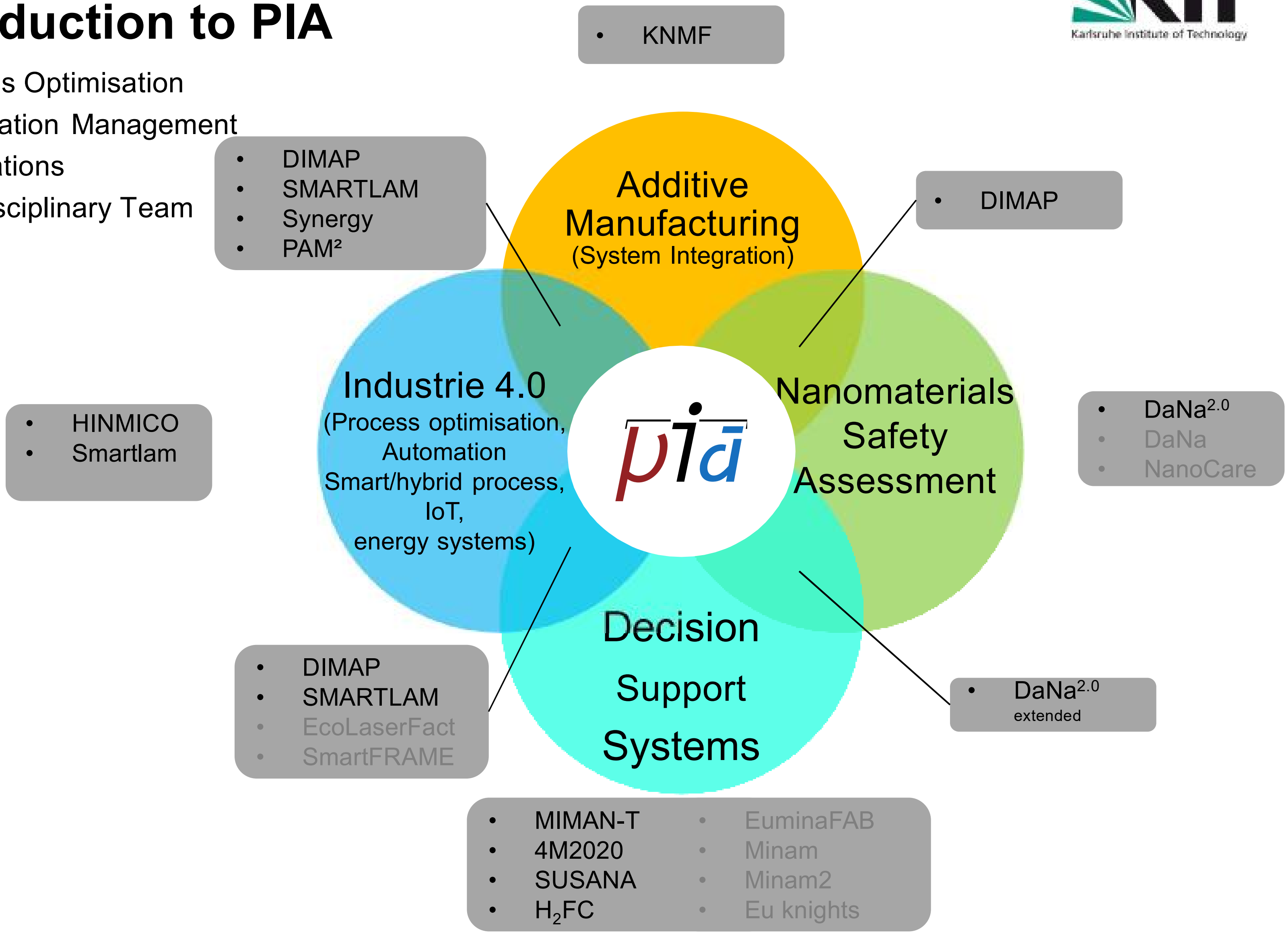
Vehicle Efficiency Laboratory

AIDA Cloud Chamber

Institute for Applied Computer Science

Introduction to PIA

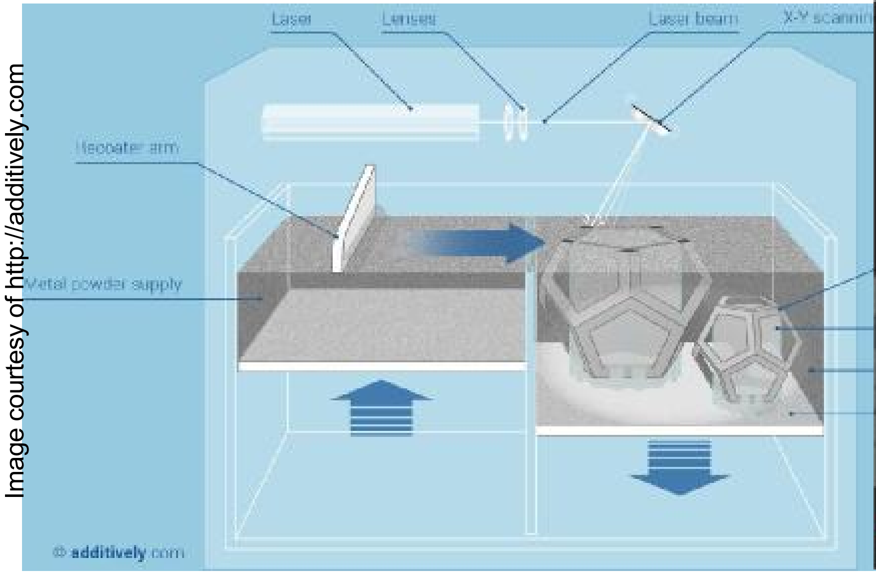
- **P**rocess Optimisation
  Information Management
  Applications
- Interdisciplinary Team

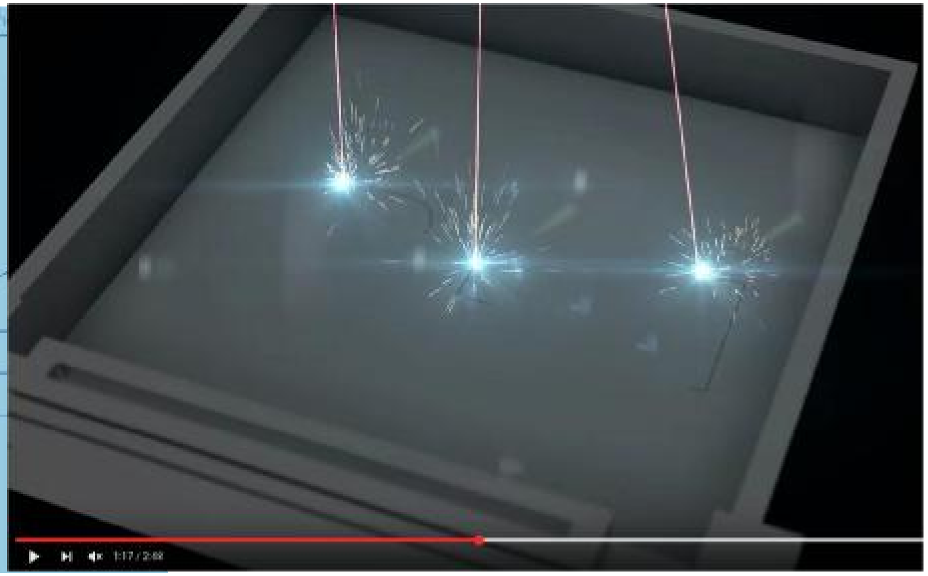


AM Technologies – Selective Laser Melting/ Sintering

- Thin layers of fine (metal) powder are distributed on a indexing table that is movable in the vertical (z-) axis
- Resulting powder layer is molten or sintered by a high power laser beam

Image courtesy of http://additively.com





- Advantages: High density, wide range of metals applicable
- Drawbacks: Slow process, surface finishes are limited
- Possible Materials: Stainless steels, tool steels, titanium, nickel based alloys, ceramics

AM Technologies – Fused Filament Fabrication

- Material filament ist unwound from a coil or continuously fed from strains
- Deposition of individual layers by feeding material through heated nozzle

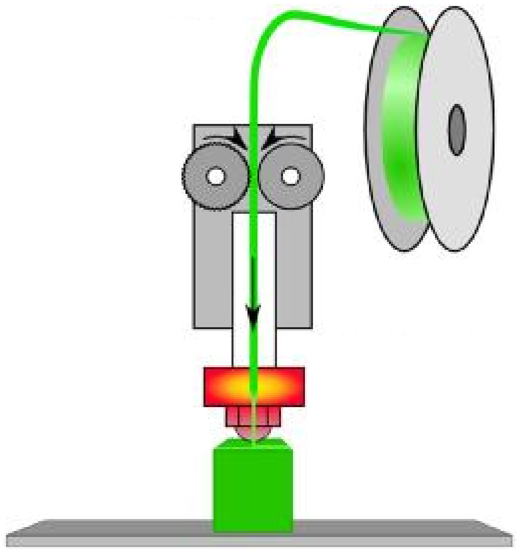


Image courtesy of http://spacediy.es/

- Advantages: Cheap, huge variety of machines available, compact size
- Drawbacks: Ribbing (visible layers), low part strength, delamination problems
- Possible Materials: ABS, PLA, PC, PPSF, PEI, materials with fillers (wood, copper)

AM Technologies – Stereolithography (SLA)

- Photocurable polymer, typically liquid resin
- Layer by layer hardening by applying focussed light or UV light

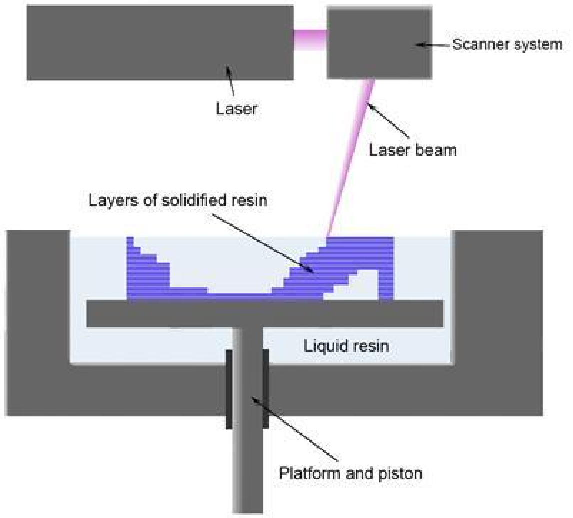


Image Courtesy of http://isambardkingdom.com/

- Advantages: High resolution, smooth surfaces, high mechanical strength
- Drawbacks: Limited material range, high printing costs compared to FFF
- Possible Materials: Epoxy based photopolymers

AM Technologies – Inkjet / Multijet printing

- Similar to classic inkjet printing small droplets are dispensed by a single or multiple printheads
- Printed layer are either cured (photopolymers) or cooled (wax)

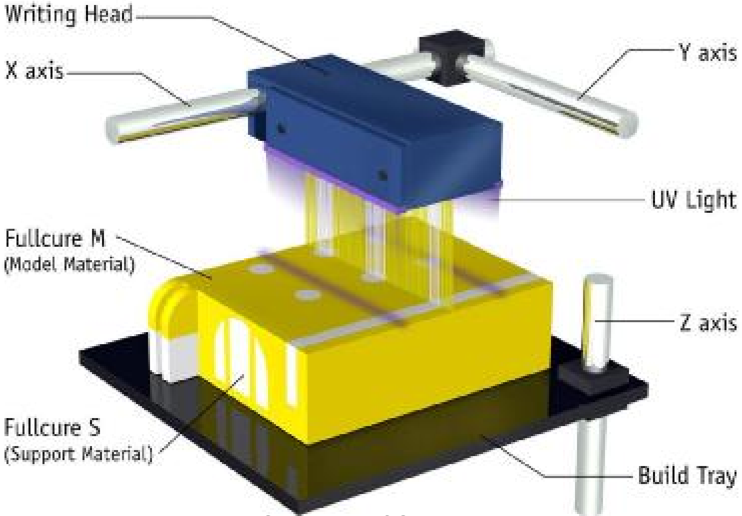


Image Courtesy of Stratasys Ltd.

- Advantages: Very accurate, smooth surface, Quick print time (Multijet)
- Drawbacks: Separate process for melting supports, slow (Inkjet)
- Possible Materials: ABS, PA, TPE, resins

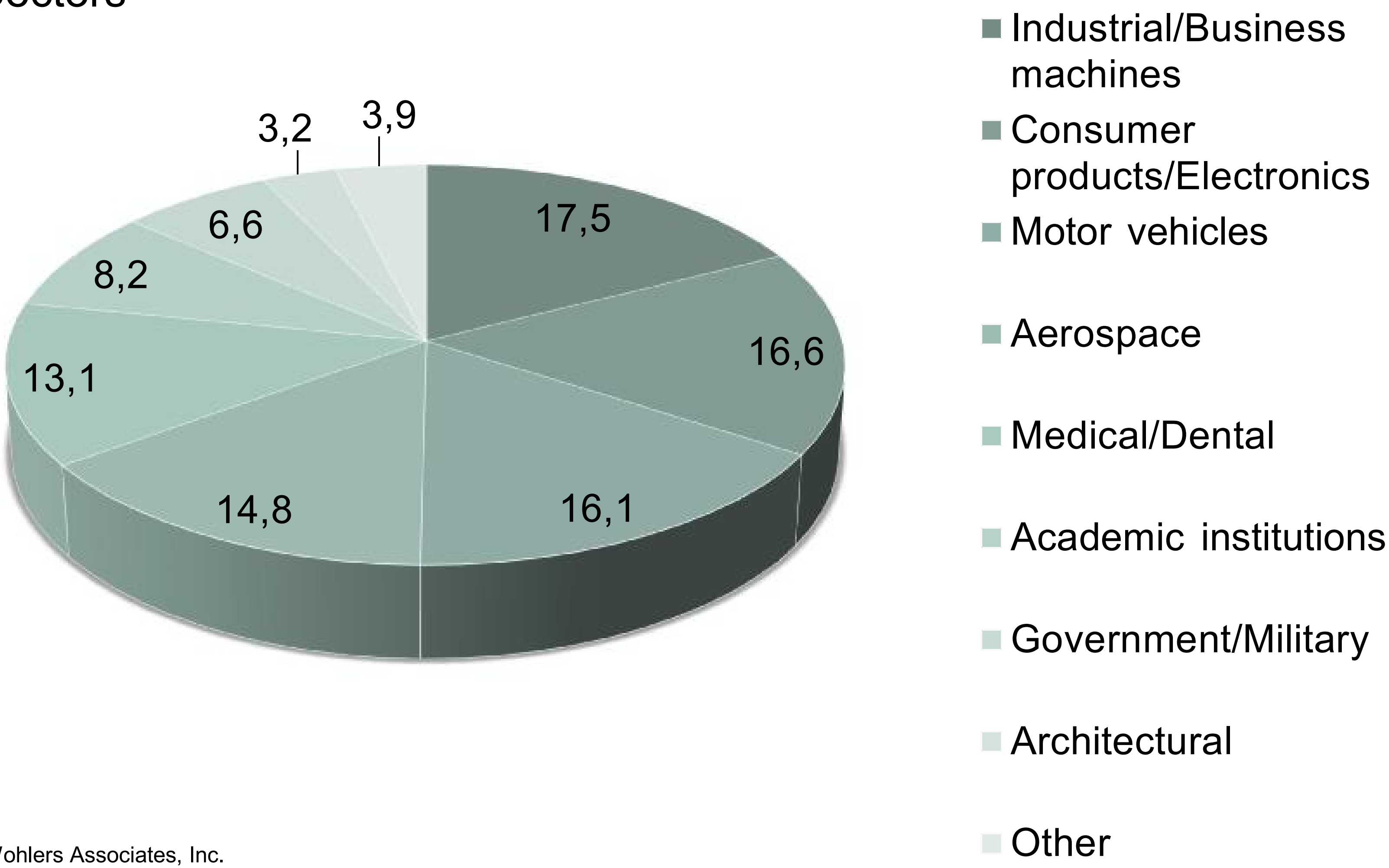
AM Technologies – Comparison

Karlsruhe Institute of Technology

Process	Min. Resolution z-axis [µm]	Min. Resolution xy-axis [µm]	Build Platform [mm]
Fused filament fabrication (FFF)	20	> 250 (depending on nozzle size)	Up to 914 x 610 x 914
Selective laser sintering/melting (SLS/SLSM)	50	200-300	Up to 800 x 400 x 500
Stereolithography (SLA)	20	150	Up to 2100 x 700 x 800
Inkjet/Multijet printing	16	100-200	Up to 1000 x 800 x 500

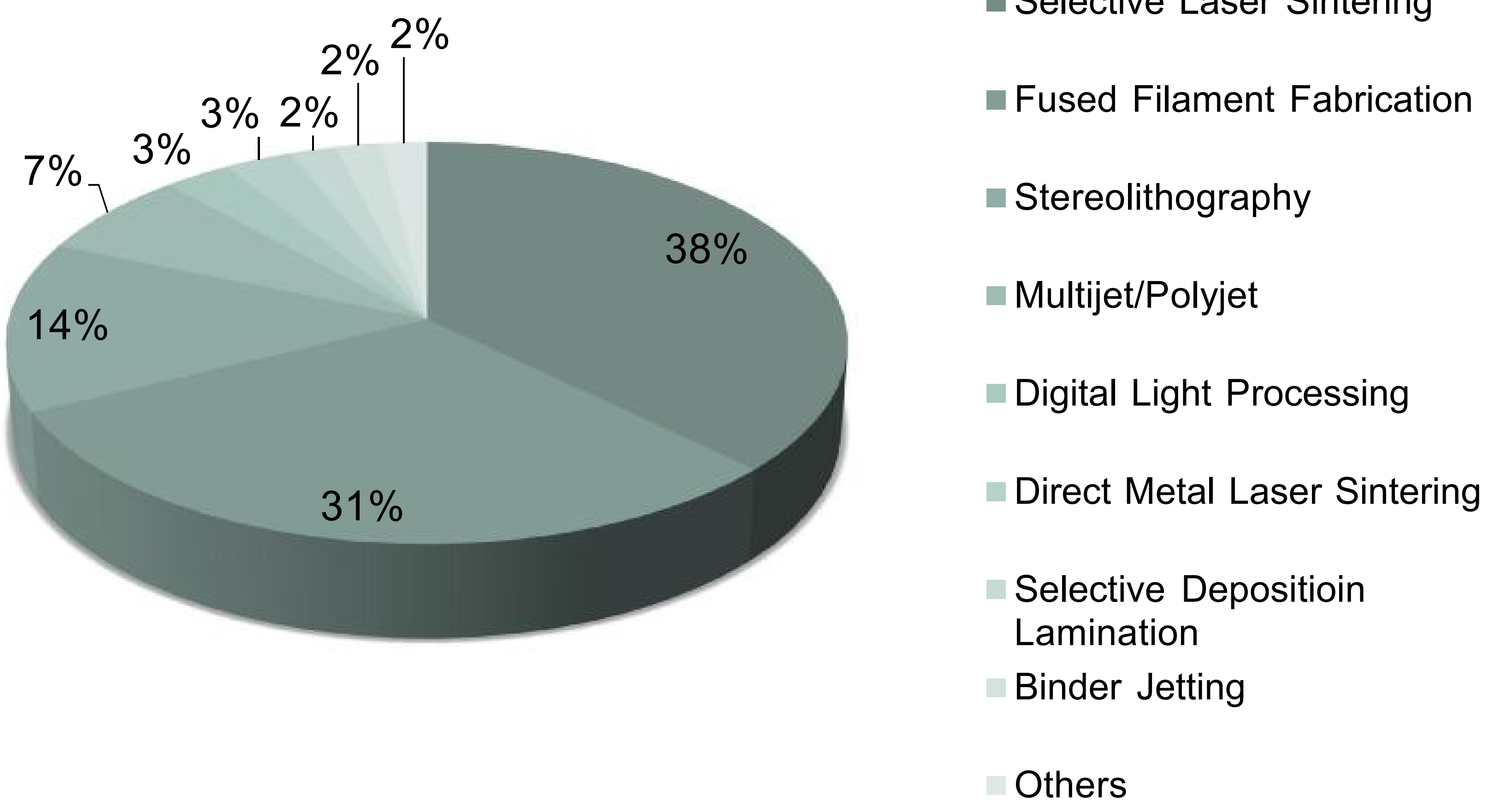
Market status - Sectors

- Sectors



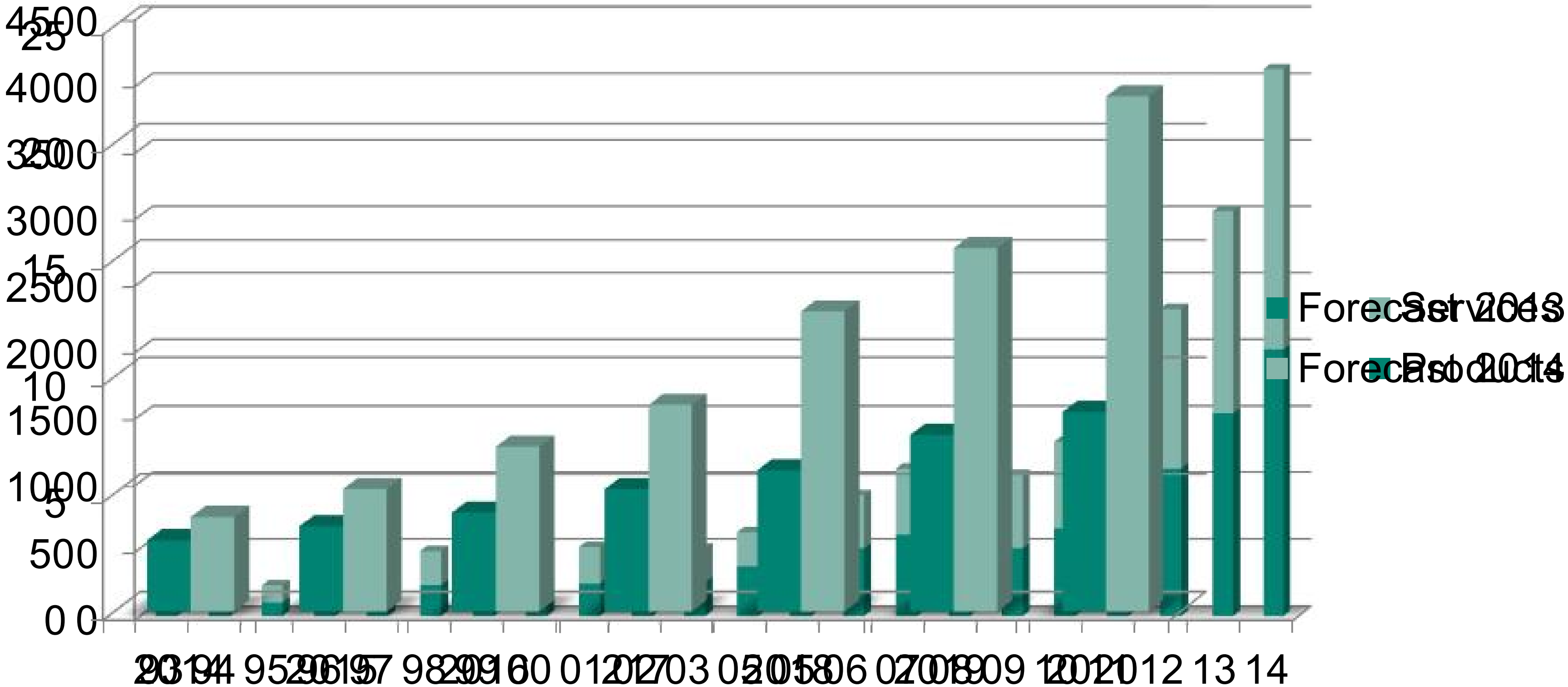
Source: Wohlers Associates, Inc.

Market status – Materials & Technologies



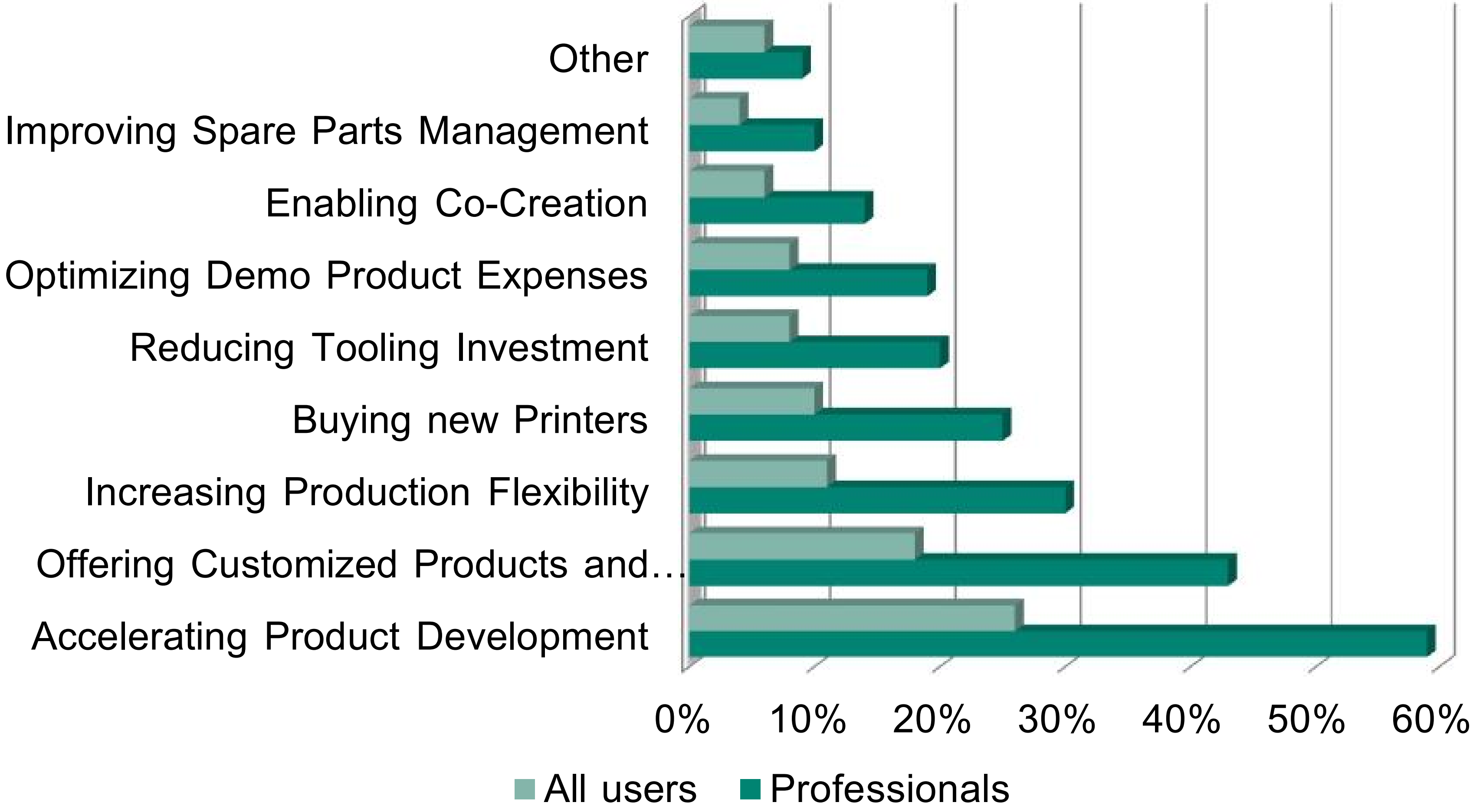
Market status – Past and future

- Average annual growth over past 26 years: 27.3%, over last 5 years: 33,8%
- Current worldwide revenue: 4.103 billion US $, being split between AM products (1.997 Billion) and AM services (2.105 billion)



Source: Wohlers Associates, Inc.

Market status – Priorities for users in 2016



Source: Sculpteo.com „The State of 3D Printing“ 2016 report

Applications – Multi-Material Printing

- Creation of parts with functionally graded materials:
  - Hardness
  - Flexibility
  - Adhesive properties
  - Stiffness
  - Color

Image Courtesy of Kiril Vidimce

Image Courtesy of Synthesis Design + Architecture

Images Courtesy of Massachusetts Institute of Technology

- Possible Applications:
  - Compliant joints
  - Artistic sculptures
  - Heat Dissipation

Image Courtesy of Stratasys Inc.

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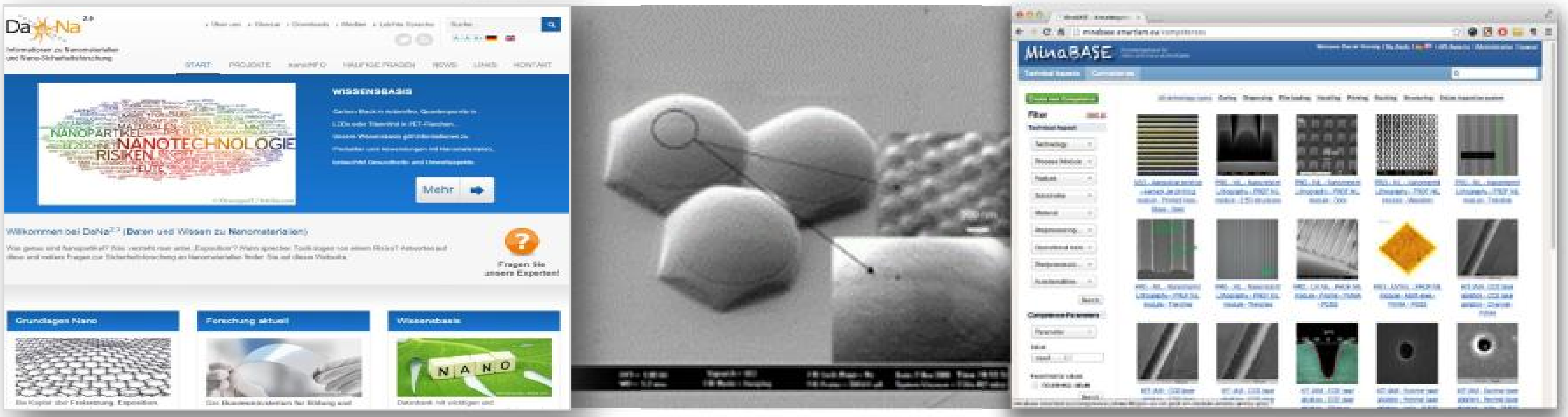
Industry 4.0
an overview

Institute for Applied Computer Science



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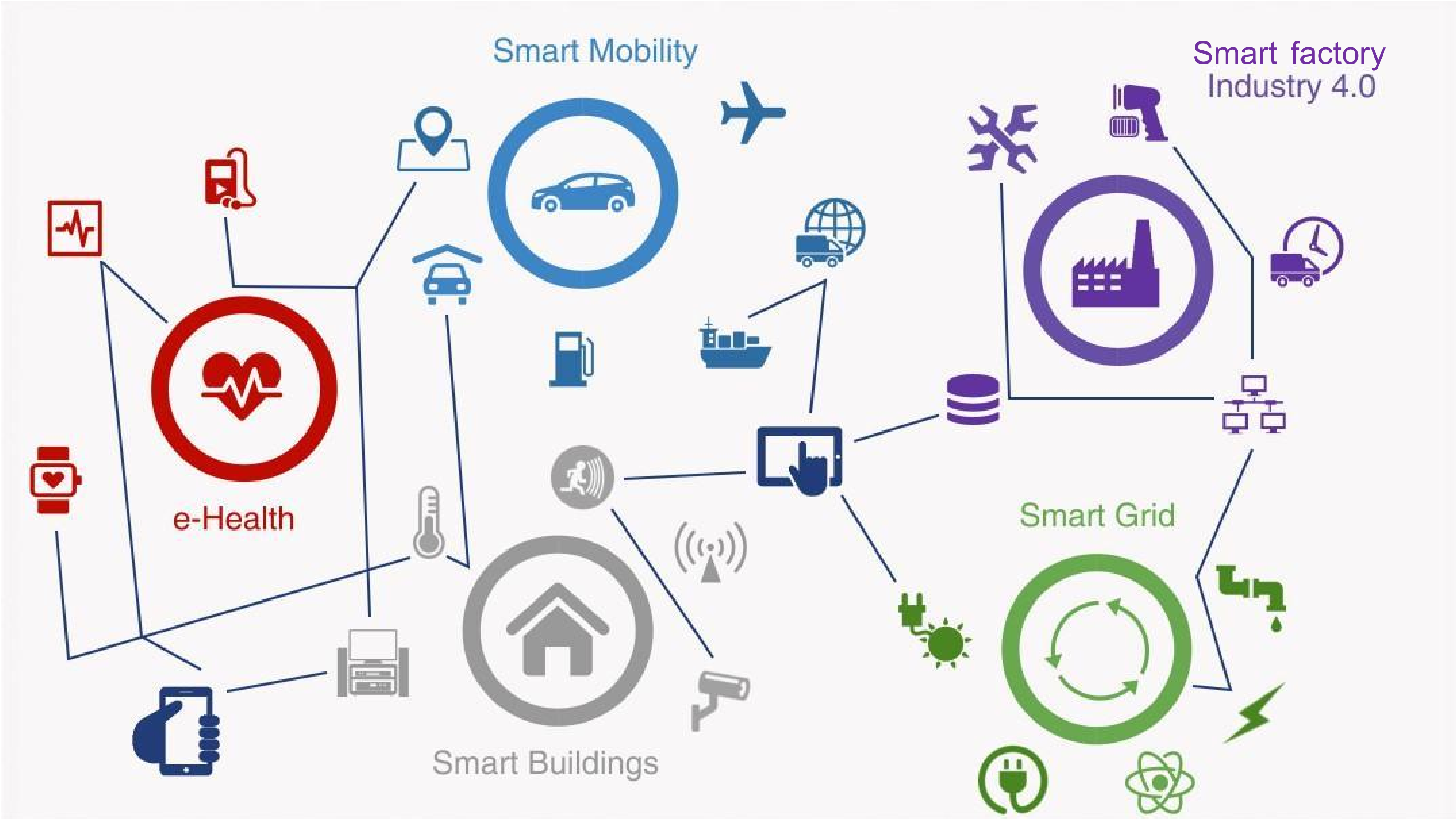
www.kit.edu

Industrie 4.0 The Mission

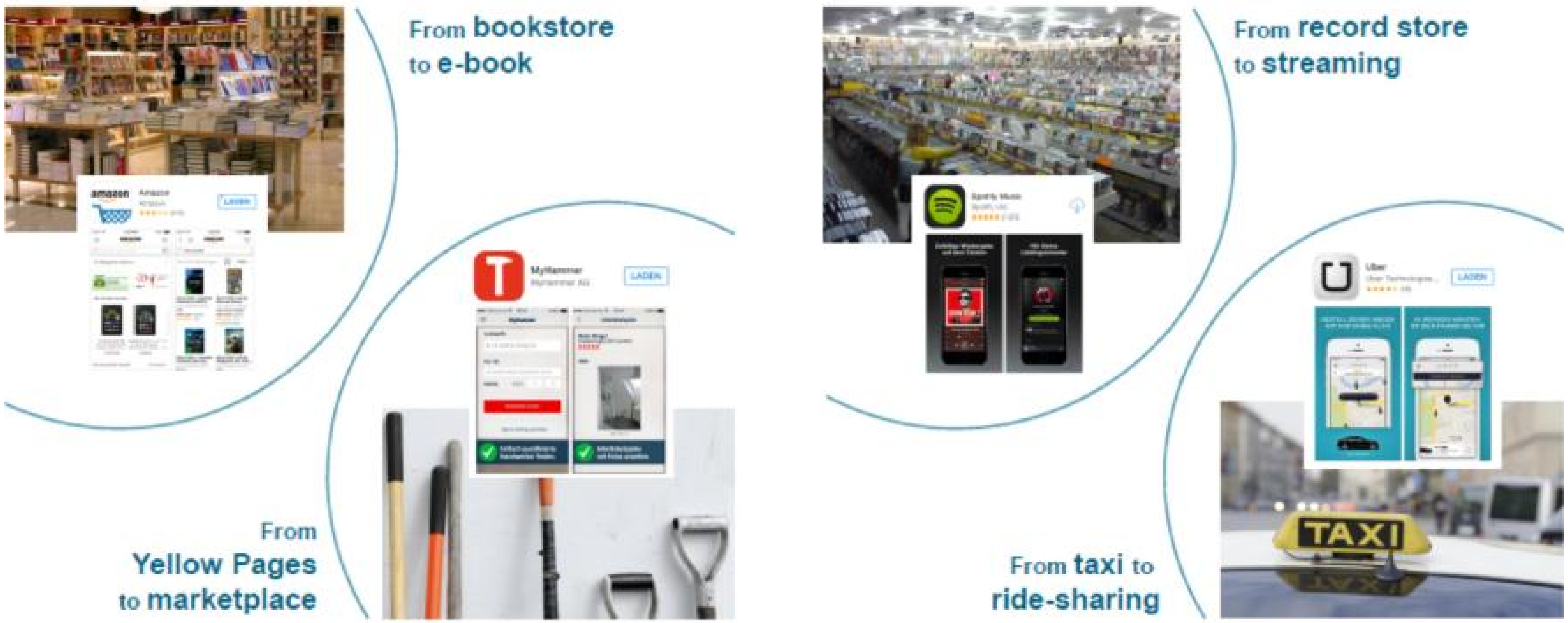
Fourth Industrial Revolution

The domains of the IoT



Source: Bosch

The Internet of Thing



Source: Siemens

The Human in the Centre…


Self organised and distributed artificial intelligence
Fast and automatic network integration , highly flexible
Open standards
Virtual real-time image
Digital integrated life-cycle-management
Safe and secure added-value networks
Humans as actors and in the centre
KIT
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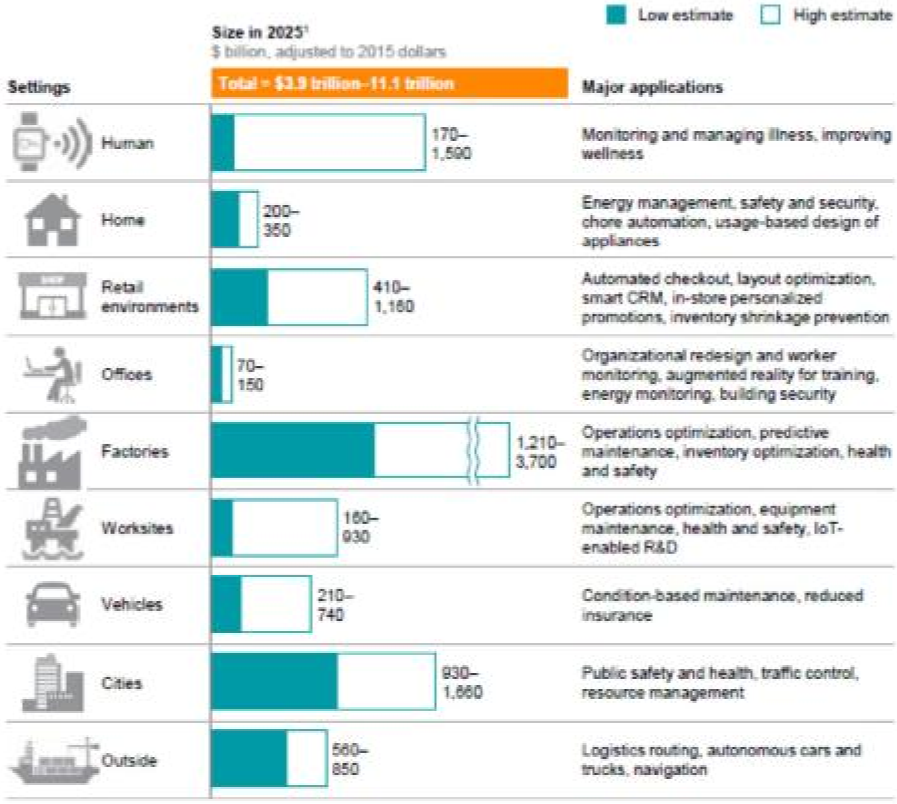
Industry: the biggest market for the IoT

Exhibit E3

Potential economic impact of IoT in 2025, including consumer surplus, is $3.9 trillion to $11.1 trillion

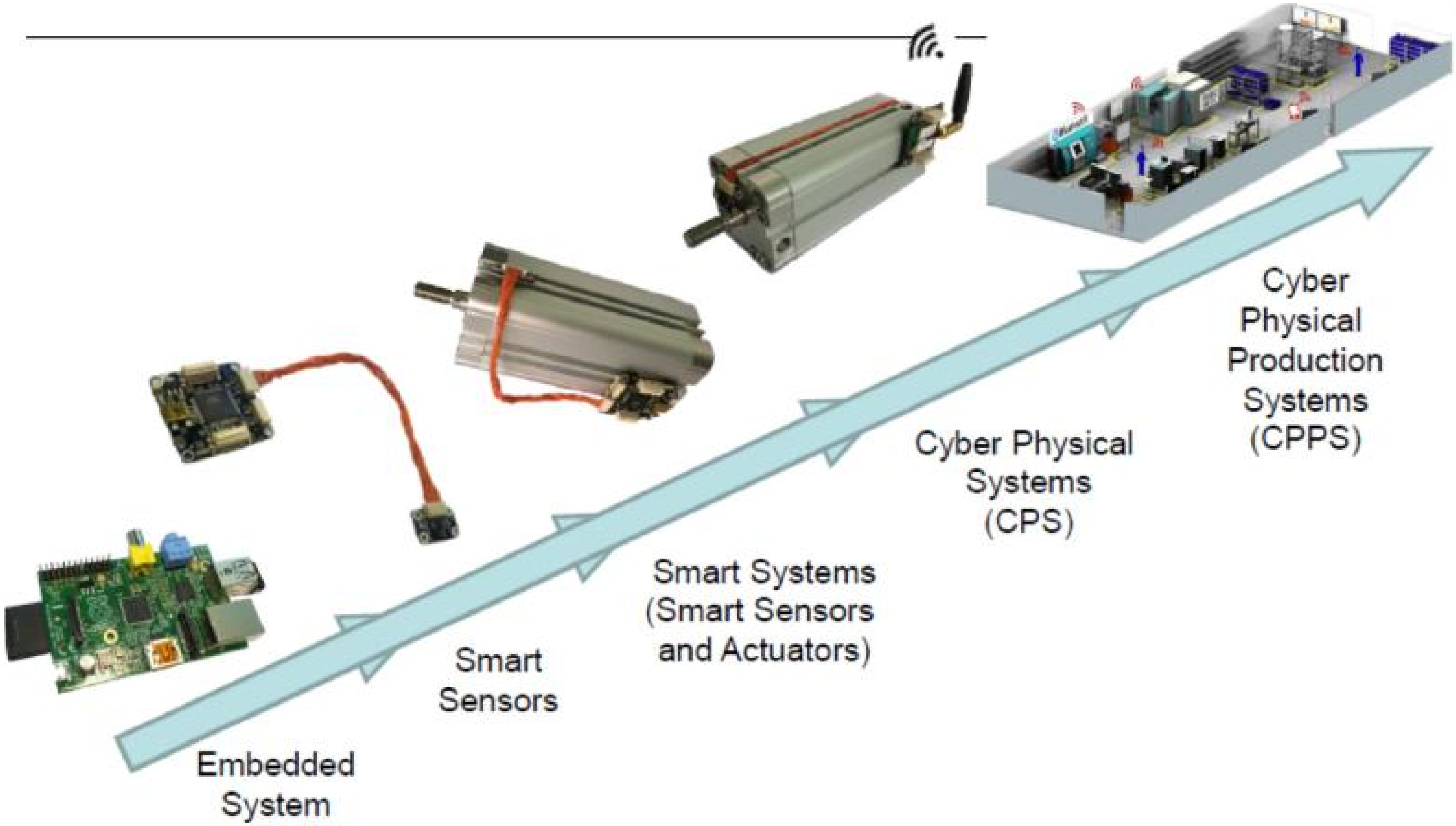


1 Includes sized applications only.
NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

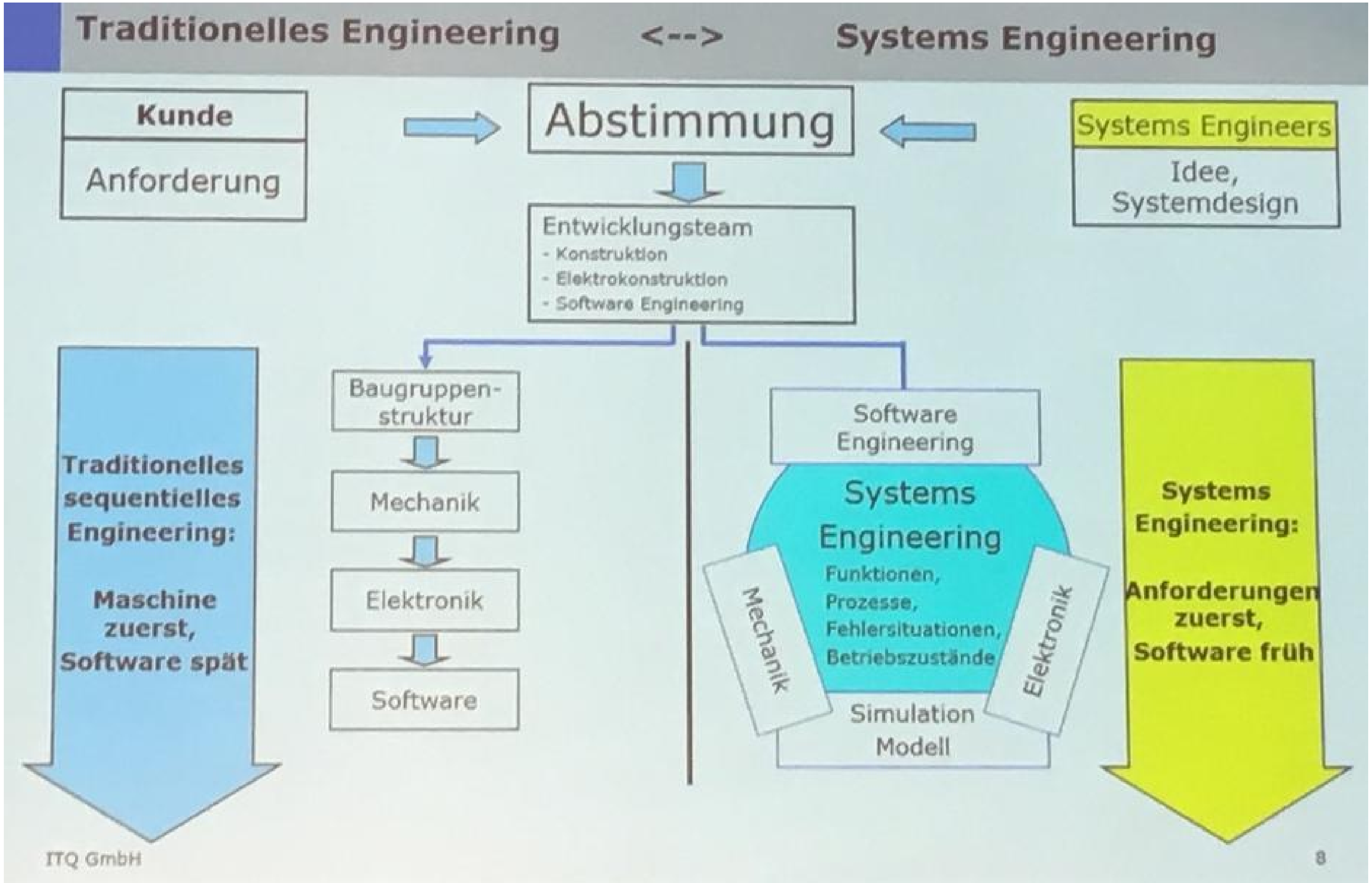
Source: McKinsey

Embedded System enabling CPS and CPPS



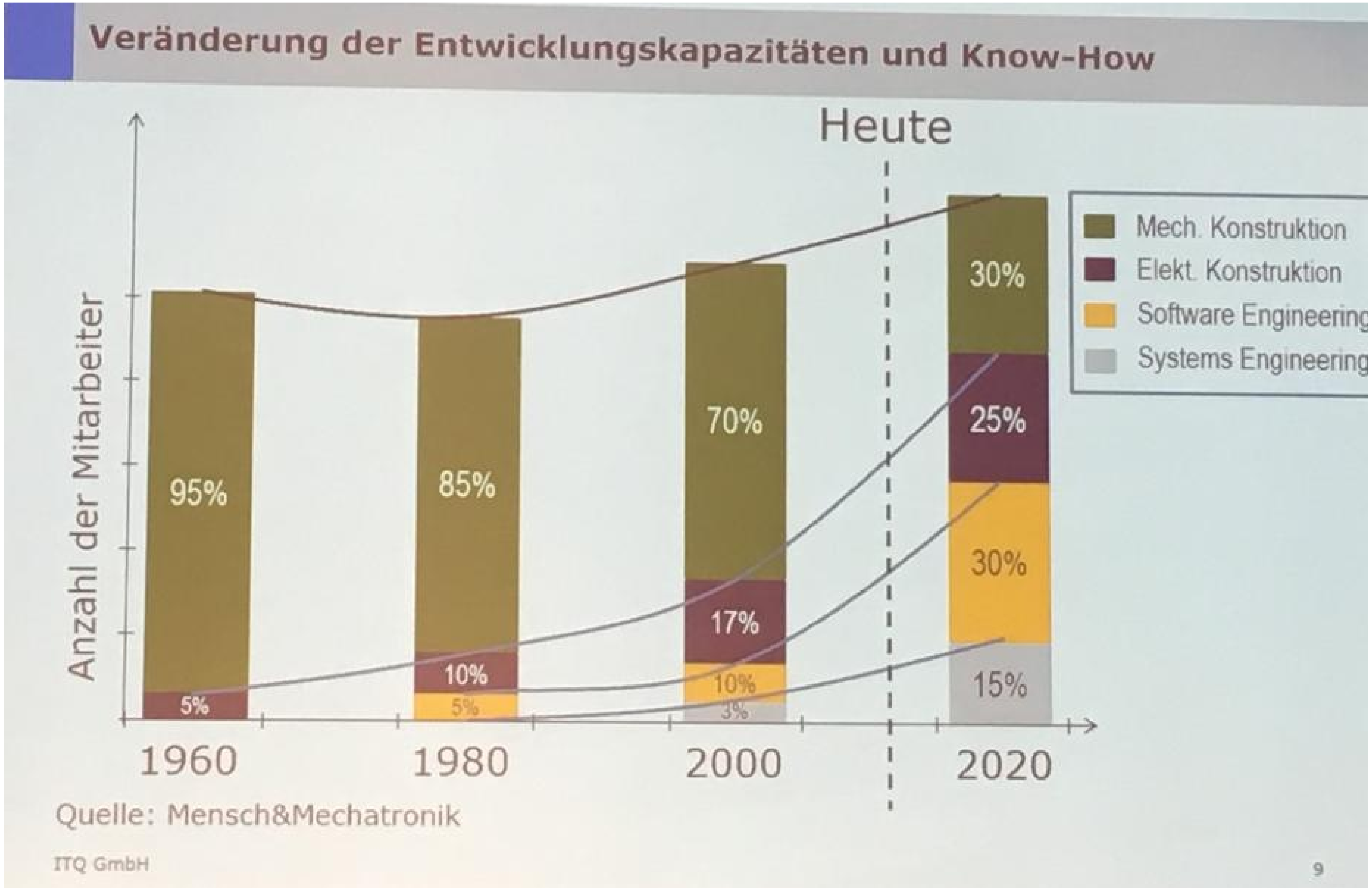
Opportunities and Challenges

Changes in the way of working



Source: ITQ

Changes in the way of working



R&D – Project Examples

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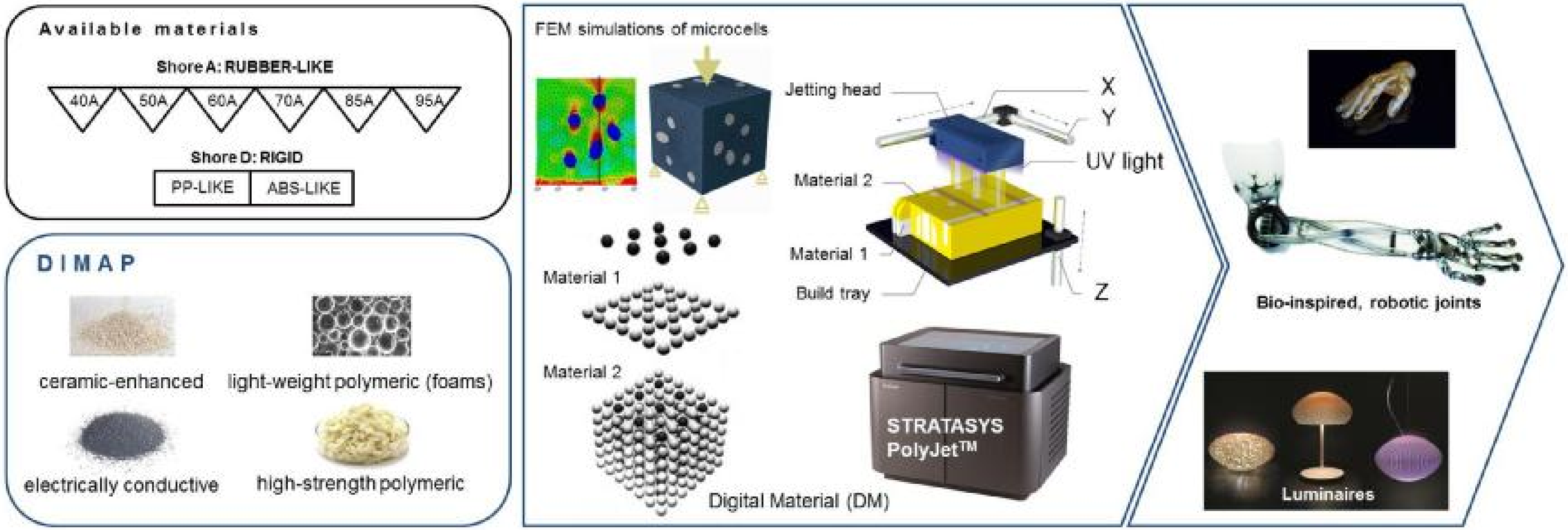


- Multijet printing of novel materials
  - Material development
  - Process development
  - Nano-Safety Management

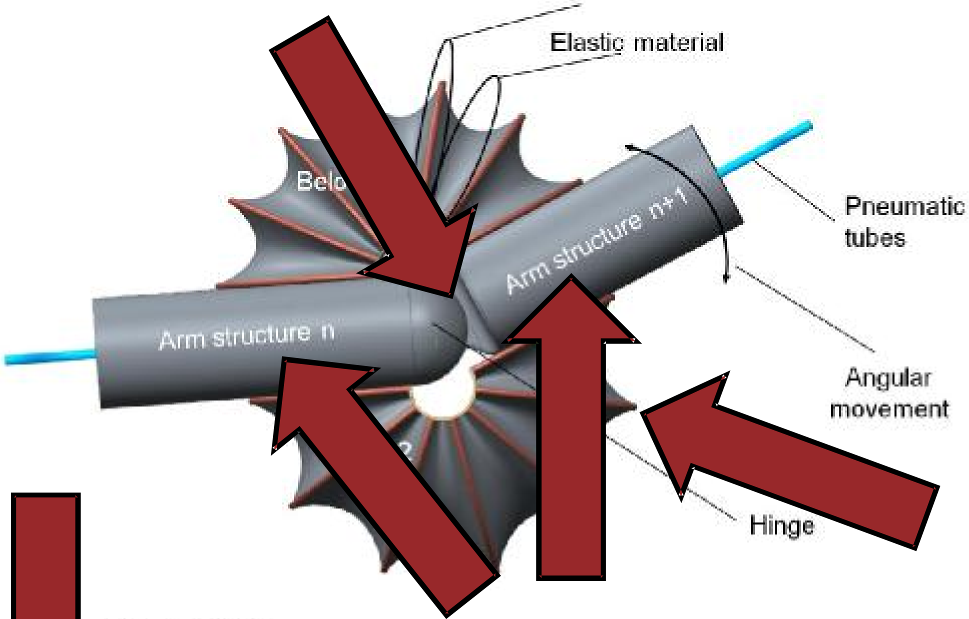
DiMAP
DIGITAL MATERIALS FOR 3D PRINTING

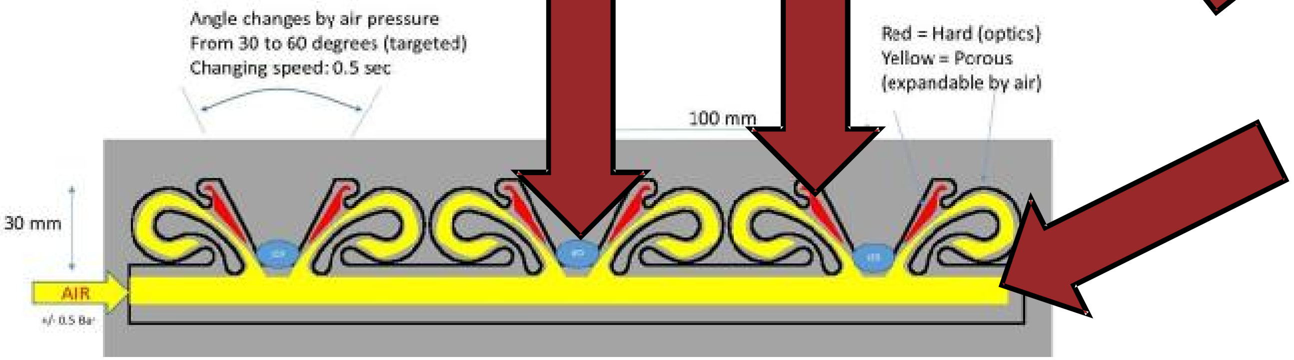
R&D – Project Examples

Karlsruhe Institute of Technology

Material development

- Ceramic enhanced material
- Lightweight polymer material
- High strength polymer material
- Electrically conductive material





DiMAP
DIGITAL MATERIALS FOR 3D PRINTING

Additive Manufacturing

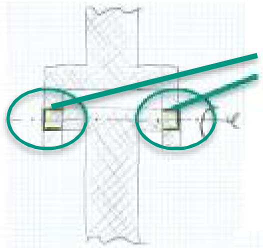
DIMAP DIGITAL MATERIALS FOR 3D PRINTING

KIT Karlsruhe Institute of Technology

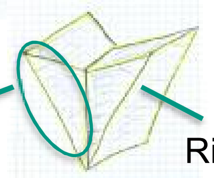
Example: Robotic Arm

- Mechanical requirements:

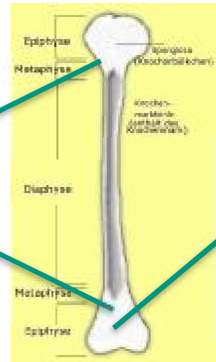
  Hinge: max. tensile modulus and tensile strength (ceramics)



  Bellow: elastic folds in combination of high strength polymeric materials



  Arm structure: high strength polymeric material (shell structure) in combination of lightweight polymeric materials (hard foams) (max density 20Kg/m^3)



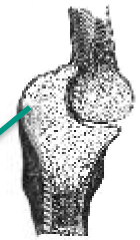


Image Courtesy of FESTO

- Thermal requirements: min. *115°C*

- Electrical properties: max. *10μΩ/cm,* 24V, low current

R&D – Project Examples

Material development

- Ceramic enhanced material
- Lightweight polymer material
- High strength polymer material
- Electrically conductive material

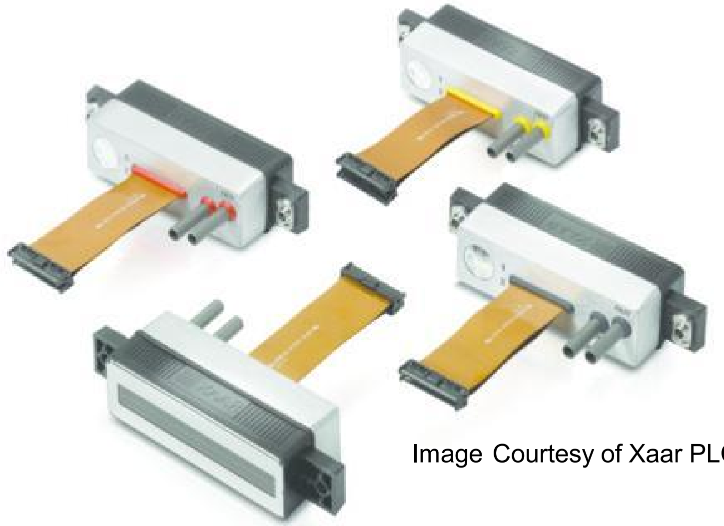
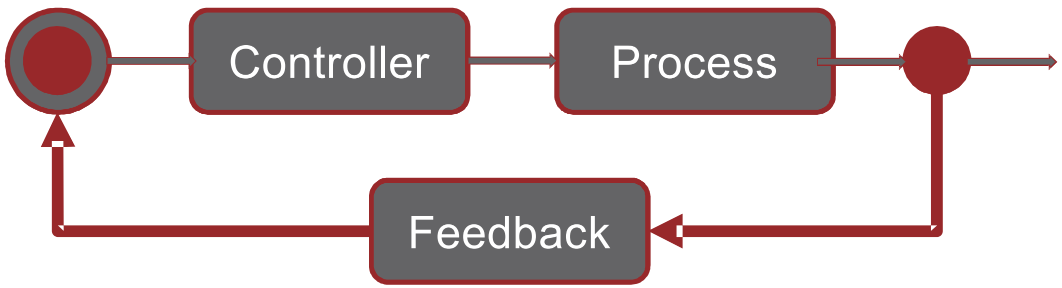


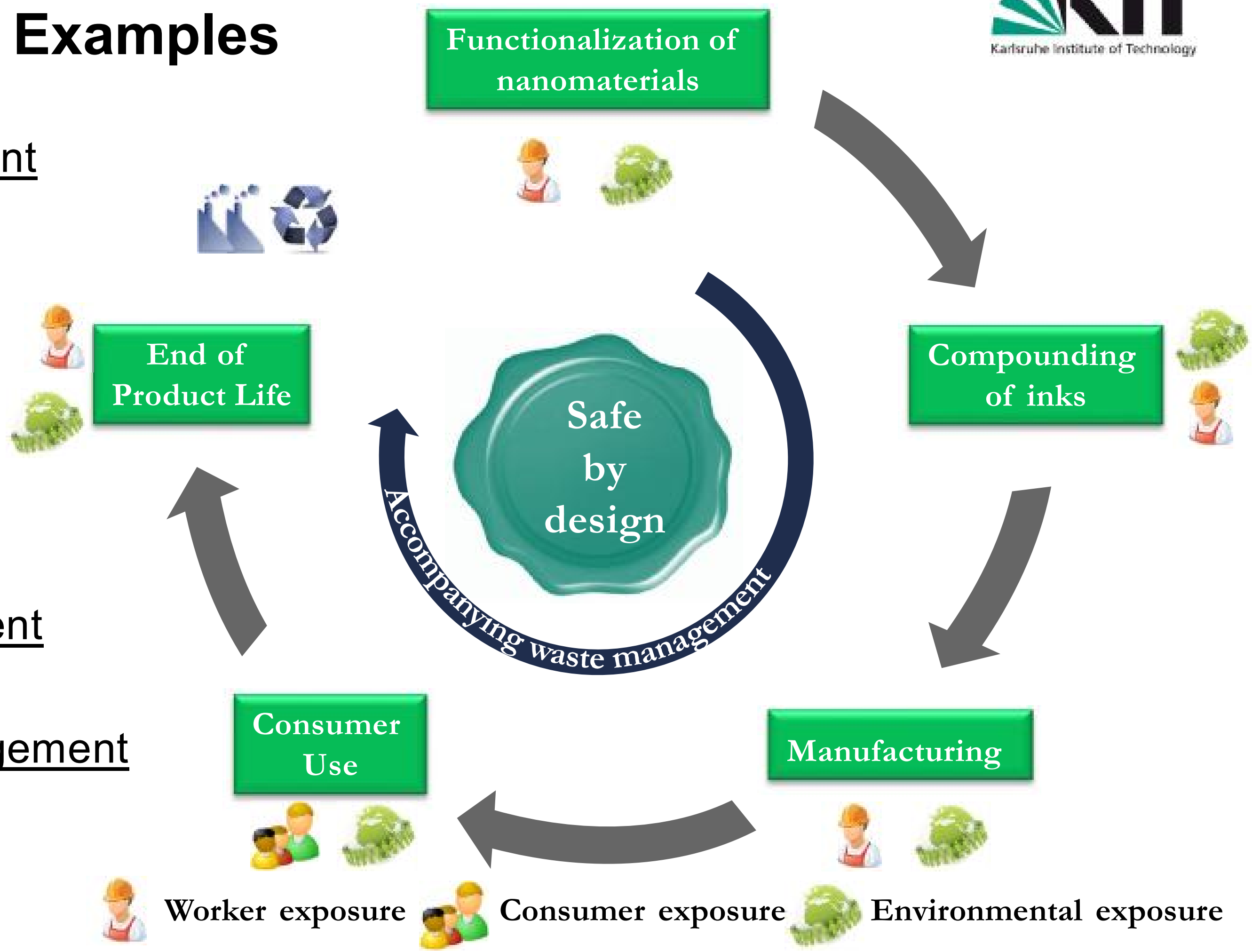
Image Courtesy of Xaar PLC

Process development



DIGITAL MATERIALS FOR 3D PRINTING

R&D – Project Examples



Material development

Process development

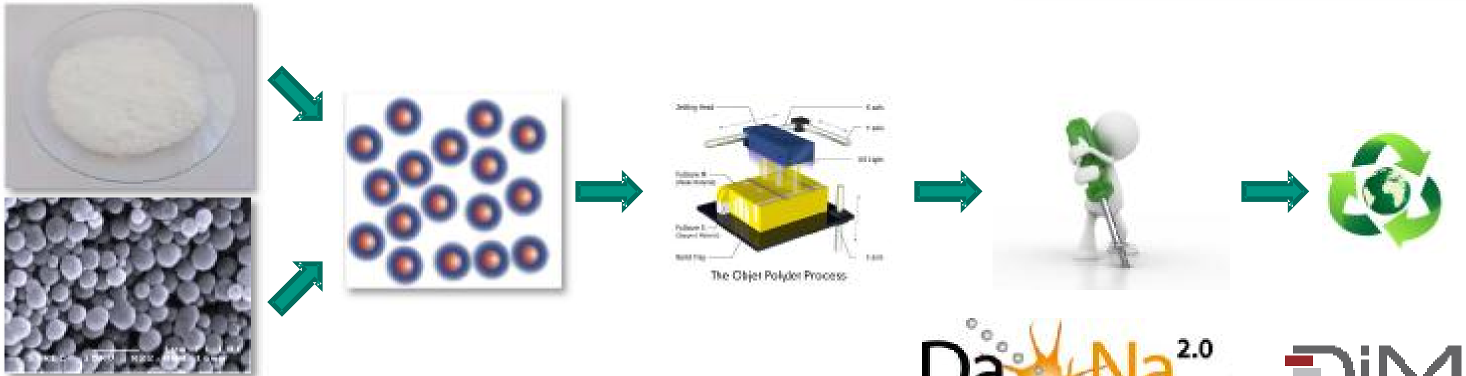
Nano-Safety Management

DIGITAL MATERIALS FOR 3D PRINTING

Nano Safety

- Nano materials in science and consumer environment
  - Database for public information
  - Collection of relevant scientific findings

- Ink development for additive manufacturing
  - Workplace and consumer safety
  - Assessment of production & daily use risks



Additive Manufacturing

Conductive ink

Classic:

- Screen Printing and Photolithography

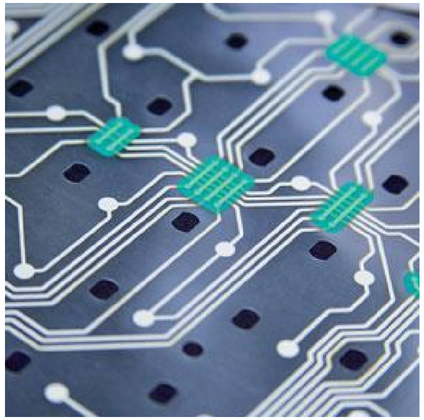
3D Printing:

- No material yet available

-> Polymer with silver nanoparticle

-> concurrent properties:

  - Low Viscosity
  - Low resistivity (High metal content)
  - Surface tension
  - Small non agglomerate particles



Parameter	Requirement	Description
Solids %	≤50% w/w (as starting points)	
Particle size	D(50) = 75-90 nm d(90) = 95-130 nm	
Viscosity	12-20cP at printing temperature (<60°C)	It is not recommended to heat PVN inks above 60°C
Surface tension	25-35 dyn/cm	
Stability test at room temperature (1 month) (Shelf life test)	Viscosity change ≤5% Particle size change ≤5%	Re-dispersible by mild shaking
Stability test at 60°C (8, 24 hours) (Stability during printing time)	Viscosity change ≤5% Particle size change ≤5%	
Accelerated sedimentation rate	<0.38 μm/sec @T=10% transmission	Tested with Lumisizer centrifuge
Jetting test	Jetting latency > 10min	

Additive Manufacturing

DIGITAL MATERIALS FOR 3D PRINTING

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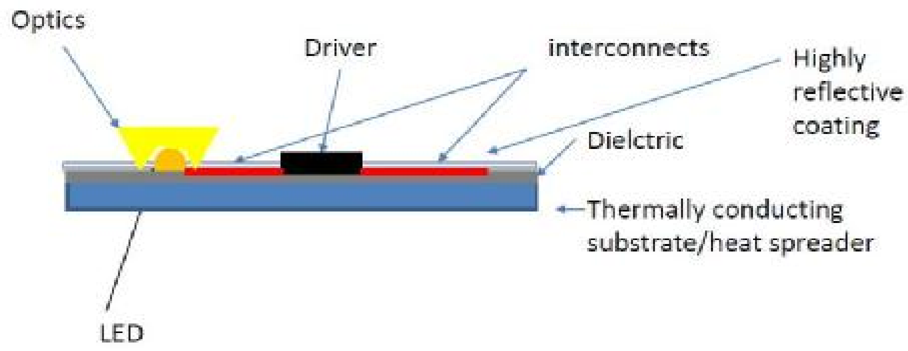
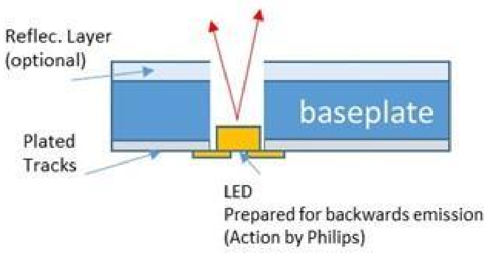
Example: Luminaire PCB design

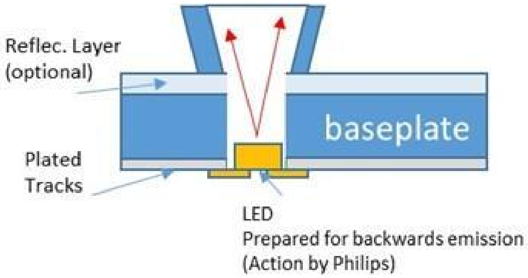


Requirements towards inks:

- Optical
  - Use of Pigments (e.g. TiO_2) as dispersion in the ink-matrix for a high reflectance
- Electrical
  - At least 50% metal particles in the ink
- Thermal (expansion)
  - 10^(-4) to 10^(-5) : original aim = 10^(-6)
  - inks filled with AlN or TiN particles

Design concept (cross section)





Additive Manufacturing

Example: Robotic Arm

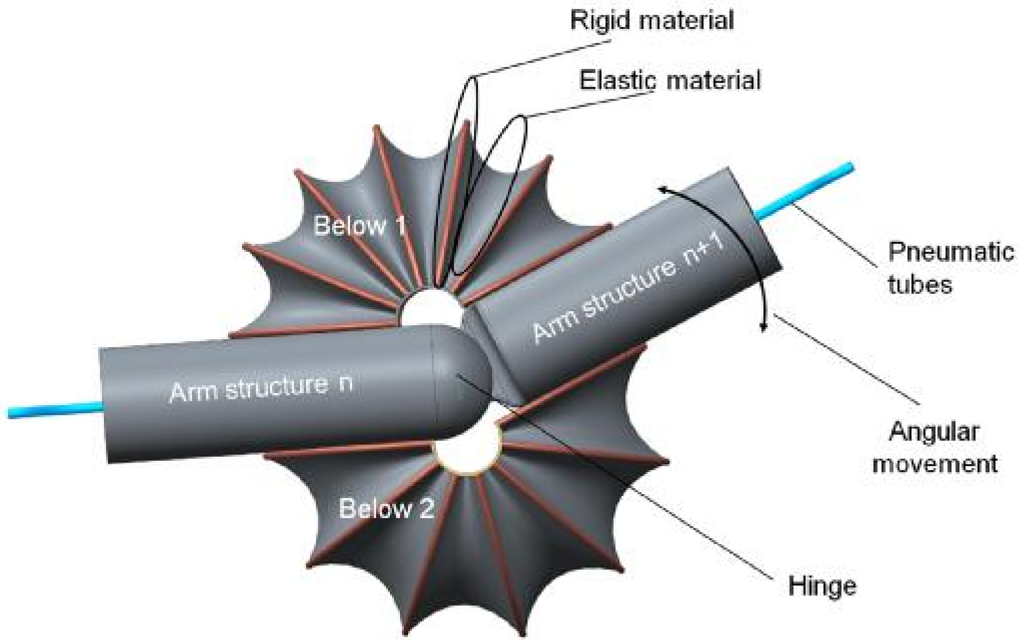
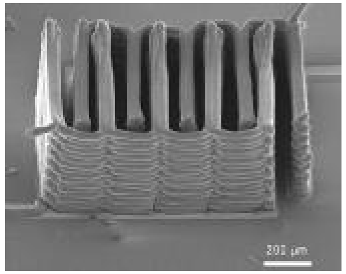


Image Courtesy of FESTO

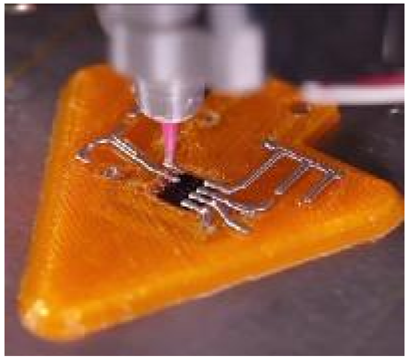
Printed electronics

The use of conductive materials already allow the production of:

- Circuit (inclusive passive electronic elements)
- 3D antenna
- Sensors (Magnetic, force, resistance strain gauge)
- Batteries
- OLED-Displays/ lighting
- Etc.



Source: Harvard University



Source: Voxel8

Source: Neotech AMT

Source: isorg

Possible application domain:

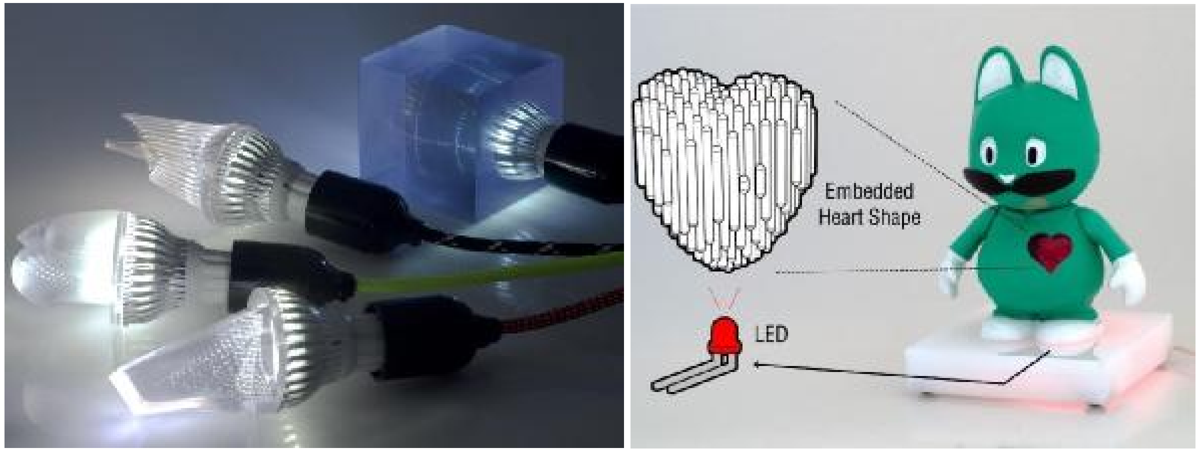
- Communication mobile
- Medical
- Consumer good

Source: Harvard University

Printed electronics - Research

Through layer construction, objects could have embedded features such as:

- Circuit
- Sensors
- Display
- Etc.



Bildquelle: Disney Research

Bildquelle: Berkeley University

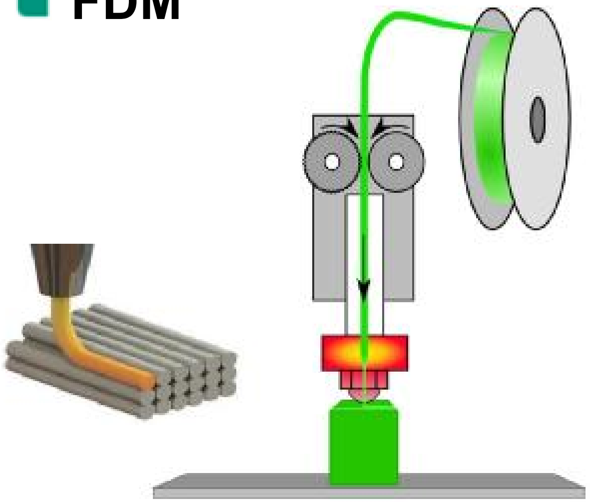
Bildquelle: Disney Research

Possible application:

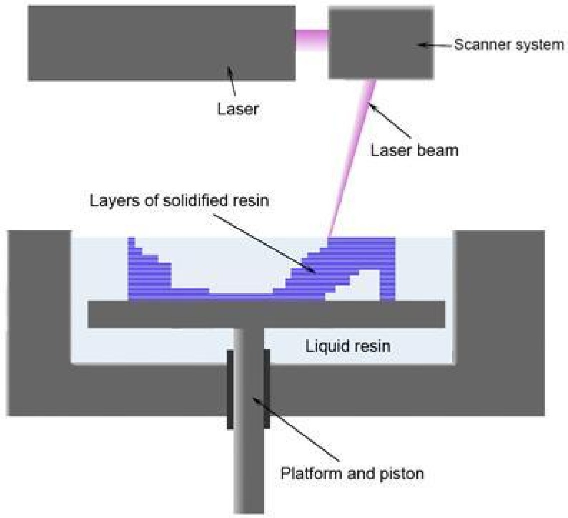
- Game
- Lighting device
- Food monitors

Additive Manufacturing

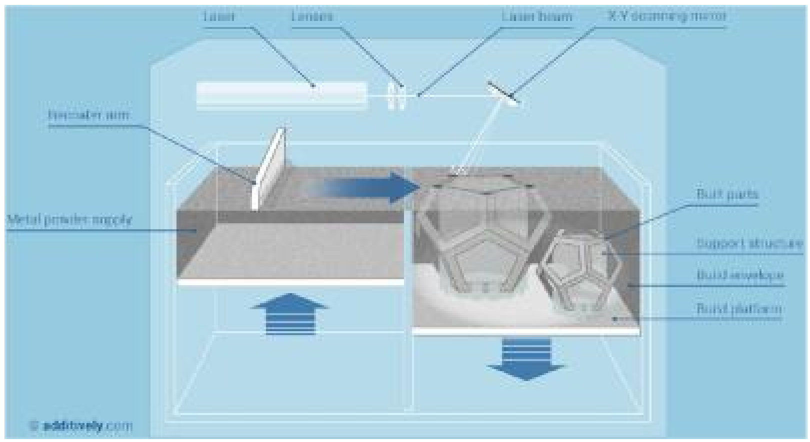
FDM



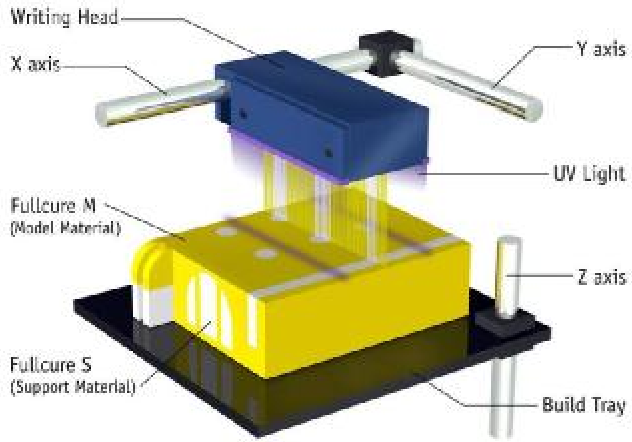
SLA



SLM



Inkjet



Additive manufacturing

Processes & Materials for customized / small scale production

Improvement of existing manufacturing approaches

- Machine learning / DoE approaches
- Process optimization (machine parameters, path planning)
- Optimization based on multiple criteria (robustness, building speed, preciseness...)
- Application in different areas (i.e. additive manufacturing/laser machining)


Image courtesy of Stratasys

Materials for different AM techniques

- Filled filaments for fused filament fabrication (or FDM™)
- Ceramic or metal enhanced inks for inkjet/multijet printing
- Characterization of materials (viscosity, thermal/electrical properties)


Image courtesy of sculpteo.com

Additional functionality via 3D printing and hybrid process chains

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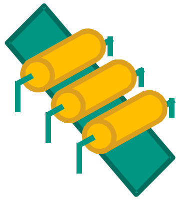
3D Today

Conductive circuit

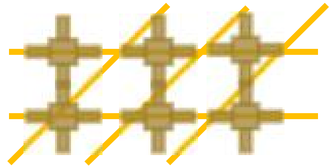
Sensors

2D Today - 3D Future

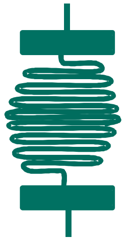
Chip Bonding



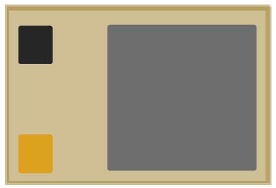
3D interconnects



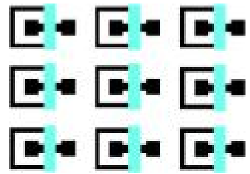
Multilayer circuit



Resistors



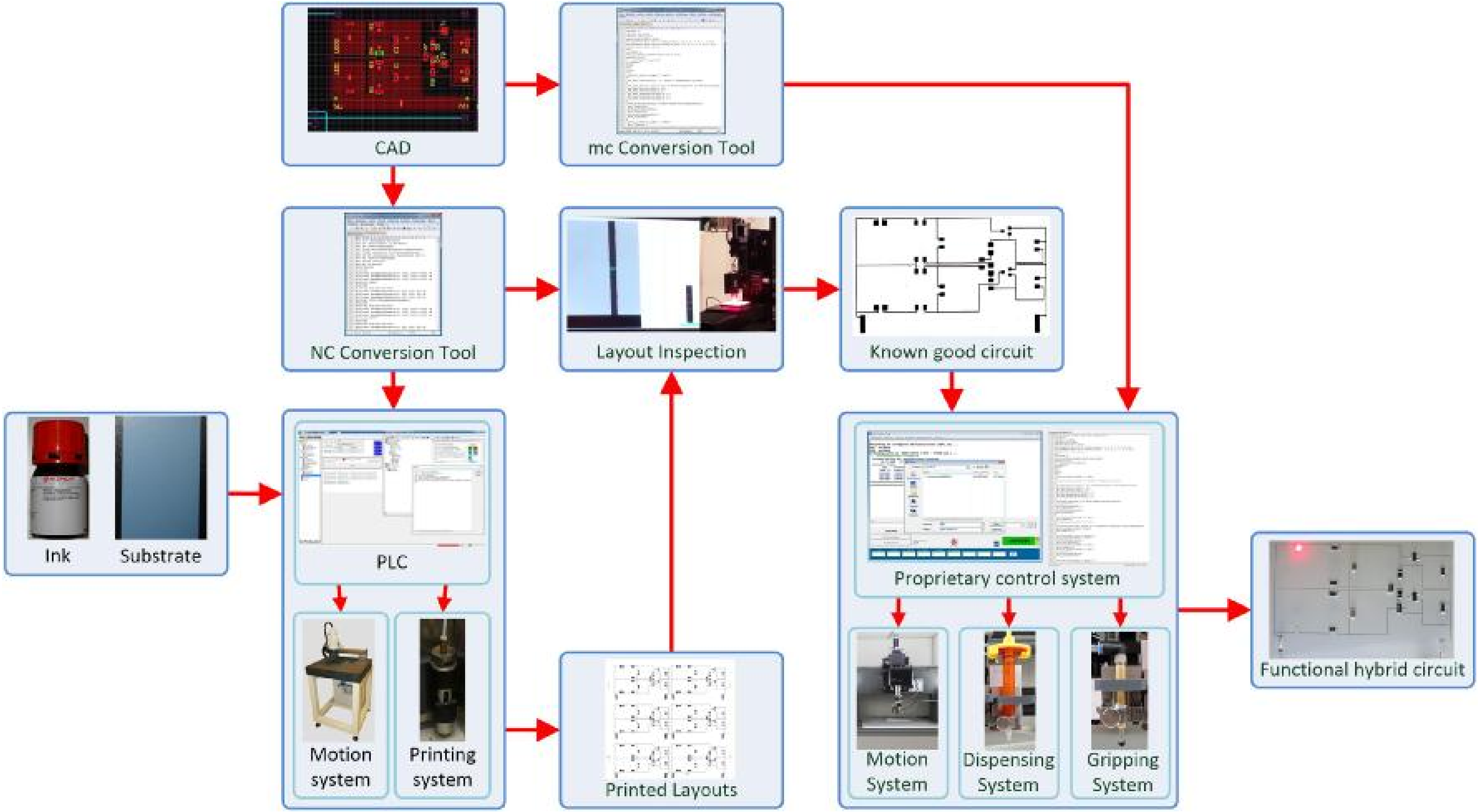
Capacitors



Transistor circuit

Ref: Neotech

Computer-to-Print & digital manufacturing from electrical hybrid circuits



AG Dr. Ulrich Gengenbach

Potential of printing technologies for 3D electronic component

Prototypes

Flexible production (Industry 4.0 concept)

Tailor made and customised production

Shorter time to market

- Flexible und easy to adapt design parameters during prototype development
- Time and cost advantage for mass customised product

Optimised product development

- Design optimisation (lighter and less waste)
  → Cost saving and more environment friendly

More efficient supply chain

- Stock reduction for electronic components

Wider application spectrum and new application

- Flexible and fine support (Smart Wearable Devices)
- 3D Printing

Diverse challenges for electronic printing

Resolution

- The electronic properties are dependent on resolution

Producibility

- Geometry requirement
- Temperature influence (e.g. during sintering) for the fabrication of multi-material components.
- Material requirements

Introduction of industry standards

- First frameworks are being introduced

Environmental impact

- Recycling challenges for multi-material components
- Use of process gas

Health impact

- Use of nanoparticles, organic solvent, dispersant and further additives

Process optimization, modelling & simulation

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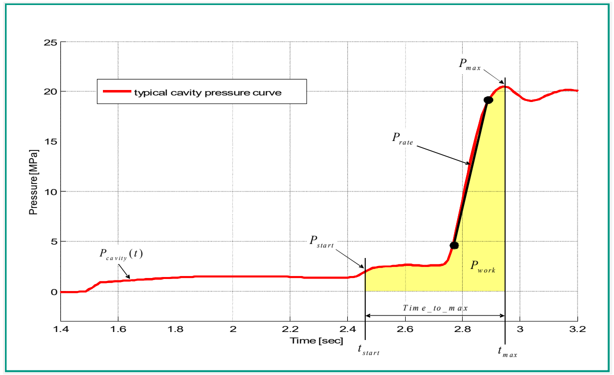
- Optimization of manufacturing parameters by
  - Machine learning / DoE approaches
  - Process modelling, choice of parameters
  - Optimization based on multiple criterias (robustness, tolerances...)

Statistical analysis of parameters

Interaction	P-value				
	F^e_{max}	P^c_{work}	P^i_{work}	P^c_{max}	P^i_{max}
T_m V_i	0.992	0.951	0.963	0.828	0.686
T_m P_h	0.888	0.995	0.871	0.872	0.964
T_b V_i	0.801	0.642	0.882	0.945	0.389
T_b T_m	0.785	0.446	0.935	0.121	0.651
T_b P_h	0.747	0.97	0.678	0.329	0.302
P_h, V_i	0.016	0.045	0.002	0.169	0.027

Characteristic numbers calculated from pressure curves



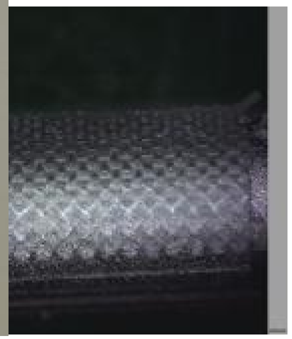
→ Current focus on micro-fabrication techniques and increasingly on additive manufacturing (multijet printing)

HINMICO

DiMAP DIGITAL MATERIALS FOR 3D PRINTING

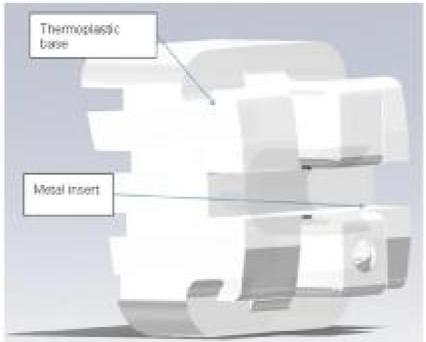
Process optimization, modelling & simulation

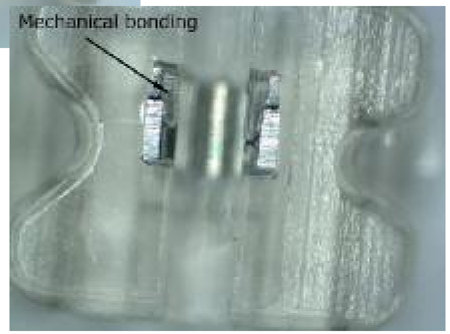
Orthopedic screw with enhanced cell adhesion capability



Process optimization, modelling & simulation

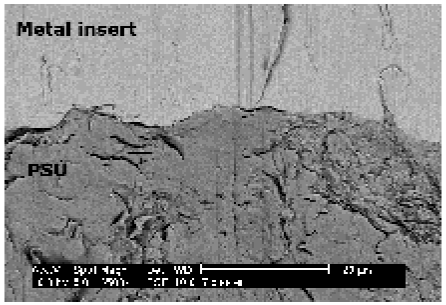
Multi material dental bracket



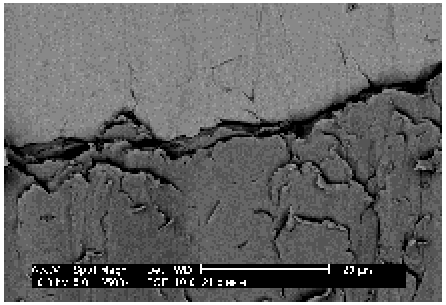


Immersion time in artificial saliva at 60 ºC:

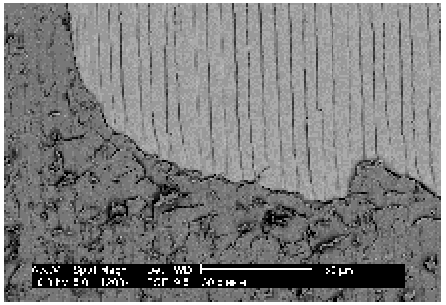
7 days



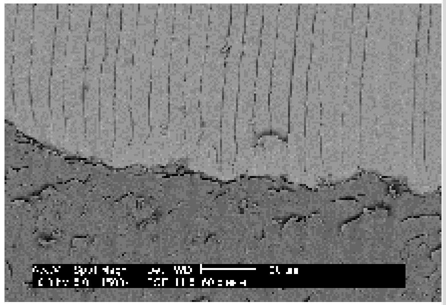
21 days



30 days



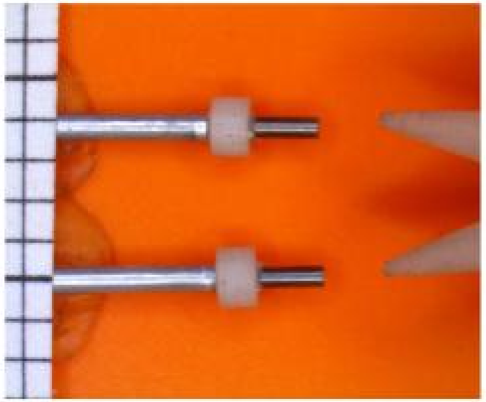
60 days



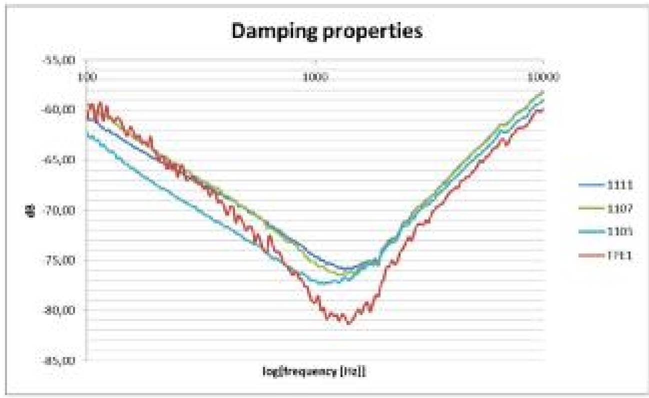
Process optimization, modelling & simulation

Cantilever assembly for HiFi cartridges

Tubes with injected TPE rings in mould



Tubes with injected TPE rings and sprue

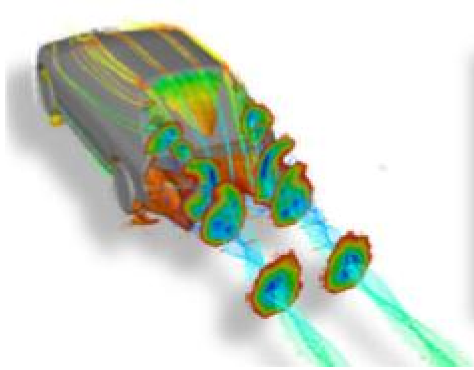


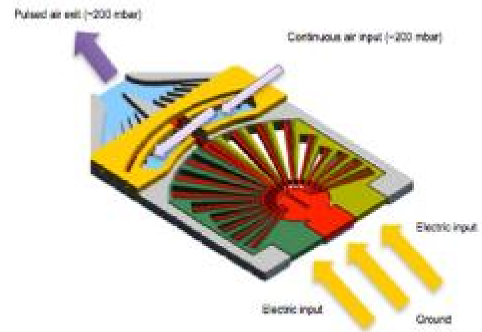
Process optimization, modelling & simulation

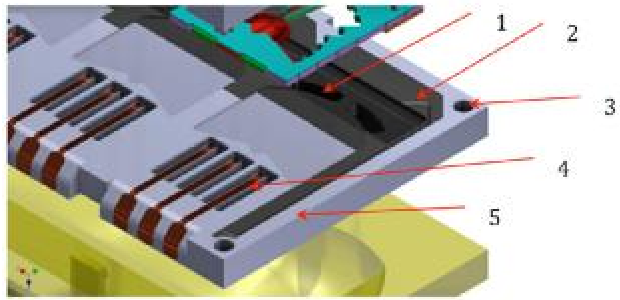
HINMICO
High throughput integration technologies for multimaterial functional Micro COmponents

KIT
Karlsruhe Institute of Technology

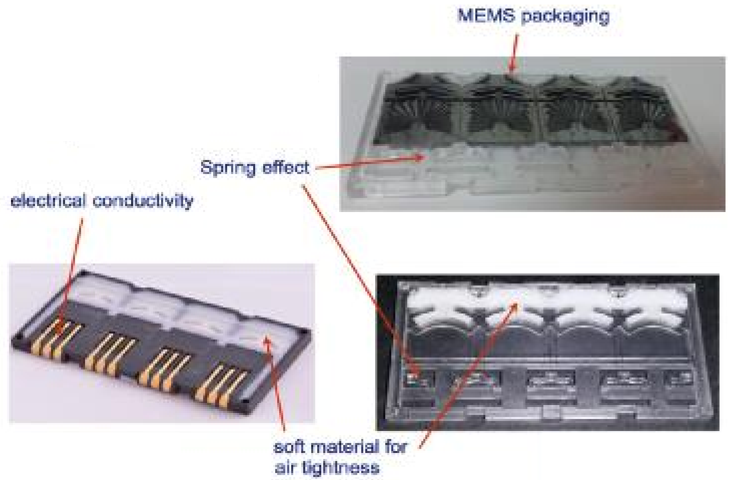
Housing for MEMS actuators







Grey parts are in soft plastic material. Dark parts are in hard plastic material



Process optimization, modelling & simulation

Diplexer for high frequency communication

Conventional machinining

Injection molded (Base)

After metalization

With Lid

Flexible Manufacturing

Modularity concept

Scalable, simple, adaptable system

- Flexible layout of the modules
- Extensible module process

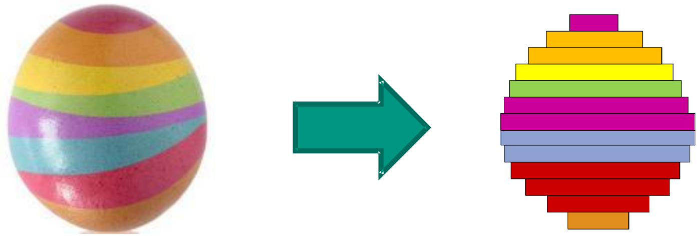
Autonomous, put together process module

- Work piece holder
- Transfer system

… produce complete micro systems in a „Star-trek“-like manner…

Variable Module size

Decentralised production



Design for **traditional** production processes

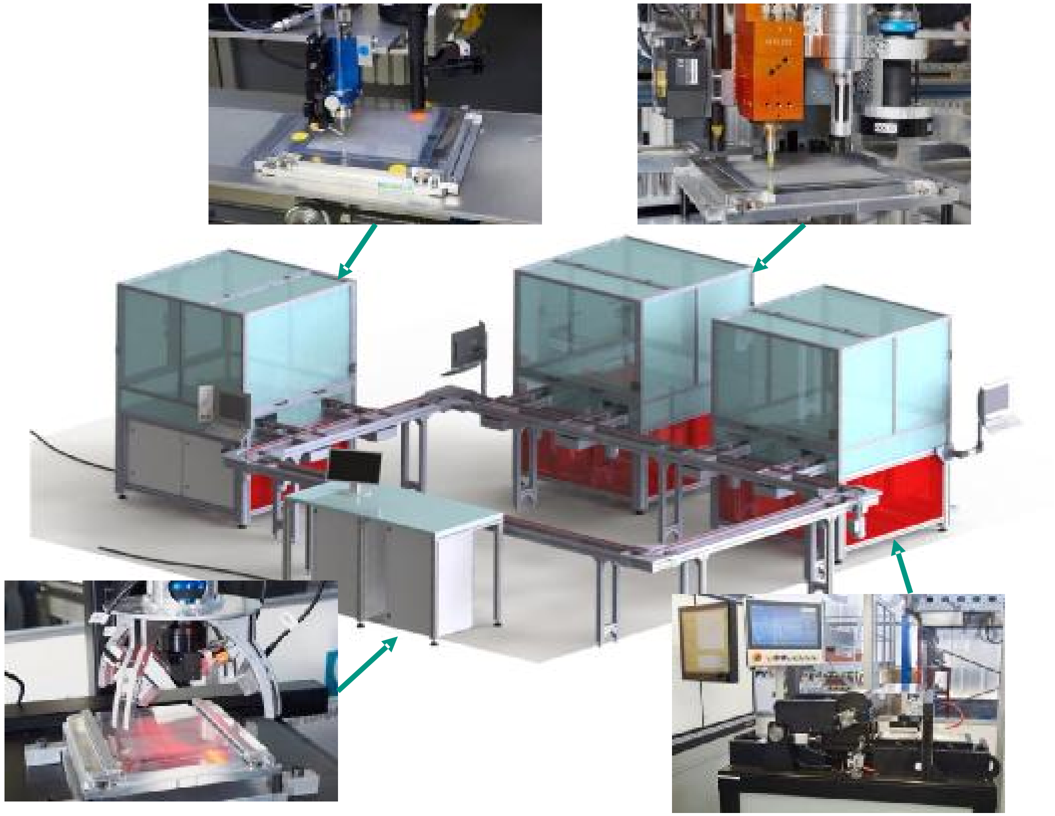
Design for **SmartLAM** production processes

Flexible Manufacturing

SMARTLAM

KIT Karlsruhe Institute of Technology

Modularity concept



- SMARTLAM 6 modules + control unit
  - Lamination
  - Laser welding
  - Laser structuring
  - Printing module (aerosoljet printing)
  - Assembly
  - Inspection
  - \+ Centralised control
  - \+ Supporting databank

Flexible Manufacturing

Application 1 – LED lighting

- Light source embedded into surgical instrument
- Product includes 1. planar light-guide LED chip source, electronic control, switch and power source
- Sealed and to have high hermiticity for medical accreditation.
- Custom size and light specifications for different surgical procedures
- Specification will evolve over time
- Disposable
- Cost/volume critical – e.g. Veterinary market

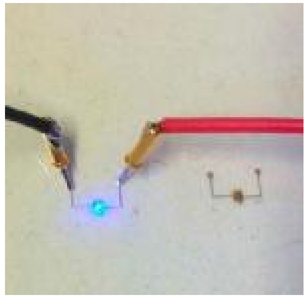
Source: DLED

Flexible Manufacturing

Example of hybrid integration of a LED chip

Functional element :

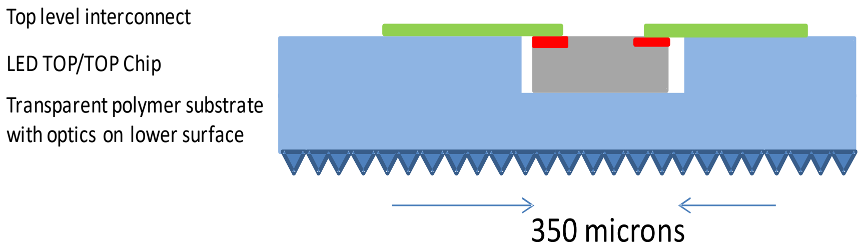
- Integration of independent parts (*Dies*)
- Contacting via printing techniques (*Via´s*)

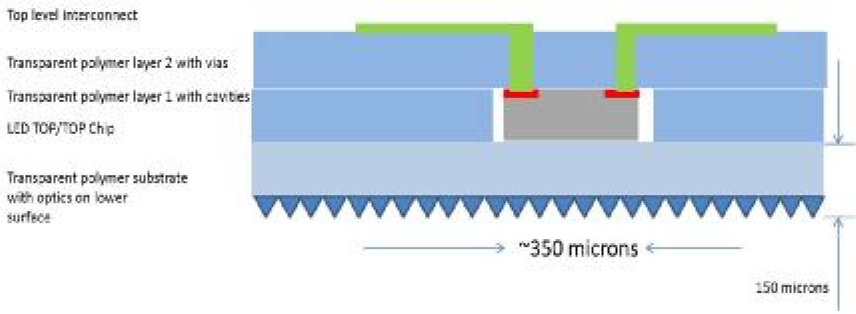


source: Smartlam

Necessary working steps*:*

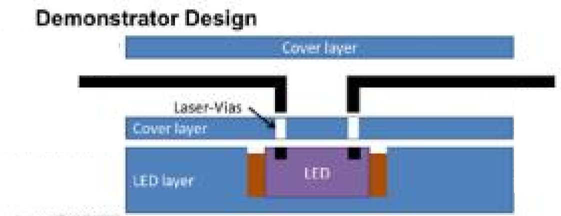
- Laser welding of the pockets
- Positioning and mounting of the *dies*
- Two strategies for contacting after the positioning of the foil.
  - Direct pressure on the filled cavities
  - Addition of top layer, that has been pre-drilled and subsequent filling with ink



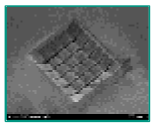
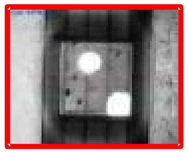


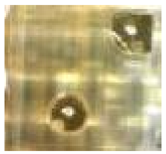
Flexible Manufacturing

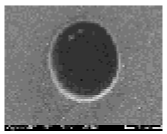
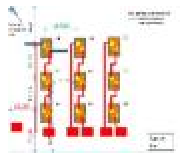
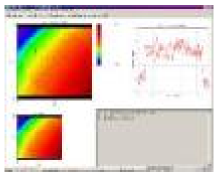
Individual LED module process chain



Milling of pockets → Chip placement → Lamination → Hole drilling → Printing of conductor paths → Sintering → Lamination → Cutting

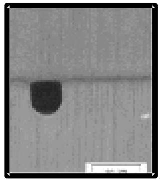







Flexible Manufacturing

Application 2 – Fluidic microchip



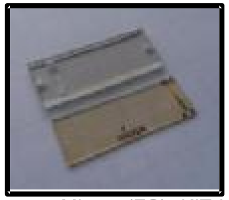
Source: KIT-IAM

Microfluidic components (channels, pockets, trenches)

Example microfludic chip

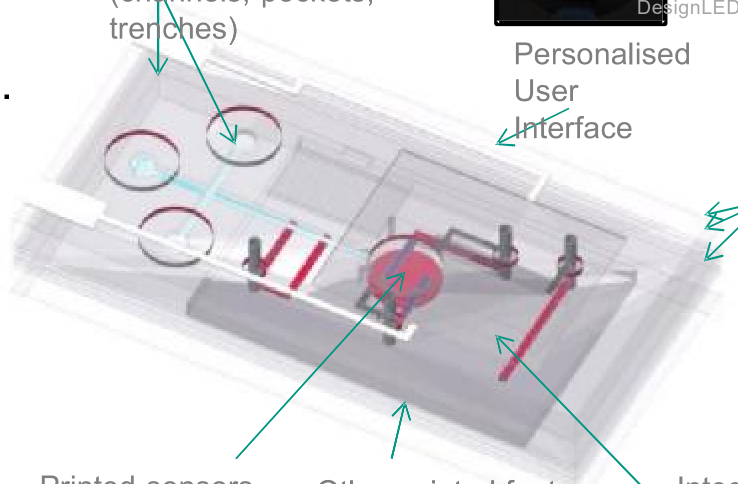
Source: DesignLED (UK)

Personalised User Interface



Source: Micrux (ES), KIT-IAM

2,5D shape based on *multilayers* of function-alised (multimateri al) polymer films



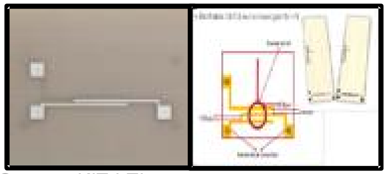
Approach

- The modular design approach consist of *2,5D parts, produced by "digital" manufacturing processes* (e.g. Aerosol Jet Printing, Laser, add. Manufacturing)
- Introduction of a design environment for rule-based combination of features and partly automated production

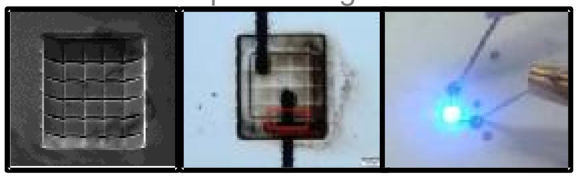
Printed sensors e.g. electrodes for electrophoresis

Other printed features, e.g.batteries

Integration of discrete components, e.g. positioning and



Source: KIT-LTI

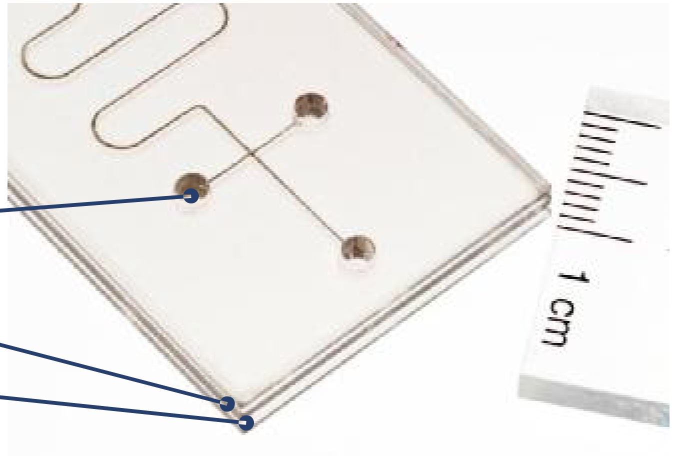


Source: KIT-IAM, KIT-LTI, KIT-IAI

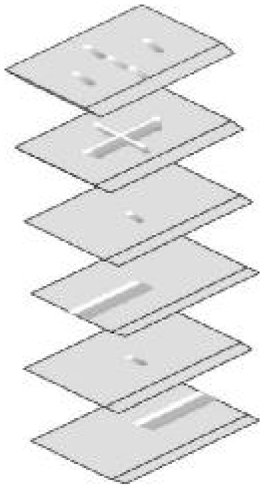
Flexible Manufacturing

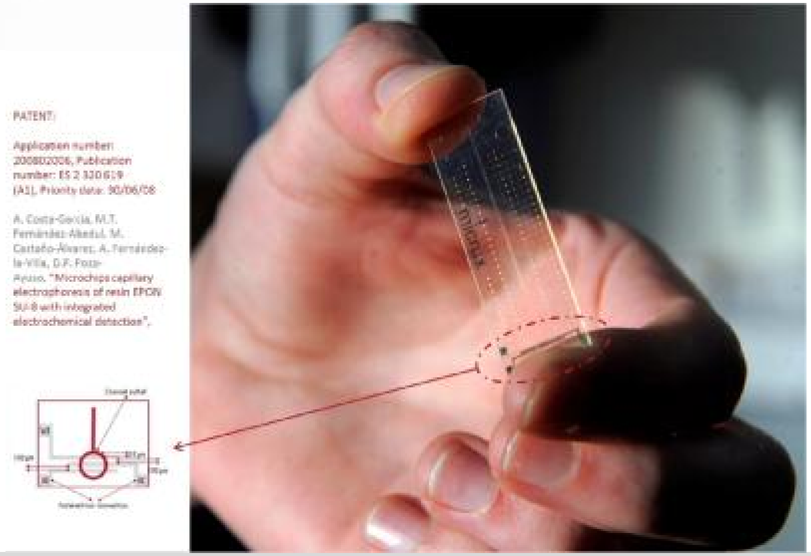
Application 2 – Fluidic microchip

- Fluidic-Chip with 3 polymer sheets:
  - cover with reservoir
  - sheet with channel design
  - base plate



- 3d channel structure with 6 polymer sheets





Flexible Manufacturing

SMARTLAM

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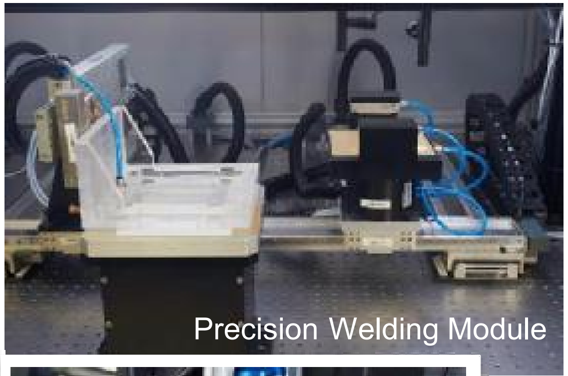
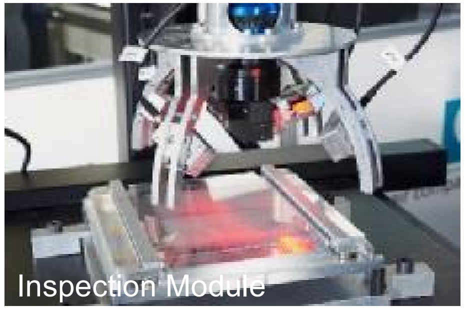
Modules implementation

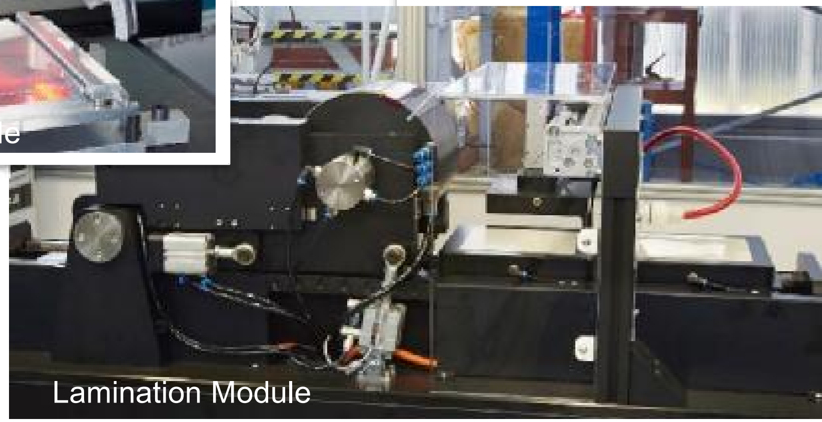

Laser Welding Module


Precision Welding Module


Assembly Module


Aerosol Jet Module


Inspection Module


Lamination Module

INDUSTRY 4.0

SMARTLAM

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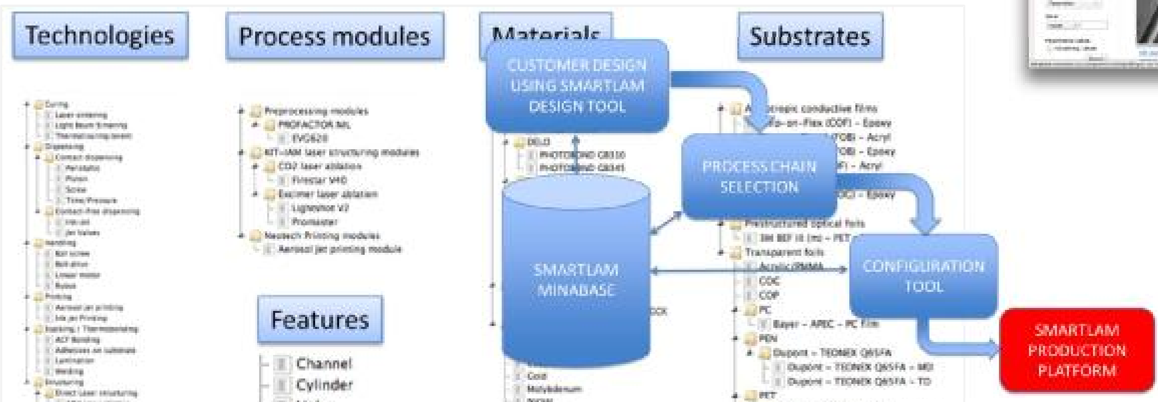
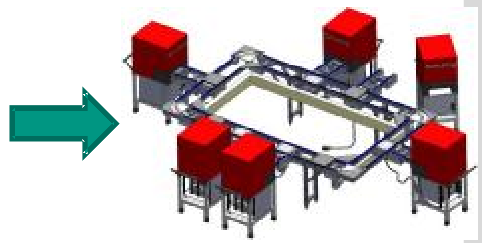
Databases and Process selection tools

- Process database
  - Assessment & description of competences
  - Methods & concepts for describing dependencies
  - Data model from design to manufacturing stage

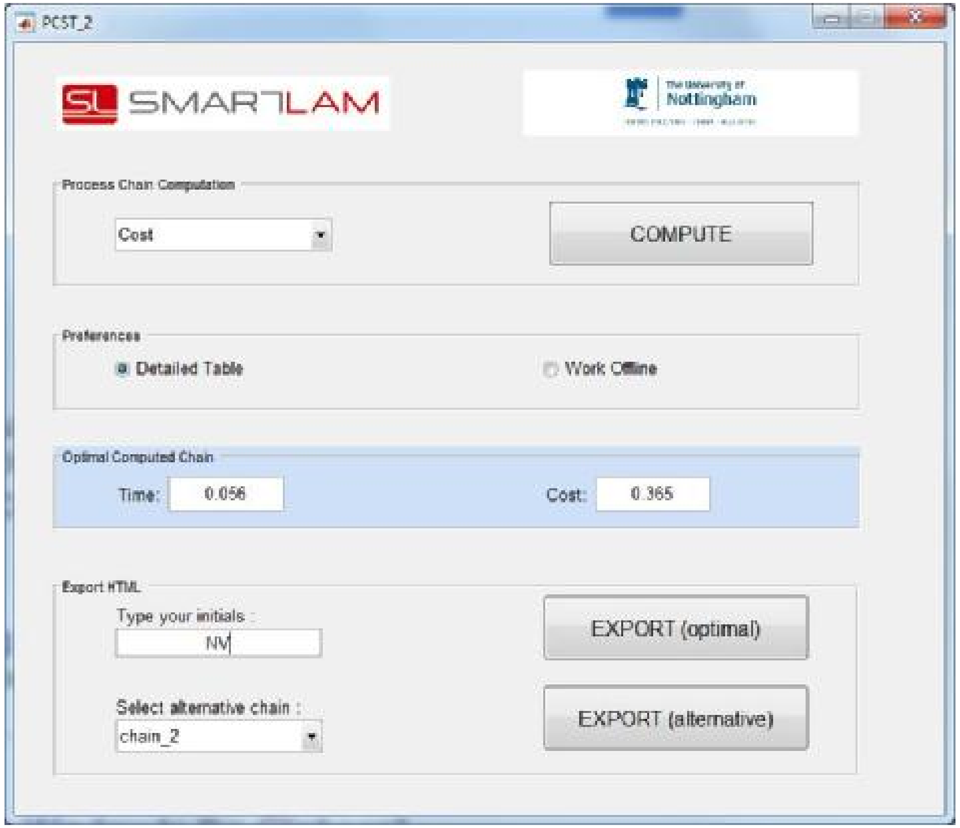




  - Accessible from all over the world
  - On- and inline modification of production
  - Modularity for adaption of process to changing conditions

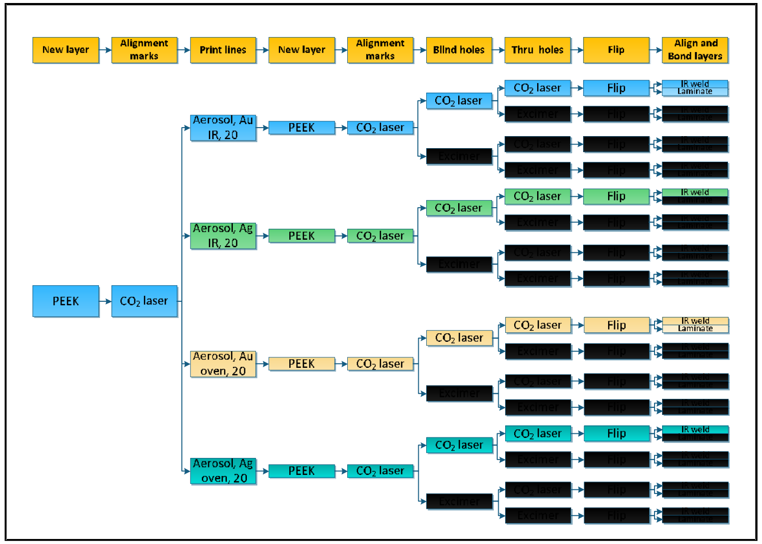
INDUSTRY 4.0

Databases and Process selection tools




computed process chains

	step_1	step_2	step_3	step_4	Cost	Time
chain_1	154	157	154	158	0.3650	0.0560
chain_2	154	156	154	158	0.3650	0.0560



Industrie 4.0

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A world always more connected

1995
15 million
people with
internet
access

1997
6 million
object with
internet
access

2020
7 billion
with
internet
access

2020
50 billion
objects
connected
to Internet

DaNa2.0 – Short Overview

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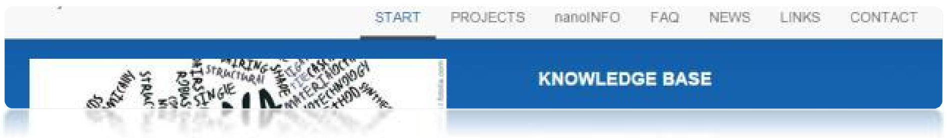
Key Tasks of the DaNa - Knowledge Base Nanomaterials

(DaNa = Database Nanomaterials)

- **Communication** of current nanotechnology safety research
  - Scientific Literature Review & Quality Management
    - Collecting – Evaluating & Processing of Nanosafety Information for Website
  - for Interested Laymen, Stakeholders, Scientists
- **Umbrella project** for German Nanosafety Research projects
  - NanoCare, NanoNature, ERA-Net SIINN

www.nanoobjects.info



DaNa2.0 – Key Facts

- Project duration: 2013 - 2019 (prev. project DaNa 2009 – 2013)
- Project Budget € 3.7 Mio
- Funding by German Ministry of Education & Research (BMBF), supported by Swiss authorities (FOEN, FOPH)

- **Project Partners – Expertise in Material Science, Human- & Eco-Toxicology**
  - Core Team
  - External Experts

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Website www.nanoobjects.info

- Up-To-Date Information on NanoSafety
  - 26 market-relevant Nanomaterials
  - Body barriers
  - Cross-cutting issues
  - Basics
  - SOPs

- Application-oriented information together with toxicological facts

- 4 levels of details from laymen to experts

→ more than 130.000 visitors in 2016
→ more than 1.000 quality-approved literature citations on the website

Website www.nanoobjects.info

- > 130.000 visitors in 2016

Countries	Visitors [in %]
1. Germany	52,9
2. USA	8,3
3. India	5,3
4. Switzerland	4,6
5. Austria	4,4

Continents	Visitors [in %]
1. Europe	73,5
2. Asia	12,5
3. Americas	10,3
4. Oceania	1,3
5. Africa	1,2

Americas: North, Middle & South America

~ 1 % of all visitors from Brazil, mainly São Paulo, Rio de Janeiro & Florianópolis

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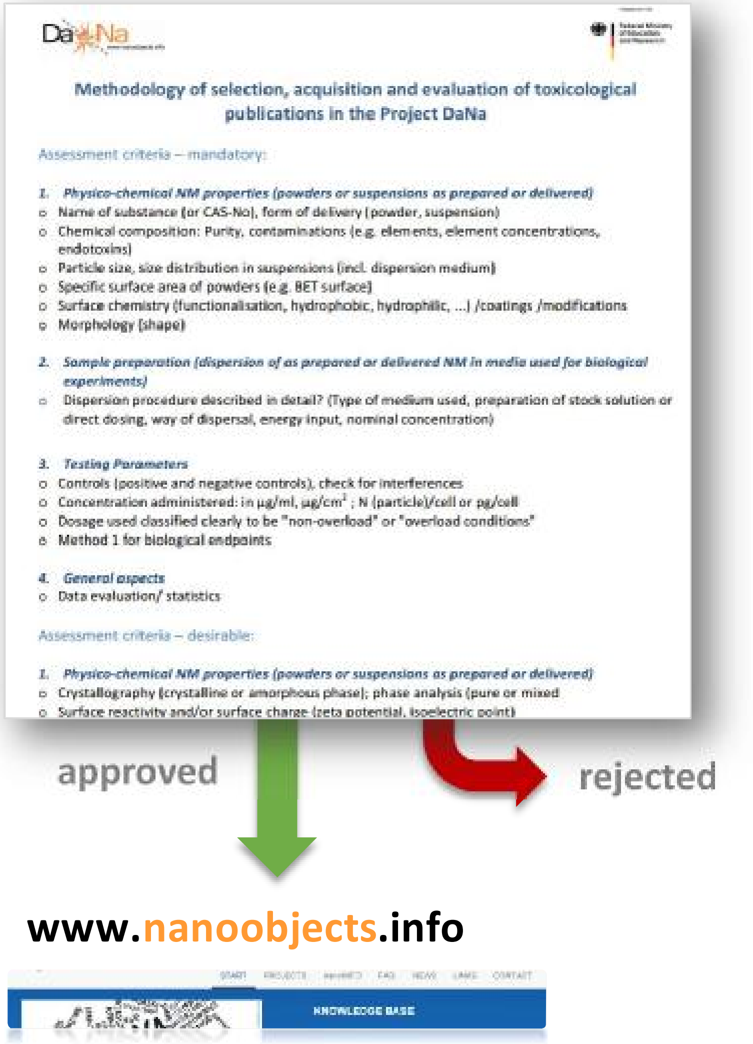
Literature Quality Management

- Evaluation of peer-reviewed literature with publicly available quality criteria
  - Topics Human- & Eco-Toxicology
  - Sorting of approved & rejected literature using the DaNa Literature Criteria Checklist
  - > 1.000 quality-approved literature citations on the website


DaNa

Methodology of selection, acquisition and evaluation of toxicological publications in the Project DaNa

Assessment criteria – mandatory:

1. *Physico-chemical NM properties (powders or suspensions as prepared or delivered)*
   - Name of substance (or CAS-No), form of delivery (powder, suspension)
   - Chemical composition: Purity, contaminations (e.g. elements, element concentrations, endotoxins)
   - Particle size, size distribution in suspensions (incl. dispersion medium)
   - Specific surface area of powders (e.g. BET surface)
   - Surface chemistry (functionalisation, hydrophobic, hydrophilic, ...) /coatings /modifications
   - Morphology (shape)
2. *Sample preparation (dispersion of as prepared or delivered NM in media used for biological experiments)*
   - Dispersion procedure described in detail? (Type of medium used, preparation of stock solution or direct dosing, way of dispersal, energy input, nominal concentration)
3. *Testing Parameters*
   - Controls (positive and negative controls), check for interferences
   - Concentration administered: in µg/ml, µg/cm² ; N (particle)/cell or pg/cell
   - Dosage used classified clearly to be "non-overload" or "overload conditions"
   - Method 1 for biological endpoints
4. *General aspects*
   - Data evaluation/ statistics

Assessment criteria – desirable:

1. *Physico-chemical NM properties (powders or suspensions as prepared or delivered)*
   - Crystallography (crystalline or amorphous phase); phase analysis (pure or mixed
   - Surface reactivity and/or surface charge (zeta potential, isoelectric point)

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Research strategy:

- Process development in the area of additive manufacturing
- Hybrid process chains and smart, digital and flexible manufacturing
- I4.0 applications with particular focus on smart energy usage
- Risk and life cycle analysis

UNESP:

- Further cooperation
- Student exchange
- Collaborative projects in domain specific areas
- Teaching and training activities

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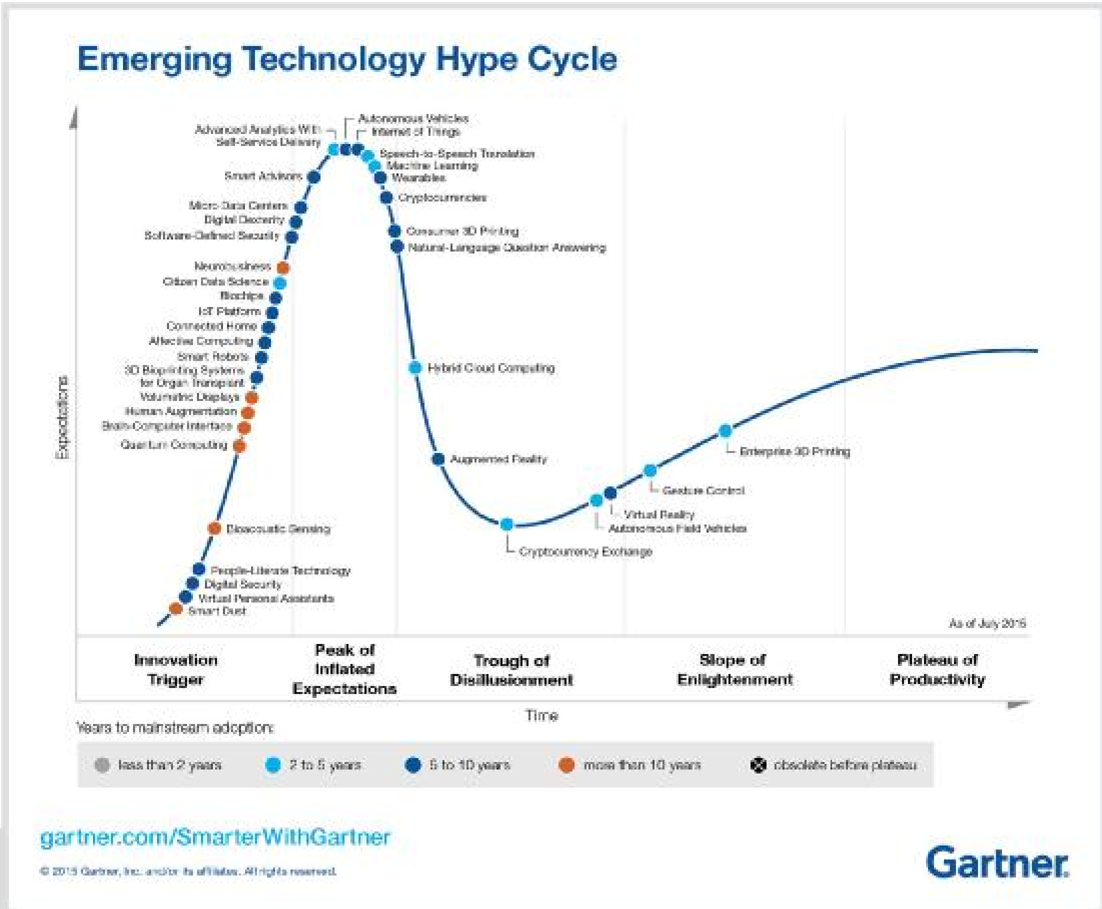
The Future

Gatner Hype-Cycle

Karlsruhe Institute of Technology

- In order to fully implement I4.0 all stakeholders (component suppliers, equipment manufacturers, factory operators, OEMs, users,…) should adopt it.
- Companies have to adapt (change business model) fast or may die.



Thanks a lot…