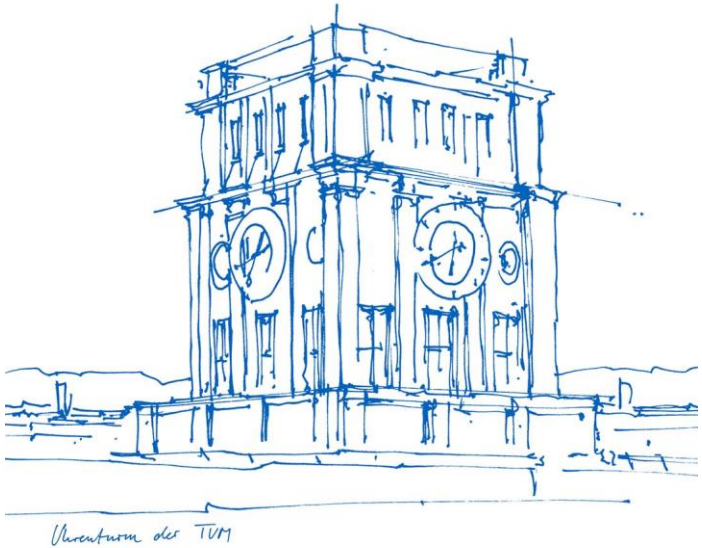
Laboratory for Product Development and Lightweight Design
TUM School of Engineering and Design
Technical University of Munich

# Welcome to LPL!

Markus Zimmermann

Munich, July 10, 2023

LPL




# Design and Optimization of Complex Technical Systems

# Content

- Laboratory
- Projects
- Collaboration Modes

# LPL Team


**Lab Management**
Prof. Dr. Markus Zimmermann
Dr.-Ing. Markus Mörtl

**Postdoc**
Dr. Anand Sureshbabu

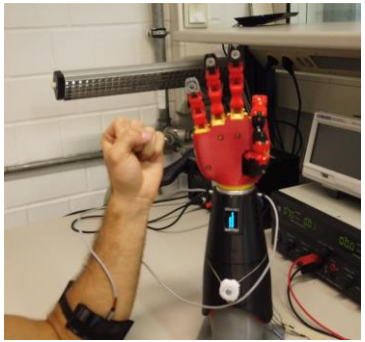
**Associated Lecturer**
Dr.-Ing. Stefan Sicklinger

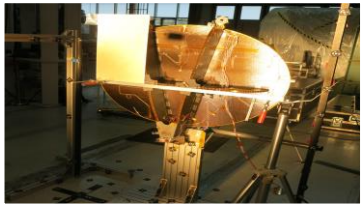
**Administration**
Edith Marquard
Marion Riedel
Katja Zajicek
Eva Körner
Robert Weiß

**Technical Staff**
Manfred Bauer
Karl-Ludwig Krämer
Michael Schweiger
Josip Stokic

**Research Assistants**
Maximilian Amm
Nicola Barthelmes
Eduardo Della Noce
Felix Endress
Jintin Frank
Martin Frank
Klemens Hohnbaum
Miguel Martins Pacheco
Philipp Radecker
Mahadevan Ravichandran
Jasper Rieser
Eduardo Della Noce
Akhil Sathuluri
Philipp Schröder
Johannes Soika
Jakob Trauer
Tobias Wanninger
Duo Xu
Lucien Zapfe
Yunzhe Zhang
Klara Ziegler

# Lab Infrastructure





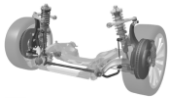
# Markus Zimmermann

**Academic Training**

- TU Berlin, Mechanical Engineering
- University of Michigan, Mechanical Engineering
- Ecole Polytechnique
- MIT, PhD

**BMW**

- Body design
- Crash design
- Vehicle dynamics
- Interdisciplinary projects



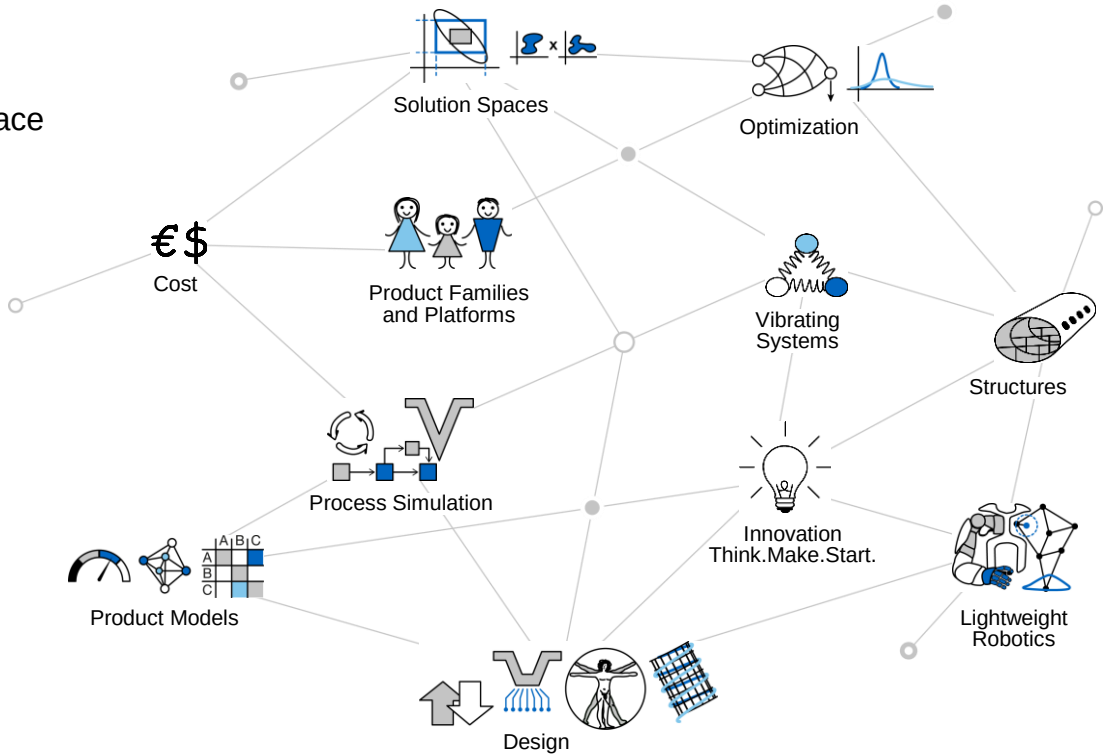
**Technical University of Munich**

- Since November 13th 2017

# Research

Solution Space Engineering

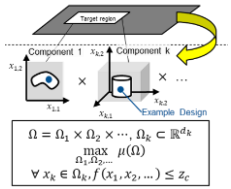
Lightweight Structures

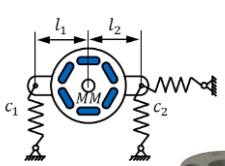


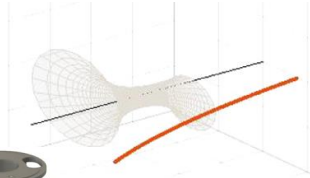

Methods & Processes

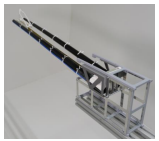
Robot Systems

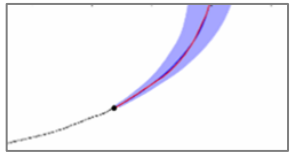
# Research


Target region
Component 1
Component k
Example Design
$\Omega = \Omega_1 \times \Omega_2 \times \cdots, \Omega_k \subset \mathbb{R}^{d_k}$
$\max_{\Omega_1,\Omega_2,\ldots} \mu(\Omega)$
$\forall\, x_k \in \Omega_k, f(x_1, x_2, \ldots) \leq z_c$

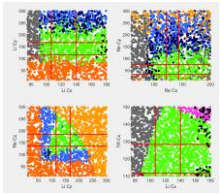

$l_1$
$l_2$
$c_1$
$c_2$
MM

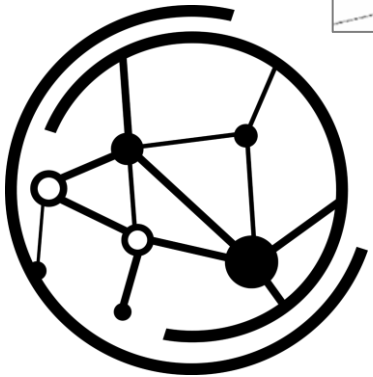


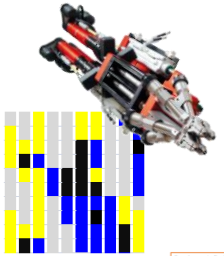


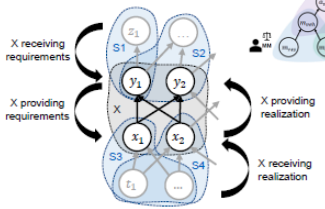


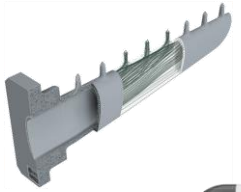

Knowledge
Evaluation
Design
Dependency Graph
What are the relevant design variables and performance measures?
Bottom-up mapping
How to quantify the performance?
Top-down mapping
What are the conditions to reach all design goals?

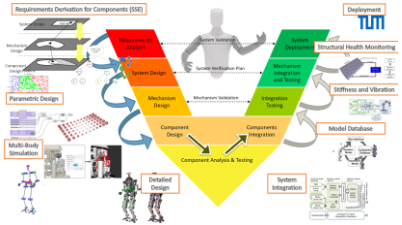


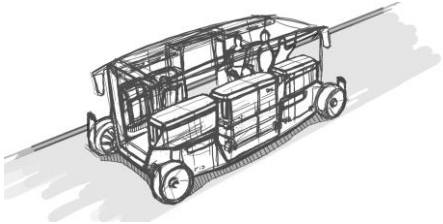


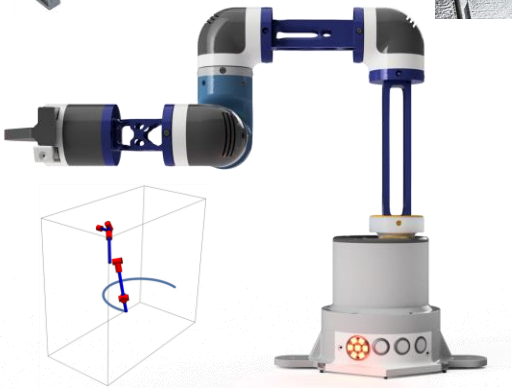



X receiving requirements
X providing requirements
X providing realization
X receiving realization
S1
S2
S3
S4

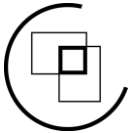



Requirements Derivation for Components (SSE)
Deployment
Requirements Analysis
System Validation
System Deployment
Structural Health Monitoring
System Design
System Verification Plan
Mechanism Integration and Testing
Parametric Design
Mechanism Design
Mechanism Validation
Integration Testing
Stiffness and Vibration
Component Design
Components Integration
Model Database
Multi-Body Simulation
Component Analysis & Testing
Detailed Design
System Integration





# Teaching



Solution Space Engineering

Methods & Processes

Lightweight Structures

Robot Systems

**MDO**
Multidisciplinary Design Optimization (E)
*Lecture (Master)*

**DPDS**
Design and Partitioning of Dynamic Systems (E)
*Lecture (Bachelor/Master)*

**FVW**
Composite Materials (D)
*Lab Course (Bachelor/Master)*

**KOMA**
Cost Management (D)
*Lecture (Master)*

**TopOpt**
Topology Optimization(E)
*Lab Course (Bachelor/Master)*

**Leichtbau**
Lightweight Design (D)
*Lecture (Bachelor)*

**FEM**
Finite-Element Method (D)
*Lab Course (Bachelor/Master)*

**MPD**
Methods of Product Development (E)
*Lecture (Master)*

**ExoskeleTUM**
Exoskeleton project (E)
*Seminar (Bachelor)*

**Leichtbau**
Lightweight Design (D)
*Lab Course (Bachelor/Master)*

**PKE**
Product Development – Concept & Design (D)
*Lecture (Bachelor)*

**EDCP**
Experience the Development of Complex Products (E)
*Lab Course (Bachelor/Master)*

**SemBio**
Bio-inspired Design (E)
*Seminar (Bachelor/Master)*

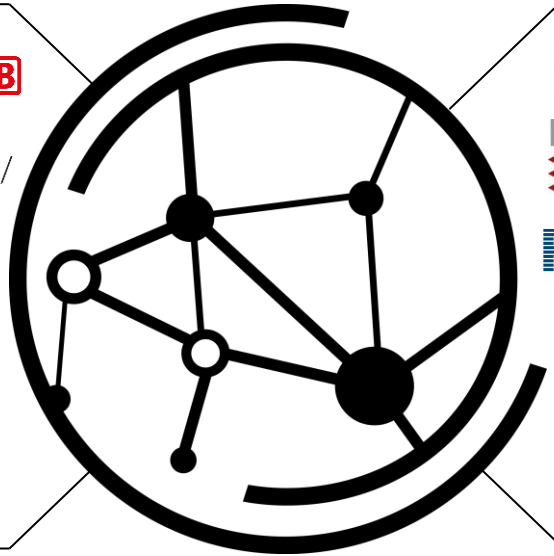
**TMS**
Think.Make.Start. (E)
*Lab Course (Master)*

**RobOpt**
Numerical Optimization for Robot Design and Control (E)
*Lab Course (Bachelor/Master)*

# Partners

**Industry Partners**

**Academic Partners**



**Startups & Initiatives**

# Content

- Laboratory
- Projects
- Collaboration Modes

# LCL Robots

Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

## Low-Cost Lightweight Robots on Demand

**Funding:** Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

**Partner:** voxeljet MiMed HAWE HYDRAULIK

**Contact:** Anand Suresh, Ph.D

**Scope:** LPL and the Institute of Micro Technology and Medical Device Technology (MIMED, Lüth) are jointly developing a process for the semi-automatic design of low-cost robots. The innovation of the project consists in bundling the considerable progress made in recent years in different robotics fields (integration of AI technologies in the design process, 3D printing manufacturing technology, drive and design concepts for lightweight robots) in order to realize low-cost, customizable and rigid lightweight robots for the mass market for the first time.

**Anticipated results:** Tools for automatic robot design and load path optimization, design methods for vibration isolation, demonstrator

V1.2.6 V1.2.6.

**Journal Paper:** Sathuluri, A.; Sureshbabu, A.V.; Frank, J.; Amm, M.; Zimmermann, M. Computational Systems Design of Low-Cost Lightweight Robots. *Robotics* **2023**, *12*, 91. https://doi.org/10.3390/robotics12040091

# DIVA

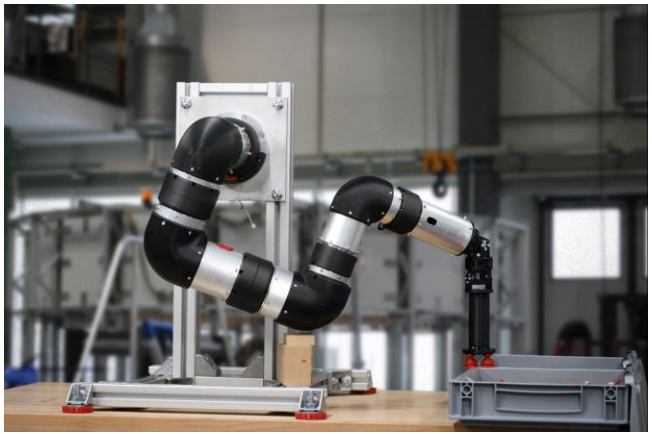
## Intuitive Design in Contrast to the V-model and its Analysis

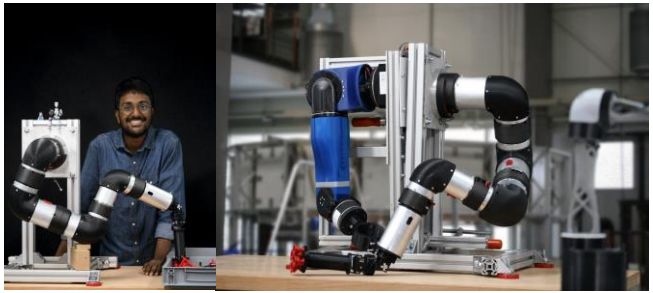
**Funding:** State of Bavaria

**Contact:** Anand Suresh Ph.D; Lukas Krischer, M.Sc.; Akhil Sathuluri, M.Sc.; Yunzhe Zhang, M.Sc.

**Scope:** Bottom-Up approaches are the norm when it comes to design of humanoid robots. The DIVA approach works towards automatic design of robots by adapting a top-down, user requirements driven approach to the problem. To realize this, the project involves one half of the robot adopting the experience-based bottom-up approach and comparing it to the top-down approach developed by the Lab.
The experience-based part is termed D-ROB for designer robot while the top-down approach is named V-ROB for V-Modelling inspired design.

**Results:** Design methodology for top-down development of robotic components.





**ICRA Paper:** Sathuluri, A., Sureshbabu, A. V., & Zimmermann, M. (2022). A systems design approach for the co-design of a humanoid robot arm. *arXiv preprint arXiv:2212.14256*. ICRA 2023, London

# DSL4RAS

Domain Specific Language for robot-like Systems

**Funding:** Deutsche Forschungsgemeinschaft (DFG)

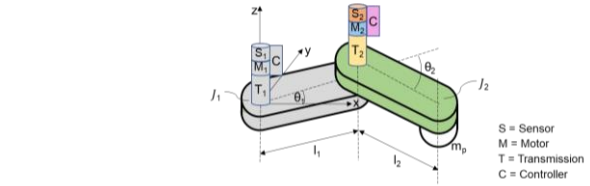
**Partners:** Institute of Machine Elements (FZG), Institute of Automation and Information Systems (AIS)

**Contact:** Klara Ziegler, M.Sc.

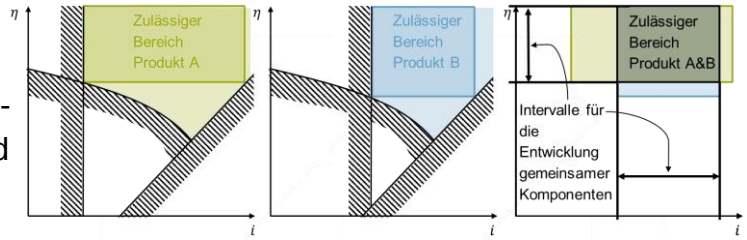
**Scope:** Designing robot-like systems involves several domains. DSL4RAS aims at developing domain specific languages that are compatible with each other. With them, co-design of mechanical elements, like gears, mechatronic elements, like motors, control logic and sensor design shall be enabled. A particular focus lies on quantitative detail modelling of mechanical characteristics of gears, in particular on degradation effects. Three TUM labs work together in a DFG-supported project.

**Anticipated Results:** Design languages for all relevant components of robot-like systems, modelling procedures, procedure model for systems design and product family design

System and component Modelling




Solution Spaces for Product Family Design



# KME – ExoTool

Development of a Robot-like, Portable Tool with Advanced Ergonomic Functions

**Funding:** KME – Kompetenzzentrum Mittelstand GmbH

**Partner:**

**Contact:** Anand Suresh, Ph.D

**Scope:** Our lab along with the Chair of Ergonomics (LfE) are jointly developing the ExoTool. The ExoTool is the combination of a new type of body-mounted robotic system and existing tools (e. g. standard drills). The ExoTool defines a new type of tool that complements classic hand-held power tools by adding essential ergonomic functions. It is designed for workers in construction sites and enables them to work more productively with less physical strain. Specifically, it is intended to (1) detect loads acting on tool and user, (2) reduce loads on the user and (3) dampen vibrations.

**Anticipated Results:** Two prototypes of a human-centered support tool with vibration isolation, static load reduction and access to load and position data

# PLUTO

Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

Product family design of smallsats for optimal thermal management

**Funding:** Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

**Partners:** EMM GmbH

**Contact:** Philipp Radecker M. Sc.

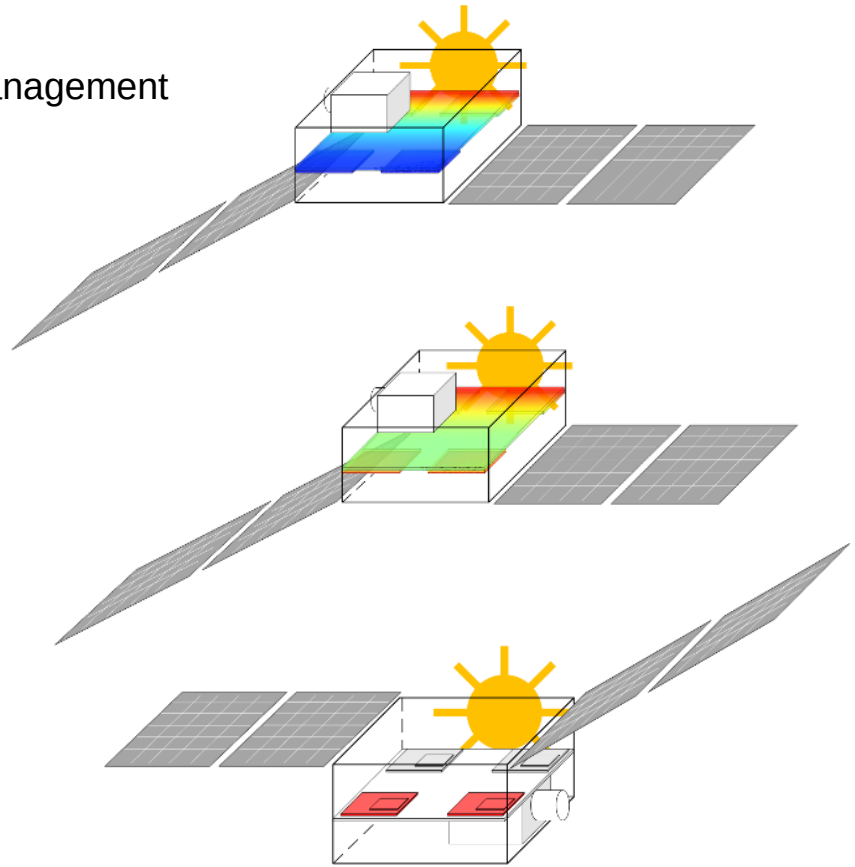
**Scope:** LPL and EMM GmbH are jointly developing a thermal management system for cubesats by using a digital twin as well a conecpt for distributed computation within the satellite. Therefore, the position of the computation units are optimized.

**Anticipated results:**

(1) Optimized placement of the components within the cubesat concering thermal management

(2) Digital twin for thermal management

(3) Validation of the procedure using a prototype



Supported by:

Federal Ministry for Economic Affairs and Climate Action

# ProVeS

Developing an intelligent CFRP rim

**Funding:** Federal Ministry for Economic Affairs and Climate Action (BMWK)

**Partners:** SemsoTec Group

**Contact:** Klemens Hohnbaum, M.Eng.

**Scope:** Knowing a rim's state at any time enables a reliable prediction of upcoming changes in its condition and safety of use.

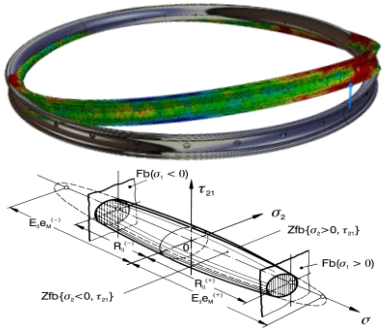
**Anticipated results:**
Predicting the rim's state allows to reduce the global security factor, resulting in less material used in the production process without trade-offs in structural integrity.

This creates a lighter rim with higher race performance while reducing carbon emissions.

**Sensing**

**Machine Learning**

**Simulation**



Supported by:

Federal Ministry for Economic Affairs and Climate Action

# PROVING

## Aircraft Structure Design for Additive Manufacturing

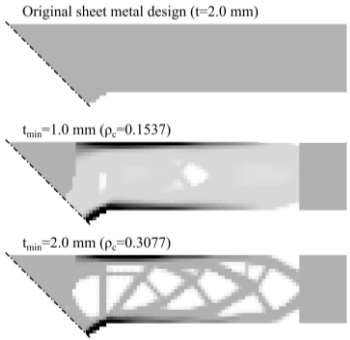
**Funding:** Federal Ministry for Economic Affairs and Climate Action (BMWK)

**Partners:** BAM, BOEING, EASA, EES, IABG, MSC Software, oerlikon, RS.aero

**Contact:** Felix Endress, M.Sc.

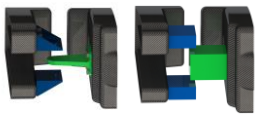
**Scope:** For aerospace applications metal additive manufacturing bears potentials for lightweight design and cost-effective low volume productions. Yet, the development and design of mechanical systems is complex, due to great influences of the build process (anisotropic material behaviour, failure modes, etc.) and various DfAM principles and opportunities. Therefore, Additive Manufacturing characteristics are investigated and fed back into the development process.

**Anticipated results:** Approaches for the optimization-driven product development of aircraft structures are being developed, considering process, material and design characteristics of metal additive manufacturing. Reduction of physical testing and improved optimization and simulation results.




Results of topology optimization

Design study



Crack in AM specimen

Design Domain Distribution

Supported by:

Federal Ministry for Economic Affairs and Climate Action

# PrintYourLab

## Optimizing Microfluidic Structures for Medical Applications

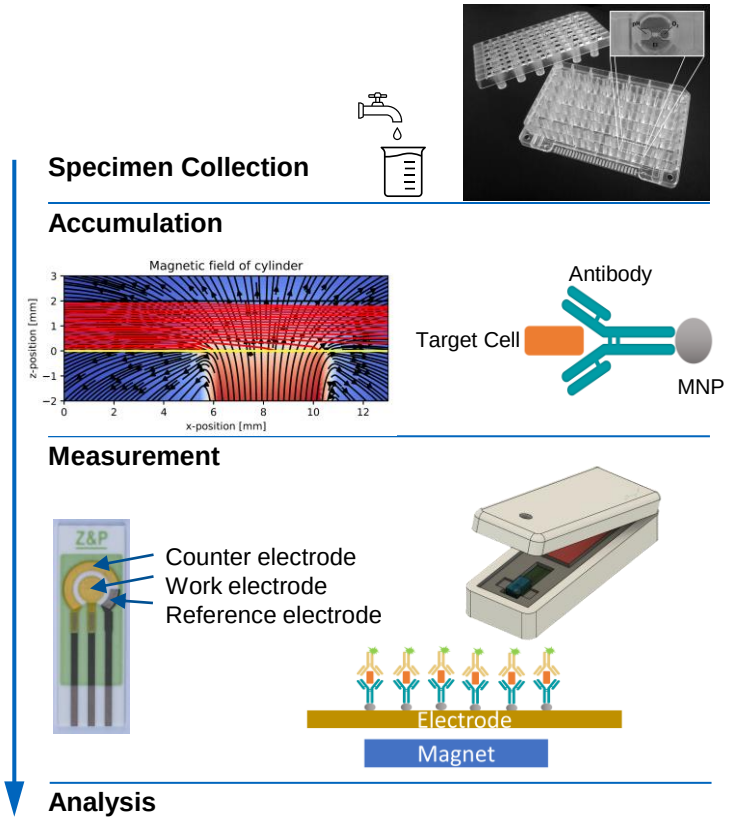
**Funding:** Federal Ministry for Economic Affairs and Climate Action (BMWK)

**Partners:** domatec Technology & Services for Facility and Hygiene; Steinbeis; Technische Universität München

**Contact:** Tobias Wanninger, M.Sc.

**Scope:** The goal of the project is to develop a handheld device which can perform water analysis regarding contamination with pathogenic microorganisms on site and within a small period. The development of suitable microfluidic structures are required to perform the rapid test and detect specific microorganism. The structure itself is to be automatically designed and optimized by a topology optimization method based on target cell specific requirements.

**Anticipated results:** Rapid test for water facilities based on immunomagnetic separation and electro-chemical impedance spectroscopy. Development of a requirement-driven automatic design method for microfluidic structures.



# SePos

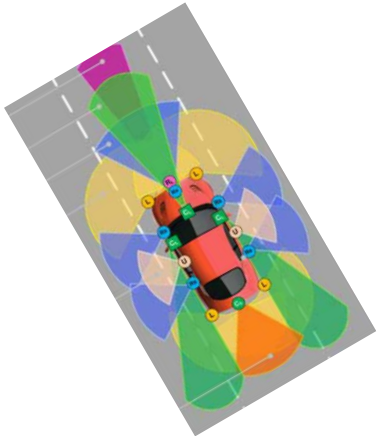
Optimal Sensor Positioning for Highly Automated Vehicles

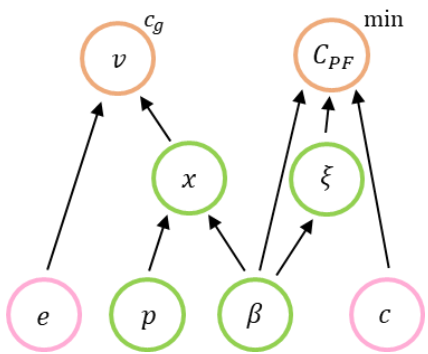
**Funding:** SePos 1: AUDI AG; SePos 2: Cariad

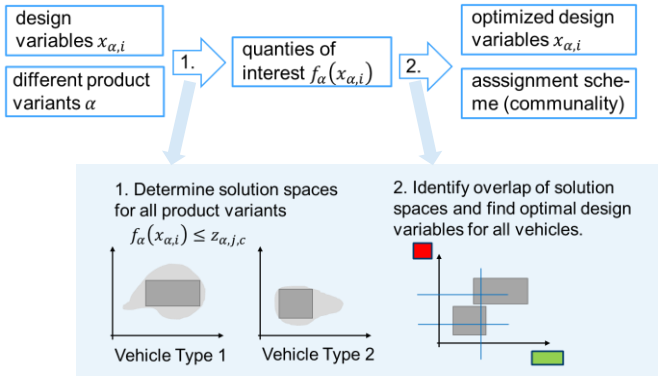
**Contact:** Nicola Barthelmes, M.Sc.

**Scope:** Perception of the surroundings is the basis for all algorithms that decide the actions of an autonomous vehicle (AV). Number and specifications of different perception sensors (e.g., camera, lidar, radar) have to be decided in an early development phase. Several vehicle types and their various configurations constitute a product family. Sharing sensors among vehicles may save cost, however, may decrease performance. The parameters of the final design of the Ego vehicle are still unknown, e.g., its dimensions or dynamic behavior. The sensor setup has to be optimal for a manifold of different scenarios, described by the behavior of the Ego vehicle, other static and dynamic objects, traffic infrastructure and environmental conditions.

**Anticipated Results** For optimal perception performance for each vehicle and total cost, the distribution and positionings of sensors are to be optimized.





# Solution Spaces

Towards the theoretical limit of optimal requirement decomposition using solution spaces for complex systems design

**Funding:** Deutsche Forschungsgemeinschaft (DFG)

**Contact:** Eduardo Rodrigues Della Noce, M.Sc.

**Scope:** Dividing a large system into smaller parts may reduce design complexity and enable concurrent engineering. Appropriate component requirements help to align separated and independent design work towards an overall system design goal. Existing approaches compute so-called *solution spaces* that are the Cartesian product of permissible regions for component properties. The key idea here is to compute and maximize *generalized component solution spaces*. If properties of all components are realized within their respective component solution spaces, the overall design goal will be reached with maximum design freedom.

**Anticipated Results:** Tools for Systems Design, Solution Space Engineering and Optimization.

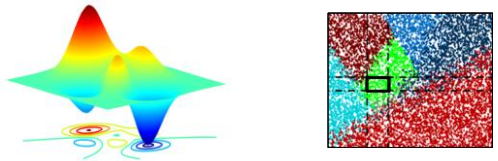


*Fig. 1: Design based on classical optimization (left) and on solution space optimization (right).*

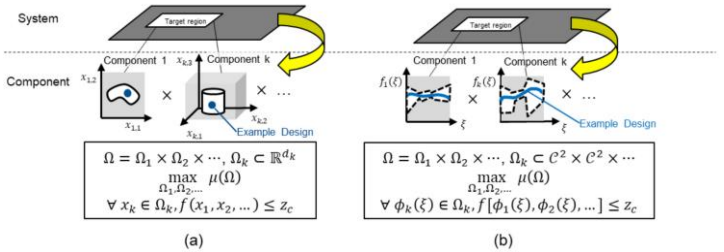
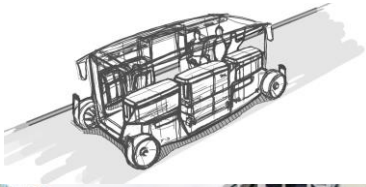



*Fig. 2: Solution spaces for components that are characterized by (a) finite dimensional design vectors and variables and (b) functions.*

# STEAM

Solutions for Transport Networks with Electric Advanced Mobility



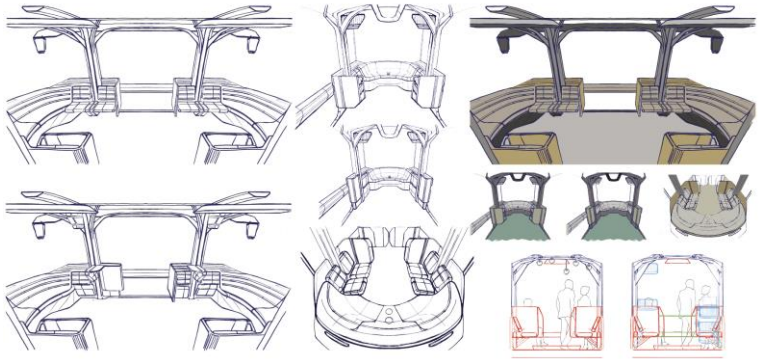
**Funding:** BMBF Clusters 4 Future – Mcube

**Partners:**

**Contact:** Nuno Miguel Martins Pacheco, M.Sc.

**Scope:** Develop user-centered vehicle usage concepts for passenger and freight transportation (integrated transportation). Through increased flexibility and efficiency in public transport, we aim to merge individual, public, and freight transportation for optimal usage.

**Anticipated results:** Prototype of interior concept



# FCC

Support structure for next generation Muon detector at CERN

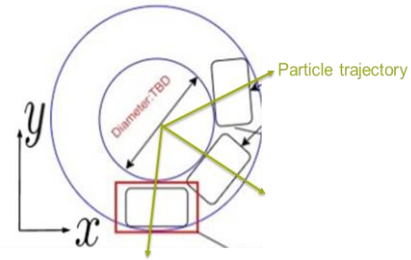
**Funding:** Bavarian-Czech Academic Agency

**Partners:** CTU Prague, Max Planck Institute of Physics

**Contact:** Mahadevan Ravichandran, M.Sc.

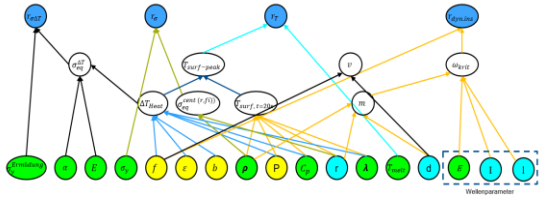
**Scope:** Muon detectors are to be huge components to be arranged in vertical circles to detect particles in the Future Circular collider at CERN. These detectors are to be supported by a structure that meets the accuracy and stiffness requirements on the detectors. The project aims to develop a method to design the support structures.

**Anticipated Results:** A method to develop the support structure design for different boundary conditions

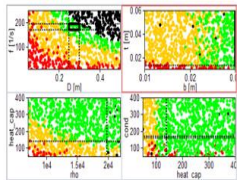



Circular collider with detectors
In different boundary conditions

Current generation muon detector tubes at a partner institute



Attribute Dependency Graph relating design variables and quantities of interest



Analysis of solution spaces

# IvarNext

A service robot for a nuclear fusion reactor

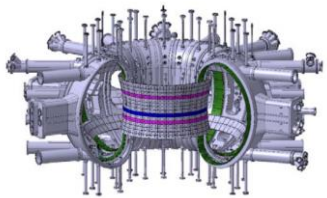
**Funding:** Max-Planck-Institut für Plasmaphysik

**Contact:** Akhil Sathuluri

**Scope:** For the inspection of a Tokamack fusion reactor, a robot is to be built that can inspect the reactor chamber in a high vacuum and move smaller objects. For this purpose, a nose following control system is being developed, which moves the snake-shaped robot inside the reactor.

**Anticipated Results:**

1. Automatic movement of the robot to a home position inside the reactor chamber
2. Manual control for inspection and movement of objects.



ASDEX Upgrade

Supported by:

Federal Ministry for Economic Affairs and Climate Action

# TuWAs

Transformation hub for powertrain value chains in forming industry

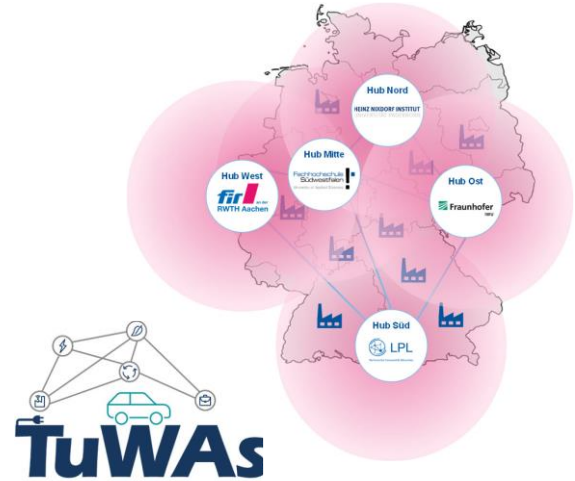
**Funding:** Federal Ministry for Economic Affairs and Climate Action (BMWK)

**Partners:** Fraunhofer IWU, Hochschule Südwestfalen, Heinz Nixdorf Institute, FIR e.V. at RWTH Aachen

**Contact:** Lucien Zapfe, M.Sc.

**Scope:** The project focuses on the transformation process of the automotive powertrain value chain in the forming industry due to the e-mobility. The objective is the successful transformation of the companies and to provide important impulses for the preservation of jobs, know-how and manufacturing networks in Germany and Europe.

**Anticipated Results:** Establishing of a transformation hub that enables companies in the forming industry managing the challenges presented by major future trends.




Supported by:

Federal Ministry for Economic Affairs and Climate Action

# BUENA

## Cross-sector industrialization of additive production

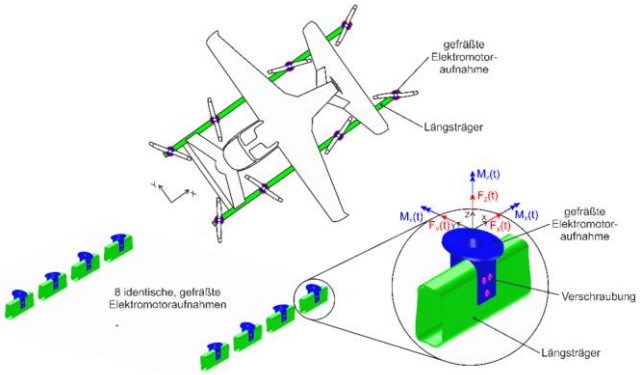
**Funding:** Federal Ministry for Economic Affairs and Climate Action (BMWK)

**Partners:** IABG VOITH BOEING FIT iwb nebumind Fraunhofer IAPT Bergische Universität Wuppertal

**Contact:** Philipp Schröder, M.Eng.

**Scope:** BUENA's project consortium has identified several issues as barriers to additive manufacturing (AM). In order to resolve these, the aim is to industrialize AM across all sectors. In this way, it is intended to contribute to the promotion of material- and energy-efficient lightweight construction. The project will be limited to the widely used laser powder bed fusion and direct energy deposition processes. Within this framework, the project aims to map or predict the costs and emissions of an AM component holistically over its life cycle. The technological realization of the project is carried out by a digital twin.

**Anticipated Results:** A digital twin including cost and emission model. Using this the costs and emissions of the life cycle can be included early in the development process.




Aerospace component to be developed

# Mu-Flash GEN 2

Target design for Tumor Therapy with Micro Beams

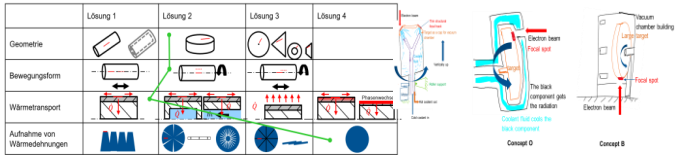
**Funding:** Albrecht Struppler Fellowship, TUM IAS

**Partners:** Klinikum rechts der Isar, Institute of Radiation medicine

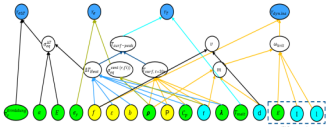
**Contact:** Mahadevan Ravichandran

**Scope:** Microbeam radiation therapy is novel and highly promising Technique for cancer treatment. It relies on high-intensity, high-dosage micrometer-sized X-ray beams produced by electrons hitting a fast-rotating so-called X-ray target. It is to be designed and optimized to withstand extreme mechanical power requirements of 1.5 MW to suit human treatment. An equivalent prototype is to be built and tested to validate the design.

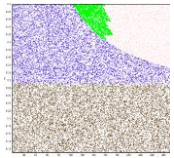
**Anticipated Results:** Tools for concept generation and analysis in new product development, practical application of solution space engineering, developed product for extreme thermo-mechanical loadingf



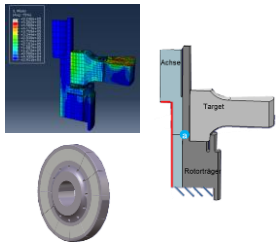

Morphological Chart and ideas for concept generation



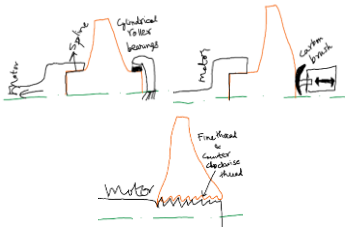
Attribute Dependency Graph relating design variables and quantities of interest



Analysis of solution spaces




Heat transfer simulations




Testing methods

# Completed Projects

completed

# Mu-Flash

## Tumor Therapy with Micro Beams and Compact Radiation Source

**Funding:** DFG

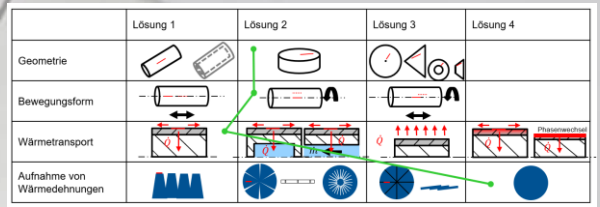
**Partners:** Helmholtz-Zentrum München, Klinikum rechts der Isar, Institute of Cancer Research, Forschungszentrum Jülich, FH Munich, University Mainz

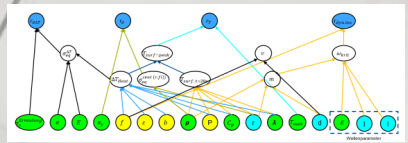
**Contact:** Mahadevan Ravichandran

**Scope:** Microbeam radiation therapy is a novel and highly promising technique for cancer treatment. It relies on high-intensity micrometer-sized x-ray beams, produced by electrons hitting a fast-rotating so-called x-ray target. It has been designed and optimized to withstand extreme mechanical and thermal loads while satisfying multi-disciplinary requirements from physics and medicine and ensuring manufacturability.

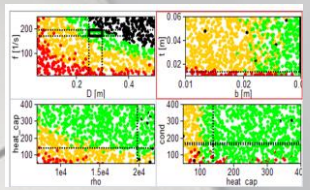
**Results:** Tools for concept generation and analysis in new product development, practical application of solution space engineering, systems for measurement of key performance parameters. **Prototype in hardware.**

Morphological Chart / Zwicky Box

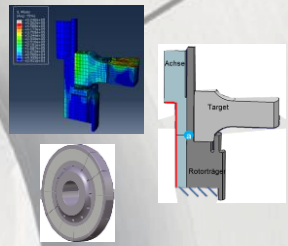


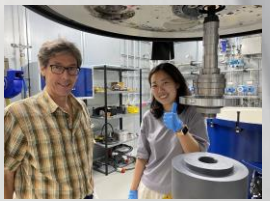
Attribute Dependency Graph relating
design variables and quantities of interest



Analysis of solution spaces




Heat transfer simulations



Team after successful preliminary spinning test

Completed 2022

# SysDeNoR

SysDeNoR

ZEIDLER FORSCHUNGS STIFTUNG

## System Design of Vibration and Noise Reduction

**Funding:** Zeidler-Forschungs-Stiftung

**Contact:** Duo Xu, M.Sc.

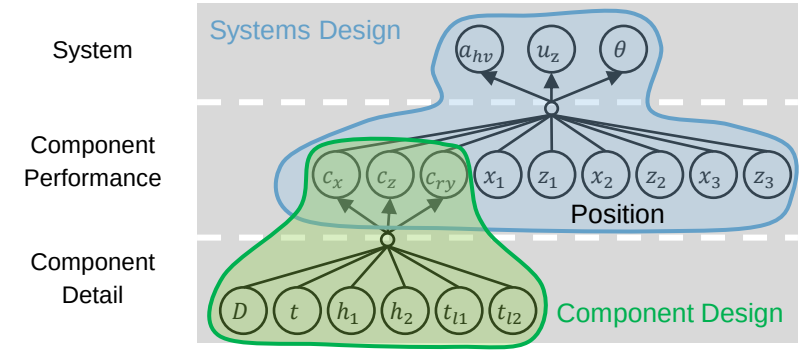
**Scope:** In this project, a top-down development method for the design of vibrating mechanical systems was developed that decomposes the overall system requirement into component level requirements based on Solution Space Engineering.

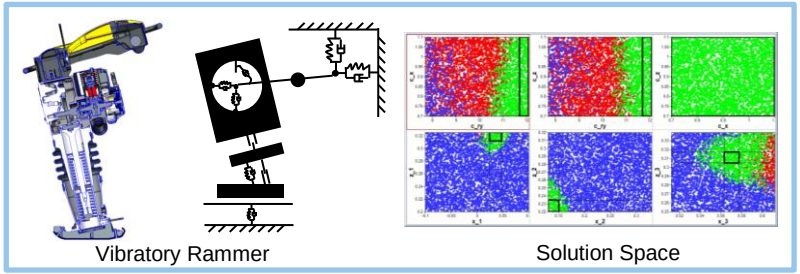
**Results:**

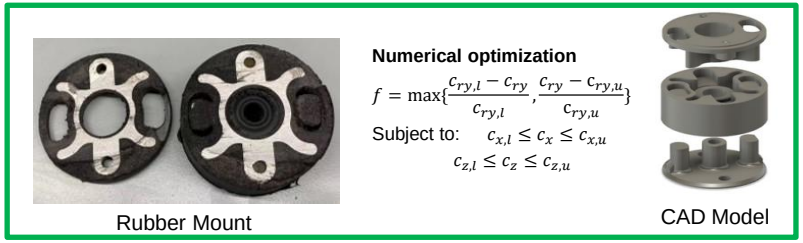
(1) Systematic top-down design method for vibrating systems to avoid iterations,

(2) Tools for precise derivation of quantitative component requirements.

(3) Three demonstrators including a real-world soil compaction device.



Completed 2022

# VibraInCo

Decomposition of vibrating structures and system requirements for independent component design

**Contact:** Jintin Frank, M.Sc.

**Partners:** Max Planck Institute for Extraterrestrial Physics

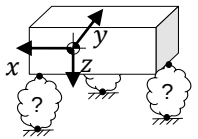
**Scope:** A requirement on the system eigenfrequency is decomposed for subsystems using solution spaces which enables independent component design. The system requirement is satisfied whenever the component design satisfies the decomposed requirements. Design optimization can be carried out separately for each component with requirements as constraints.

**Result:** (1) Method to define one-sided limits as requirements for independent component design.

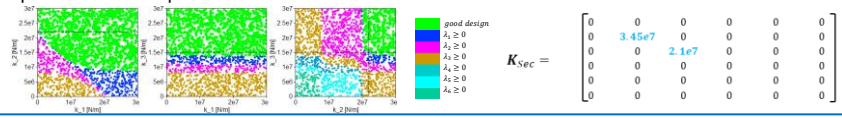
(2) Solutions for Athena WFI primary structure and support structure with optimal mass (within requirements).

System requirement

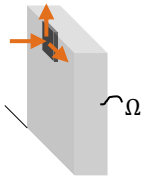
$$\omega_0^2 = \min_{\mathbf{u}(\mathbf{x})} \left( \frac{V_S(\mathbf{u}(\mathbf{x})) + V_{body}(\mathbf{u}(\mathbf{x}))}{T_{body}(\mathbf{u}(\mathbf{x}))} \right) \geq \omega_c^2$$




Requirements decomposition




Component design (support body)

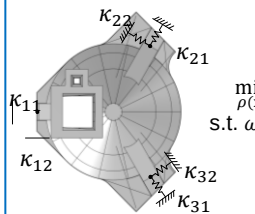



$$\min_{\rho_e} \quad m(\rho_e(x))$$
$$s.t. \quad \lambda_{min}(\mathbf{K}_S - \mathbf{K}_{Sc}) \geq 0$$
$$\mathbf{KU} = \mathbf{F}$$
$$0 < \rho_e \leq 1$$

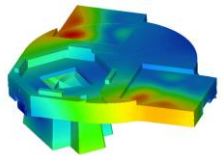
Classical TopOpt

TopOpt with improved constraint formulation

Component design (primary structure)




$$\min_{\rho(\mathbf{x})} \quad m(\rho(\mathbf{x}))$$
$$\text{s.t. } \omega_n(\mathbf{K}_c) \geq \omega_c$$



Completed 2022

# OptProLaS

KME

## Component Optimization Considering the Process Influences during Laser Beam Melting

**Funding:** KME – Kompetenzzentrum Mittelstand GmbH

**Partner:** iwb, STÖGER AUTOMATION, MTU Aero Engines, vectoflow measurements in fluids

**Contact:** Jasper Rieser, M.Sc.; Jakob Trauer, M.Sc.

**Scope:** Selective laser melting is a complex and relatively expensive additive manufacturing (AM) process. Geometrical deviations, residual stresses and build failure often pose challenges for users in practice. The aim of this project was to investigate how complex metallic components must be designed to better meet the special requirements AM while fully exploiting the great potentials of this powerful manufacturing techniques.

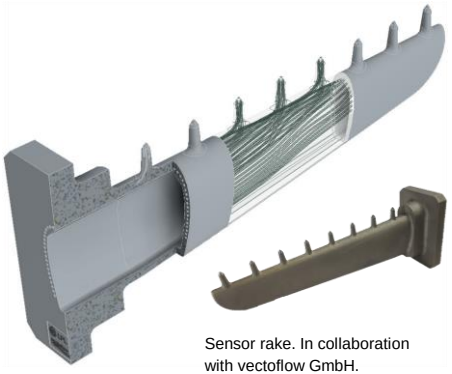
**Results:**

(1) A *procedure model* for the design of AM parts covering all essential steps from requirement elicitation to the final printed part.

(2) Three demonstrator parts: a customized *screw gripper*, a *gas turbine engine emissions rake* with internal pressure channels and a light-weight aero engine *bracket*.

Gripper for a handheld screwdriver by STÖGER AUTOMATION GmbH: The support-free redesign (right) provides mass savings of 30% compared to the conventional design (left).

Aero engine bracket with optimized topology. In collaboration with MTU aero engines AG.



Sensor rake. In collaboration with vectoflow GmbH.

Completed 2022

# DRAC

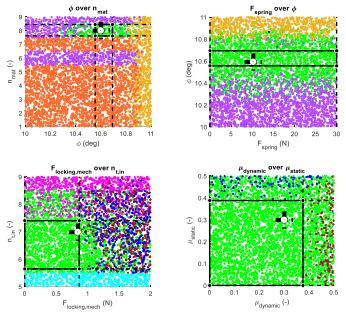
LSS Large Space Structures

## Deployable Reflector Antenna for Cubesat Missions

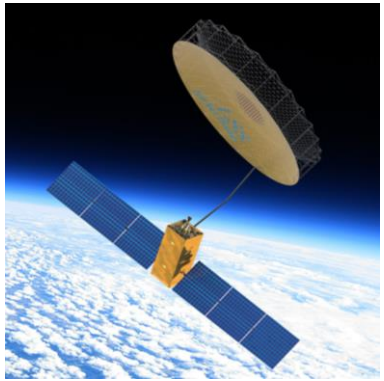
**Funding:** Large Space Structures

**Contact:** Lukas Krischer, M.Sc;

**Scope:** Cubesats have been developed for scientific and commercial aerospace missions. Due to the limited space available, it is often difficult to integrate large antennas into the satellites. In this project a deployable boom for a reflector antenna is going to be designed. The design innovative phase is guided by product development methodologies as well as quantitative top-down approaches as Solutions Space Engineering. Having concluded the design phase, a lightweight boom is designed using classical structural optimization techniques.



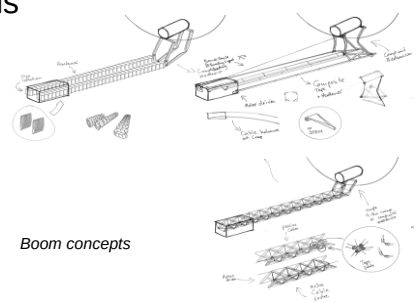
*Solution Spaces for Systems Design*



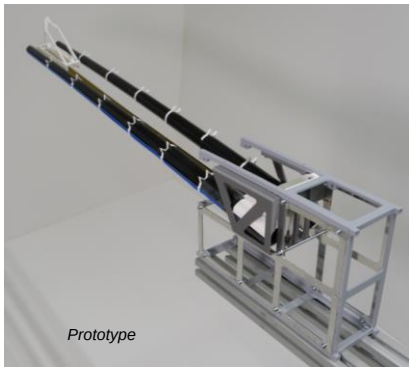
*CubSat in Space*

**Results:**

(1) New mechanism concept for boom extension,
(2) Successful prototype, and
(3) Successful application of Solution Space Engineering.



*Boom concepts*



*Prototype*

Completed 2022

# STRUBATEX

Bundesministerium für Wirtschaft und Energie

## Structural Health Monitoring-based Test Execution

**Funding:** Bundesministerium für Wirtschaft und Energie (BMWi)

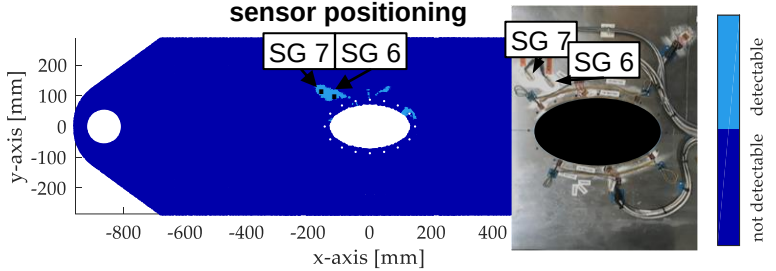
**Partners:** IABG, Bauhaus Luftfahrt

**Contact:** Simon Pfingstl, M.Sc.

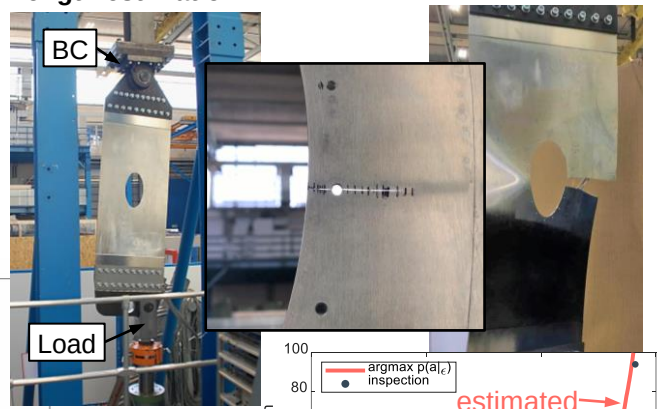
**Scope:** The development process of aircraft structures requires many fatigue tests. During these tests, engineers must inspect the aircraft structure continually to avoid final fracture of any component. Structural health monitoring may reduce time and cost associated with these inspections. Evaluating applied strain sensors is one possibility to monitor the structure.

**Results:** Tools based on Machine Learning Methods
(1) for positioning strain gauges,
(2) estimating crack length, and
(3) predicting crack growth.

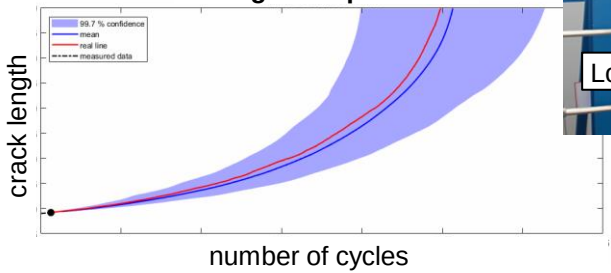
**sensor positioning**




**crack length estimation**




**crack growth prediction**



Completed 2022

# DESIM

## Simulation of Distributed Design Processes

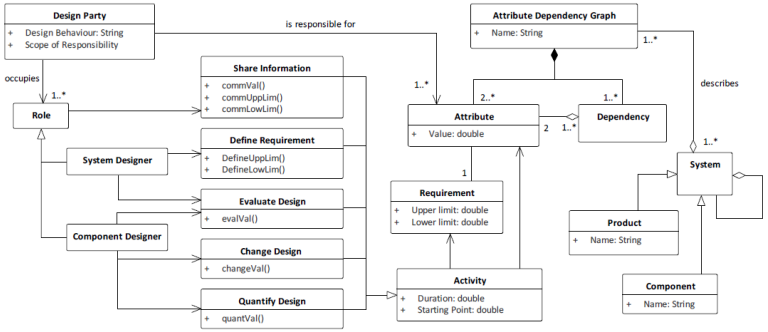
**Funding:** BMW Group

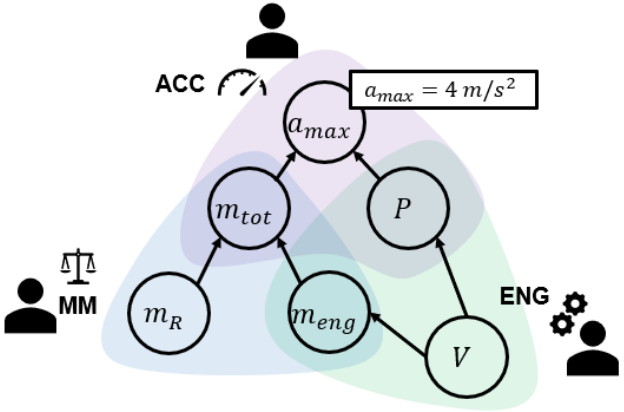
**Contact:** Ferdinand Wöhr, M.Sc.

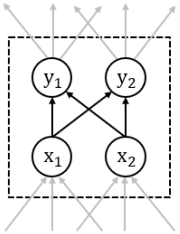
**Scope:** Development of an agent-based simulation model to evaluate distributed design processes with respect to product quality, development time and design flexibility. Key elements are:

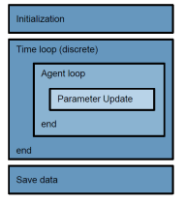
- Time-discrete simulation algorithm
- Mathematical process description
- Data model including all aspects
- Multi-scale model validation

**Results:** Combined agent-product-process model and simulation tool for improvement of organizations and development processes.



Completed 2021

# BMW Innovation

Conception and execution of internal Design Sprints like „Think. Make. Start.“

**Funding:** BMW Group

**Contact:** Nuno Miguel Martins Pacheco, M.Sc;

**Scope:** Develop new methodologies for design sprints to strengthen entrepreneurial behavior and multidisciplinary cooperation by helping our partners to identify and solve their problems using a prototyping methodology with innovative approaches and technologies. It is based on:

**(1) Observation** by identifying problems in the organization and empathize with relevant stakeholders.

**(2) Sprint:** Solving problems and develop initial solutions in close collaboration with employees of our partner companies .

**(3) Development:** Refinement of the solution concept.

**Results:** New methodology to

(1) support the innovation culture at BMW and

(2) help employees to create new solutions.

Completed 2022

# iKOMPASS

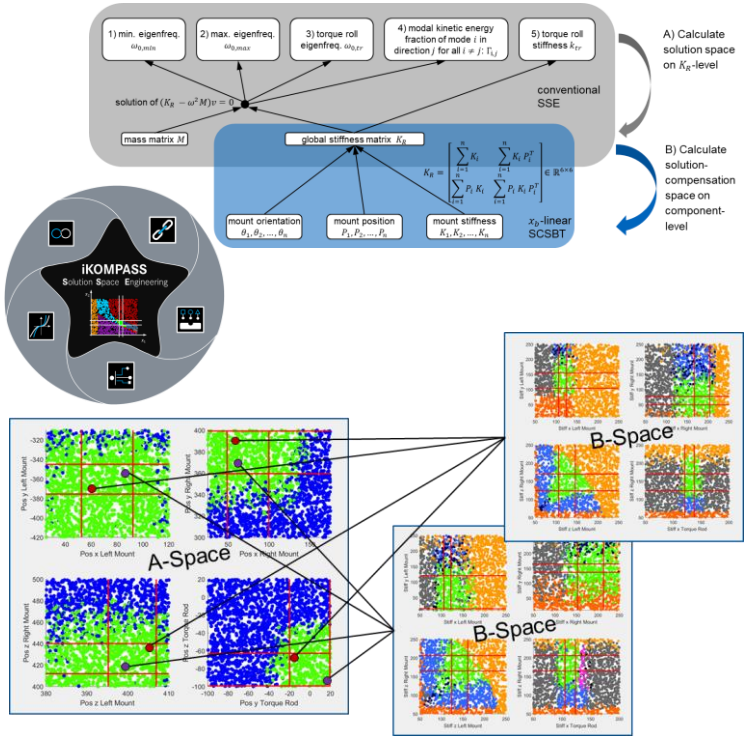
## Integrated Conceptual Design with Solution Space Engineering

**Partner:** Mercedes-Benz AG

**Contact:** Julian Stumpf, M.Sc.

**Scope:** For the design of engine mount systems, the conflict of objectives regarding NVH requirements means that Solution Spaces become very small and developers have insufficient flexibility in the early phase of product development to cope with the uncertainties due to the high level of system complexity. To counteract the uncertainty the focus of this project is the integration of requirements on the system level from different disciplines, already in the concept phase of development. Maximum flexibility for crucial design variables that need to be fixed in an early stage of development process is reached with the calculation of solution-compensation spaces with built-in tolerance. This ensures that all requirements can be met at a later stage of the development process, thus minimizing the number of iteration.

**Results:** Top-down methodology for the design of dynamic systems with respect to modal design criteria.



Completed 2022

# Product Family Design

STÖGER AUTOMATION

## Modular Product Family Design for Screw Driving Systems

**Funding:** Stöger

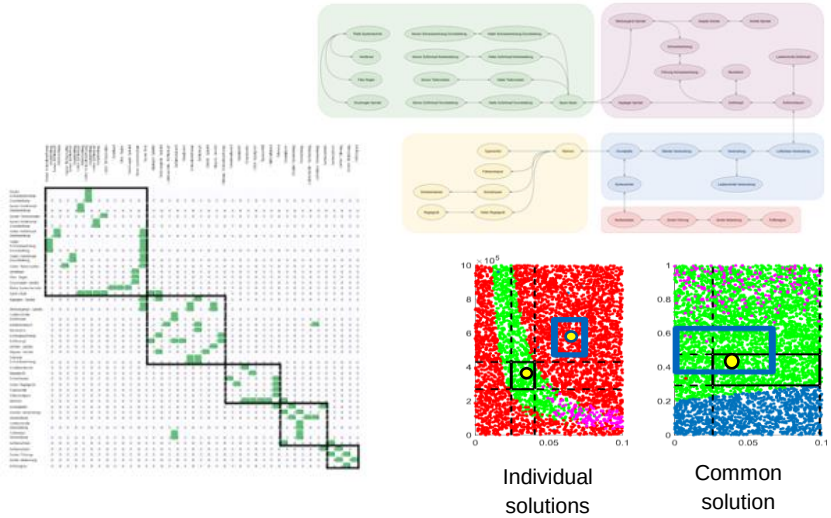
**Contact:** Sebastian Rötzer, M.Sc.

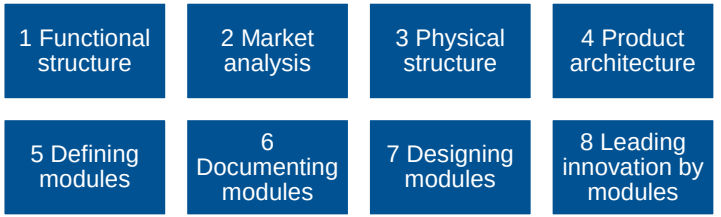
**Scope:** In the competitive market of highly automated screwdriving and fastening systems, companies need new methods for systematic product development for *specific customer requirements*. Modular product family design and customer orientation are key to extending mechanical excellence with digital functionality.

**Results:**

(1) A *method* for the design of product family architecture, connecting customer-oriented functions with specific product components.

(2) One *demonstrator* = a product architecture with full transparency about important design decision.




Top: example of screwdriving system. Bottom: Eight steps of the procedure applied in this project

# Content

- Laboratory
- Projects
- Collaboration Modes

# Kooperationsformate

| F&E Projekt | Gefördertes Projekt | Schulungs-Projekt | Studienarbeiten |
|---|---|---|---|
| 3 Monate – 5 Jahre | 1 – 4 Jahre | Individuell | Bis 6 Monate |
| Ab ca. 160 k€ / Jahr | 0 € (Firma erhält evtl. Zuwendungen) | 6k – 10k € pro Tag (nach Vorbereitungsaufwand) | 0 € |
| Forschung ergebnis-offen, individuell und evtl. in Kooperation mit anderen Partnern | Forschungsantrag ggfs. mit weiteren Partnern | Standardaufgaben ohne Forschungsinhalte | Betreuung durch Lehrstuhl- und Firmen-Mitarbeitende |
| Mitarbeiter*in vor Ort | Mitarbeiter*in vor Ort | Mitarbeiter*in vor Ort | Keine Mitarbeiter*in vor Ort |
| Übertragung der Rechte an Firma möglich | Öffentlich, bei KME verbandsintern | Urheberrechte beim Dozenten | Rechte beim Studierenden |

# Collaboration Modes




**R&D project**

- 3 month – 5 years
- > aprox. 160 k€ / year
- Forschung ergebnis-offen, individuell und evtl. in Kooperation mit anderen Partnern
- employee on site
- Übertragung der Rechte an Firma möglich

**Funded project**

- 1 – 4 years
- 0 € (Company receives fundings)
- Research proposal, possibly with further partners
- employee on site
- Öffentlich, bei KME verbandsintern

**Training project**

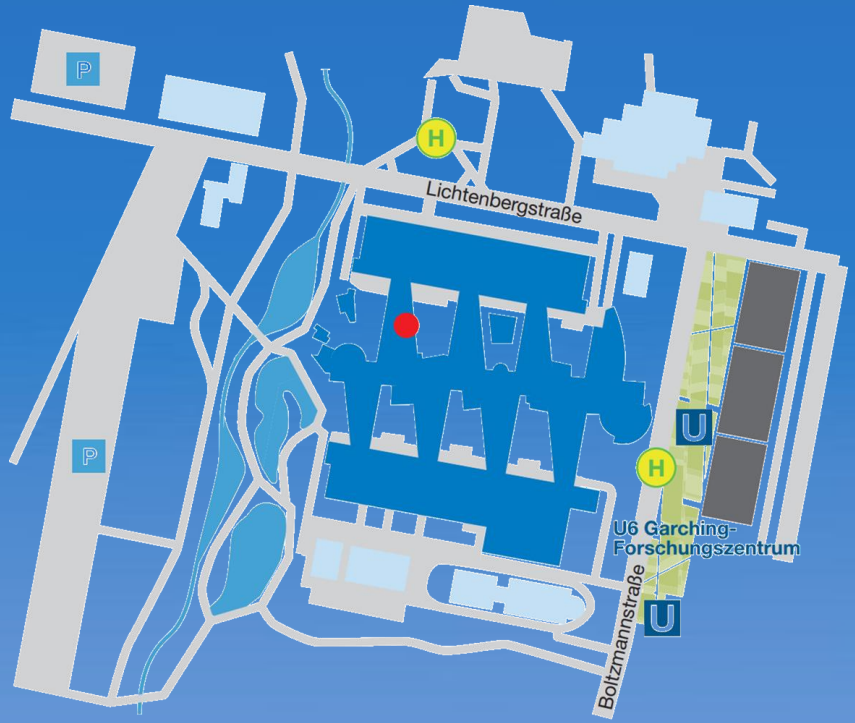
- Individuell
- 6k – 10k € a day (nach Vorbereitungsaufwand)
- standard tasks, no research
- employee on site
- Urheberrechte beim Dozenten

**Student research project**

- Up to 6 months
- 0 €
- Betreuung durch Lehrstuhl- und Firmen-Mitarbeitende
- no employee on site
- Rechte beim Studierenden

# Contact

- Technical University of Munich
  TUM School of Engineering and Design
  Department of Mechanical Engineering
  Laboratory for Product Development and Lightweight Design
  Boltzmannstr. 15
  D-85748 Garching b. München
- Building 6, 2nd floor
- Website: **www.mec.ed.tum.de/lpl**
- Contact: **zimmermann@tum.de**
- Phone: +49 89 289-15150



# Thank you for your attention!

LPL

Design and Optimization of Complex Technical Systems