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Institute of Lightweight Engineering and Polymer Technology (ILK)  
\*Holder of Chair of Function-Integrative Lightweight Engineering

# Introduction to Lightweight Engineering

COMP-ECO Workshop on Multifunctional Composite and Smart Structure DESIGN

Warszawa, 26<sup>th</sup> June 2023

# Overview

- Fundamental terms in lightweight engineering
  - Lightweight engineering categories
  - Principles of lightweight engineering
  - Fields of action in lightweight engineering
  - Lightweight designs

# History – Aviation in the GDR



World's first jet-powered passenger aircraft 152

Chief developer Brunold Baade:

- Director of the Institute for Lightweight Construction and the Economic Use of Materials (IfL) in Dresden-Klotzsch
- 1955 to 1961 Lecturer at the Faculty of Aeronautics at the Technical University of Dresden

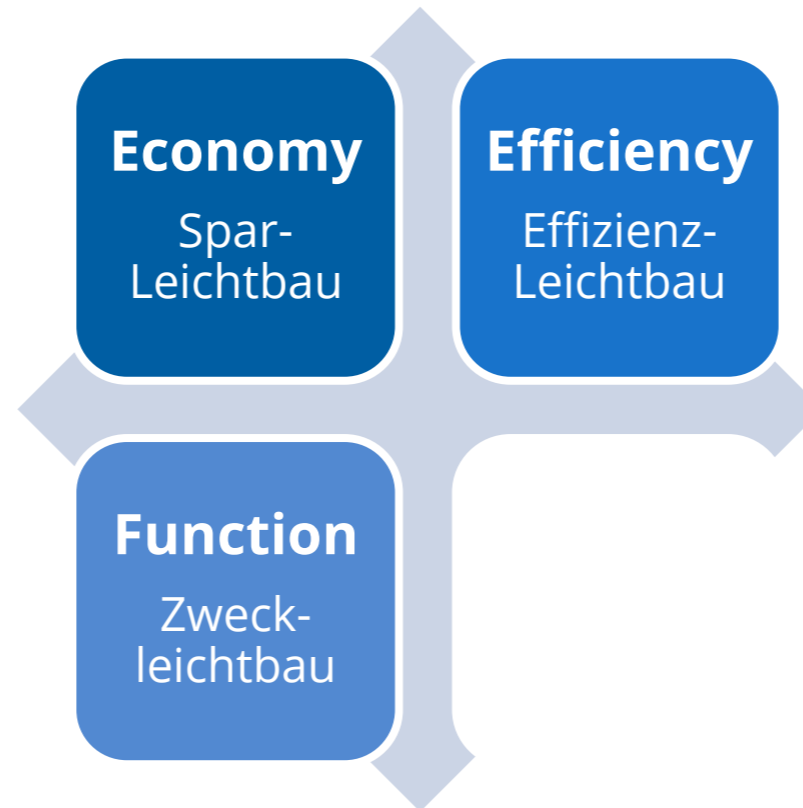
# Lightweight Engineering Categories – Why do we practice lightweight engineering? (according to Wiedemann)

## Direct material cost savings

Direkte Kosteneinsparung  
beim Material

## Mass reduction to enable system functions

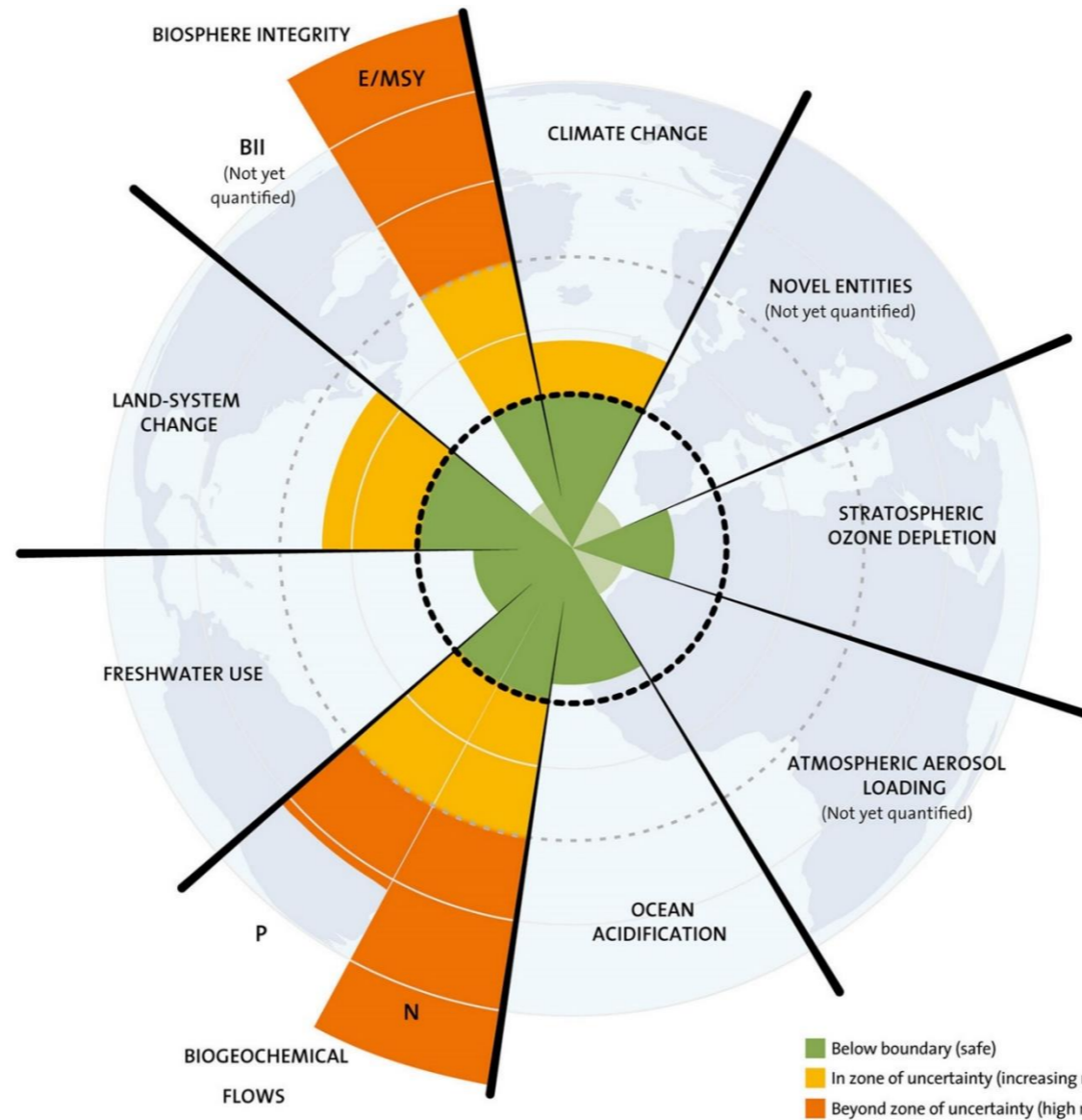
Massenreduktion, um System-  
funktionen zu ermöglichen



## Indirect savings via low mass or improved function

Indirekte Einsparung über geringe  
Masse oder verbesserte Funktion

# Novel Challenges: Planetary Boundaries



Source: Stockholm Resilience Center

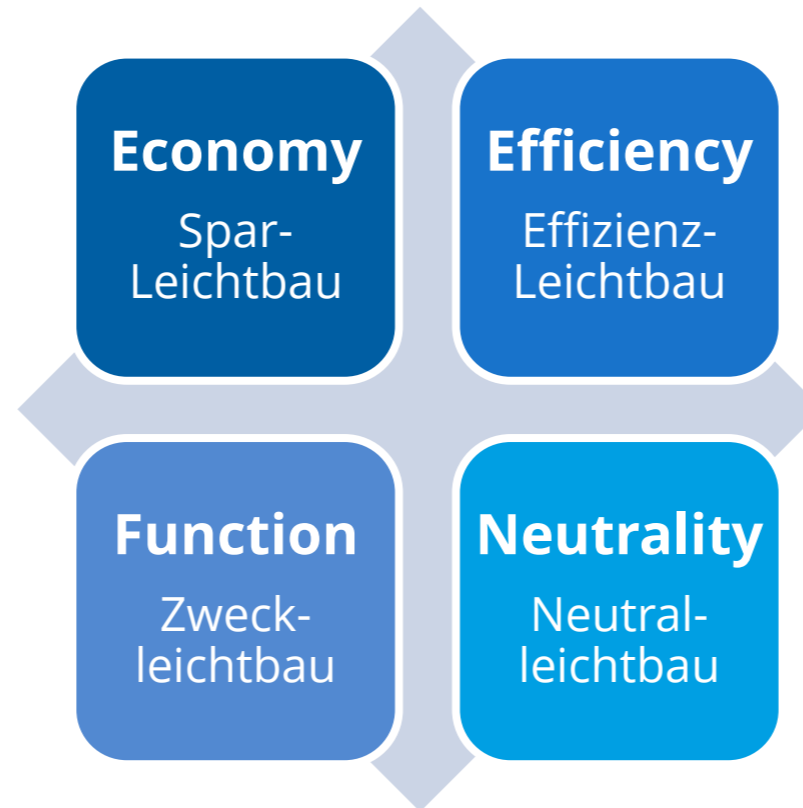
# Lightweight Engineering Categories – *Why do we practice lightweight engineering?* (according to Wiedemann + ILK approach of Neutral Lightweight Engineering)

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## Indirect savings via low mass or improved function

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## Minimizing the ecological footprint

Minimierung des ökologischen  
Fußabdrucks

Advanced Dresden model

# Neutral Lightweight Design

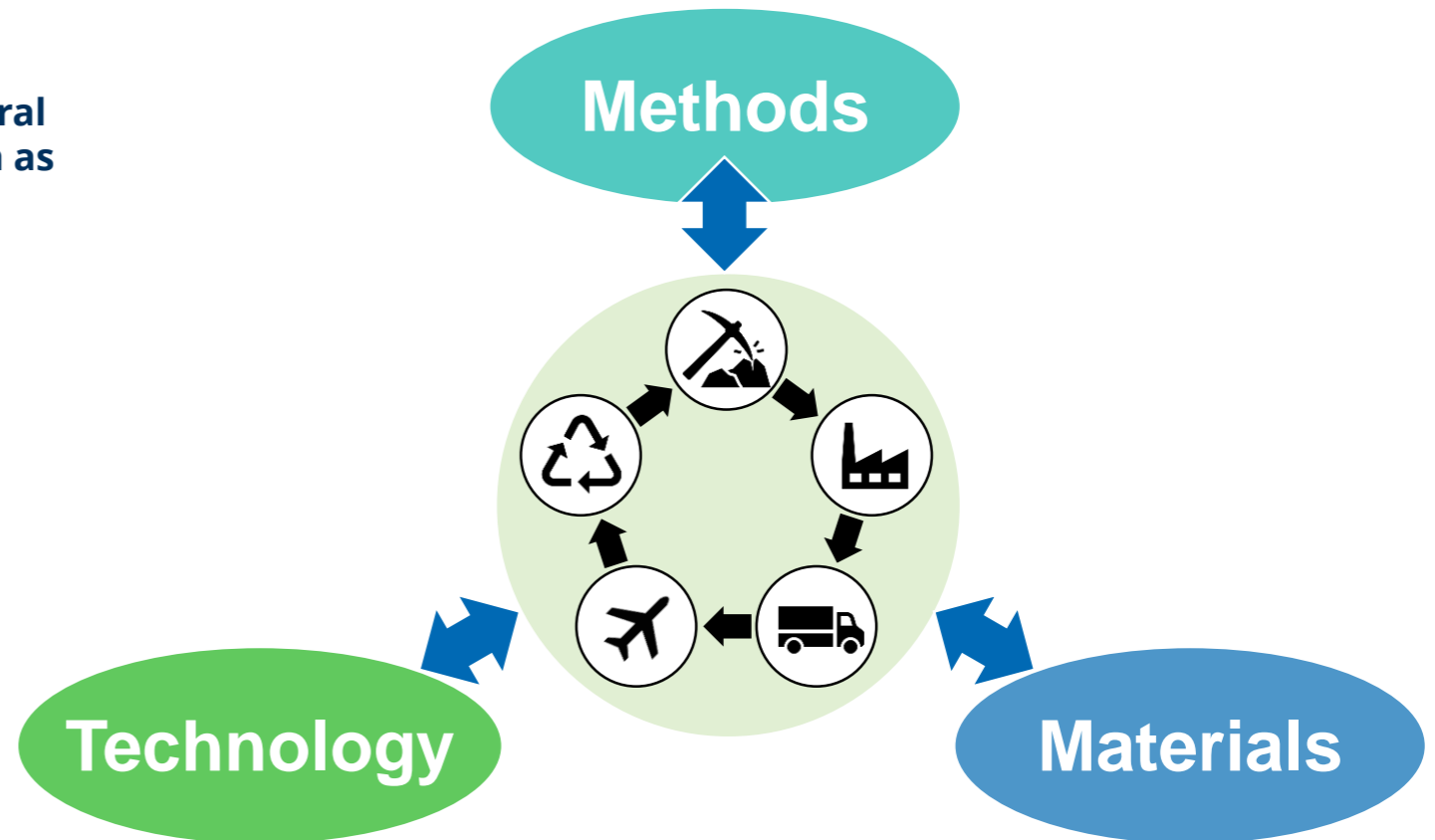
Further development of lightweight system engineering to include methods and technologies for the creation of products that are manufactured in closed, ecologically balanced material cycles, with the aim of maximally reducing the potential for environmental hazards over the entire life cycle.



# Action fields of Neutral Lightweight Design

## Handlungsfelder des Neutralleichtbaus

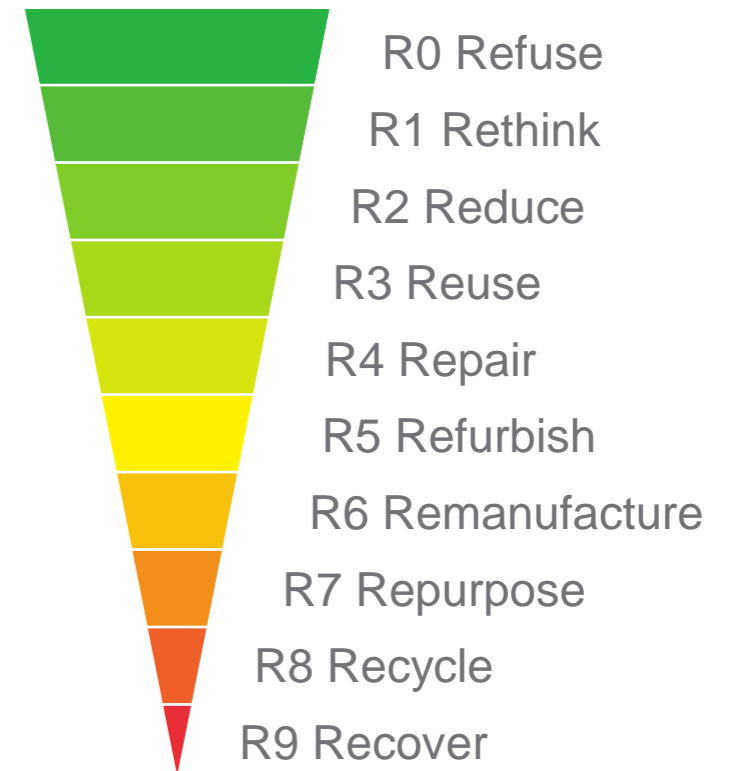
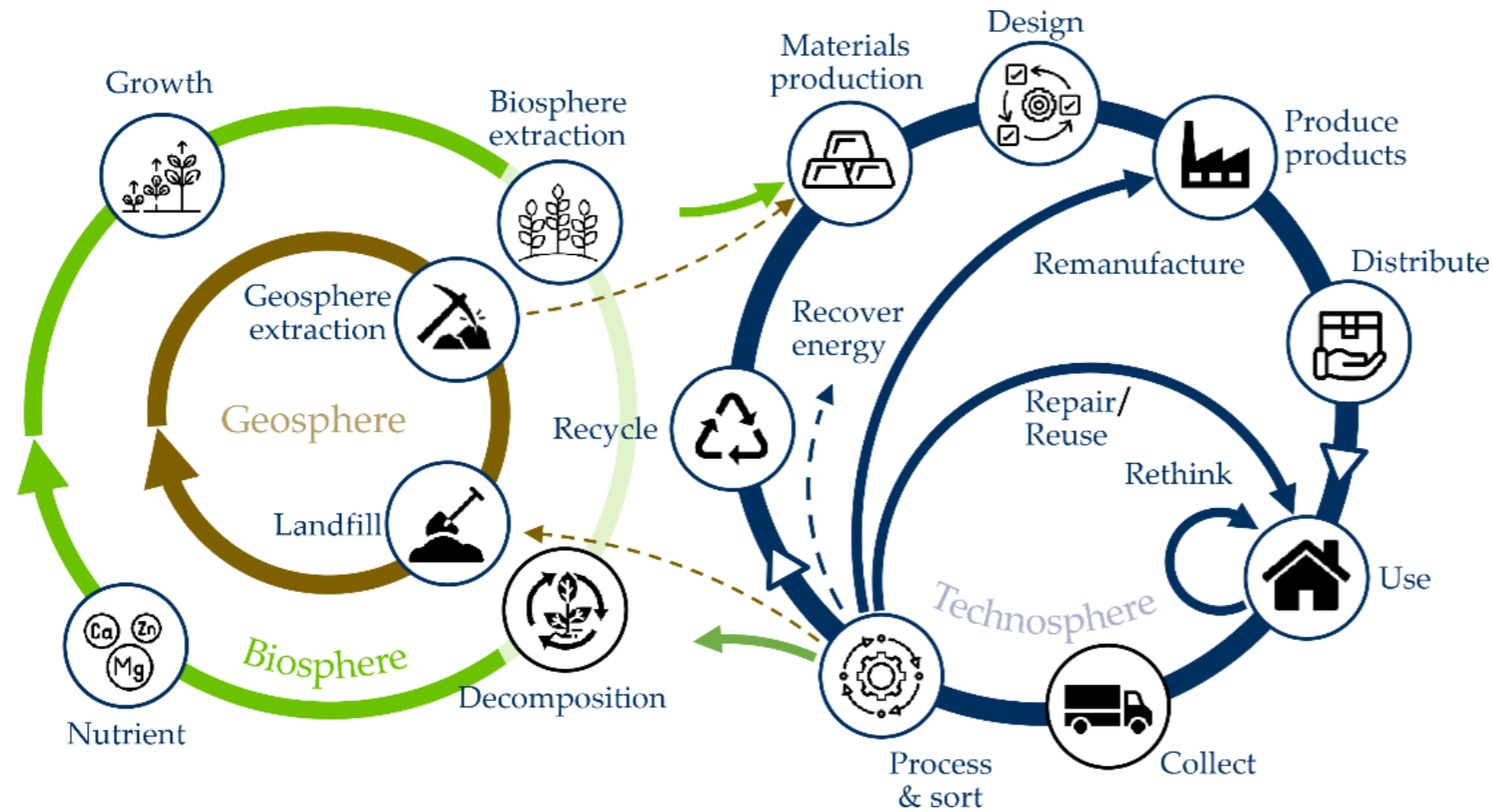
- In addition to technical and economic criteria, neutral lightweight construction includes ecological criteria as development goals
- The entire product life cycle must be evaluated in terms of its environmental impact.
- **The ideal of Neutral Lightweight Design is a resource-neutral circular economy.**



Die ILK-Entwicklungskette seit 1995



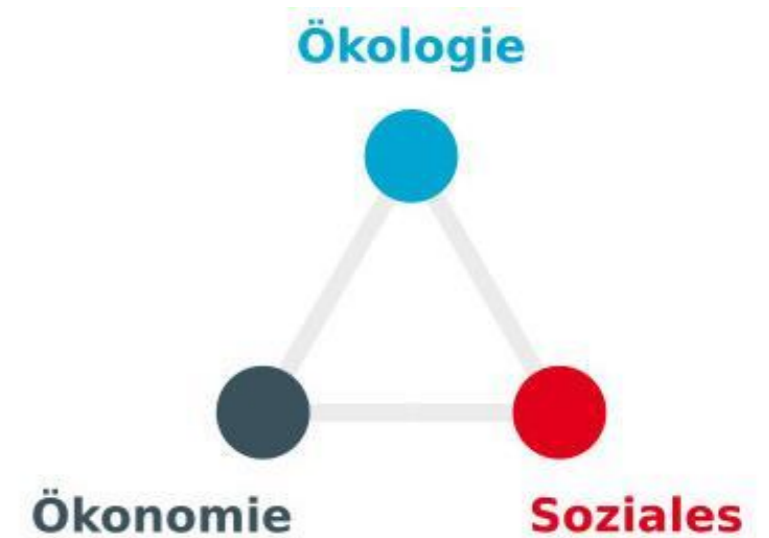
# Engineering Circularity



# 4th Lightweight Era - Sustainability as a Key Objective

Climate- and resource-neutral development, production and products in compliance with social principles and economic goals

- Consistent implementation of a Design to Climate
- Consistent use of LCA and LCE in the development process (transparent accounting limits)
- Exclusive use of recycled materials or previously unused waste/valuable material streams (9R-strategy)
- Reuse of available assemblies and components
- Development of climate-positive materials, e.g. with a negative CO2 balance (e.g. natural fibres, C-fibres, ...)
- Solar thermal power-heat coupling in production Innovative data analysis technologies for the development of closed-loop systems



*Nachhaltigkeitsdreieck*

# Principles of Lightweight Engineering – *How do we practice lightweight engineering?*

(according to Prof. Baade and Prof. Haldenwanger)

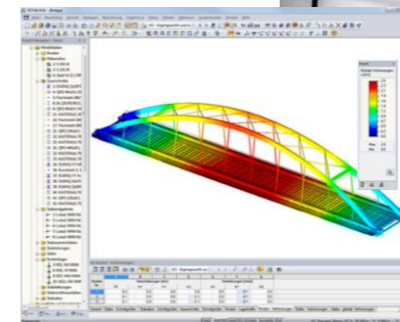
The principles of lightweight engineering provide the basis for the development and design of lightweight products.

They are therefore the premise for sustainable and innovative product development, especially in light of today's global challenges.

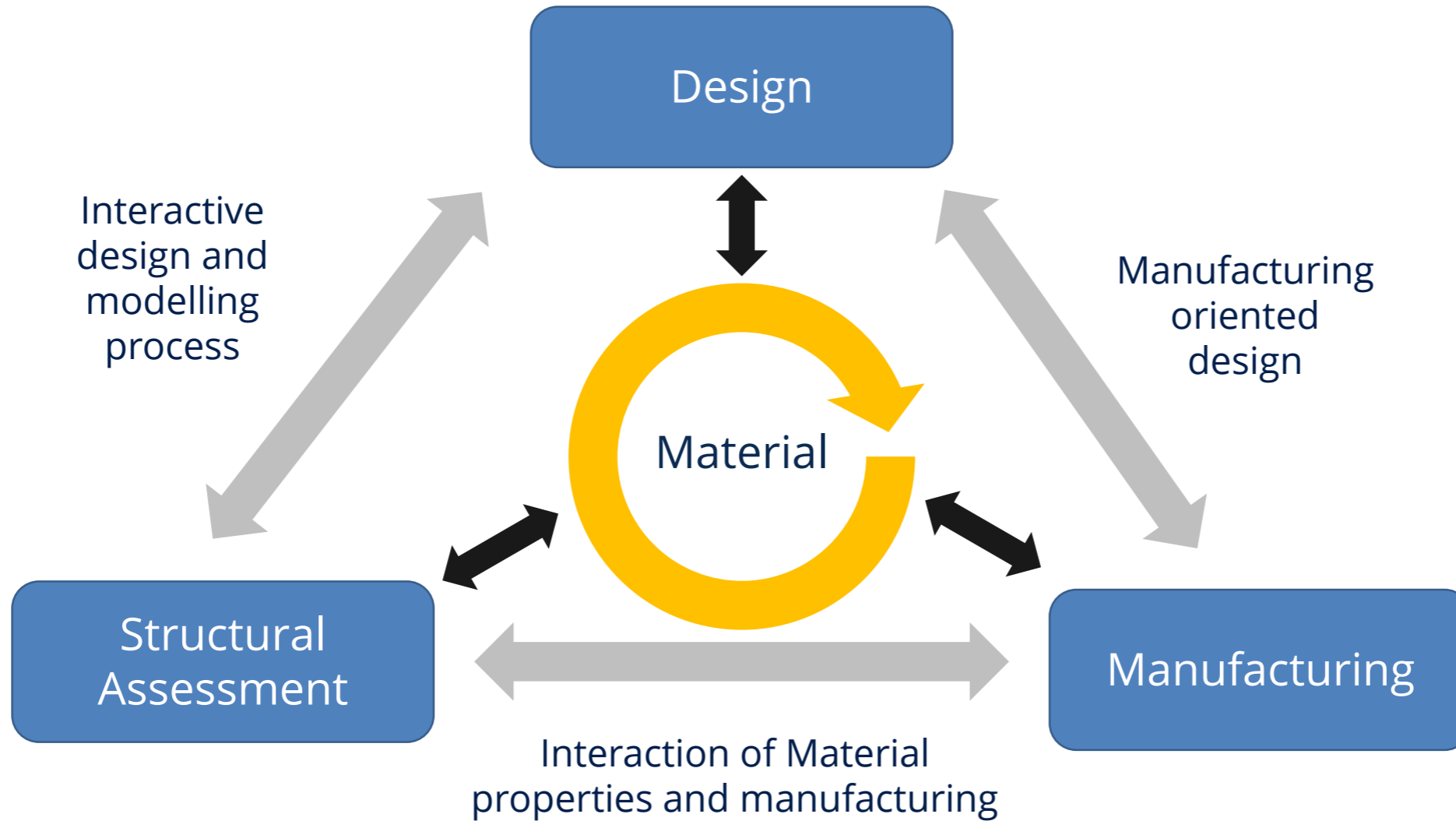
- **Lightweight material design** (Stoffleichtbau)
- **Multi-Material hybrid design** (Verbundleichtbau)
- **Formed lightweight design** (Gestaltleichtbau)
- **Conditional lightweight design** (Bedingungsleichtbau)
- **Conceptual lightweight design** (Konzeptleichtbau)



Glasfaserverstärkter Kunststoff  
Quarzasfaserverstärkter Kunststoff  
Kohlenstofffaserverstärkter Kunststoff  
Metall (Aluminium, Titan)  
Metall-Kunststoff-Mehrschichtverbund



# Fields of Action in Lightweight Engineering



# Principles of Lightweight Engineerings – *How do we practice lightweight engineering?*

(according to Prof. Baade and Prof. Haldenwanger)

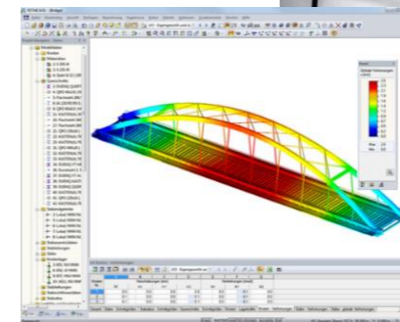
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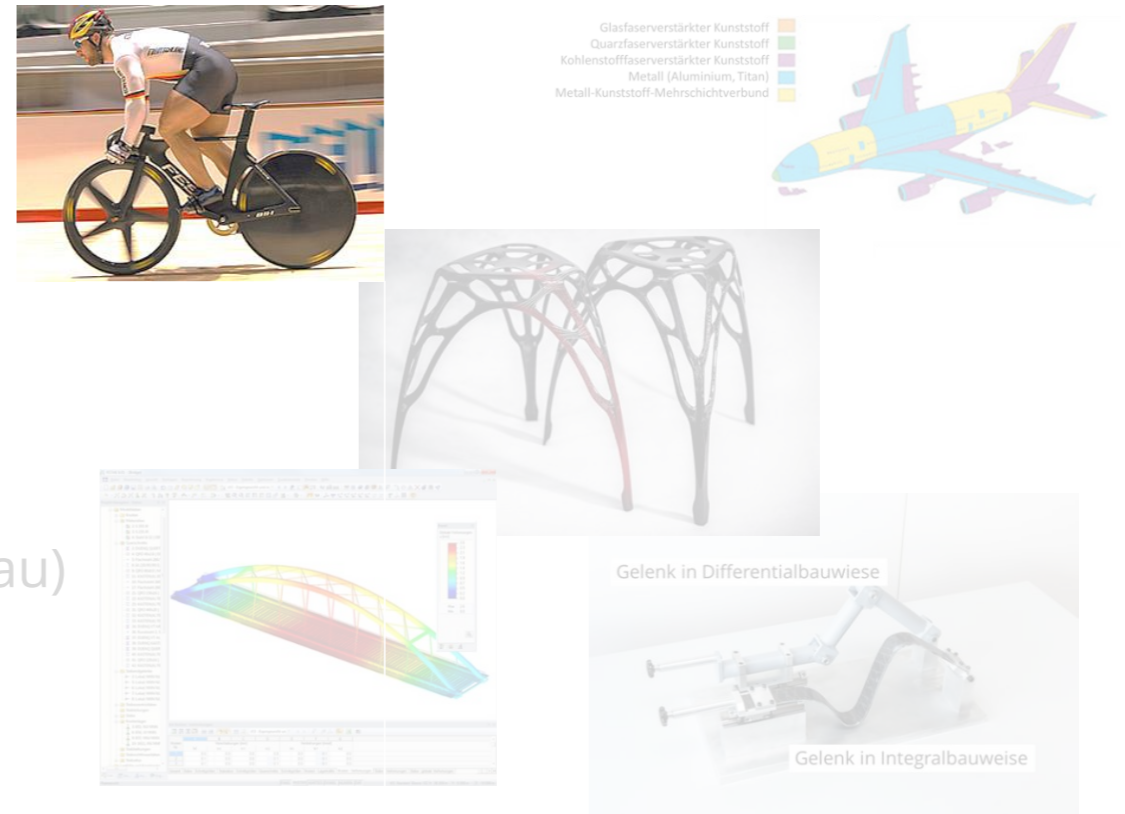
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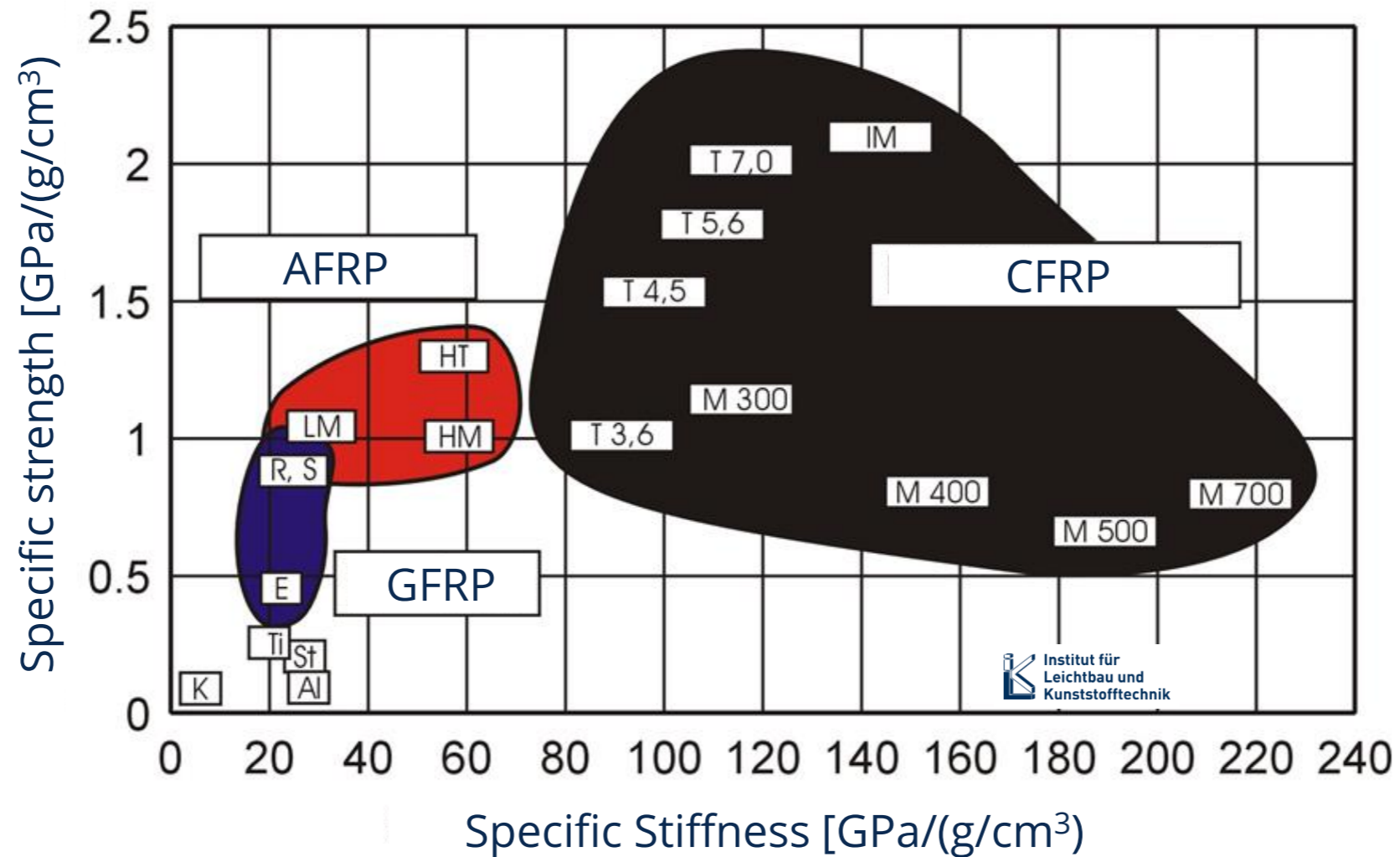
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# Lightweight Material Design

Use of high-performance materials with low density

Specific properties of fibre-reinforced epoxy resins



## Lightweight Material Design

Use of high-performance materials with low density

FES bicycle made of highly stiff CF-EP



Source: FES

Centrifuge for uranium enrichment with CF-EP reinforcement



Source: URENCO



# Lightweight Material Design

Use of high-performance materials with low density

Airbus A350



Hybrid rim made of CF-EP and aluminium



# Lightweight Material Design

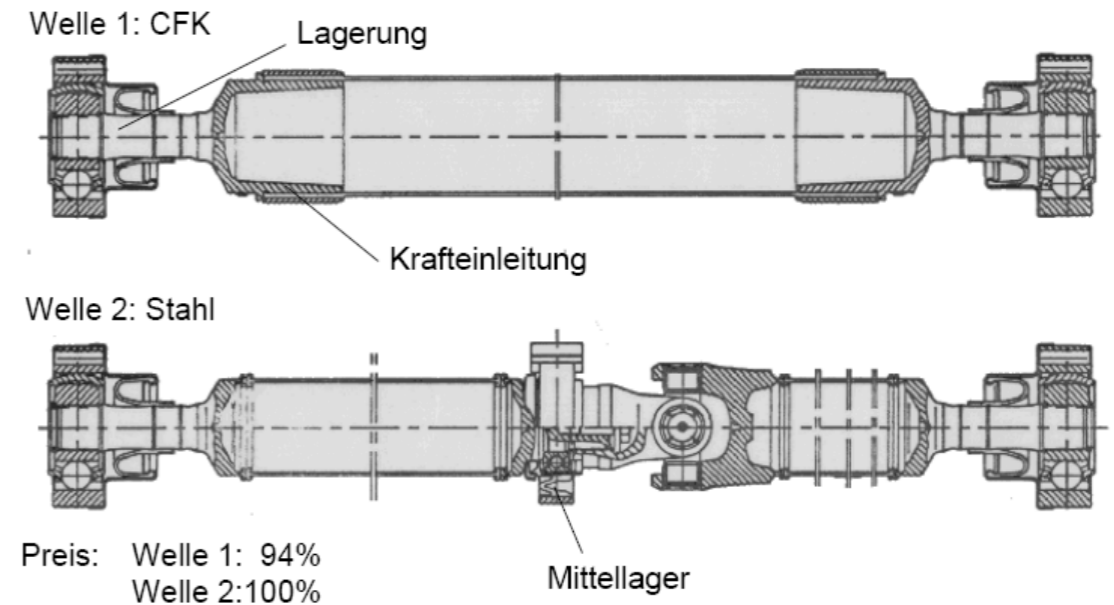
Use of high-performance materials with low density

## CF-EP shaft



Source: LZS

## GFRP cardan shaft and steel shaft with intermediate bearing



Source: RWTH Aachen, IKA

# Lightweight Material Design

Use of high-performance materials with low density

Wind turbines



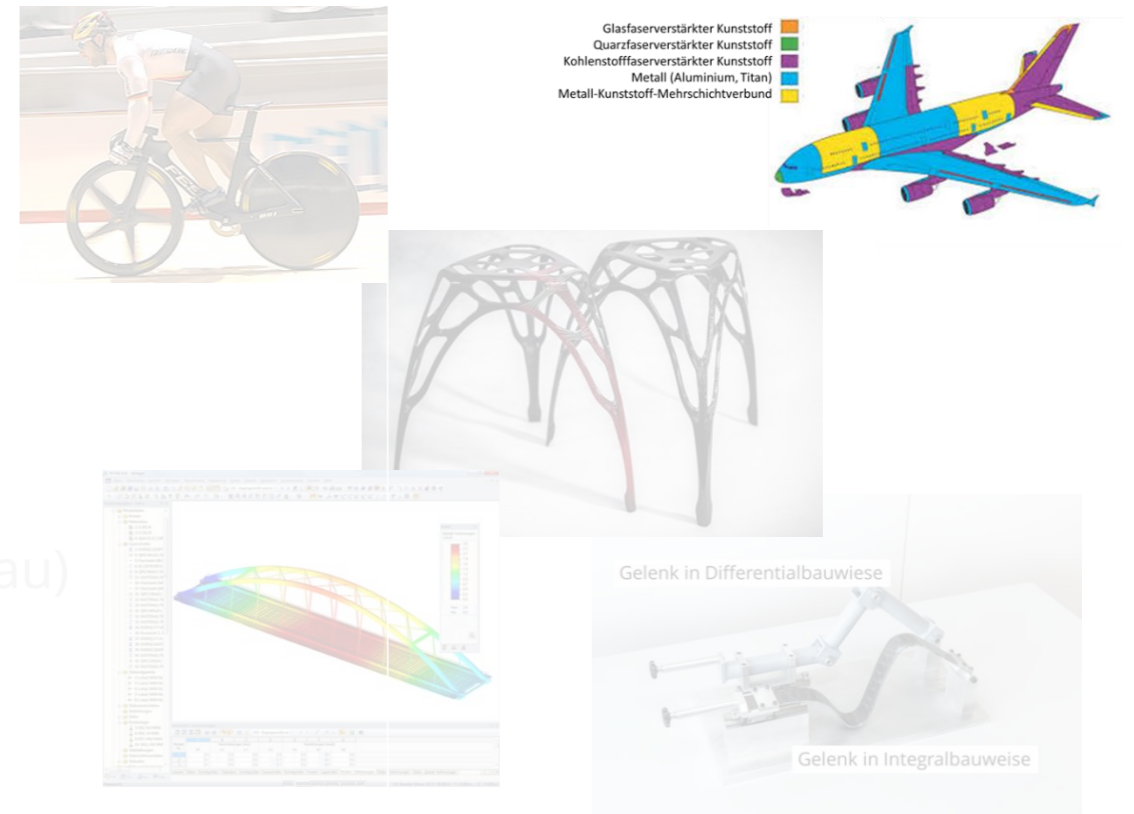
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# Excellent Specific Stiffness's and Strengths

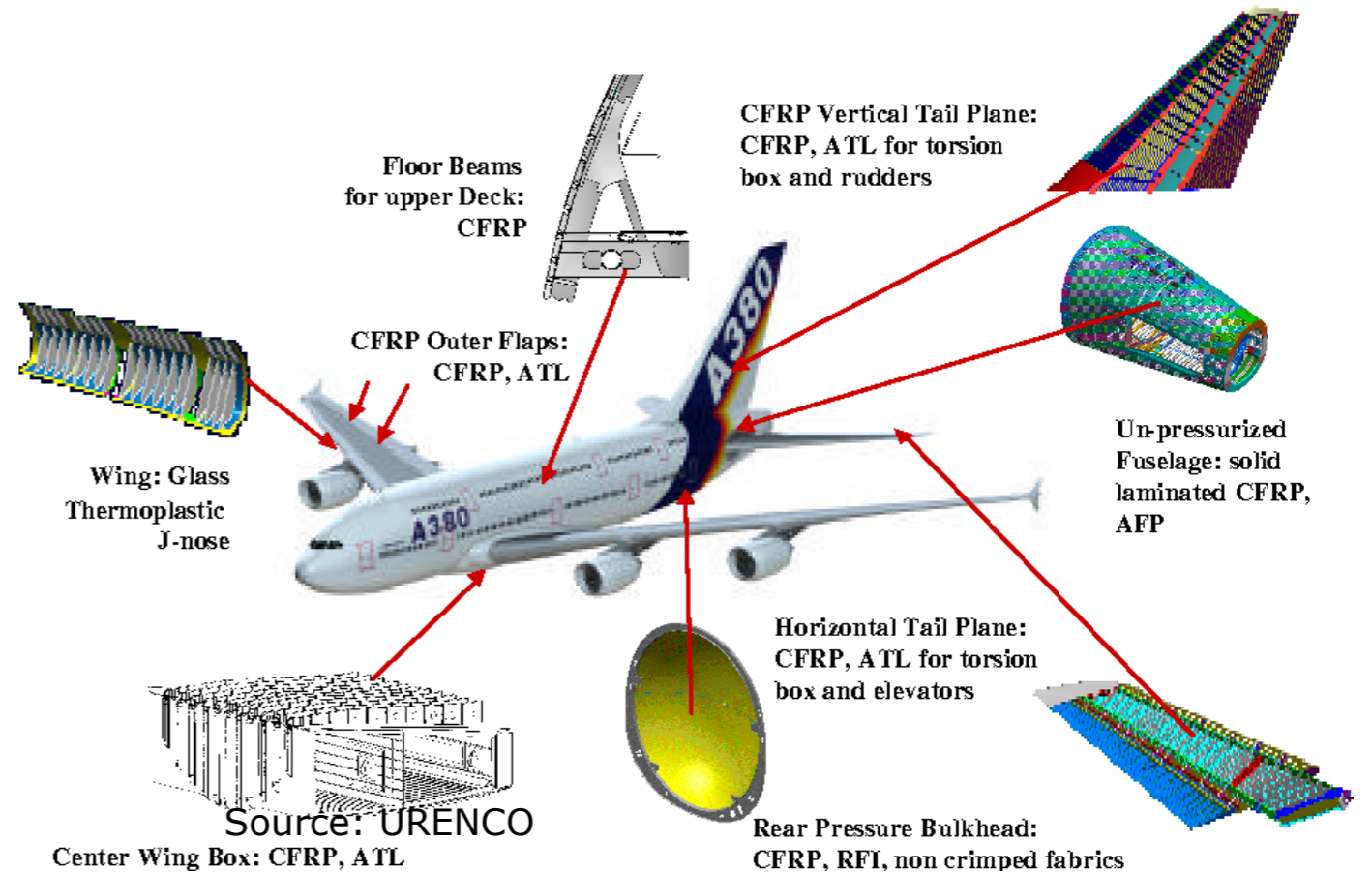
Combination of specific properties of different materials

Composite blades with Ti leading edge



Source: Rolls-Royce

Centrifuge for uranium enrichment with CF-EP reinforcement

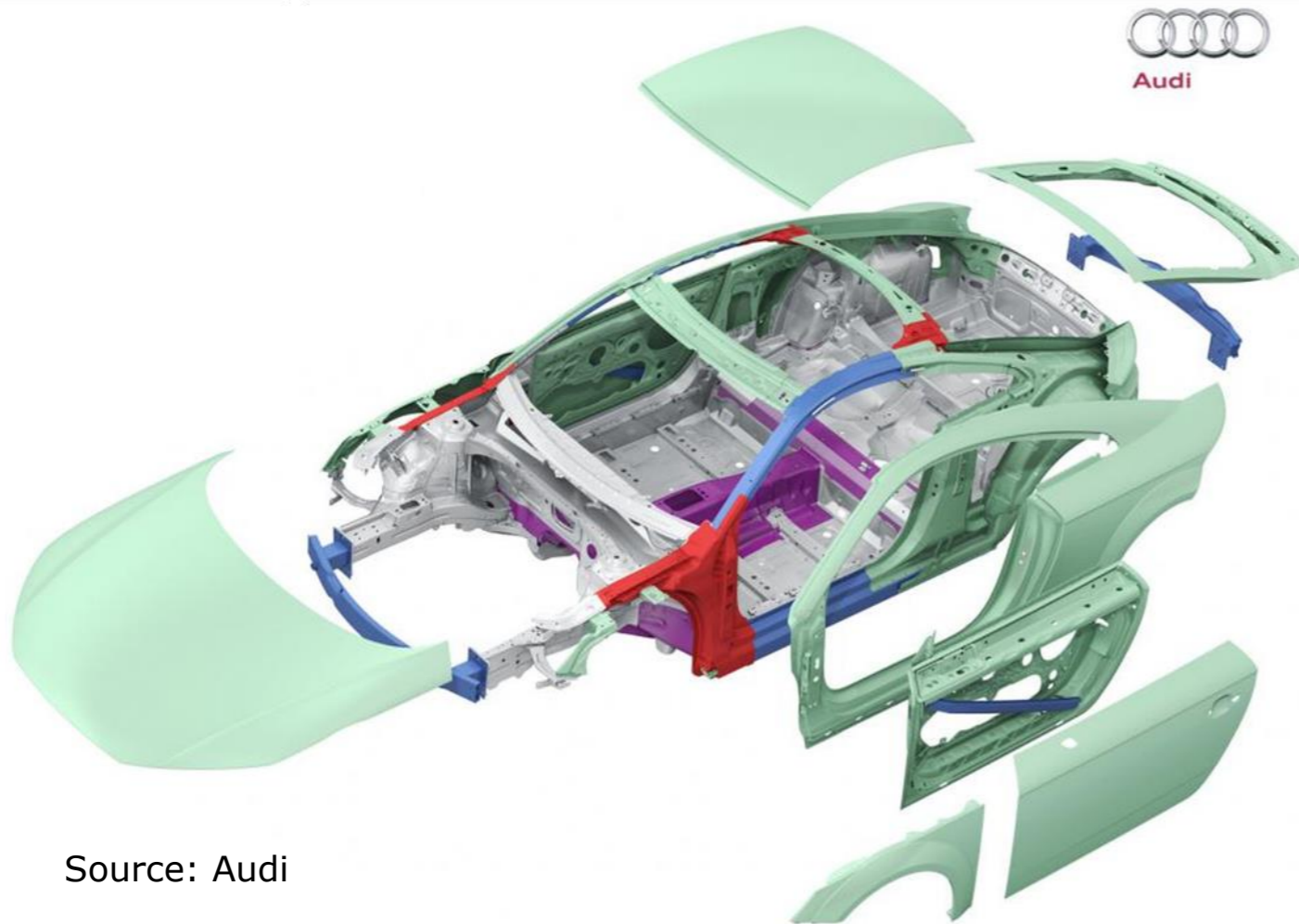


Source: Airbus

# Excellent Specific Stiffness's and Strengths

Combination of specific properties of different materials

Body in white of Audi TT



## Materials in the body structure

03/14

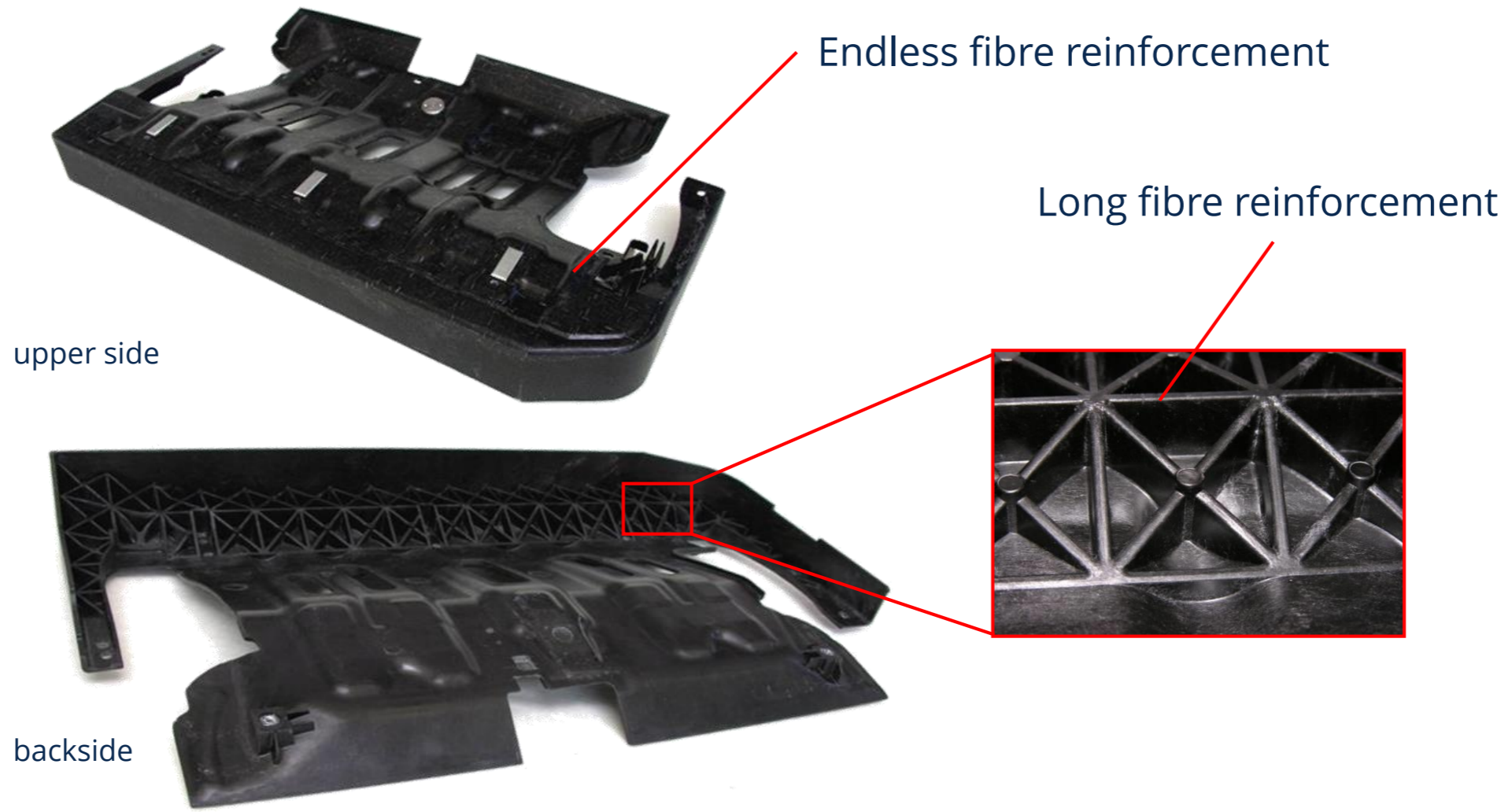
-  **Ultrahochfeste Stähle (warmumgeformt)**  
Ultra-high strength steels (hot-formed)
-  **Konventionelle Stähle**  
Conventional steels
-  **Aluminium-Profil**  
Aluminum section
-  **Aluminium-Blech**  
Aluminum sheet
-  **Aluminium-Guss**  
Aluminum castings

Source: Audi

# Excellent Specific Stiffness's and Strengths

Combination of specific properties of different materials

GF-PP car seat



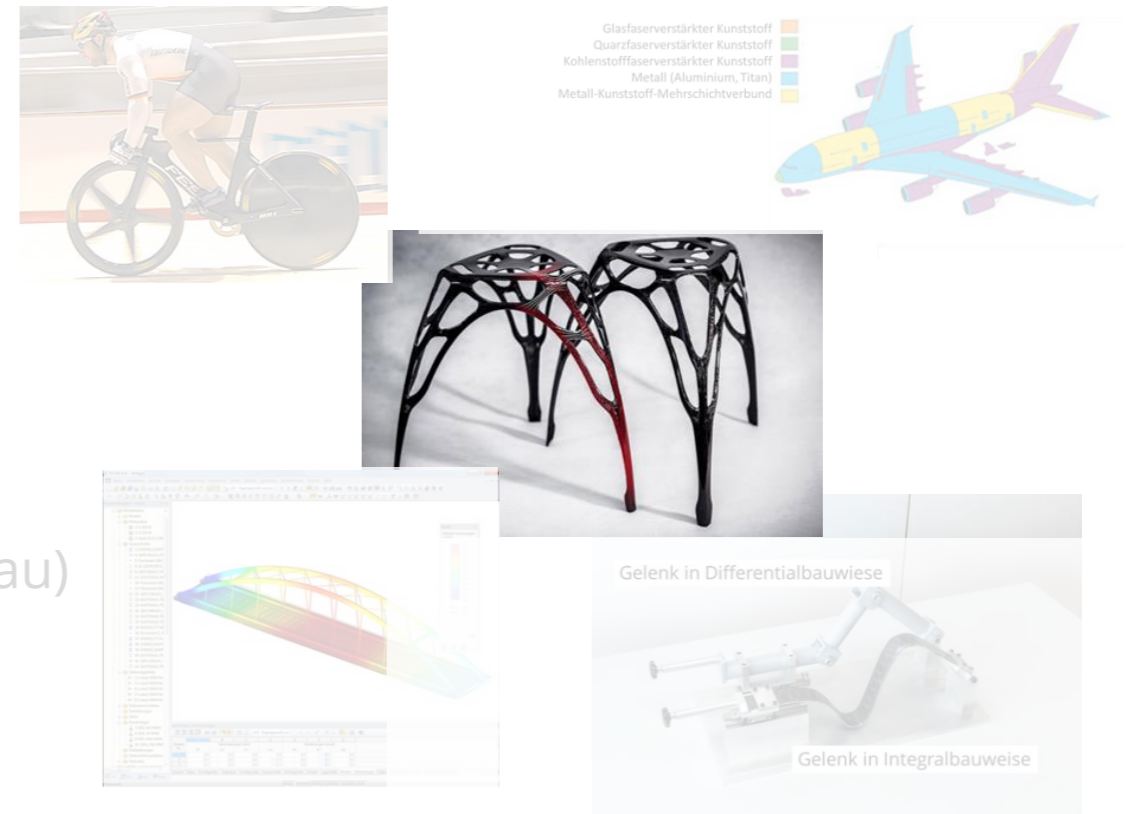
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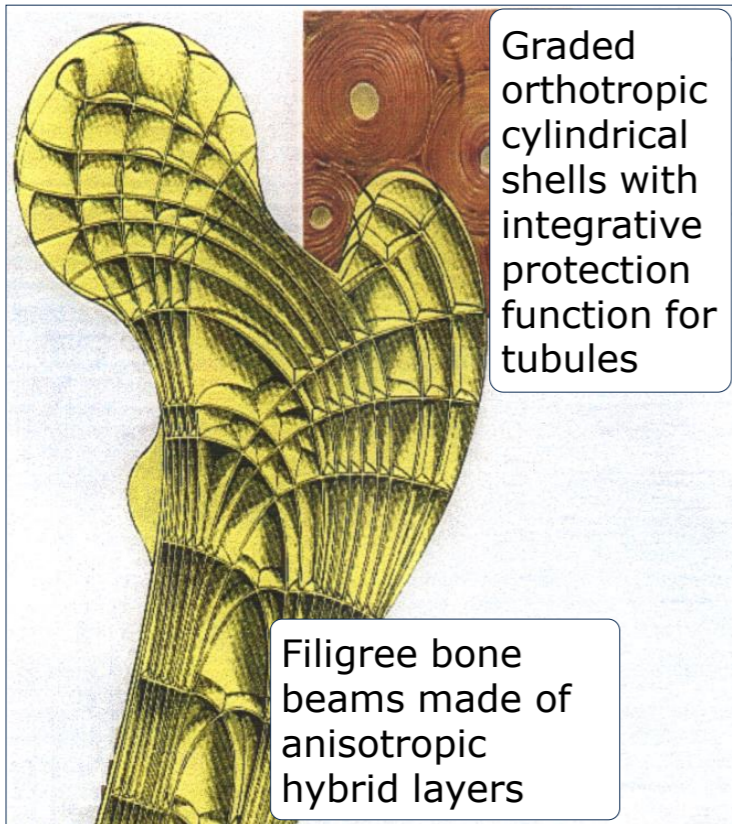


# Formed Lightweight Design

Optimisation of structural design for given design space, loads, boundary conditions and constraints

## Formed lightweight design in nature

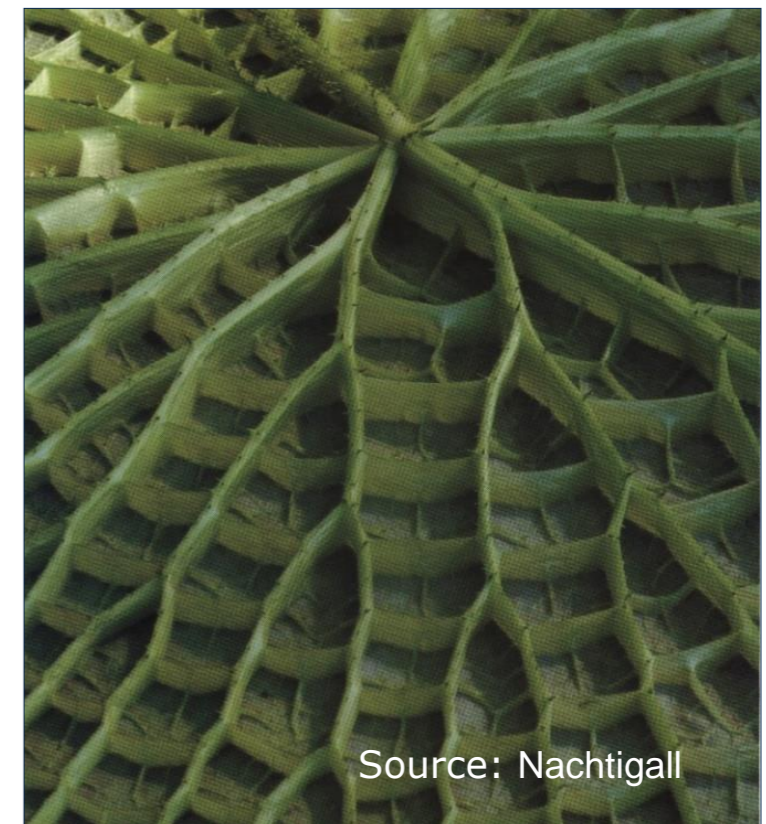
Bone structure suitable for loading



Straw with unidirectional fibre reinforcement



Filigree ribbed structure of a water lily leaf



## Formed Lightweight Design

Optimisation of structural design for given design space, loads, boundary conditions and constraints

3D printed seat console for vehicles



Generative Design &  
Additive Manufacturing



8 components into 1 part  
40% lighter  
20% stronger

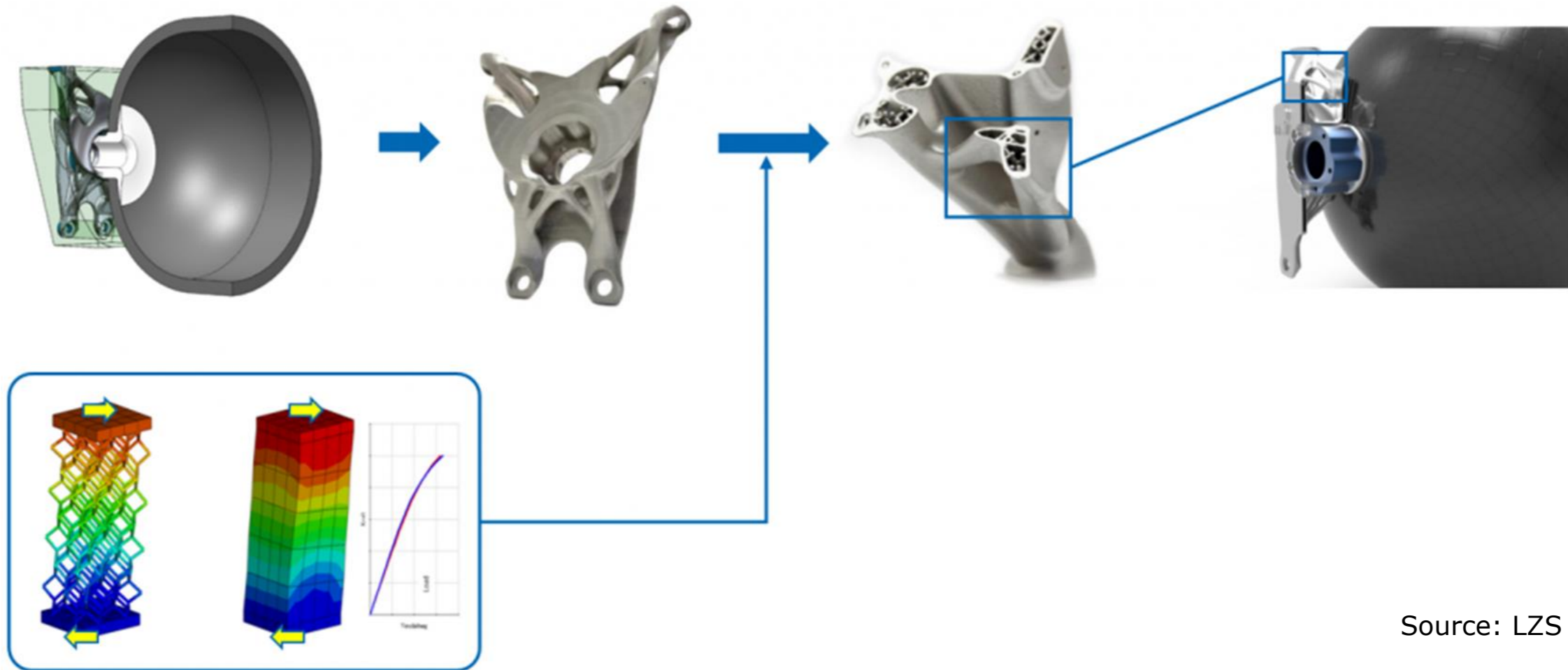


Source: General Motors

# Formed Lightweight Design

Optimisation of structural design for given design space, loads, boundary conditions and constraints

Multi scale topology optimisation



Source: LZS

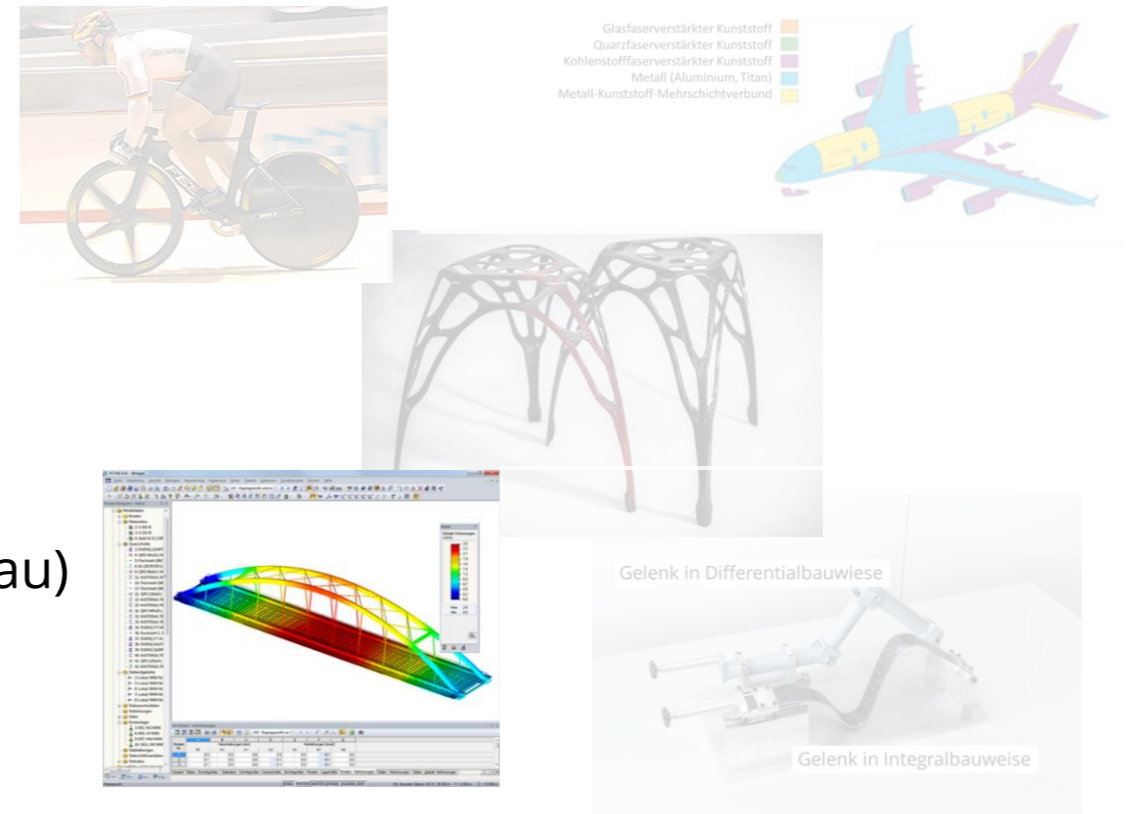
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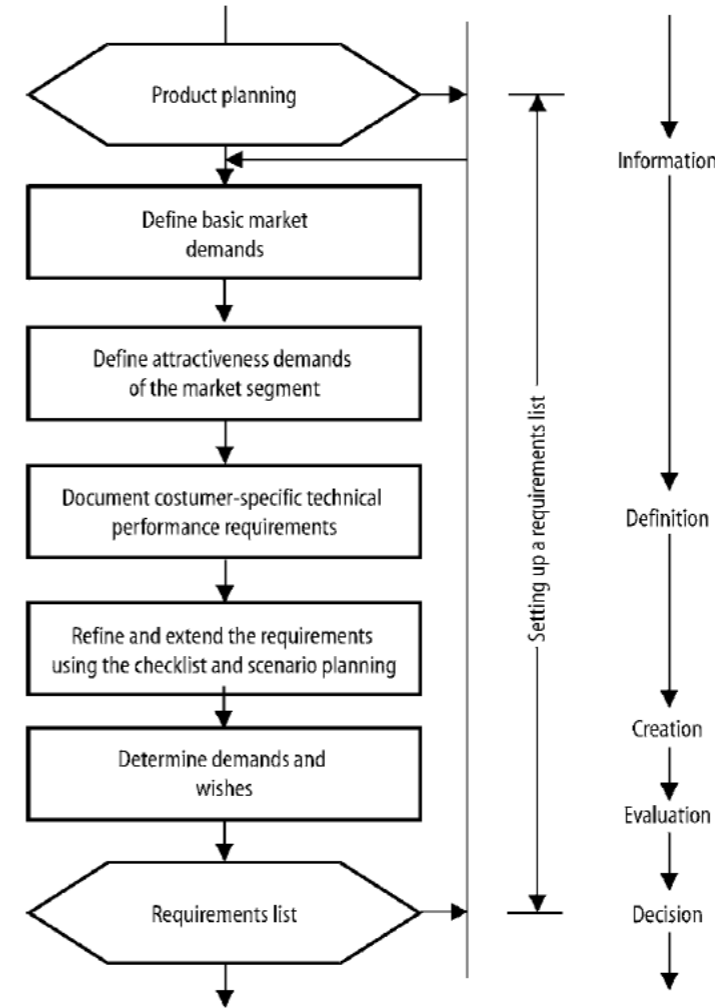
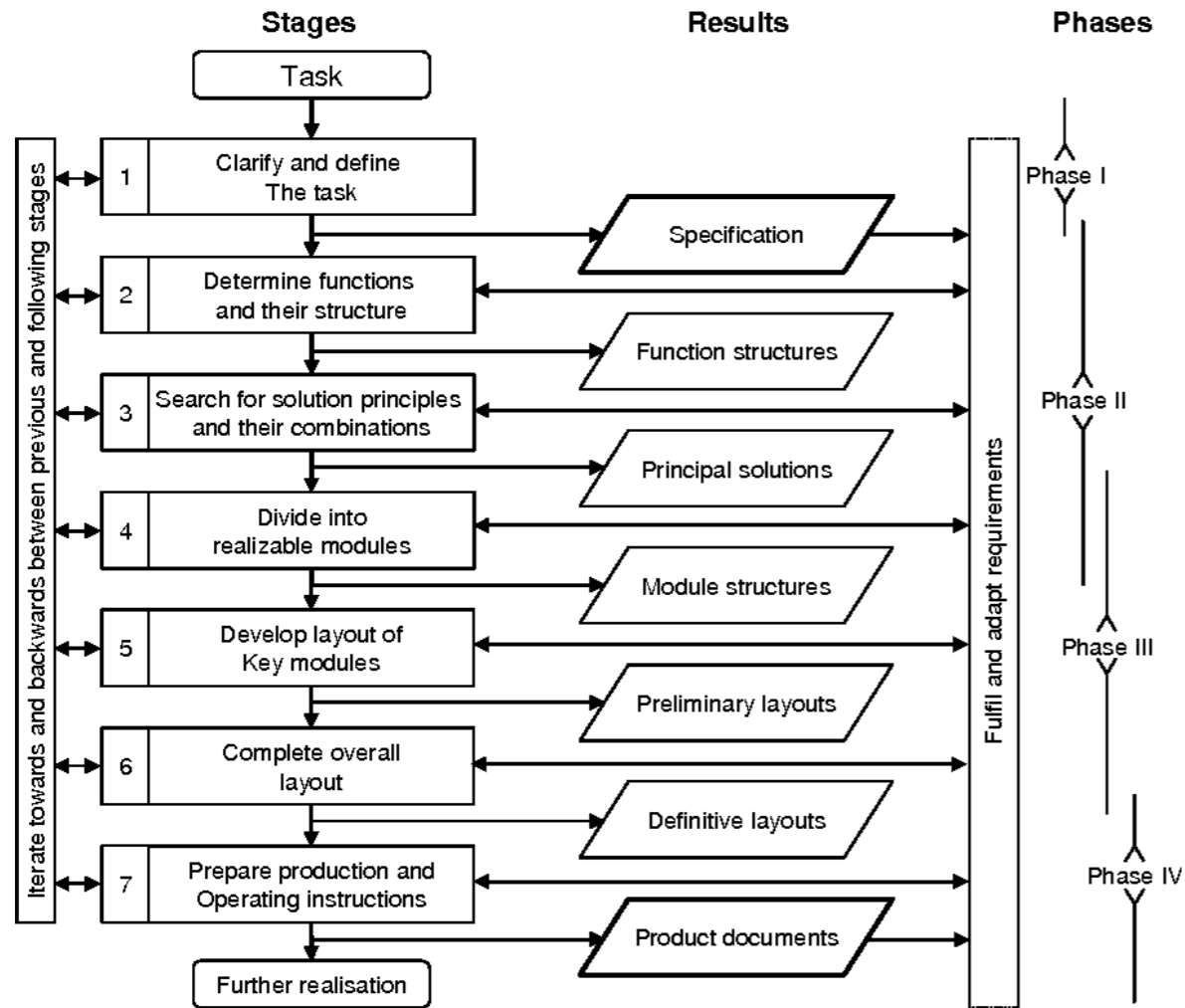


# Conditional Lightweight Design

Purposeful design and dimensioning to meet requirements

Design process according to VDI 2222

Requirements management



Source: Pahl/Beitz

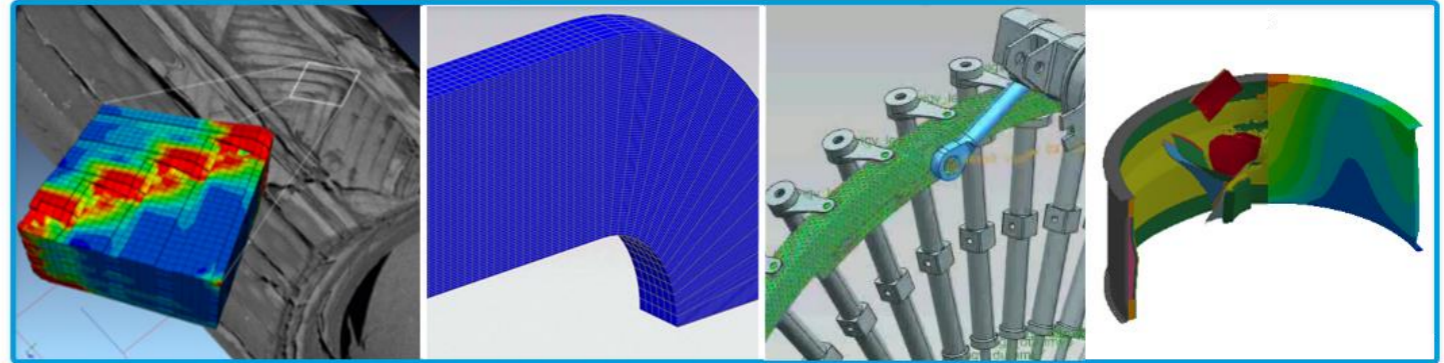
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Dimensioning Process

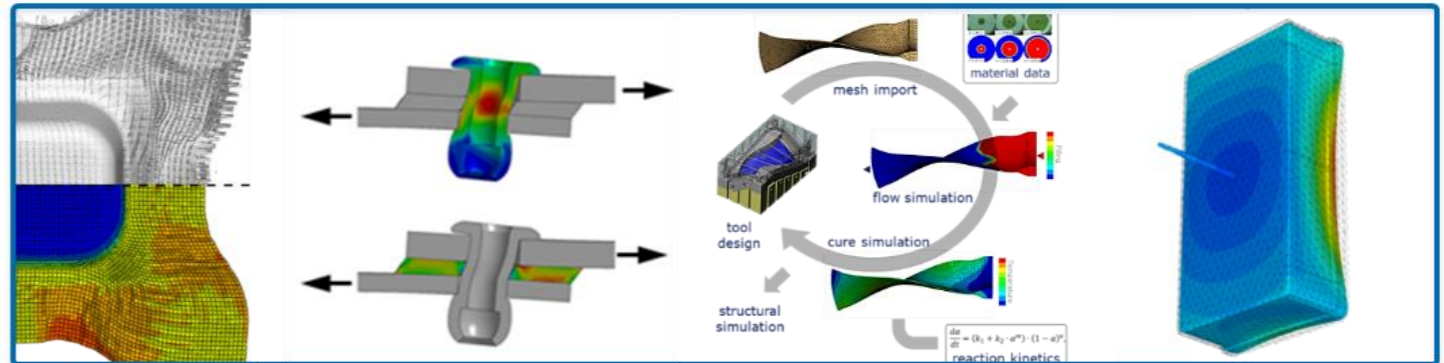
## Structures & Systems

- Materials
- Crash & Impact
- Multi physics
- Failure assessment



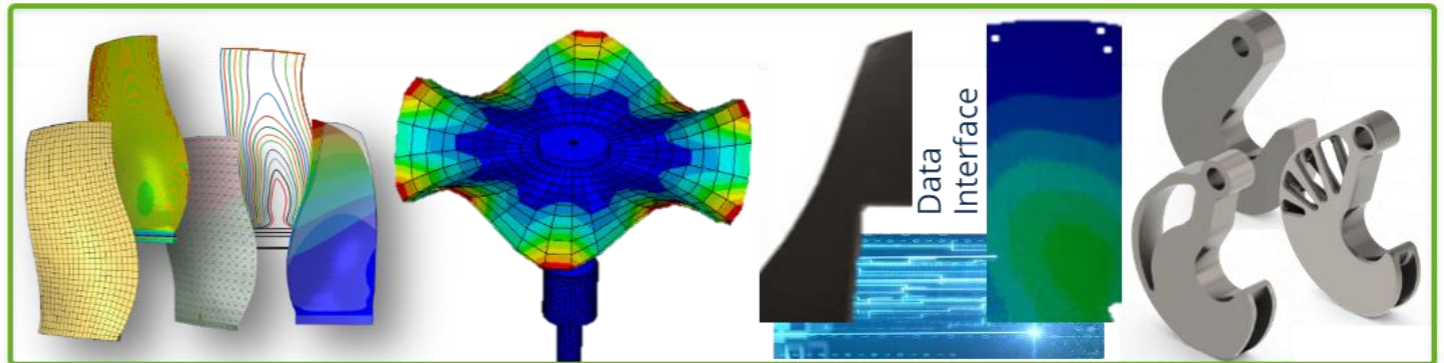
## Manufacturing Processes

- Textile deformation
- Forming
- Infusion & curing
- Joining & bonding



## Engineering Environments

- Linked Design & Analysis
- Models for Virtual Twins
- Optimization



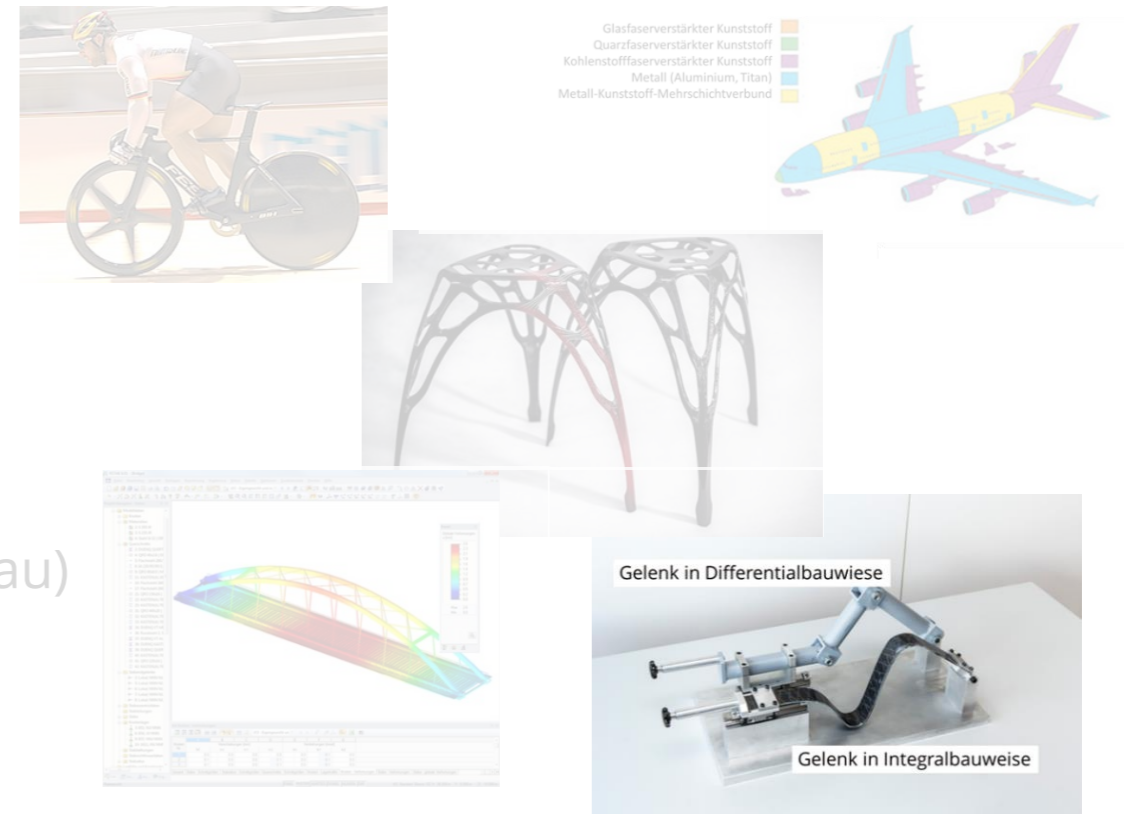
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# Conceptual Lightweight Design

Weight reduction through highly integrated design

Conventional key board



Source: Schwaiger

Flexible keyboard



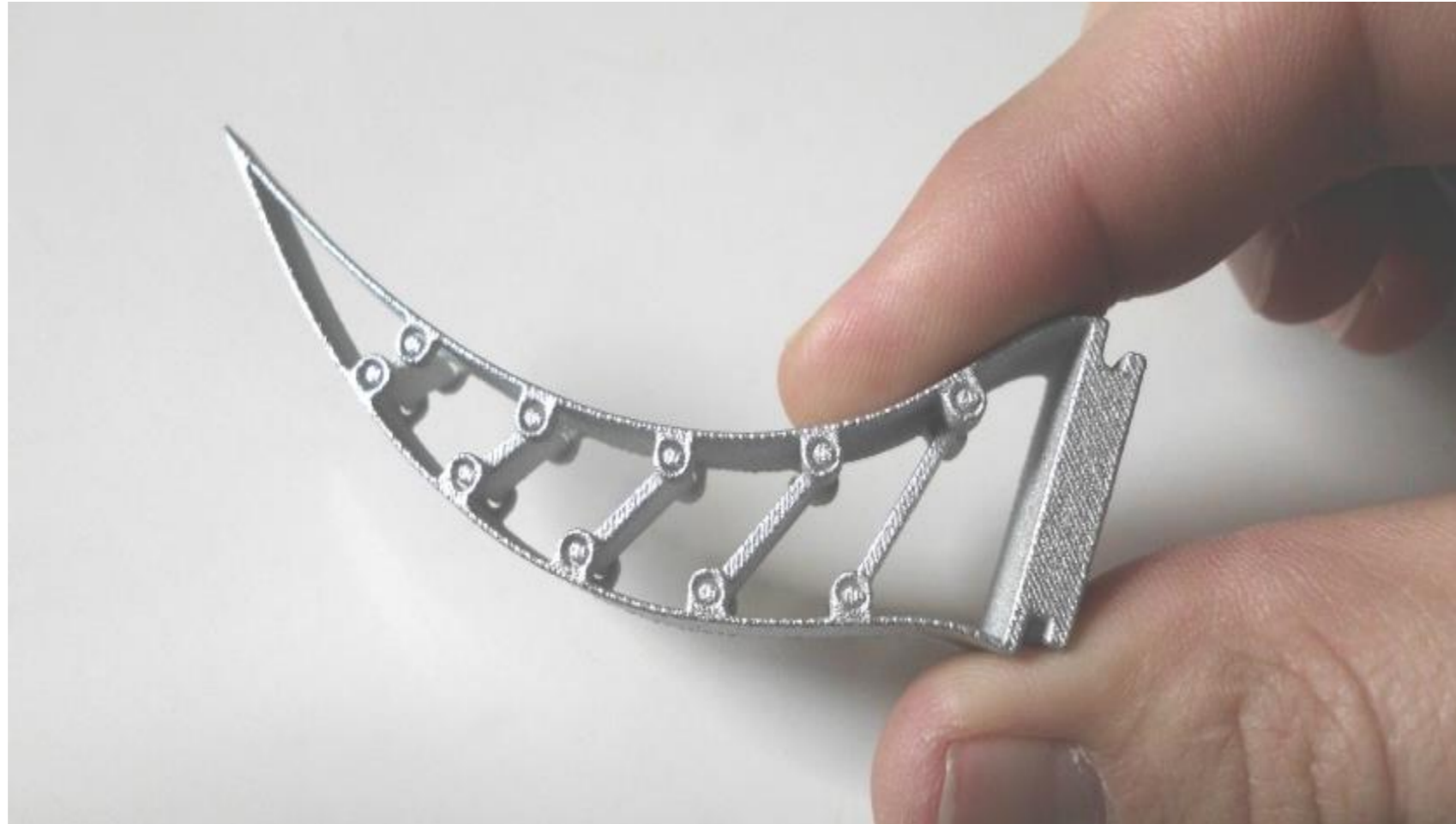
Source: LogiLink



# Conceptual Lightweight Design

Weight reduction through highly integrated design

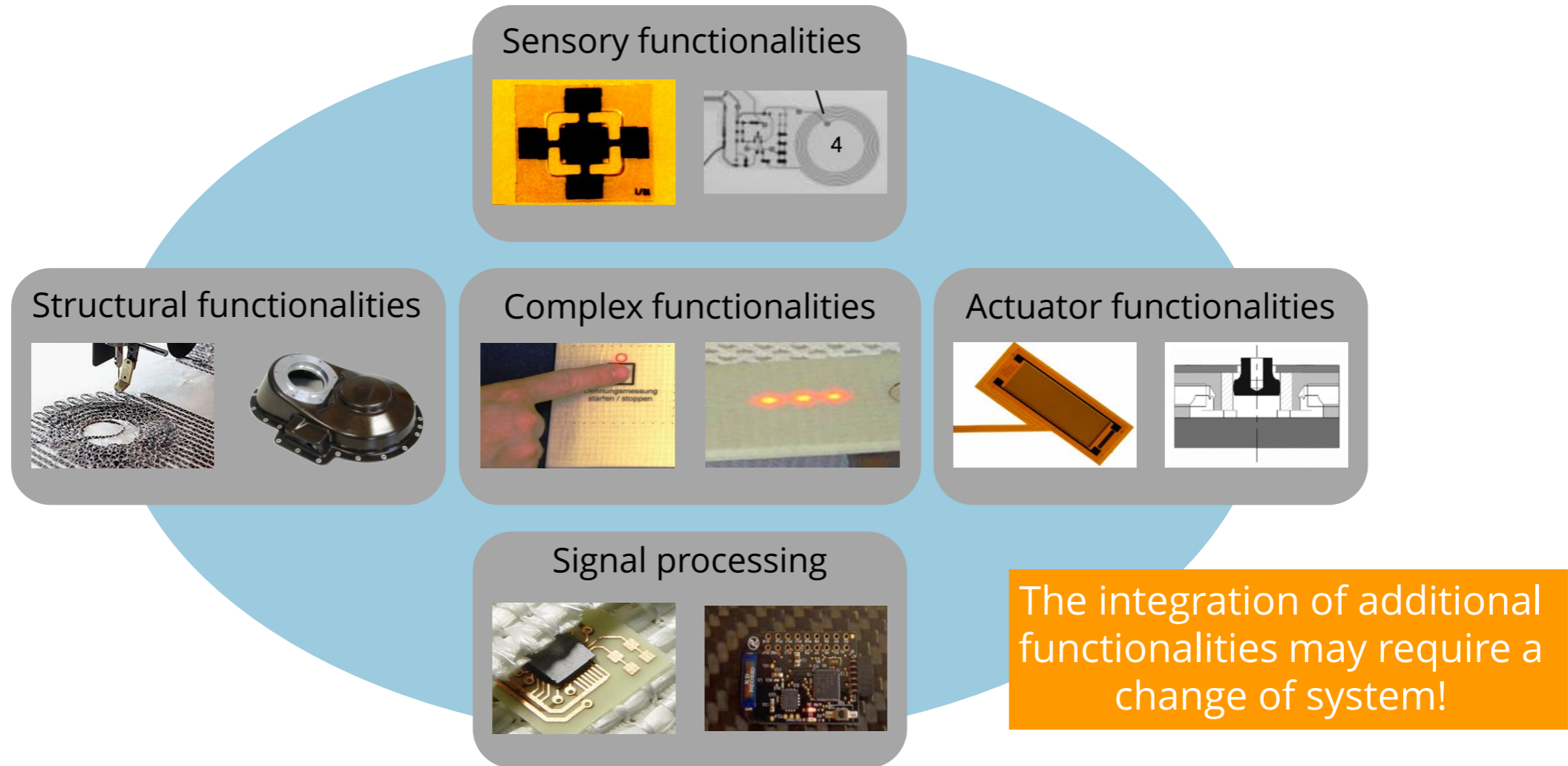
FESTO FinGripper



# Conceptual Lightweight Design

Weight reduction through highly integrated design

Integration of basic and additional functionalities



# Function-Integrative System Lightweight Engineering in Multi-Material Design: (= Eierlegende Wollmichsau = egg-laying wool milk sow)





**Thank you**  
for your attention.