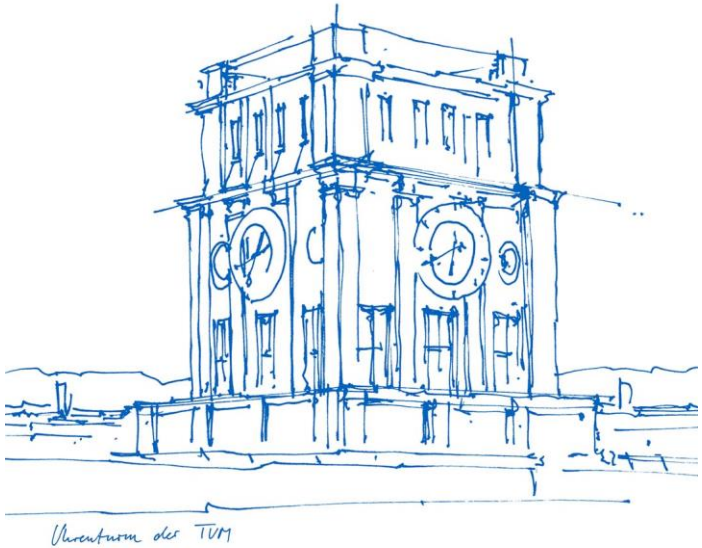
Laboratory for Product Development and Lightweight Design
TUM School of Engineering and Design
Technical University of Munich

Welcome to LPL!

LPL team

Munich, February 16, 2024

LPL



Design and Optimization of Complex Technical Systems

Content

- Laboratory
- Projects
- Collaboration Modes

Technical University of Munich

Technische Universität München

- Founded in the year 1868
- > 600 professors
- > 42.000 students

LPL Team

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

Postdoc
Dr. Anand Sureshbabu

Associated Lecturer
Dr.-Ing. Stefan Sicklinger
Dr.-Ing. Simon Pfingstl

Administration
Edith Marquard
Marion Riedel
Katja Zajicek
Eva Körner
Robert Weiß

Technical Staff
Manfred Bauer
Karl-Ludwig Krämer
Josip Stokic

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

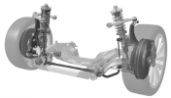
Markus Zimmermann

Academic Training

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

BMW

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



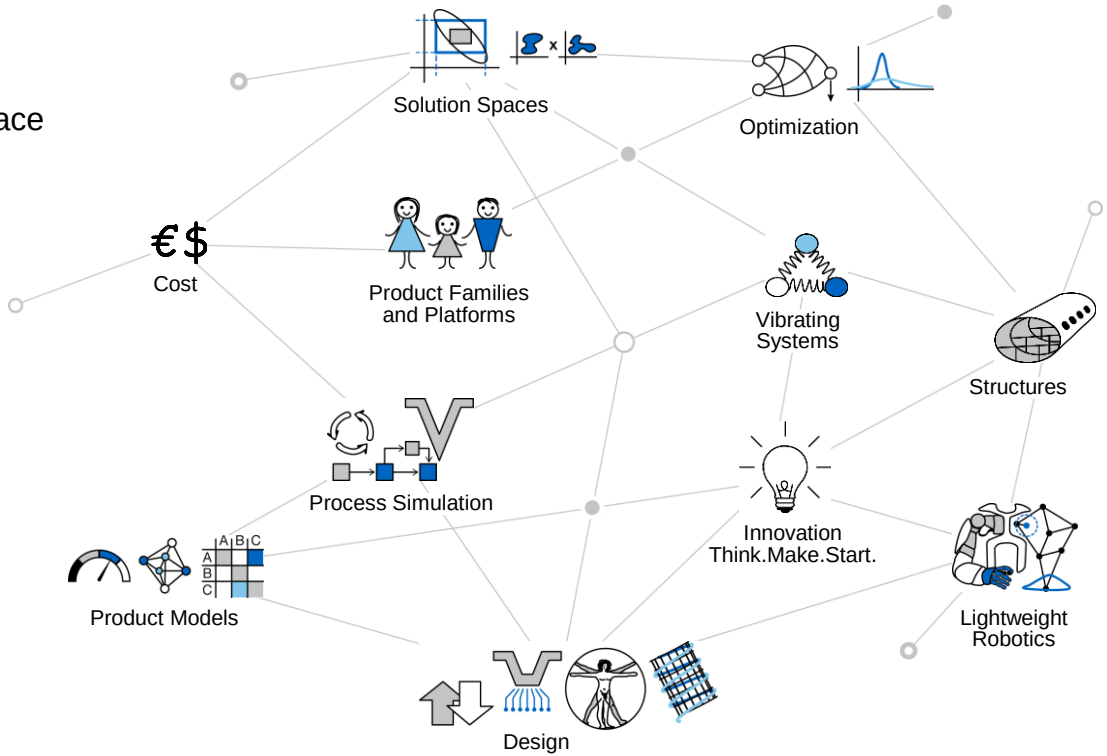
Technical University of Munich

- Since November 13th 2017

Research

Solution Space Engineering

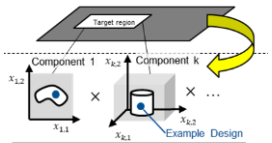
Lightweight Structures

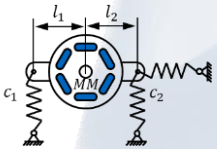


Methods & Processes

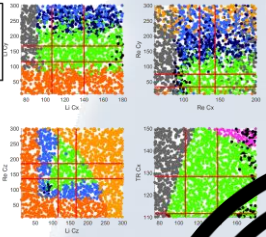
Robot Systems

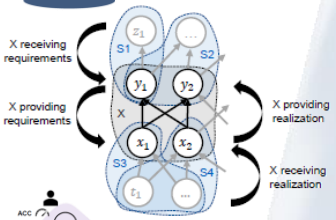
Research

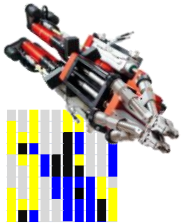


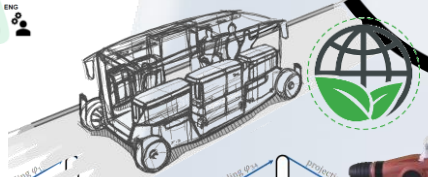


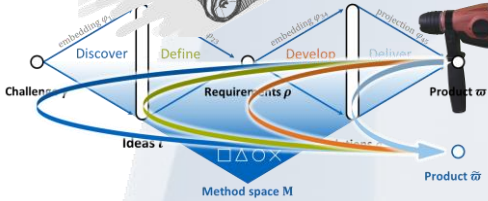
$$\Omega = \Omega_1 \times \Omega_2 \times \cdots, \Omega_k \subset \mathbb{R}^{d_k}$$
$$\max_{\Omega_1, \Omega_2, \ldots} \mu(\Omega)$$
$$\forall\, x_k \in \Omega_k, f(x_1, x_2, \ldots) \leq z_c$$

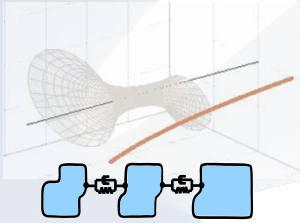


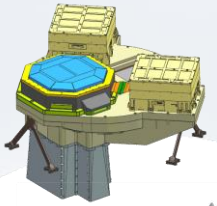


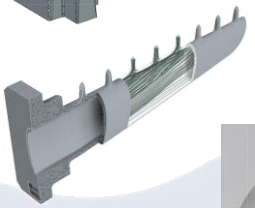




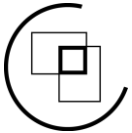








Teaching

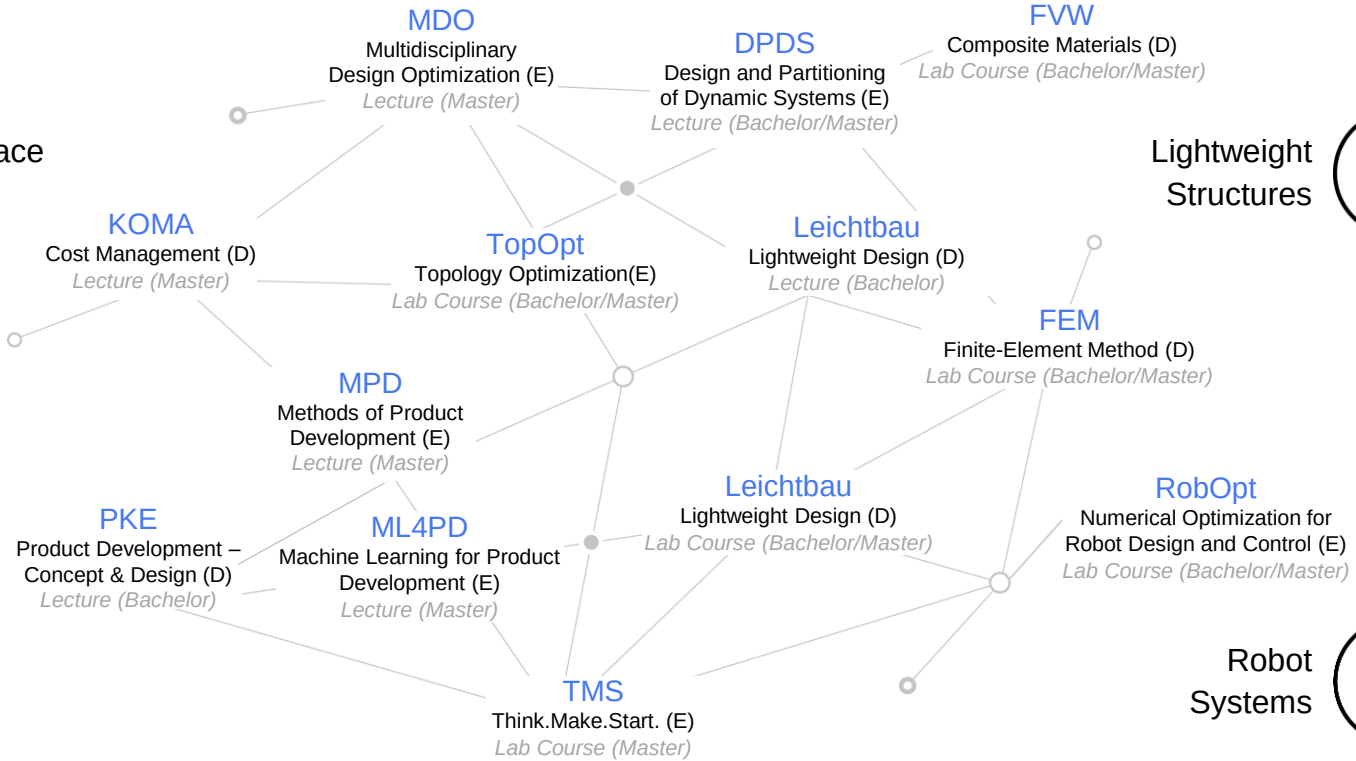


Solution Space Engineering

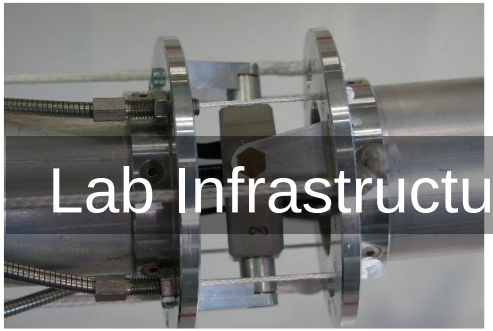
Methods & Processes

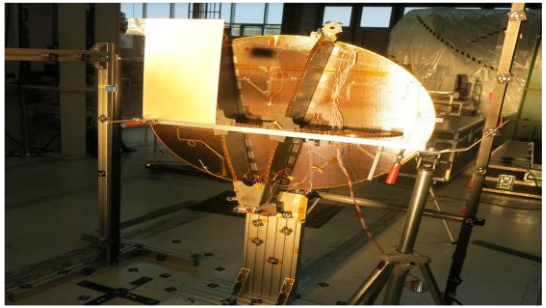
Lightweight Structures

Robot Systems



Lab Infrastructure

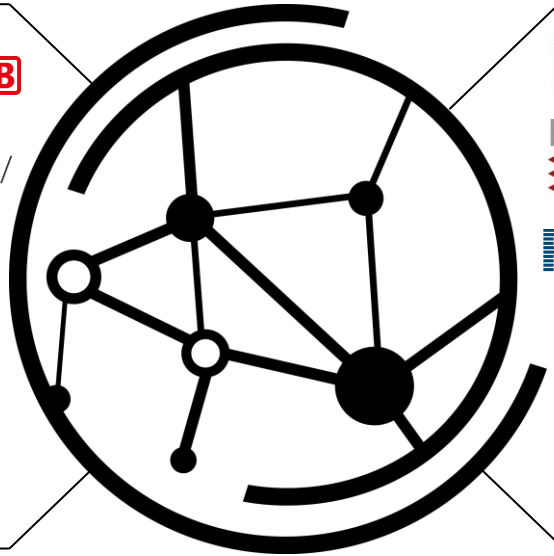




Partners

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, Prof. Lüth) are jointly developing a process for the semi-automatic design of task-specific low-cost lightweight robots. The project deals with the multidisciplinary computational design process by combining optimisation sub-problems of several sub-systems. It ties together modular robotics, structural optimisation, additive manufacturing with innovative design processes to realise customisable robots with minimal development time.

Anticipated results: Hardware and software tools for the automatic robot design with its concurrent structural optimisation

V1.2.6

V1.2.6.

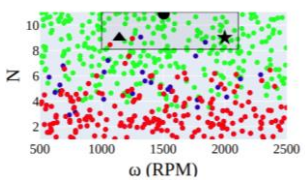
Sathuluri, A.; Sureshbabu, A.V.; Frank, J.; Amm, M.; Zimmermann, M. Computational Systems Design of Low-Cost Lightweight Robots. **Robotics 2023**, *12*, 91. https://doi.org/10.3390/robotics12040091

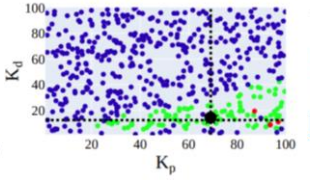
DIVA

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

Funding: State of Bavaria

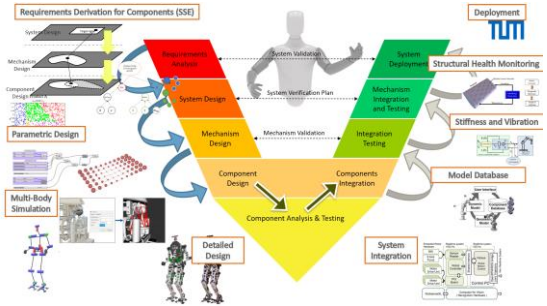
Contact: Anand Suresh Ph.D;
Akhil Sathuluri, M.Sc.; Maximilian Amm, M.Sc.





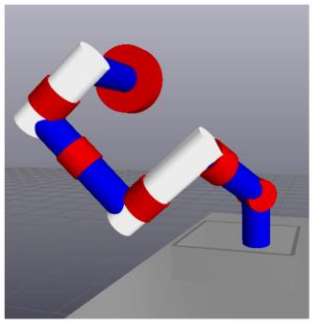
● Point optimal design ★ Selected design

▲ Closest physically feasible design



Scope: Experience driven **bottom-up** design processes have been effectively used for humanoid robot design. On the other hand, this project aims at evaluating an alternative **top-down** design strategy for developing robots. This involves a cascaded optimization strategy resulting in constructing the so-called *solution spaces.* This enables us to interpret and trade-off different design variables in the design process.

Anticipated Results: Computational design methodology for the top-down development of robot systems. Comparison of the different design philosophies.



Simulation

Reality

Problem-1:

$$\min_{\boldsymbol{x}} \ \phi(\mathrm{t_{cyc}}, \mathrm{L}),$$
$$\text{subject to,} \quad h(\boldsymbol{x}) = 0,$$
$$\boldsymbol{x}_l \leq \boldsymbol{x} \leq \boldsymbol{x}_u$$

Problem-2:

$$\max_{\boldsymbol{\zeta}} \ \mu(\Omega(\boldsymbol{\zeta})),$$
$$\text{such that,} \quad \mathrm{t_{cyc}} \leq \mathrm{t_{cyc}}(\boldsymbol{x}_p),$$
$$\mathrm{L} \leq \mathrm{L}(\boldsymbol{x}_p)$$

Sathuluri, Akhil, Anand Vazhapilli Sureshbabu, and Markus Zimmermann. "Robust co-design of robots via cascaded optimisation." *2023 IEEE International Conference on Robotics and Automation (**ICRA**)*. IEEE, 2023.

DSL4RAS

Domain Specific Language for robot-like Systems

Funding: Deutsche Forschungsgemeinschaft (DFG)

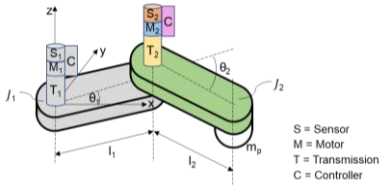
Partners: Institute of Machine Elements (FZG), Institute of Automation and Information Systems (AIS)

Contact: Klara Ziegler, M.Sc.

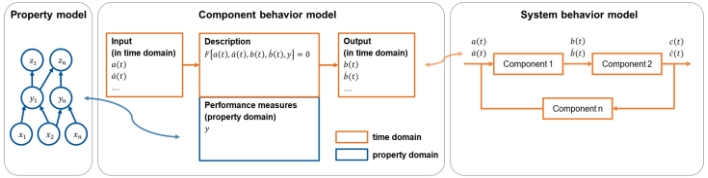
Scope: Designing robot-like systems involves several domains. DSL4RAS aims at developing domain specific languages that are compatible with each other. With them, co-design of mechanical elements, like gears, mechatronic elements, like motors, control logic and sensor design shall be enabled. A particular 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

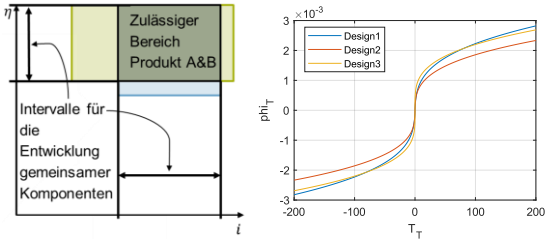
1. Framing: Problem and requirement definition



2. Modelling: Establishing bottom-up mappings



3. Design: Top-Down Mapping



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: Sergi Pagés i Diaz, M.Sc.

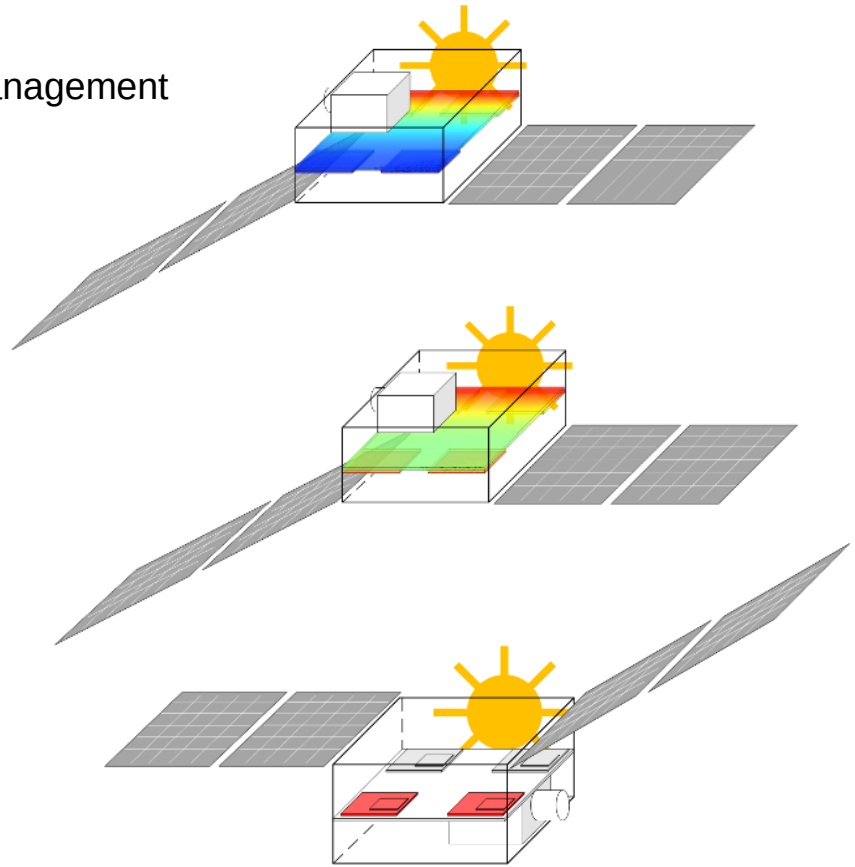
Scope: LPL and EMM GmbH are jointly developing a thermal management system for cubesats by using a digital twin as well a conecpt for distributed computation within the satellite. Therefore, the position of the computation units are optimized.

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: SensoTec 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.

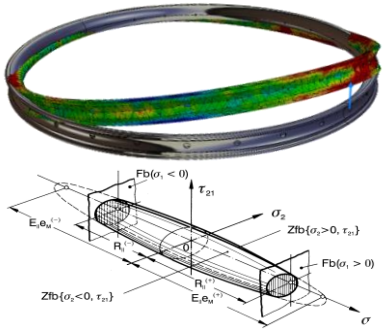
Anticipated results:
Predicting the rim's state allows to reduce the global security factor, resulting in less material used in the production process without trade-offs in structural integrity.

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

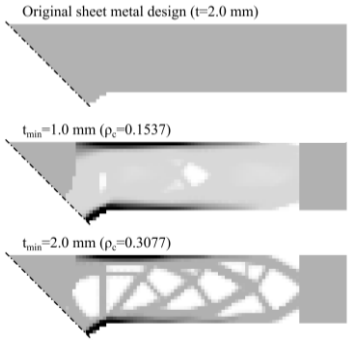
Funding: Federal Ministry for Economic Affairs and Climate Action (BMWK)

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

Contact: Felix Endress, M.Sc.

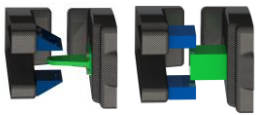
Scope: For aerospace applications metal additive manufacturing bears potentials for lightweight design and cost-effective low volume productions. Yet, the development and design of mechanical systems is complex, due to great influences of the build process (anisotropic material behaviour, failure modes, 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

PrintYourLab

Supported by:
Federal Ministry for Economic Affairs and Climate Action

Optimizing Millifluidic Structures for Medical Applications

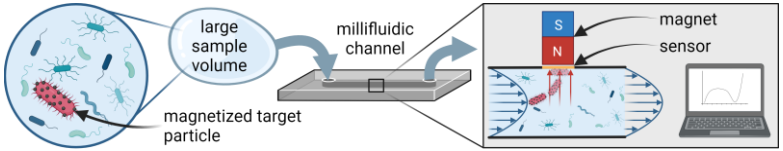
Funding: Federal Ministry for Economic Affairs and Climate Action (BMWK)

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

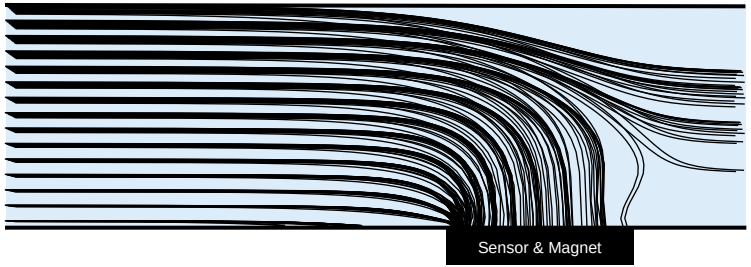
Contact: Johannes Soika, M.Sc.

Scope: The goal of the project is to develop a handheld device that can perform water analysis regarding contamination with pathogenic microorganisms on site and within a short period. The development of suitable millifluidic structures is required to perform the rapid test and detect specific microorganisms. The structure 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 millifluidic structures.



Workflow of the water analysis: 1. magnetize target particles, 2. collect large sample, 3. guide through channel, 4. separate from flow onto sensor, 5. analyse sensor signal



Result of the simulation model: Simulated particle trajectories within the millifluidic channel.

SePos

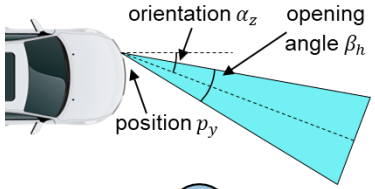
Optimal Sensor Positioning for Highly Automated Vehicles

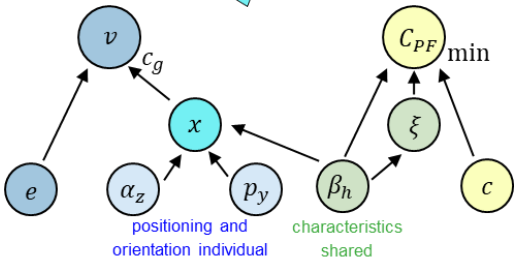
Funding: SePos 1: AUDI AG; SePos 2: Cariad

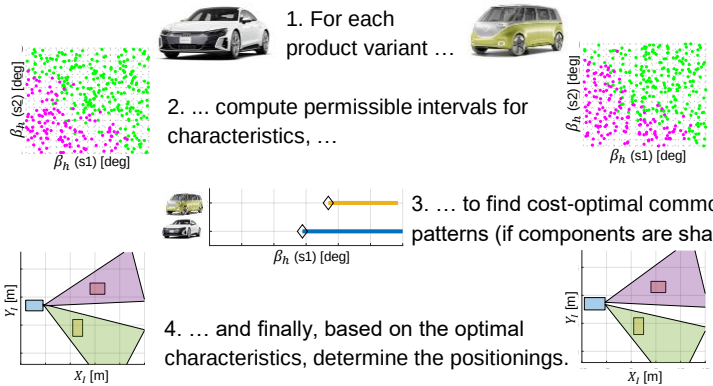
Contact: Nicola Barthelmes, M.Sc.

Scope: Perception of the surroundings is the basis for all algorithms that decide the actions of an automated vehicle (AV). Number and specifications of different perception sensors (e.g., camera, lidar, radar) have to be decided in an early development phase and the sensor setup has to be designed for a manifold of different scenarios. Several vehicle types and their various configurations constitute a product family. Sharing sensors among vehicles may save cost, however, may decrease performance. To reduce combinatorics, an approach based on the computation of solution spaces was proposed. The flexibility to share components is increased using solution-compensation spaces.

Anticipated Results: A method is developed to derive requirements on sensor characteristics and positionings for each vehicle variant. Cost of the product family is minimized and the visibility of relevant objects in the surrounding is guaranteed.







Solution Spaces

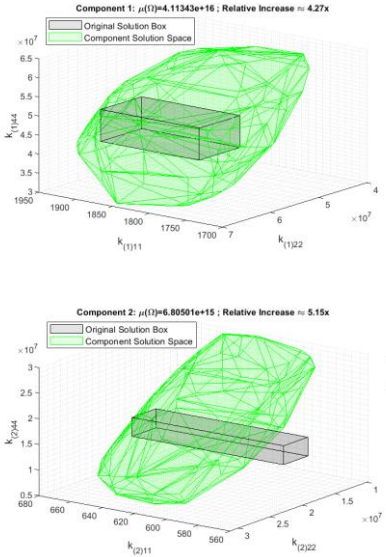
Towards the theoretical limit of optimal requirement decomposition using solution spaces for complex systems design

Funding: Deutsche Forschungsgemeinschaft

Contact: Eduardo Rodrigues Della Noce, M.Sc.

Scope: Dividing a large system into smaller parts may reduce design complexity and enable concurrent engineering. The key idea of this project is to compute and maximize *generalized component solution spaces* to enable said division. If properties of all components are realized within their respective component solution spaces, the overall design goal will be reached, while designers are still allowed to work independently with maximum design freedom.

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



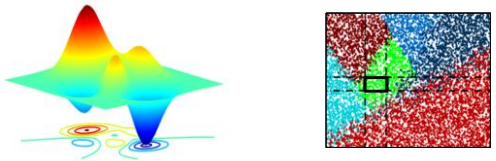


Fig. 1: Design based on classical optimization (left) and on solution space optimization (right).

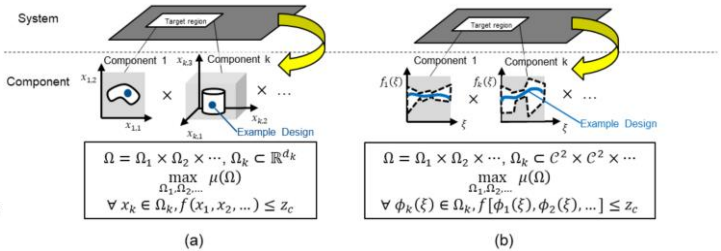


Fig. 2: Solution spaces for components that are characterized by (a) finite dimensional design vectors and variables and (b) functions.

STEAM

Solutions for Transport Networks with Electric Advanced Mobility

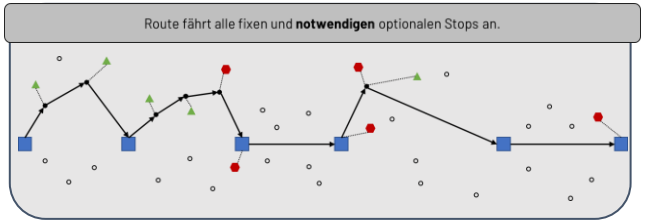
Funding: Federal Ministry of Education and Research (BMBF)

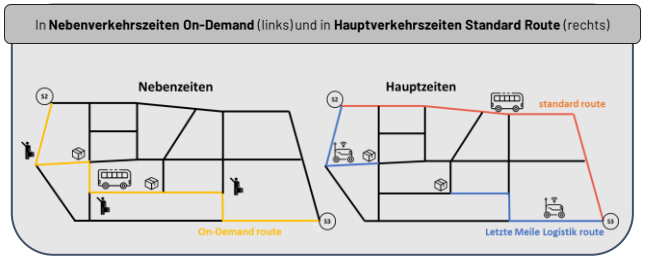
Partners: BIAS

Contact: Nuno Miguel Martins Pacheco, M.Sc.

Scope: We're researching new concepts for public transportation, specifically focusing on existing bus networks. Our goal is to make transportation more sustainable, accelerate mobility, and create space for new applications and experiences in previously unexplored areas, all while considering various stakeholders. This is what makes STEAM a unique project. We're examining the flexibility of rigid routes to optimize vehicle capacities and integrate the transportation of both people and packages in shared public spaces. This helps us reach people more effectively, maximize bus usage, and enhance the travel experience.

Anticipated results: Prototype of interior concept & VR Prototype of the experience (shown at IAA 2023).





FCC

Support structure for next generation Muon detector at CERN

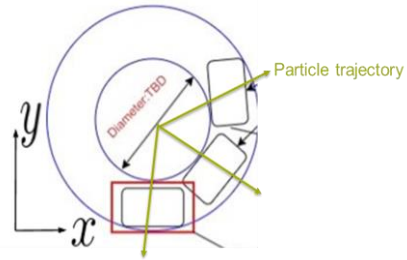
Funding: Bavarian-Czech Academic Agency

Partners: CTU Prague, Max Planck Institute of Physics

Contact: Mahadevan Ravichandran, M.Sc.

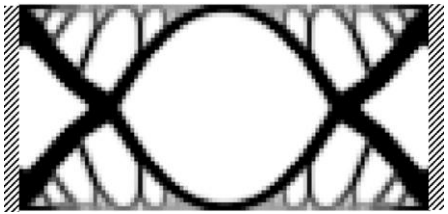
Scope: Muon detectors are to be huge components to be arranged in vertical circles to detect particles in the Future Circular collider at CERN. These detectors are to be supported by a structure that meets the accuracy and stiffness requirements on the detectors. The project aims to develop a method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

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

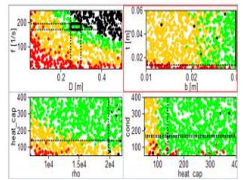


Circular collider with detectors
In different boundary conditions

Current generation muon detector tubes at a partner institute



Optimal topology results for the structure with external and self-weight

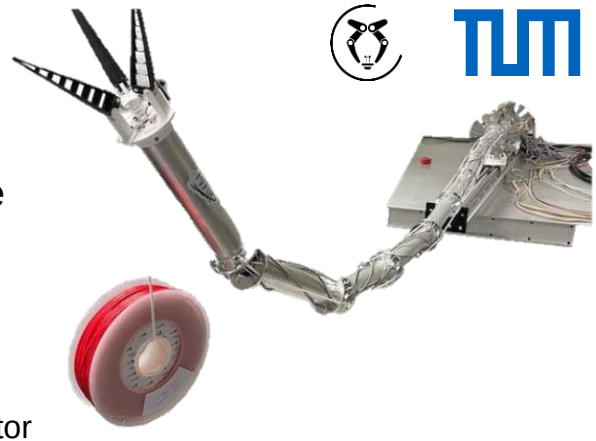


Analysis of solution spaces

IVARNext

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

In-vessel Articulated Arm for Remote Handling (IVAR) in ASDEX Upgrade



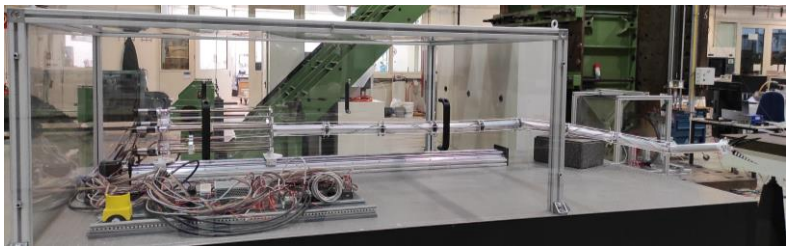
IVAR-4m

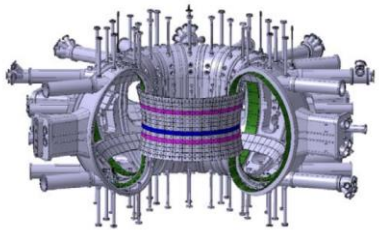
Funding: Max-Planck-Institut für Plasmaphysik

Contact: Akhil Sathuluri, M.Sc.; Maximilian Amm, M.Sc

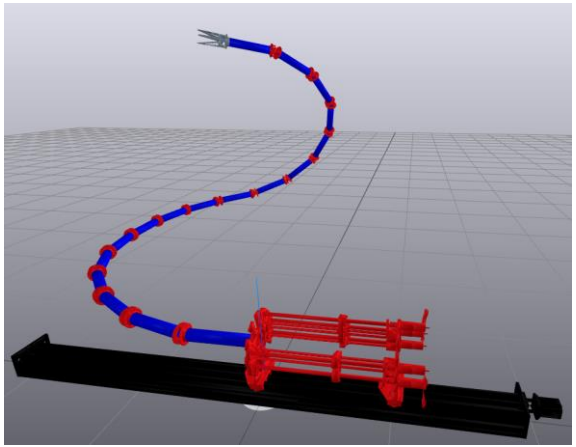
Scope: For the inspection and maintenance of the ASDEX Upgrade nuclear fusion experiment, a Tokamack fusion reactor. The robot is expected to work inside the reactor chamber under vacuum. The robot is underactuated and is controlled via a tether system using a remote actuation setup.

Anticipated Results: The robot is supposed to automatically enter the chamber and reach a required goal pose. The user then uses the camera at the end-effector for inspection and maintenance.





ASDEX Upgrade



Supported by:

Federal Ministry for Economic Affairs and Climate Action

TuWAs

Transformation hub for powertrain value chains in forming industry

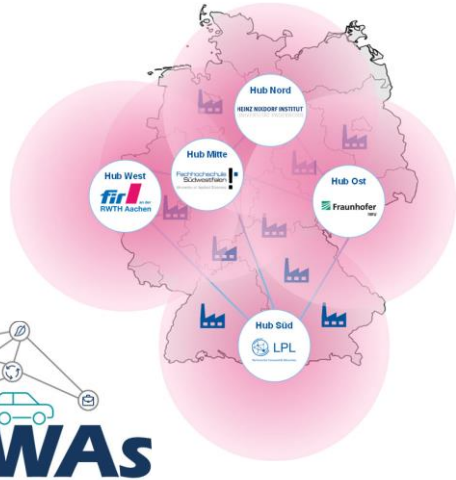
Funding: Federal Ministry for Economic Affairs and Climate Action (BMWK)

Partners: Fraunhofer IWU, fir an der RWTH Aachen, HEINZ NIXDORF INSTITUT UNIVERSITÄT PADERBORN, Fachhochschule Südwestfalen University of Applied Sciences

Contact: Lucien Zapfe, M.Sc.; Klemens Hohnbaum, M.Eng.

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)

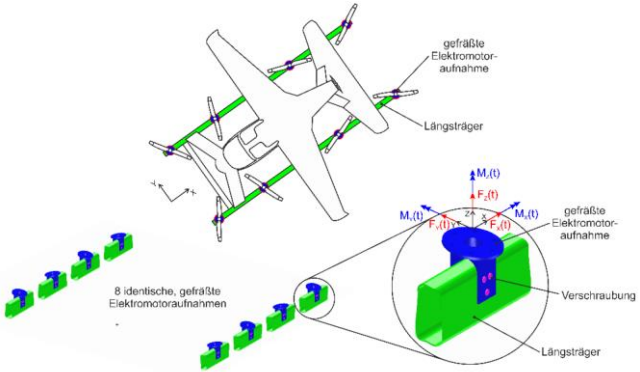
Partners: IABG VOITH BOEING FIT iwb nebumind Fraunhofer IAPT Bergische Universität Wuppertal

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.

Addressed UN- **S**ustainable **D**evelopment **G**oals



Aerospace component to be developed

Supported by:

Federal Ministry for Economic Affairs and Climate Action

KREATIVE

Konstruktionsmethodik für die hybride Additive Fertigung

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

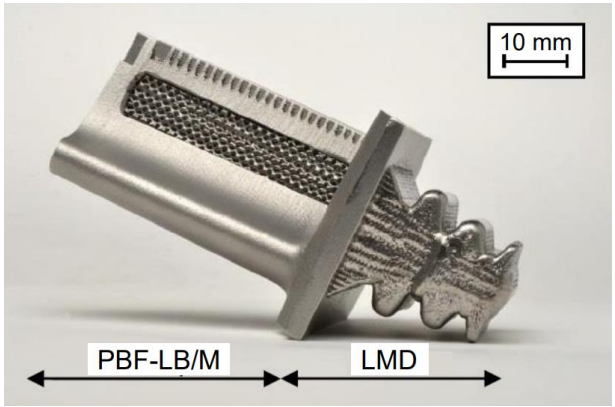
Partners: iwis, iwb, Stöger Automation

Contact: Jasper Rieser, M.Sc.

Scope: Additive manufacturing (AM) is widely considered as the Swiss army knife among the existing manufacturing techniques. With AM it is possible to manufacture parts with fairly complex geometries from many different materials. However, the cost of AM are often still too high for series production, thus limiting its use to merely prototyping. To overcome this, AM can sometimes be combined with another manufacturing technique leading to a hybrid additive manufacturing approach. The research project KREATIVE aims at exploring how parts must be designed to properly take advantage of the individual strengths of the different manufacturing techniques while also considering their weaknesses and limitations.

Anticipated Results: A design methodology for hybrid additive manufacturing.

Source: Graf, B., Schuch, M., Kersting, R., Gumenyuk, A. und Rethmeier, M., Additive process chain using selective laser melting and laser metal deposition. Lasers in Manufacturing Conference, (2015)



Hybrid manufacturing of a turbine blade

TopOpt Connections

Screw Connection Design for Topology Optimization

Funding: LPL

Partners: Technische Universität München

Contact: Tobias Wanninger, M.Sc.

Scope: Connections in topology optimization with screws are typically considered as fixed boundaries on the contact surface of the screw heads. By doing so, the boundary of the optimization is limited and the design space cannot be fully exploit. The formulation here utilize the force coming from the screws to apply pressure on structural parts which are connected to the boundary. The advantage here is that the whole contact interface can be used to support the structure. The approach is carried out in a two step procedure where at first the best attachment points of the global loads are calculated. The second step involves both global loads and screw loads to determine the final structure.

Anticipated Results: Computational methods to simultaneously optimize structural load paths and screw connections.

Mu-Flash GEN 2

Target design for Tumor Therapy with Micro Beams

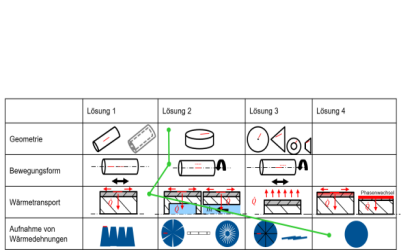
Funding: Albrecht Struppler Fellowship, TUM IAS

Partners: Klinikum rechts der Isar, Institute of Radiation medicine

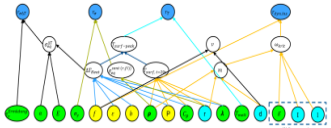
Contact: Mahadevan Ravichandran, M.Sc.

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.

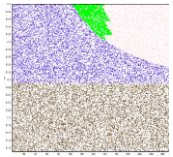
Anticipated Results: Tools for concept generation and analysis in new product development, practical application of solution space engineering, developed product for extreme thermo-mechanical loading



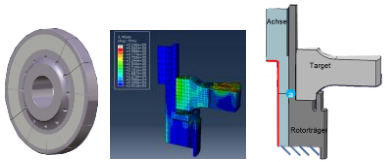
Morphological Chart and ideas for concept generation



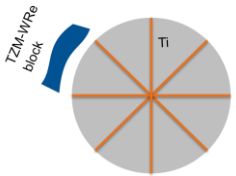
Attribute Dependency Graph relating design variables and quantities of interest



Analysis of solution spaces



Heat transfer simulations



Prototype design

SOLID - **S**mart S**o**il Compact**i**on **D**evices

Bayerische Forschungsstiftung

Digital Twins for the Design and Operation of Vibrating Systems

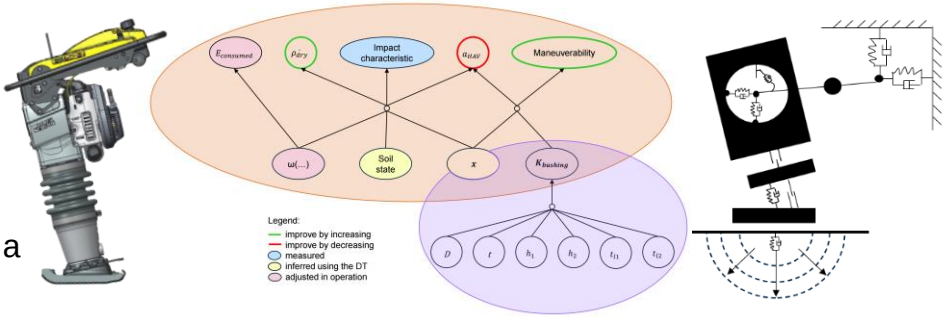
Funding: Bayerische Forschungsstiftung

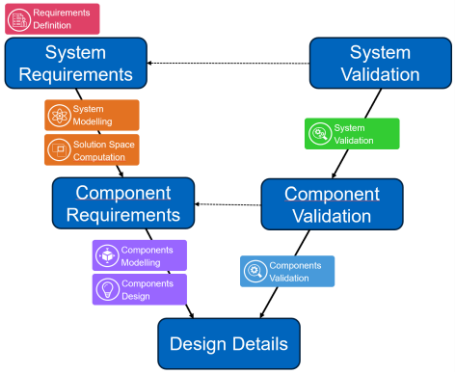
Partners: Wacker Neuson Group Zentrum Geotechnik

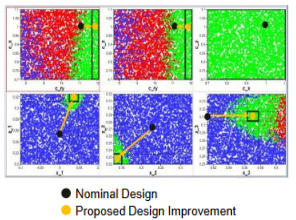
Contact: Anđela Babaja, M.Sc.

Scope: Digital twins (DTs) for vibrating systems have significant potential to improve their performance. For instance, by utilizing a simulation model for the soil compaction process, including the vibratory rammer, performance can be enhanced while mitigating dynamic loads on the operator. To ensure the safety of the operator while also achieving a productive machine, this project aims to propose a systematic human-centered design of a vibratory rammer. Solution Space Engineering approach via the V-model addresses the conflicting multidisciplinary requirements, serving as a base for creating a DT of the process.

Anticipated Results: A prototype of a vibratory rammer virtualized via DT, ultimately leading to a more optimized and reliable product.







Numerical optimization:

$$f = max\{\frac{c_{ry,l} - c_{ry}}{c_{ry,l}}, \frac{c_{ry} - c_{ry,u}}{c_{ry,u}}\}$$

Subject to:

$$c_{x,l} \leq c_x \leq c_{x,u};\ c_{z,l} \leq c_z \leq c_{z,u}$$

Completed Projects

completed

KME – ExoTool

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

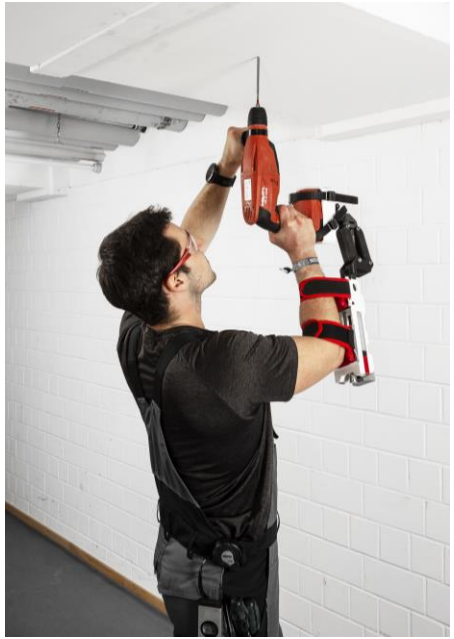
Funding: KME – Kompetenzzentrum Mittelstand GmbH

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



completed

Mu-Flash

Tumor Therapy with Micro Beams and Compact Radiation Source

Funding: DFG

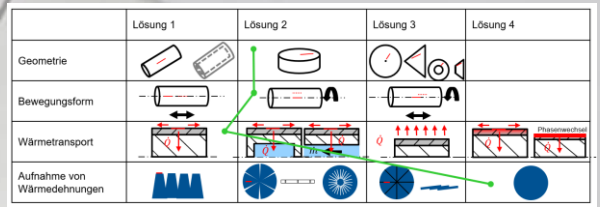
Partners: Helmholtz-Zentrum München, Klinikum rechts der Isar, Institute of Cancer Research, Forschungszentrum Jülich, FH Munich, University Mainz

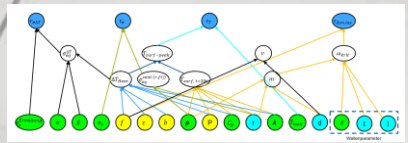
Contact: Mahadevan Ravichandran

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.

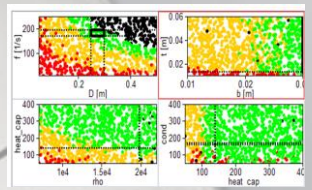
Results: Tools for concept generation and analysis in new product development, practical application of solution space engineering, systems for measurement of key performance parameters. **Prototype in hardware.**

Morphological Chart / Zwicky Box

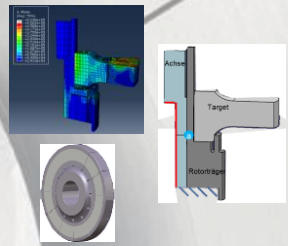




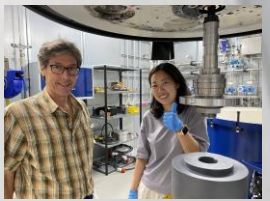
Attribute Dependency Graph relating
design variables and quantities of interest



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.

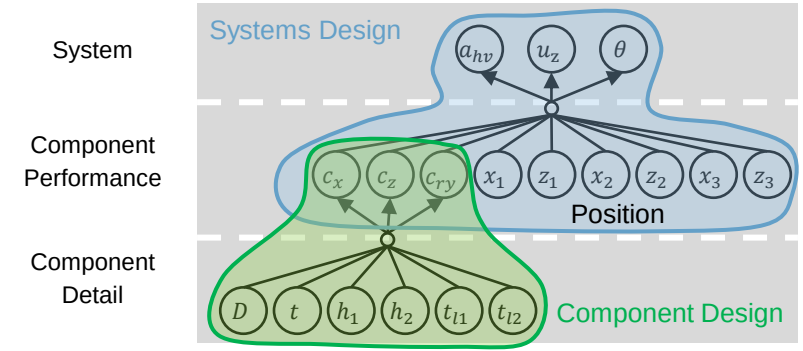
Scope: In this project, a top-down development method for the design of vibrating mechanical systems was developed that decomposes the overall system requirement into component level requirements based on Solution Space Engineering.

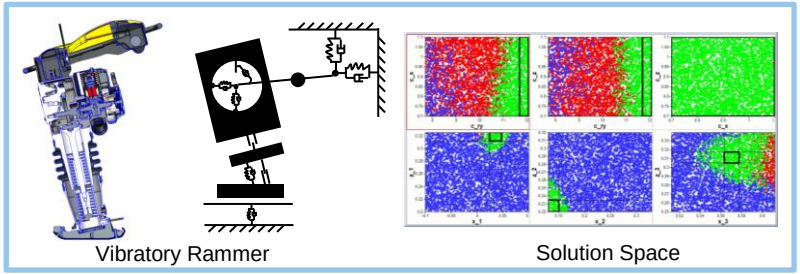
Results:

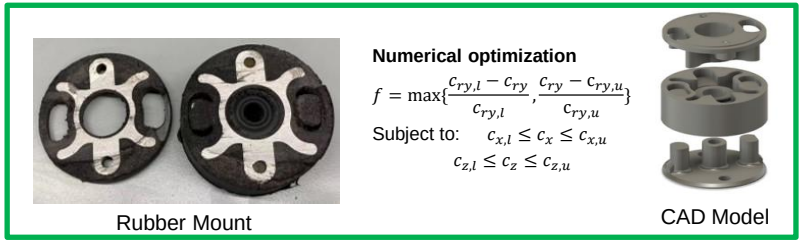
(1) Systematic top-down design method for vibrating systems to avoid iterations,

(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

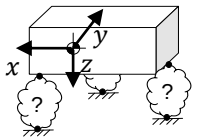
Scope: A requirement on the system eigenfrequency is decomposed for subsystems using solution spaces which enables independent component design. The system requirement is satisfied whenever the component design satisfies the decomposed requirements. Design optimization can be carried out separately for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

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

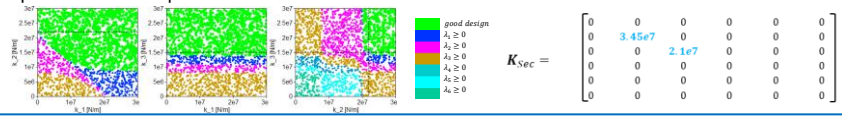
(2) Solutions for Athena WFI primary structure and support structure with optimal mass (within requirements).

System requirement

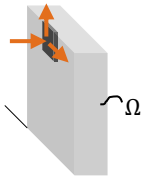
$$\omega_0^2 = \min_{\mathbf{u}(\mathbf{x})} \left(\frac{V_S(\mathbf{u}(\mathbf{x})) + V_{body}(\mathbf{u}(\mathbf{x}))}{T_{body}(\mathbf{u}(\mathbf{x}))} \right) \geq \omega_c^2$$



Requirements decomposition



Component design (support body)

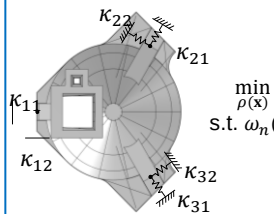


$$\min_{\rho_e} \quad m(\rho_e(x))$$
$$s.t. \quad \lambda_{min}(\mathbf{K}_S - \mathbf{K}_{Sc}) \geq 0$$
$$\mathbf{KU} = \mathbf{F}$$
$$0 < \rho_e \leq 1$$

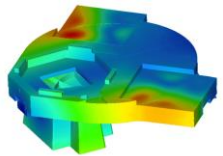
Classical TopOpt

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.

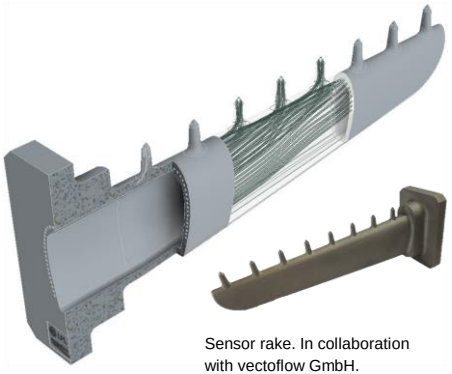
Results:

(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

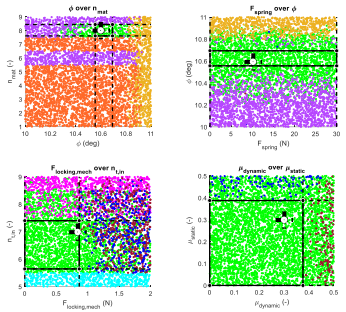
LSS Large Space Structures

Deployable Reflector Antenna for Cubesat Missions

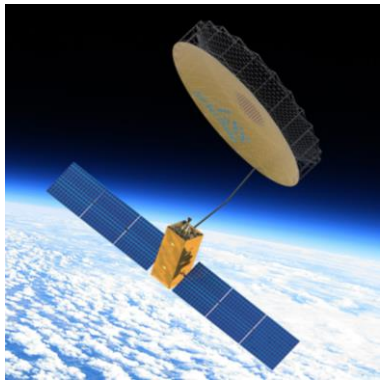
Funding: Large Space Structures

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.



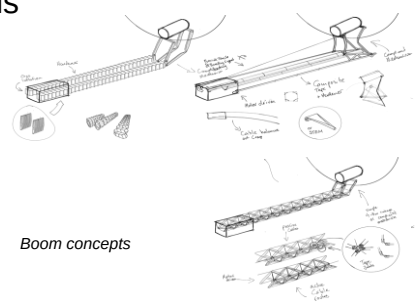
Solution Spaces for Systems Design



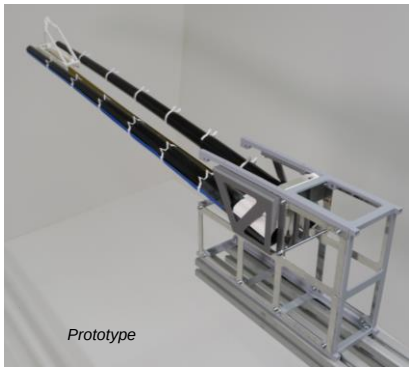
CubSat in Space

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)

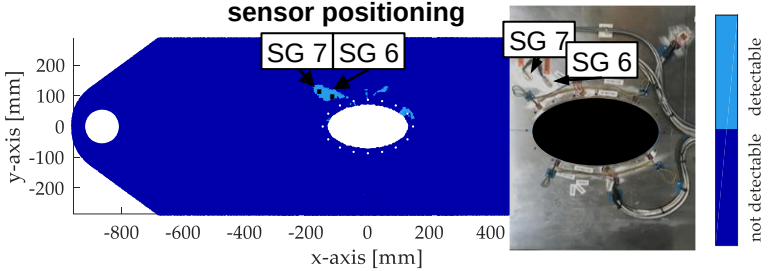
Partners: IABG, Bauhaus Luftfahrt

Contact: Simon Pfingstl, M.Sc.

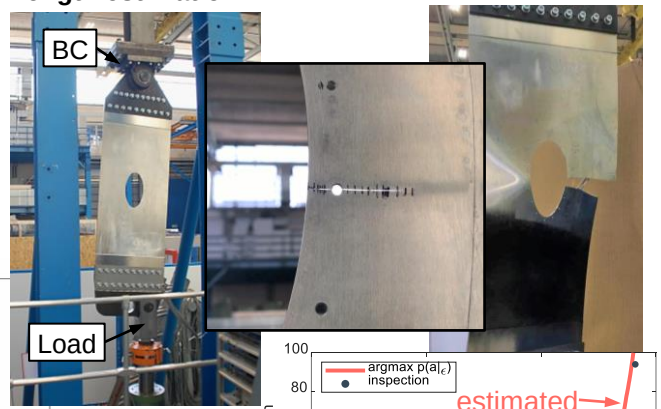
Scope: The development process of aircraft structures requires many fatigue tests. During these tests, engineers must inspect the aircraft structure continually to avoid final fracture of any component. Structural health monitoring may reduce time and cost associated with these inspections. Evaluating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

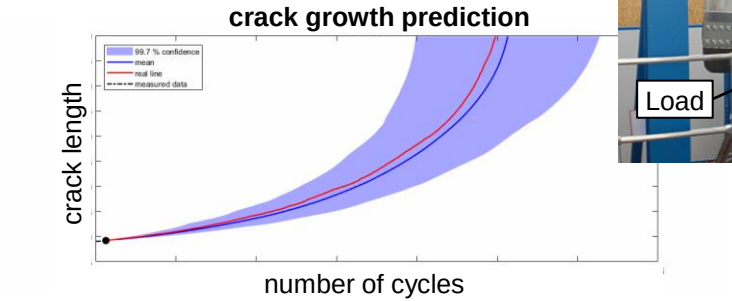
sensor positioning



crack length estimation



crack growth prediction



Completed 2022

DESIM

Simulation of Distributed Design Processes

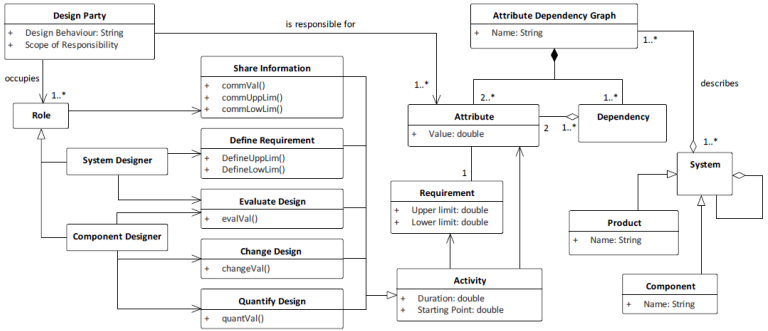
Funding: BMW Group

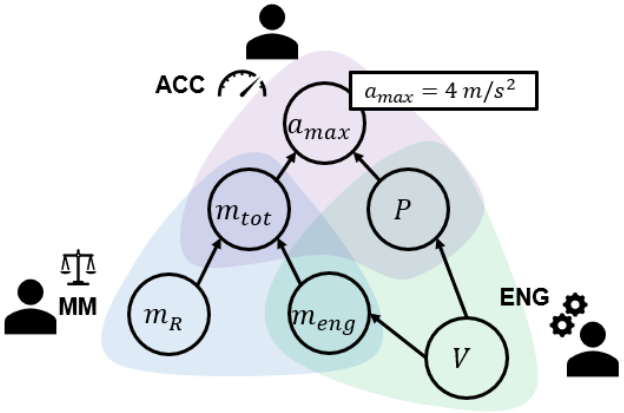
Contact: Ferdinand Wöhr, M.Sc.

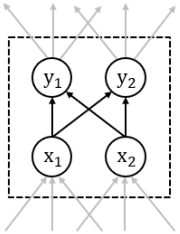
Scope: Development of an agent-based simulation model to evaluate distributed design processes with respect to product quality, development time and design flexibility. Key elements are:

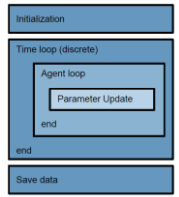
- Time-discrete simulation algorithm
- Mathematical process description
- Data model including all aspects
- Multi-scale model validation

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

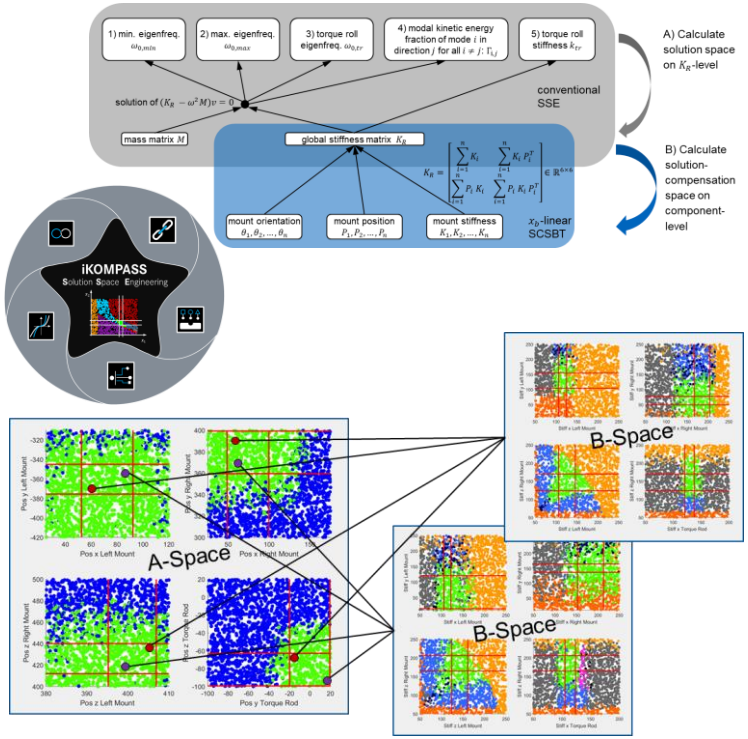
Integrated Conceptual Design with Solution Space Engineering

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

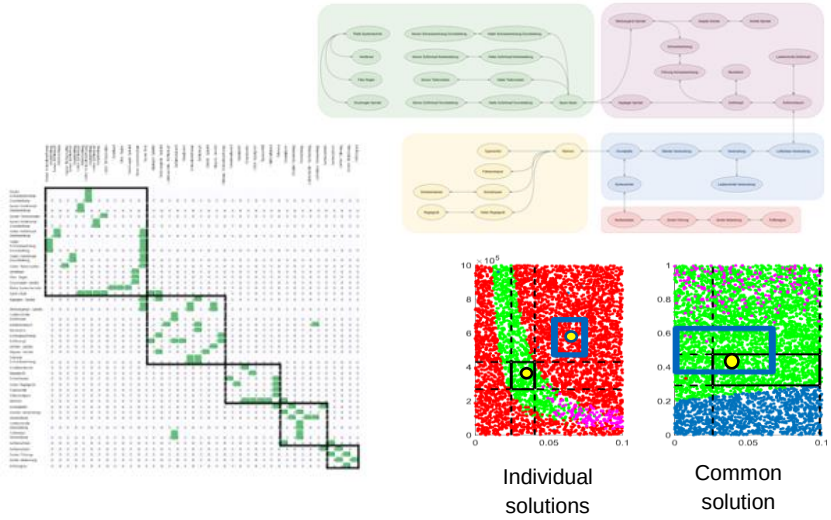
Contact: Sebastian Rötzer, M.Sc.

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.



Individual solutions

Common solution

1 Functional structure | 2 Market analysis | 3 Physical structure | 4 Product architecture

5 Defining modules | 6 Documenting modules | 7 Designing modules | 8 Leading innovation by modules

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	Funded project	Training project	Student research project
3 month – 5 years	1 – 4 years	Individuell	Up to 6 months
> aprox. 160 k€ / year	0 € (Company receives fundings)	6k – 10k € a day (nach Vorbereitungsaufwand)	0 €
Forschung ergebnis-offen, individuell und evtl. in Kooperation mit anderen Partnern	Research proposal, possibly with further partners	standard tasks, no research	Betreuung durch Lehrstuhl- und Firmen-Mitarbeitende
employee on site	employee on site	employee on site	no employee on site
Übertragung der Rechte an Firma möglich	Öffentlich, bei KME verbandsintern	Urheberrechte beim Dozenten	Rechte beim Studierenden

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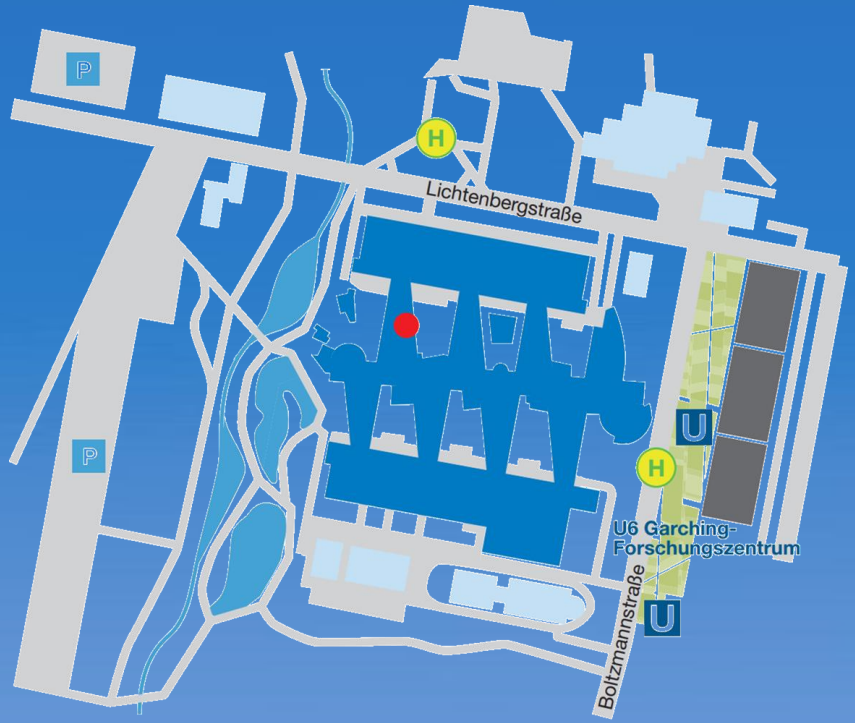
- Phone: +49 89 289-15150



Thank you for your attention!

LPL

Design and Optimization of Complex Technical Systems