Optimierung einer Positionier- und Haltevorrichtung nach Steifigkeits- und Gewichtsgesichtspunkten

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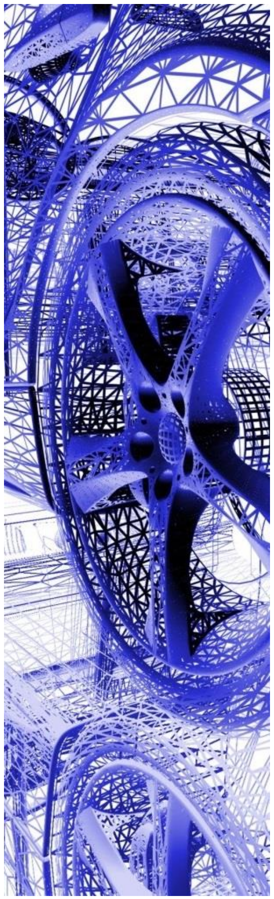
Fraunhofer IPA
as a technology consultant and innovation driver

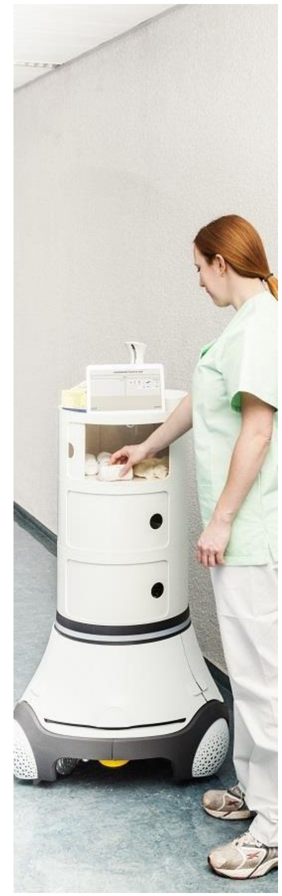
- Third-largest institute of the Fraunhofer-Gesellschaft; based in Stuttgart
- 1,000 employees I 64.2 million euros operating budget I 20.4 million euros industrial revenues
- Expertise in manufacturing engineering and automation since 1959

Note: key figures for 2015

Our Business Units
Unparalleled diversity








Business units and working fields

An interdisciplinary organization

Director Prof. Dr.-Ing. Thomas Bauernhansl

Business units:
- Automotive
- Machinery and Equipment Industry
- Electronics and Microsystems
- Power Industry
- Medical Engineering and Biotechnology
- Process Industry

Productions Organization
- Sustainable Production and Quality Management
- Factory Planning and Production Management
- Efficiency Systems

Surface Technology
- Coating Systems and Painting Technology
- Electroplating

Automation
- Controls and Drives
- Robot and Assistive Systems
- Biomechatronic Systems
- Laboratory Automation and Biomanufacturing Engineering
- Ultraclean Technology and Micromanufacturing
- Machine Vision and Signal Processing

Process Technology
- Functional Materials
- Lightweight Construction Technologies

Competence Center DiglTools for Manufacturing

Stuttgart Production Academy

Additional Locations

Application Center for Large Structures in Production Engineering AGP, Rostock	Fraunhofer Austria Research GmbH, Wien Production and Logistics Management	Fraunhofer Project Group Production Management and Informatics PMI, Budapest	Fraunhofer Project Center for electroactive Polymers at AIST Kansai	Fraunhofer Project Group for Automation in Medicine and Biotechnology PAMB, Mannheim	Fraunhofer Project Group Regenerative Production, Bayreuth

Version as of: 01.2016

Department Lightweight Construction Technologies

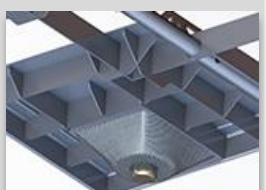
Our expertise

Health protection and dust & chip extraction technologies

- Adapted extraction strategies and airflow-optimized extraction hoods
- Designing and testing extraction hoods and systems
- Highly effective extraction solutions

Lightweight design

- Design of fiber reinforced composite materials
- FEM simulation
- Construction methods
- Parametric optimization
- Topology optimization



Quality assessment

- Solutions for the acquisition and documentation of quality data
- Concepts for the automated acquisition of quality data
- Data capture and analysis

Sawing technologies

- Machining and cutting processes
- Saw blade design and optimization
- Ultrasonic sawing

Joining technologies

- Bonding
- Friction stir welding

Machining and cutting technologies

- Coating technology
- Cooling and lubrication systems
- Robot-assisted machining
- Ultrasonic-assisted machining
- Machining processes for lightweight materials
- Simulation of machining processes

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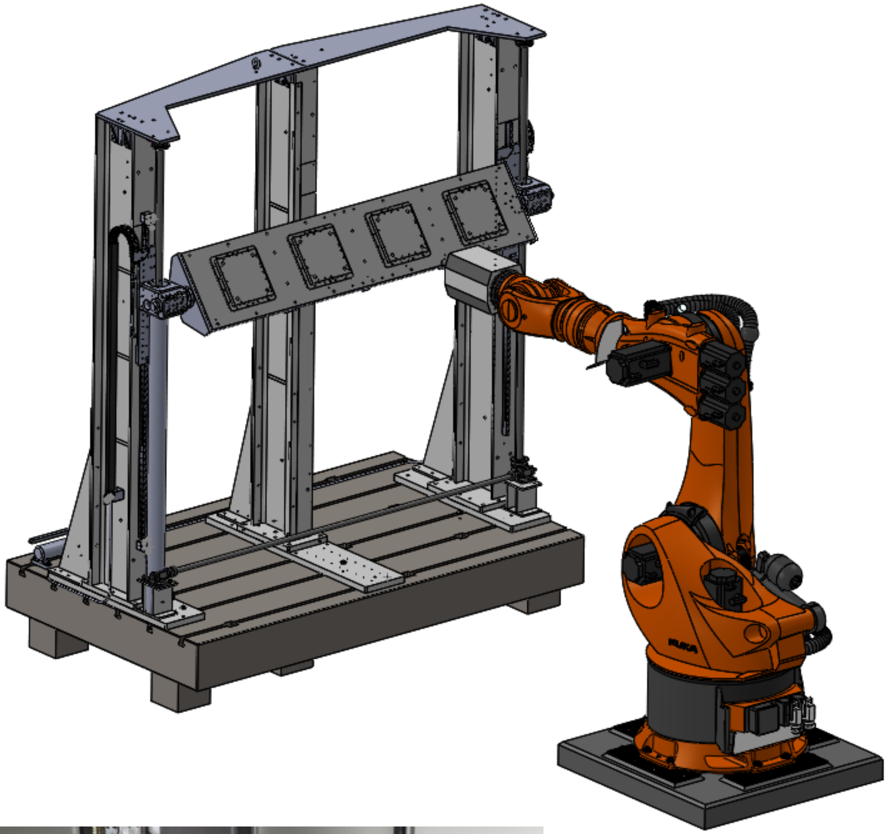
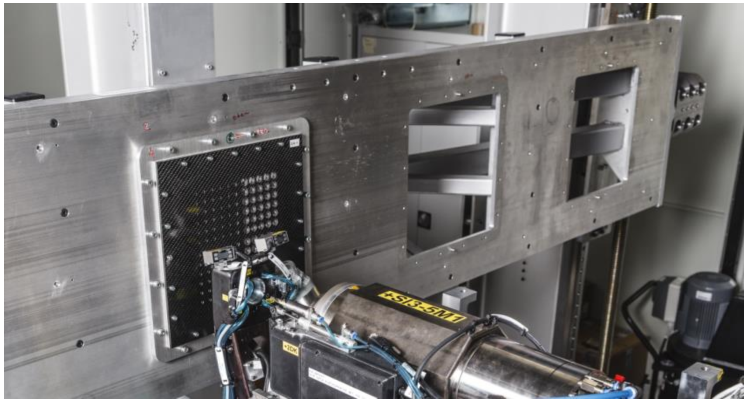
Motivation

- Robotic system for drilling large structural components
- Rating of robot kinematics and machining quality
- Test device is used as a dummy for large structural components
- High stiffness and light weight (because of manual adjustment) are required





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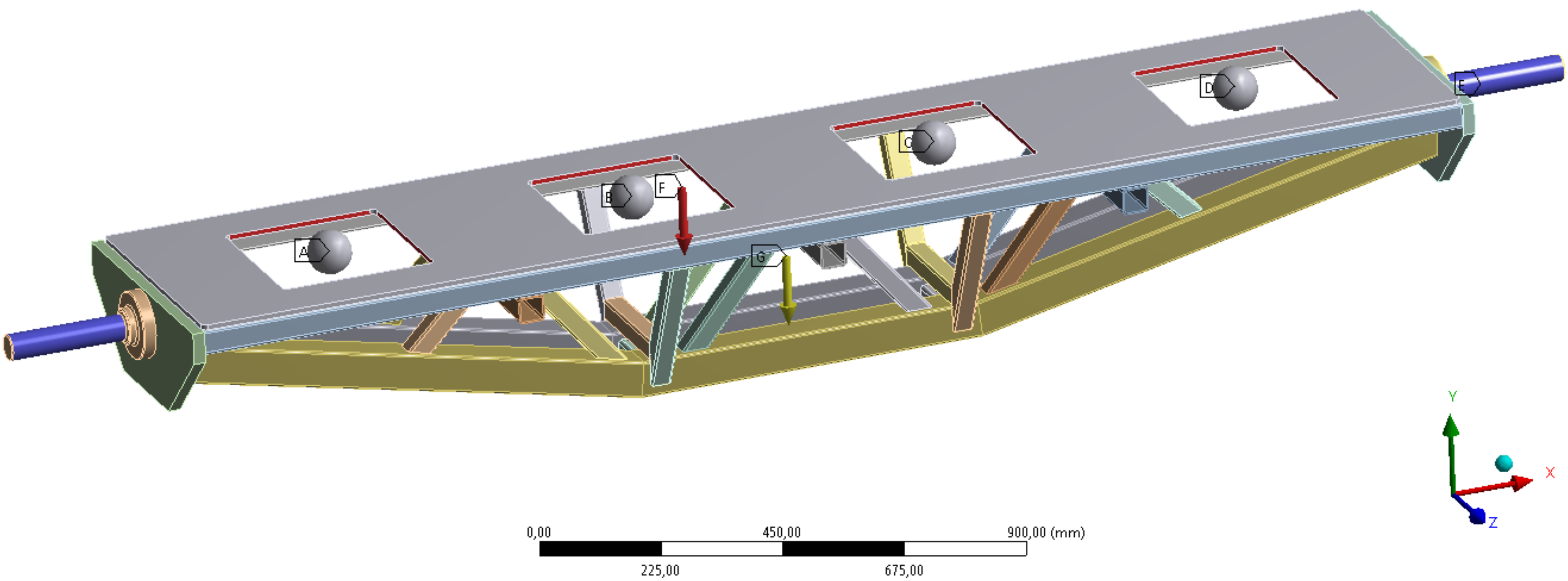
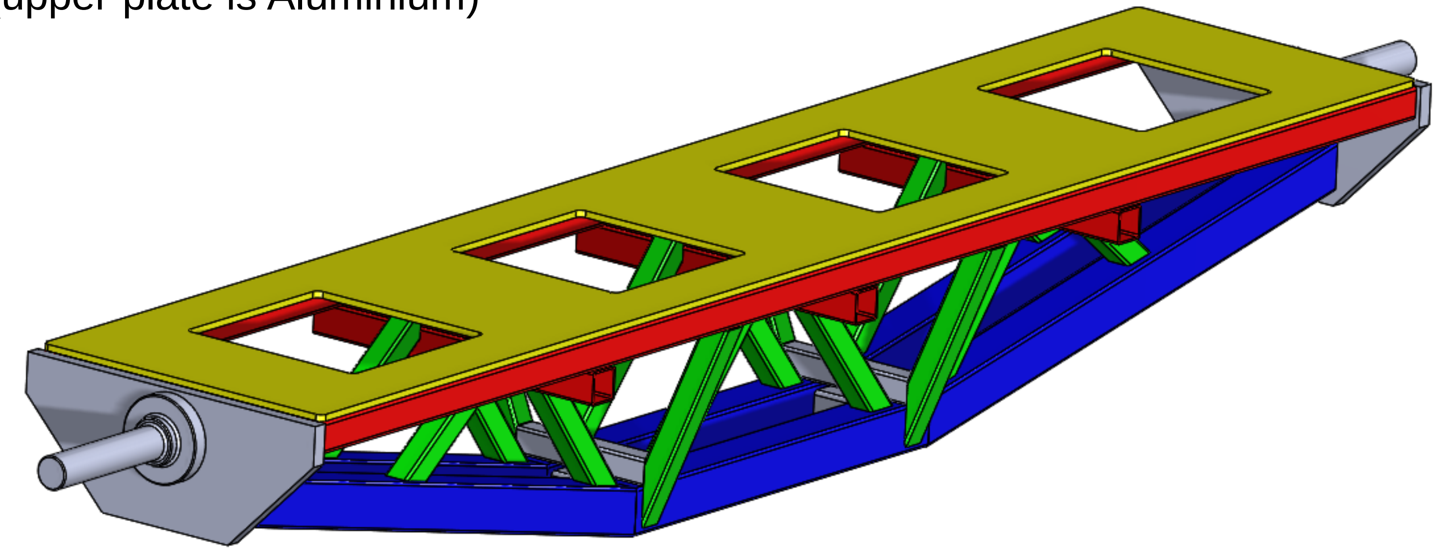
Loading

- 4 working pieces as lumped masses
- External force represents pressure during the working process
- Influence of the gravity is studied at 0°, 90° and 180° position
- Fixed support at the arbors on left and right side



Optimization Parameters

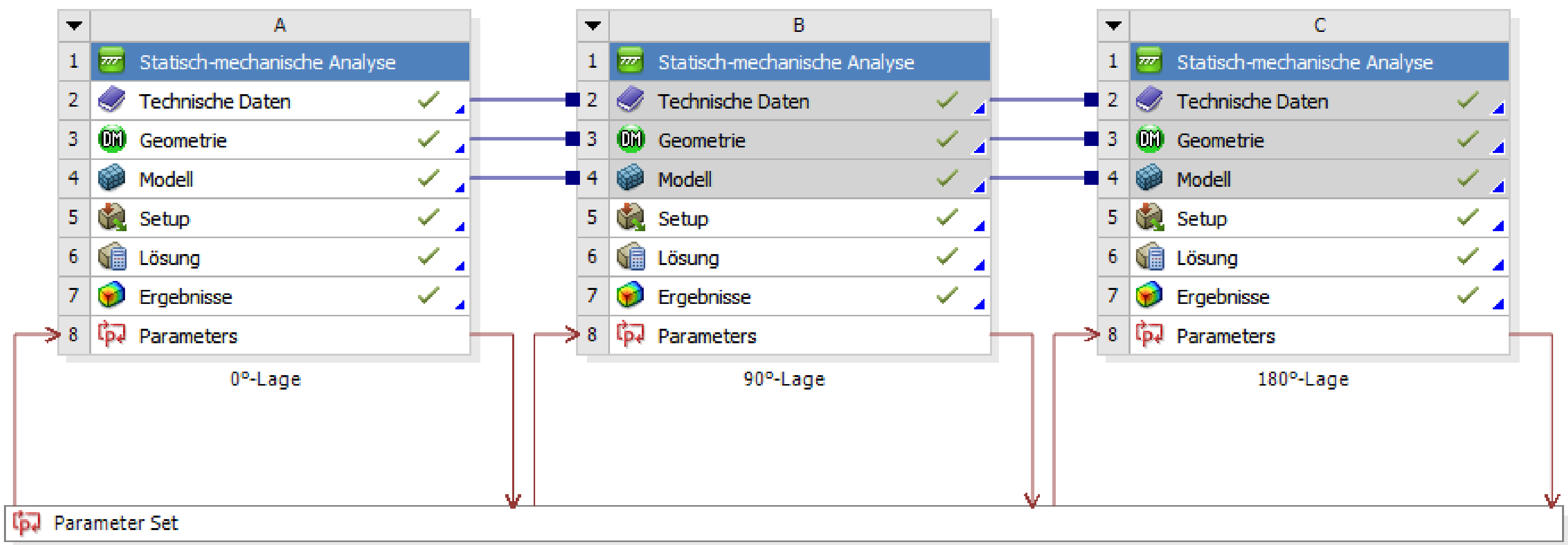
- Thickness of upper plate (initial: 10 mm)
- Width, height and thickness of **upper beams**(50 x 50 x 3 mm³)
- Width, height and thickness of **middle beams** (40 x 40 x 3 mm³)
- Width, height and thickness of **lower beams** (70 x 70 x 4 mm³)
- 2 materials for the beam structure: Steel or Aluminium
  (upper plate is Aluminium)



Simulation Model

- Three load cases in ANSYS Workbench
- Deformations of 3 load cases as outputs in parameter set

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	⊟ Input Parameters			
3	⊞ 0°-Lage (A1)			
*	New input parameter	New name	New expression	
39	⊟ Output Parameters			
40	⊟ 0°-Lage (A1)			
41	P36	Total_mass	207,19	kg
42	P55	Maximum_displacement_0	0,12087	mm
43	⊟ 90°-Lage (B1)			
44	P56	Maximum_displacement_90	0,097235	mm
45	⊟ 180°-Lage (C1)			
46	P57	Maximum_displacement_180	0,067609	mm
*	New output parameter		New expression	
48	Charts			



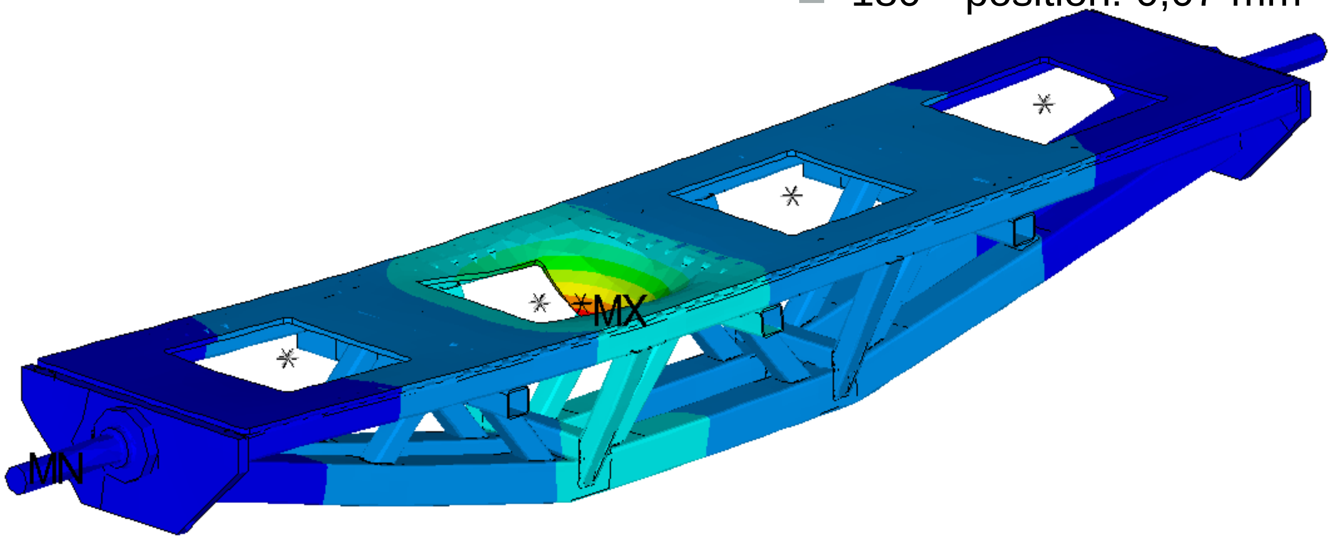
Optimization Task

Objective functions

- Minimization of mass
- Minimization of deformation of the beam structure for a positioning in 0°, 90° and 180°

Initial Design

- Mass: 207,2 kg
- Deformations:
  - 0°- position: 0,12 mm
  - 90°- position: 0,10 mm
  - 180°- position: 0,07 mm



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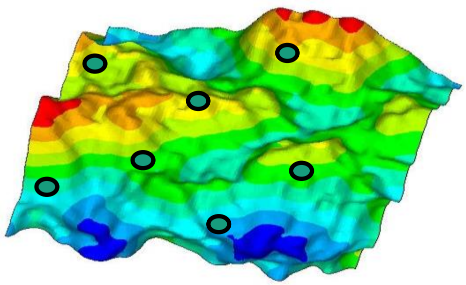
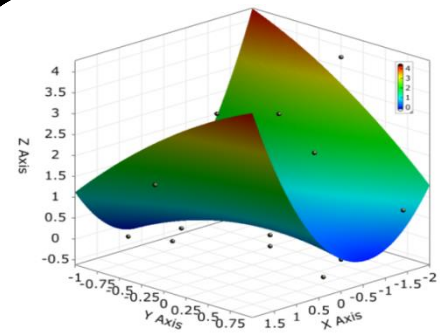
Flowchart of Sensitivity Analysis



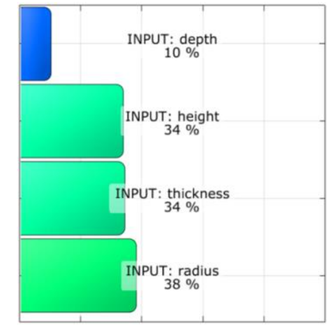
Design of Experiments

- Deterministic
- (Quasi)Random



Regression Methods

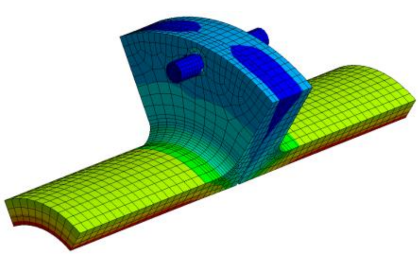
- 1D regression
- nD polynomials
- Sophisticated metamodels



Sensitivity Evaluation

- Correlations
- Reduced regression
- Variance-based

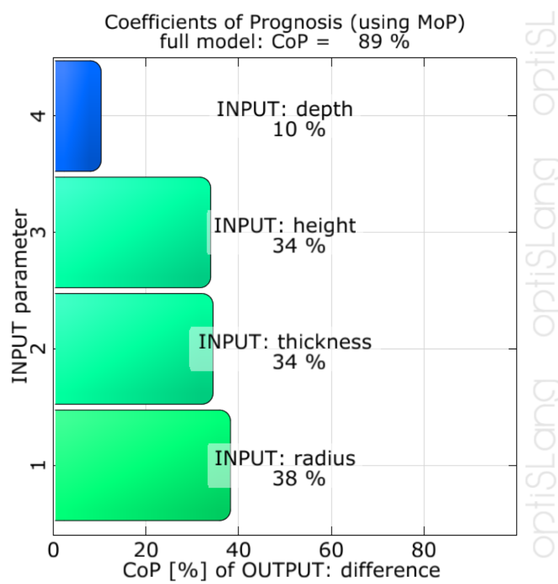
Solver

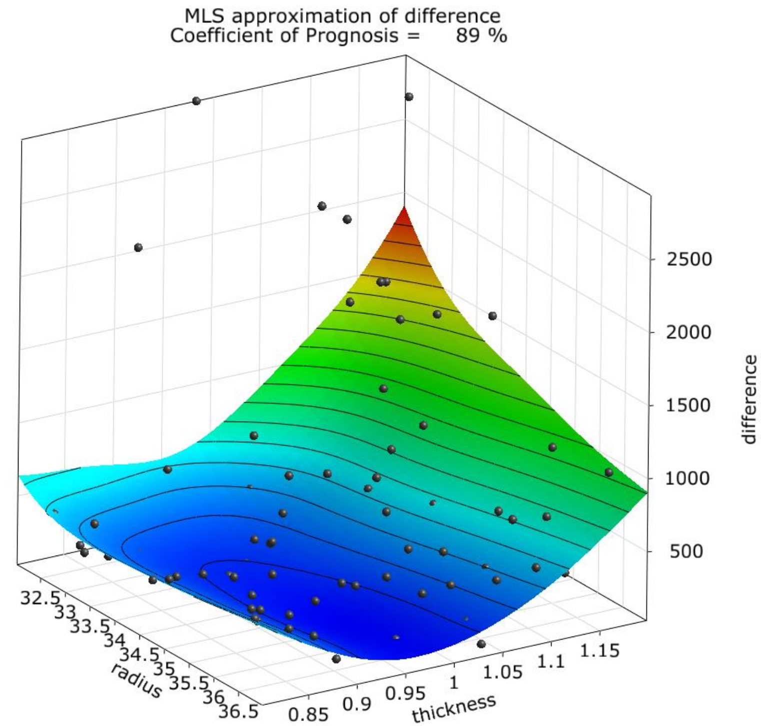


1. Design of Experiments generates a specific number of designs, which are all evaluated by the solver
2. Regression methods approximate the solver responses to understand and to assess its behavior
3. The variable influence is quantified using the approximation functions

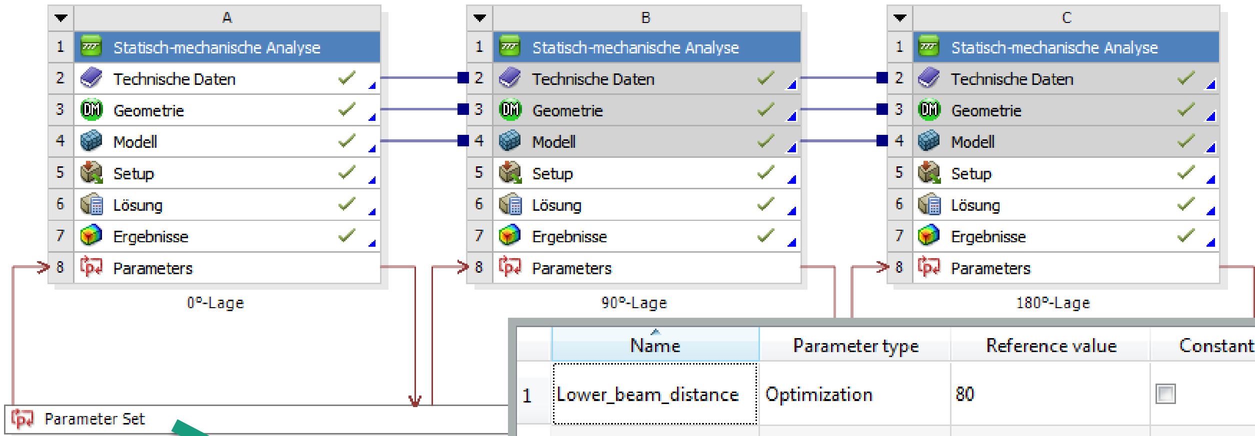
Metamodel of Optimal Prognosis (MOP)

- Approximation of solver output by fast surrogate model
- **Reduction of input space** to get best compromise between available information (samples) and model representation (number of inputs)
- Determination of **optimal approximation model**
- Assessment of **approximation quality**
- Evaluation of **variable sensitivities**





Definition of Parameter Bounds



	Name	Parameter type	Reference value	Constant	Resolution	Range		Range plot
1	Lower_beam_distance	Optimization	80	☐	Continuous	60	100	
2	Lower_beam_height	Optimization	70	☐	Continuous	40	100	
3	Lower_beam_thickness	Optimization	4	☐	Continuous	2	6	
4	Lower_beam_width	Optimization	70	☐	Continuous	40	100	
5	Middle_beam_height	Optimization	40	☐	Continuous	30	70	
6	Middle_beam_thickness	Optimization	3	☐	Continuous	2	6	
7	Middle_beam_width	Optimization	40	☐	Continuous	30	70	
8	Upper_beam_height	Optimization	50	☐	Continuous	30	70	
9	Upper_beam_thickness	Optimization	3	☐	Continuous	2	6	
10	Upper_beam_width	Optimization	50	☐	Continuous	30	70	
11	Upper_plate_thickness	Optimization	10	☐	Continuous	10	30	

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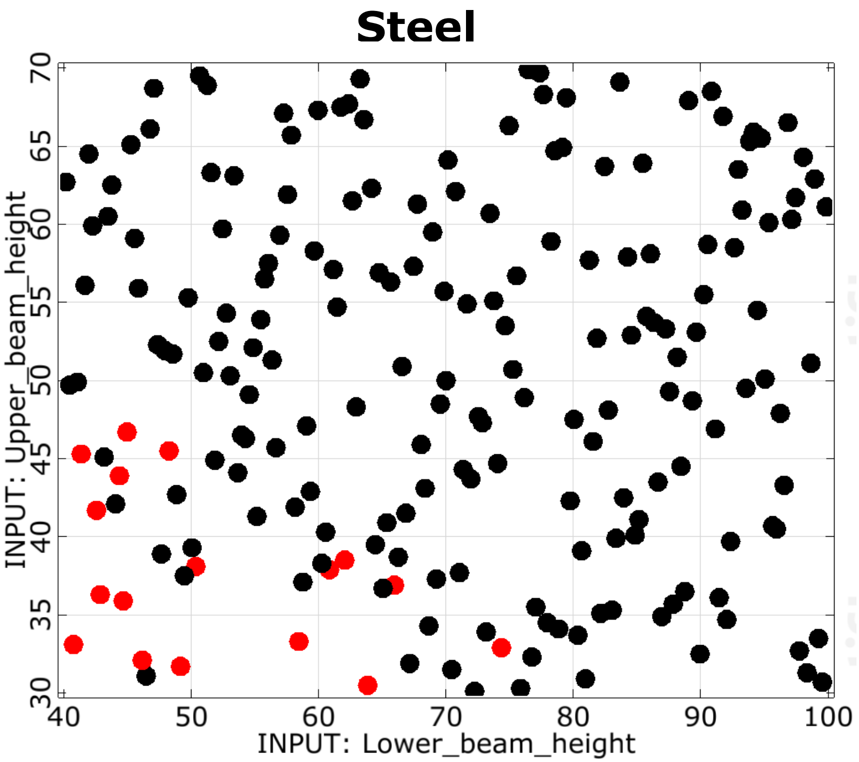
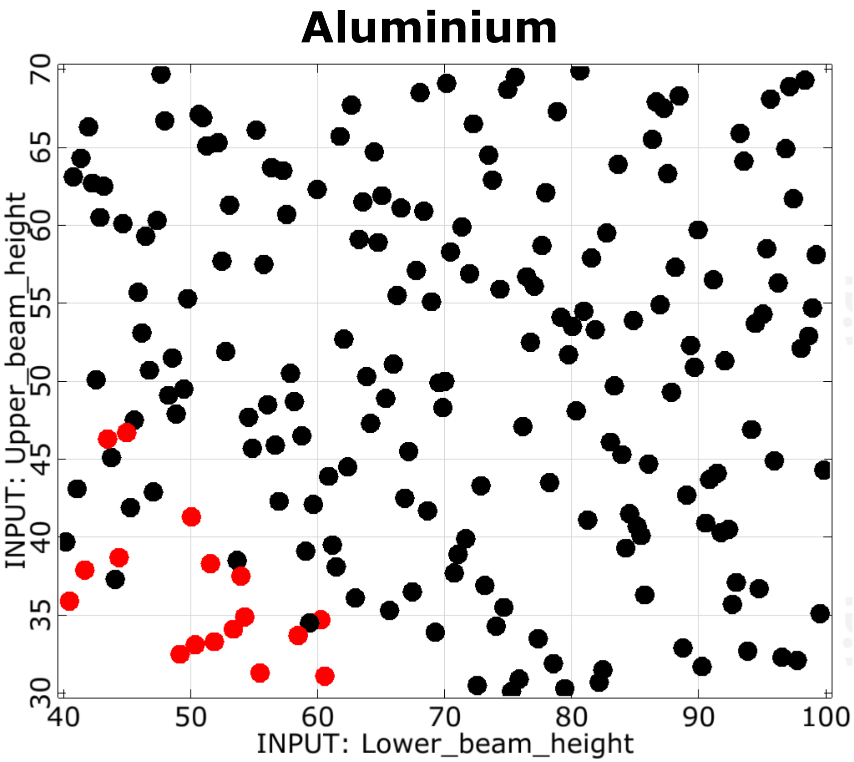
Design of Experiments

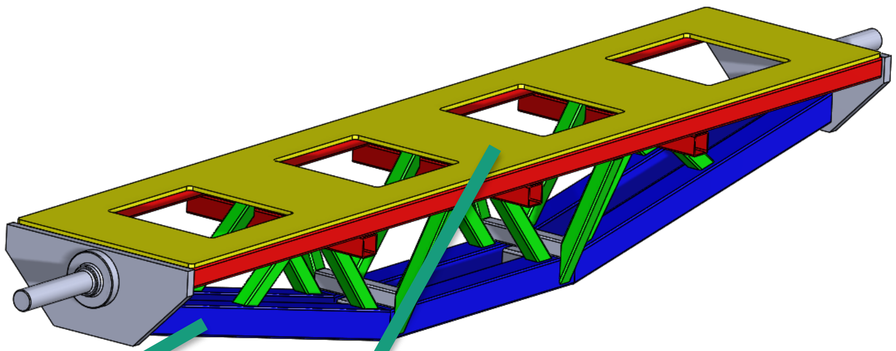
- 200 Latin Hypercube Samples
- 10% failed designs due to conflicting geometry parameters

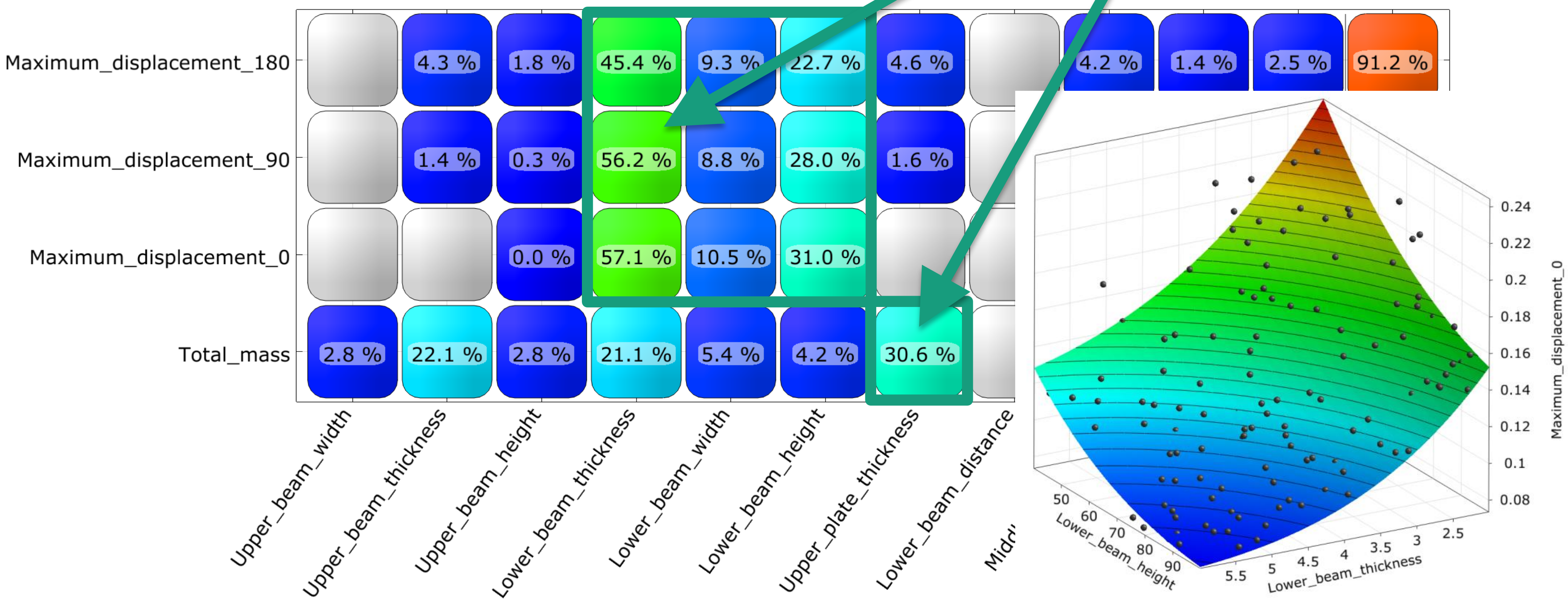




Influence of Parameters

- Thickness of upper plate is most important for the mass
- Parameters of lower beam sections have highest influence on deformations





Contents

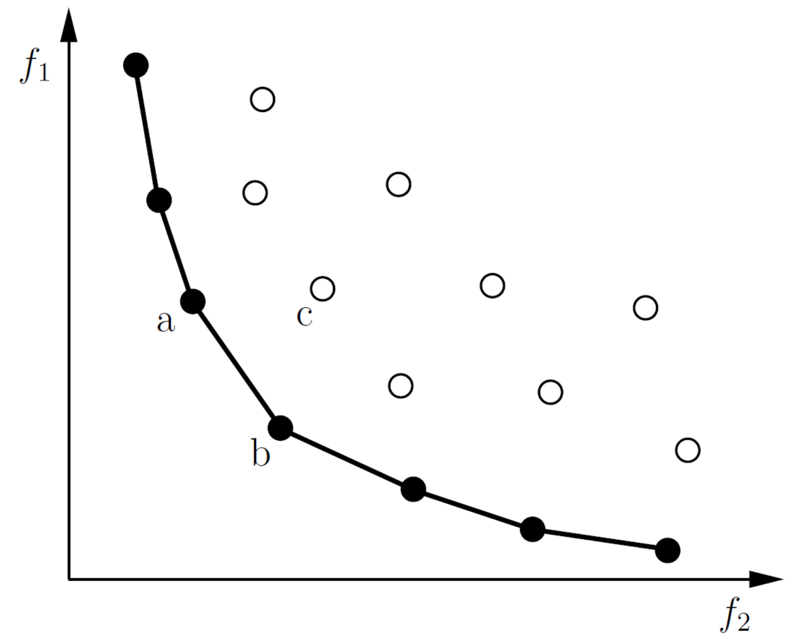
The Multi-Objective Optimization Task

- Several optimization criteria are formulated in terms of the input variables **x**

$$f_1(\mathbf{x}) \rightarrow \min$$
$$\vdots$$
$$f_n(\mathbf{x}) \rightarrow \min$$

- Uncountable set of solutions, if criteria are contradicting

➢ Good compromise between different objectives is searched



➢ **A Posteriori Preference Articulation**

- Search before making decisions

➢ Find Pareto optimal solutions and select the most suitable

Definition of Optimization Goals

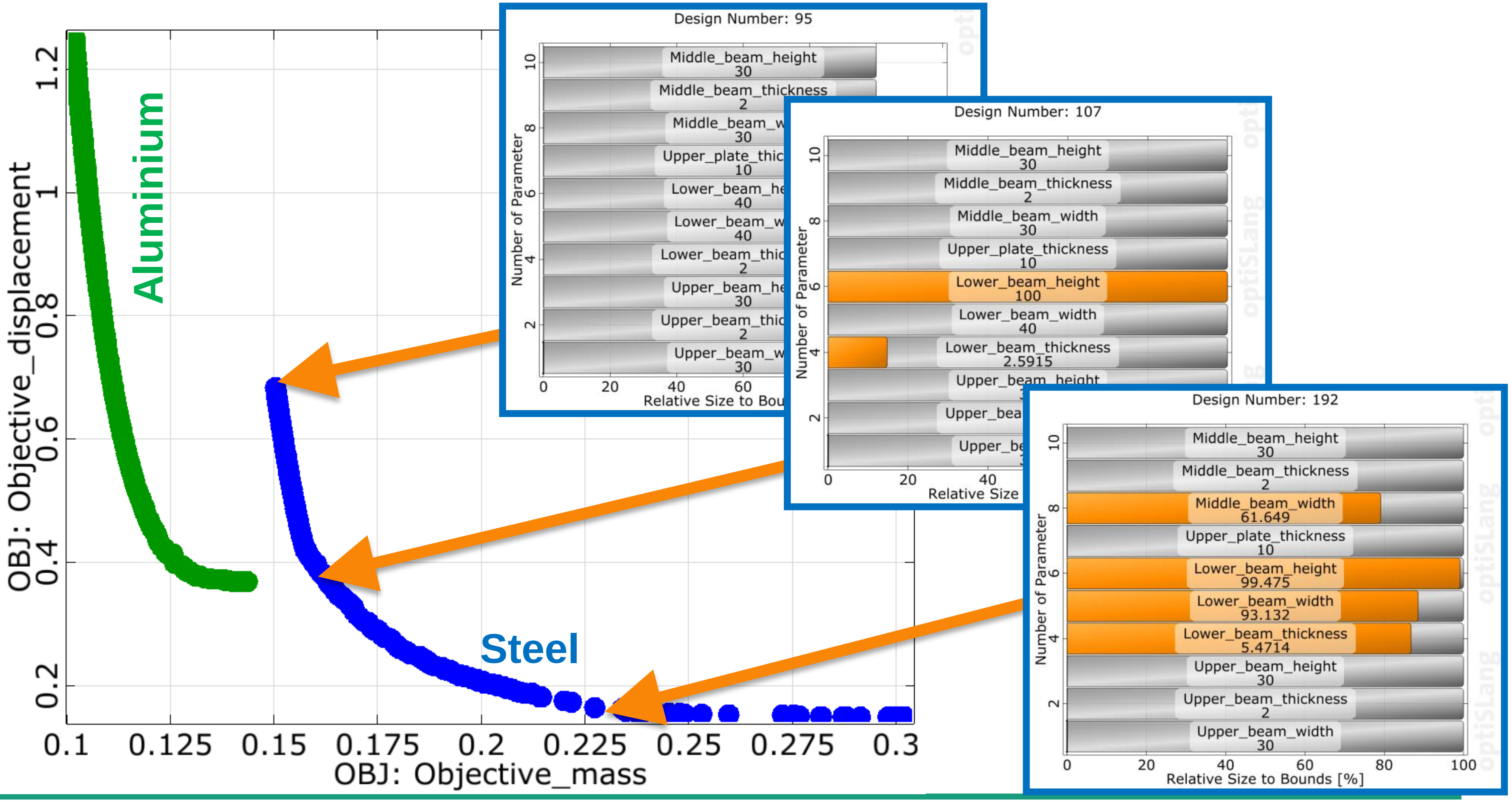
- Goal 1: Minimization of the mass (initial 207 kg)
- Goal 2: Minimization of sum of deformations in 0°, 90° und 180° position (initial 0,26 mm)

Objectives

Name	Criterion	Expression	Value
Objective_mass	MIN	Total_mass/1000	0.207195
Objective__displacements	MIN	Maximum_displacement_0+Maximum_displacement_90+Maximum_displacement_180	0.285717
new			

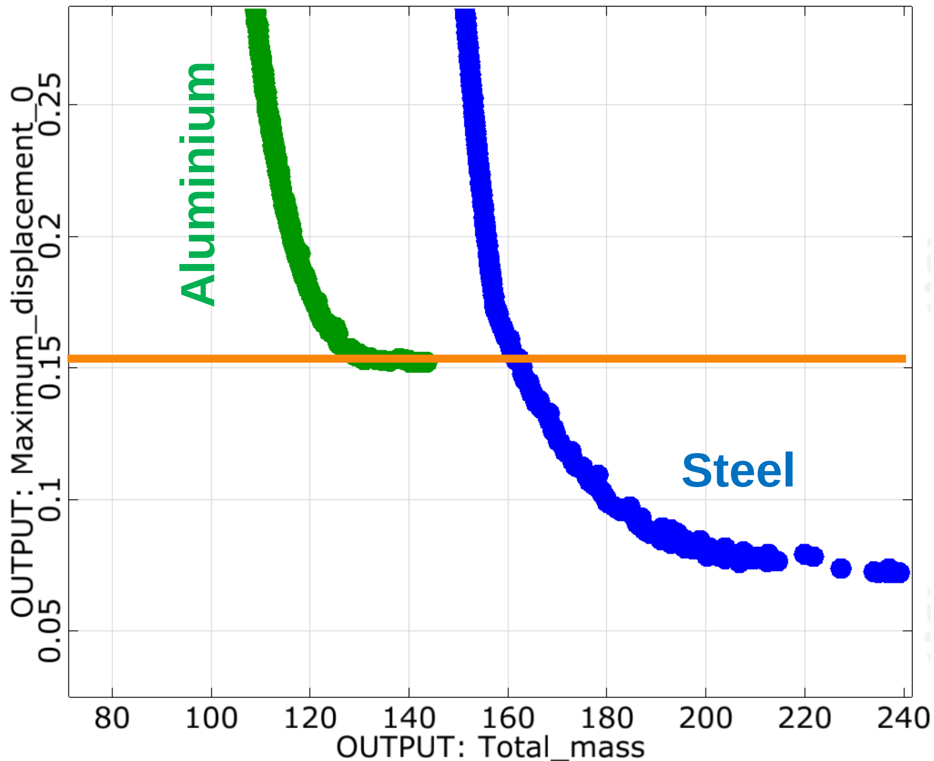
Multi-Objective Optimization using the MOP-Approximation

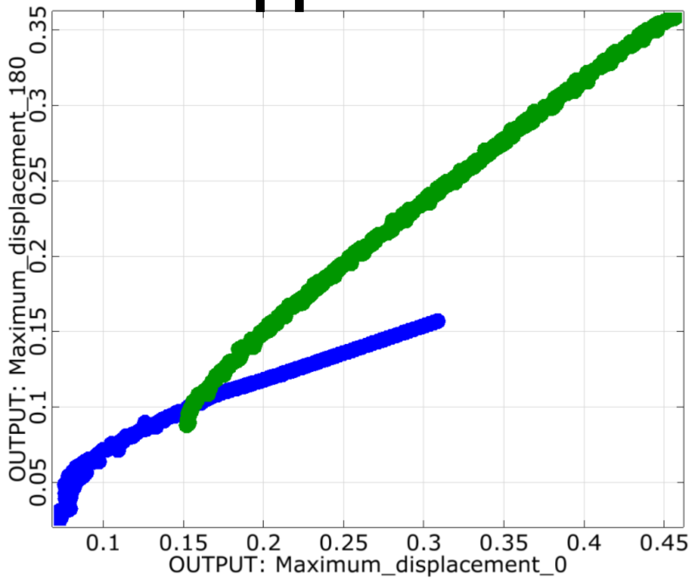
Steel construction can obtain much smaller deformations with higher mass

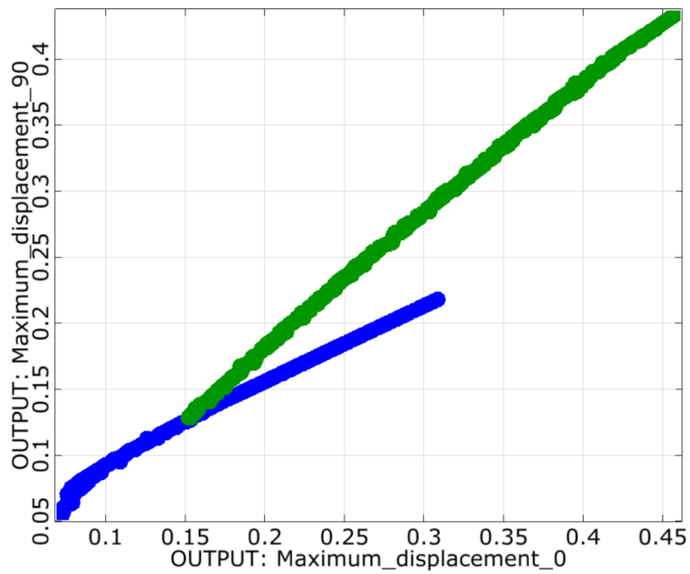


Multi-Objective Optimization with MOP-Approximation

- Deformations in 0°, 90° und 180° position are not in conflict to each other
- Deformations smaller than 0,15 mm seem to be not possible with Aluminium

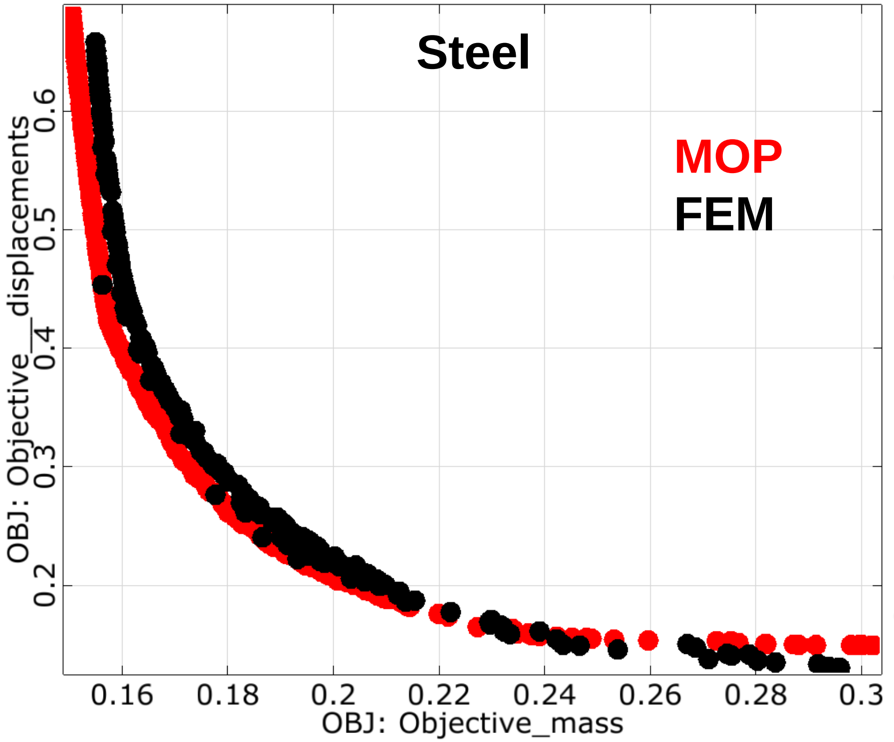


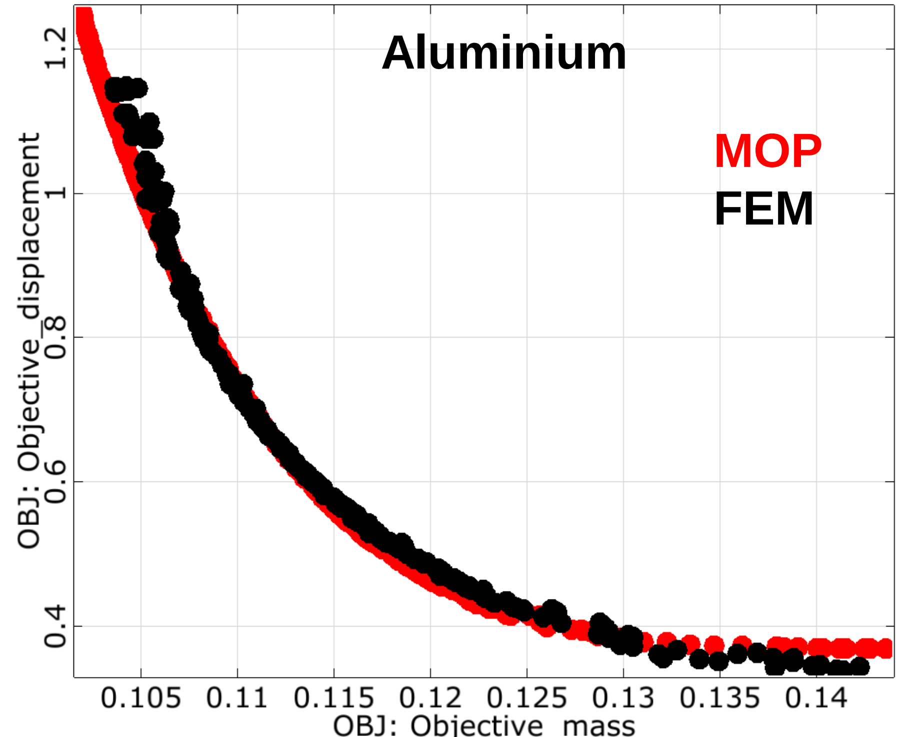




Validation of Approximated Pareto-Frontier

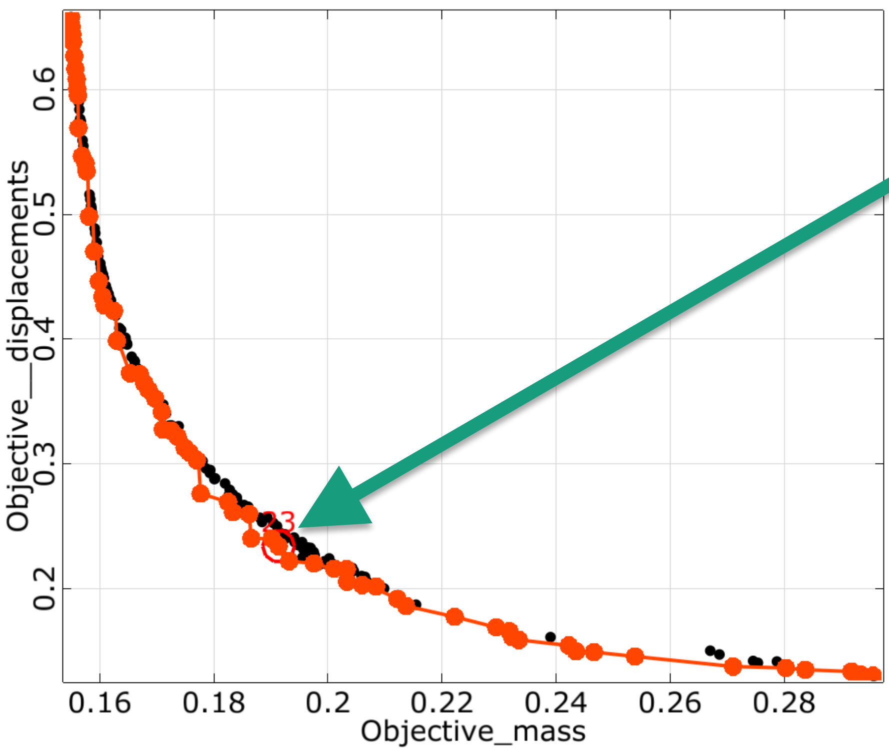
- Pareto designs on MOP-approximation agree very well with simulation results

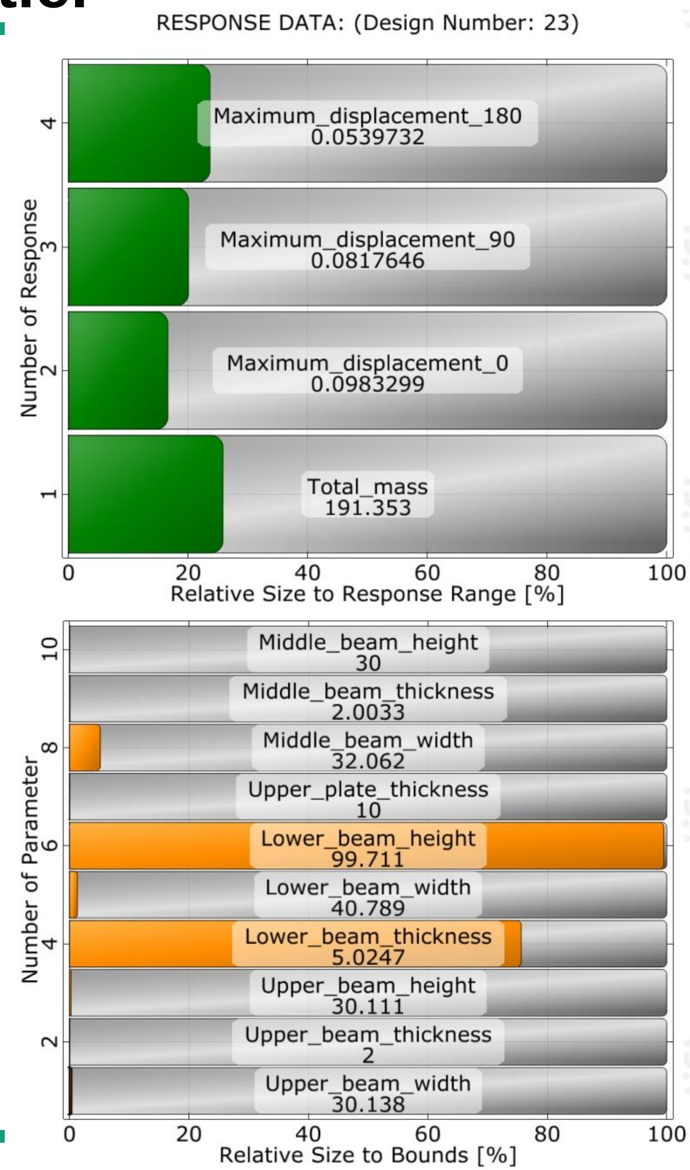




Optimal Design at the Pareto-Frontier

- Deformation is limited to 0,1mm
  - Height and thickness of lower beam are most important





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Single-Objective Optimization

- Optimization goal: minimization of the mass
- Material of beams: Steel
- Constraints: Deformations (0°, 90° und 180°) smaller than 0,1mm

Objectives

Name	Criterion	Expression	Value
Objective	MIN	Total_mass	207.195
new			

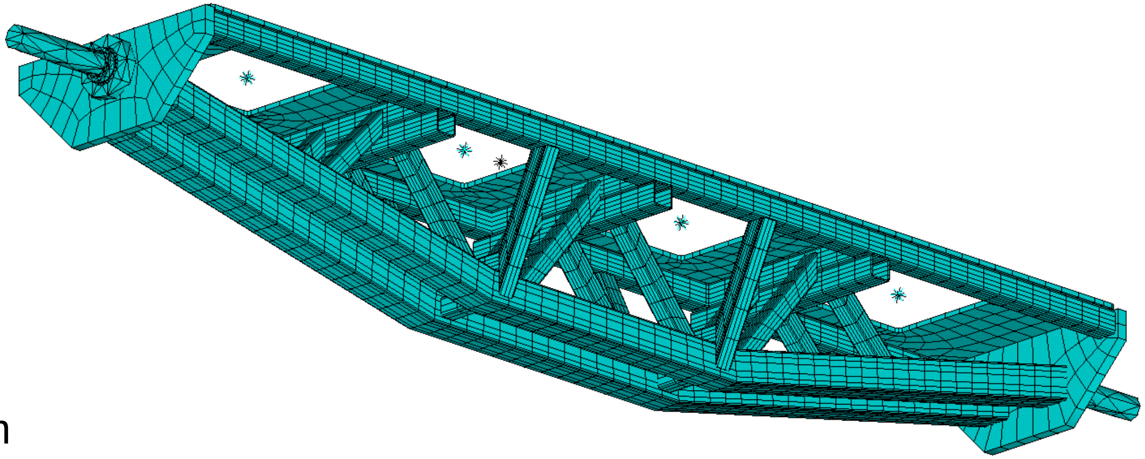
Constraints

Name	Left side expression	Criterion	Right side expression	Value
Constraint_0	Maximum_displacement_0	≤	0.1	0.120873 ≤ 0.1
Constraint_90	Maximum_displacement_90	≤	0.1	0.0972345 ≤ 0.1
Constraint_180	Maximum_displacement_180	≤	0.1	0.0676094 ≤ 0.1
new				

Optimal Design 1: Continuous Design Parameters

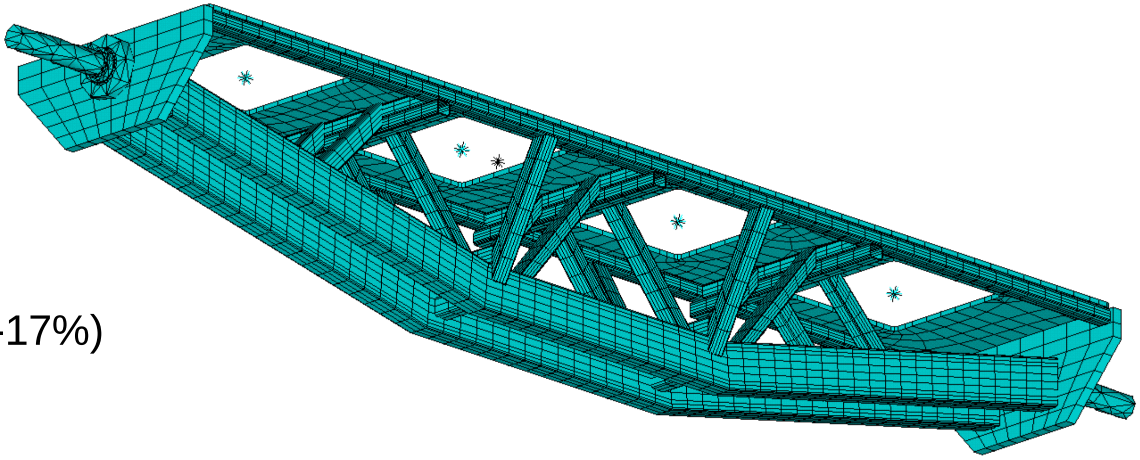
Initial Design

- Mass: 207,2 kg
- Deformations:
  - 0°- position: 0,12 mm
  - 90°- position: 0,10 mm
  - 180°- position: 0,07 mm



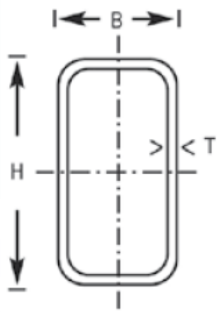
Optimized Design

- Mass: 186,1 kg (-10%)
- Deformations:
  - 0°- position: 0,10 mm (-17%)
  - 90°- position: 0,08 mm
  - 180°- position: 0,05 mm



Optimization using Discrete Design Parameters

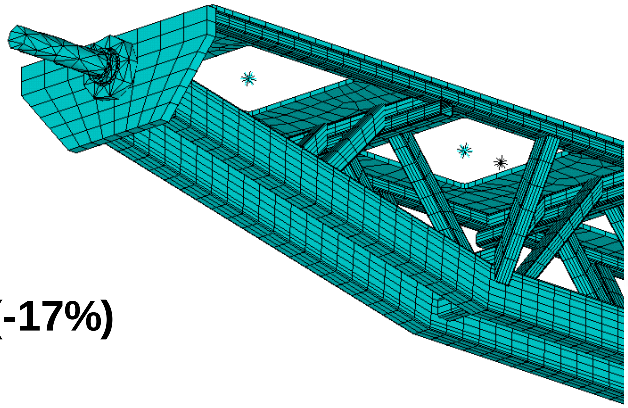
Abmessung H x B x T mm		kalt-gefertigt EN 10219 M kg/m	Quer-schnitt-fläche A cm²
40 x 20 x	2,0	1,68	2,14
	2,5	2,03	2,59
	3,0	2,36	3,01
45 x 25 x	3,0	2,83	3,61
40 x 30 x	3,0	2,83	3,61
50 x 20 x	3,0	2,83	3,61
50 x 30 x	2,0	2,31	2,94
	2,5	2,82	3,59
	3,0	3,30	4,21
	4,0	4,20	5,35
60 x 30 x	3,0	3,77	4,81
60 x 40 x	2,0	2,93	3,74
	2,5	3,60	4,59
	3,0	4,25	5,41
	4,0	5,45	6,95
	5,0	6,56	8,36
70 x 40 x	3,0	4,72	6,01
	4,0	6,08	7,75
70 x 50 x	2,0	3,56	4,54
	2,5	4,39	5,59
	[illegible]	[illegible]	6,61
	[illegible]	[illegible]	8,55
	[illegible]	[illegible]	10,40

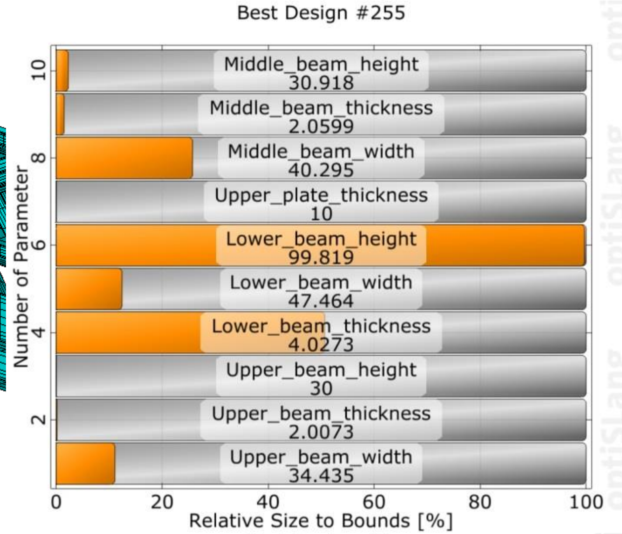


- Parameters have been chosen according to available supplier profiles

	Name	Parameter type	Reference value	Constant	Operation	Resolution	Range	Range plot
1	Lower_beam_distance	Optimization	80	☑		Continuous	60 100	
2	Lower_beam_height	Optimization	100	☐		Ordinal discrete by value	40; 50; 60; 80; 100	
3	Lower_beam_thickness	Optimization	4	☐		Ordinal discrete by value	2.5; 3; 4; 5; 6	
4	Lower_beam_width	Optimization	60	☐		Ordinal discrete by value	40; 50; 60; 80; 100	
5	Middle_beam_height	Dependent	40	☐	Middle_beam_width			
6	Middle_beam_thickness	Optimization	2	☐		Ordinal discrete by value	2; 2.5; 3; 4; 5	
7	Middle_beam_width	Optimization	40	☐		Ordinal discrete by value	30; 40; 50; 60; 70	
8	Upper_beam_height	Dependent	30	☐	Upper_beam_width			
9	Upper_beam_thickness	Optimization	2	☐		Ordinal discrete by value	2; 2.5; 3; 4; 5	
10	Upper_beam_width	Optimization	30	☐		Ordinal discrete by value	30; 40; 50; 60; 70	
11	Upper_plate_thickness	Optimization	10	☑		Continuous	10 30	

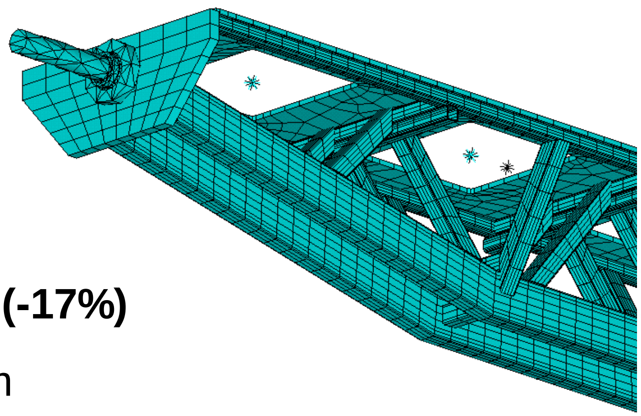
Optimal Design 2: Discrete Design Parameters

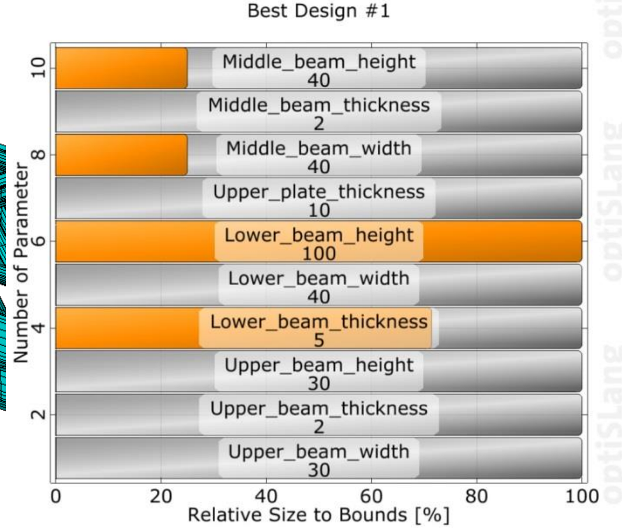




Optimized Design 1

- Mass: 186,1 kg **(-10%)**
- Deformations:
  - 0°- position: 0,10 mm **(-17%)**
  - 90°- position: 0,08 mm
  - 180°- position: 0,05 mm





Optimized Design 2

- Mass: 193,3 kg **(-7%)**
- Deformations:
  - 0°- position: 0,10 mm **(-17%)**
  - 90°- position: 0,08 mm
  - 180°- position: 0,05 mm

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Summary

- Sensitivity analysis helps to better understand the physical phenomena and to check or validate the simulation model
- Identification of important parameters helps to significantly simplify and accelerate the optimization task
- MOP-approximation can be used for fast pre-optimization step or multi-objective case studies

Thank you

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