European Commission | Horizon 2020 European Union funding for Research & Innovation

IPEK Institute of Product Engineering at Karlsruhe Institute of Technology

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The Extended Target Weighing Approach

Identification and Evaluation of Lightweight Design Potentials

Future of Automotive Lightweighting Day, 19.09.2019, Aachen

Robert Renz (IPEK), Sven Revfi (IPEK), A. Timmer, T. Michler (Opel), K. Seidel, D. Thirunavukkarasu (IKA RWTH Aachen), H. Atzrodt, C. Tamm (Fraunhofer LBF)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723893

IPEK – Institute of Product Engineering

Karlsruher Institute of Technology (KIT)

Facts

- **2** professors
- **1** managing director
- **5** chief engineers
- **80** scientists
- **20** administration & technical staff
- education
  - since 1996 over **120 Ph.D.**
  - **21** lectures
  - over **350** student assistants
  - **2000** students per semester supervised by IPEK

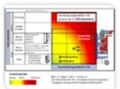
Research Fields

NVH and Vehicle Acoustics

Drive Systems

Clutches and Brakes in Drive Systems

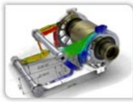
Tribology Systems



Product Generation Engineering

Development and Innovation Management

Validation of Technical Systems



Lightweight Design

Methods of Embodiment Design

Power Tools

Motivation
Example for Lightweight Design

Improved driving dynamics and **reduced emissions** are required in upcoming **vehicle** generation

Challenge for product engineer: **Reduce vehicle curb weight by x%!**

Change material
(e.g. steel ➔ aluminum)

Reduce requirements
(e.g. reduced stiffness)

Change connections
(e.g. bold ➔ adhesive)

Integrate functions
(e.g. reduce components)

Source: Opel, Astra

Optimise component shape
(e.g. due to flow of forces)

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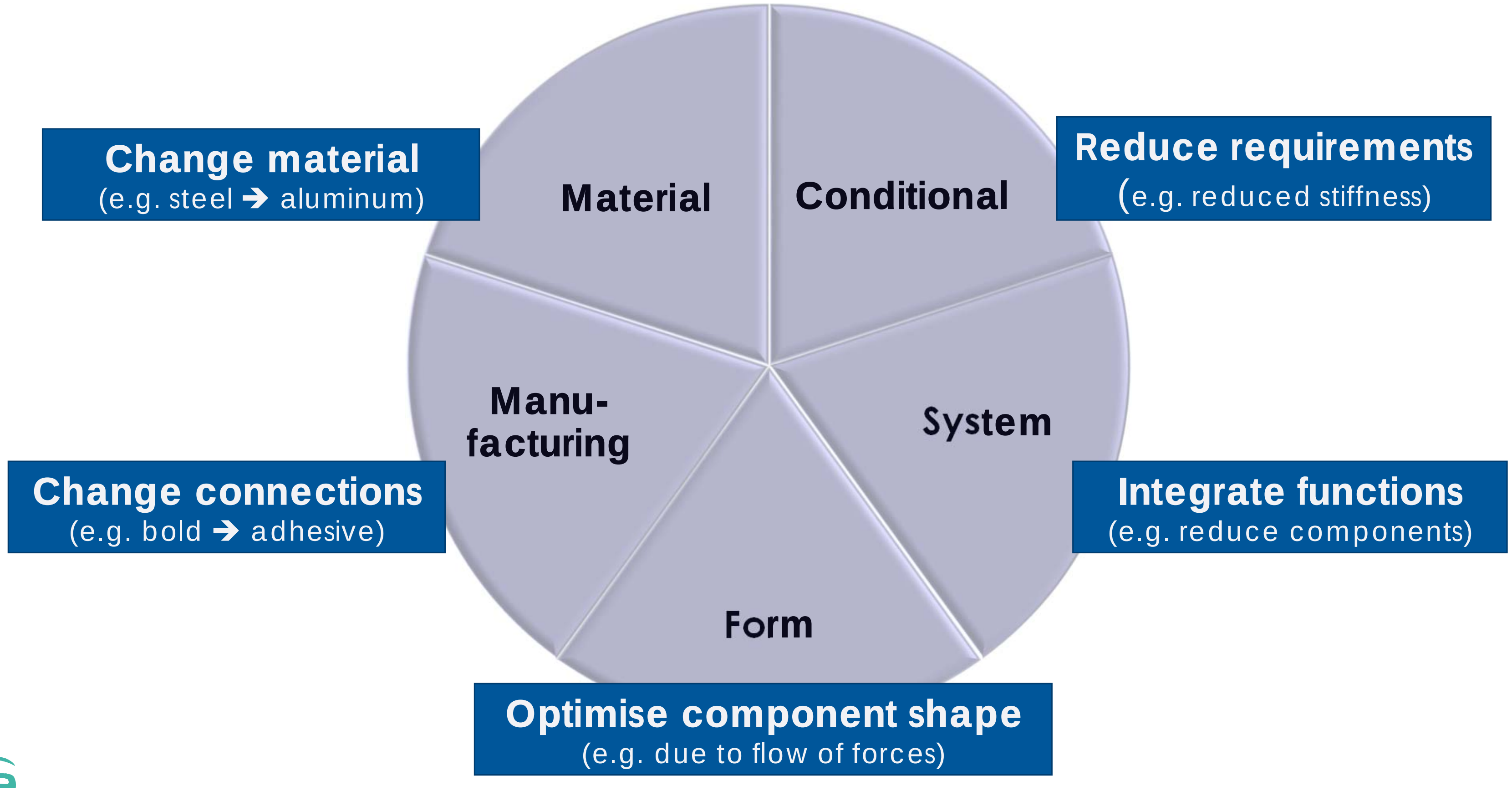
Motivation
Lightweight Design Strategies

Lightweight Design Strategies



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Motivation
Corporate Process

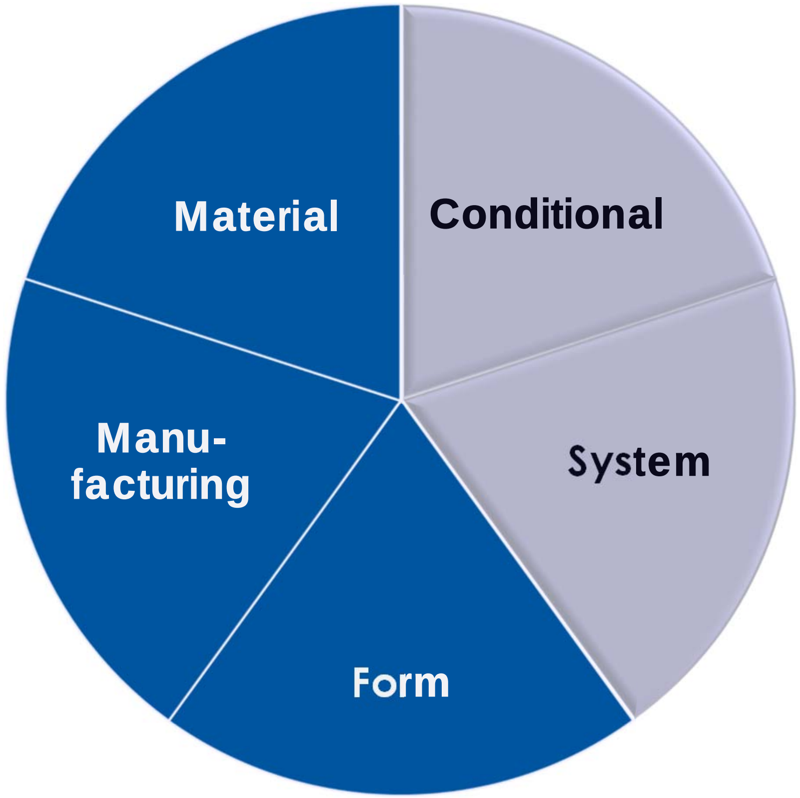
Classic **corporates** are structured in **subsystems**

↓

Main **focus** on lightweight design within **subsystems**

↓

Material, **manufacturing** and **form** lightweight design



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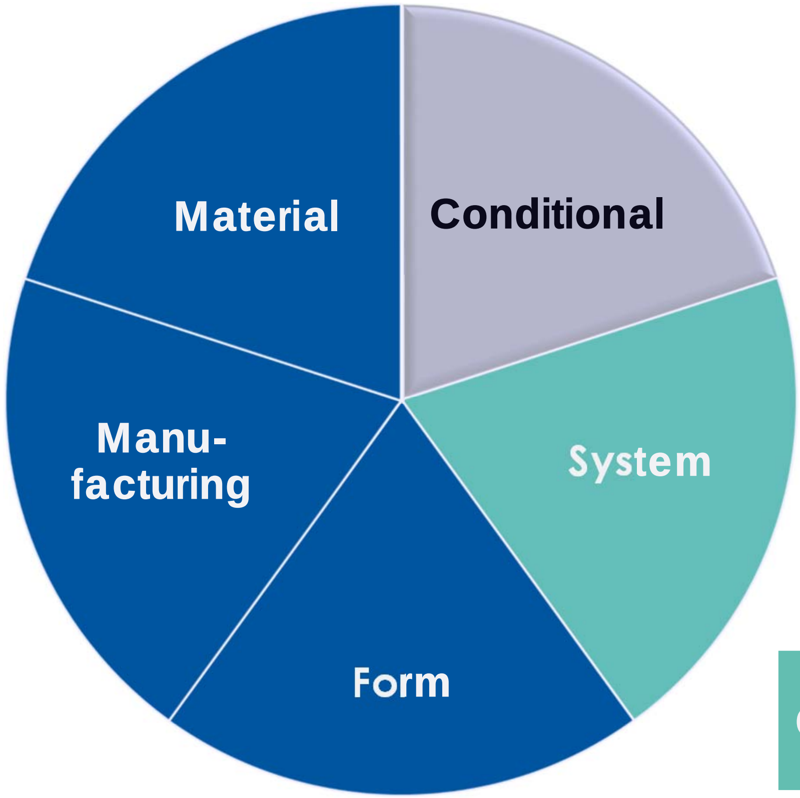
Motivation

Corporate Process vs. Methodological Approach

Classic **corporates** are structured in **subsystems**

Main **focus** on lightweight design within **subsystems**

Material, **manufacturing** and **form** lightweight design



Combination of **subsystem optima** does **not** inevitably lead to an **overall** system **optimum**

Cross-subsystem approaches necessary

Concept lightweight design

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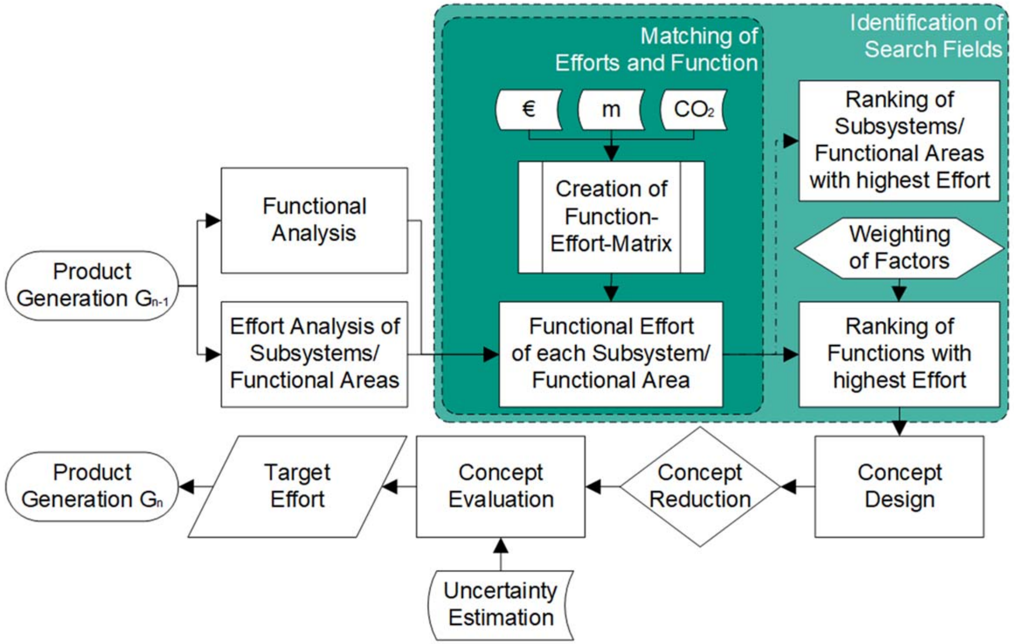
Extended Target Weighing Approach
Methodology

EXTENDED TARGET WEIGHING APPROACH (ETWA)



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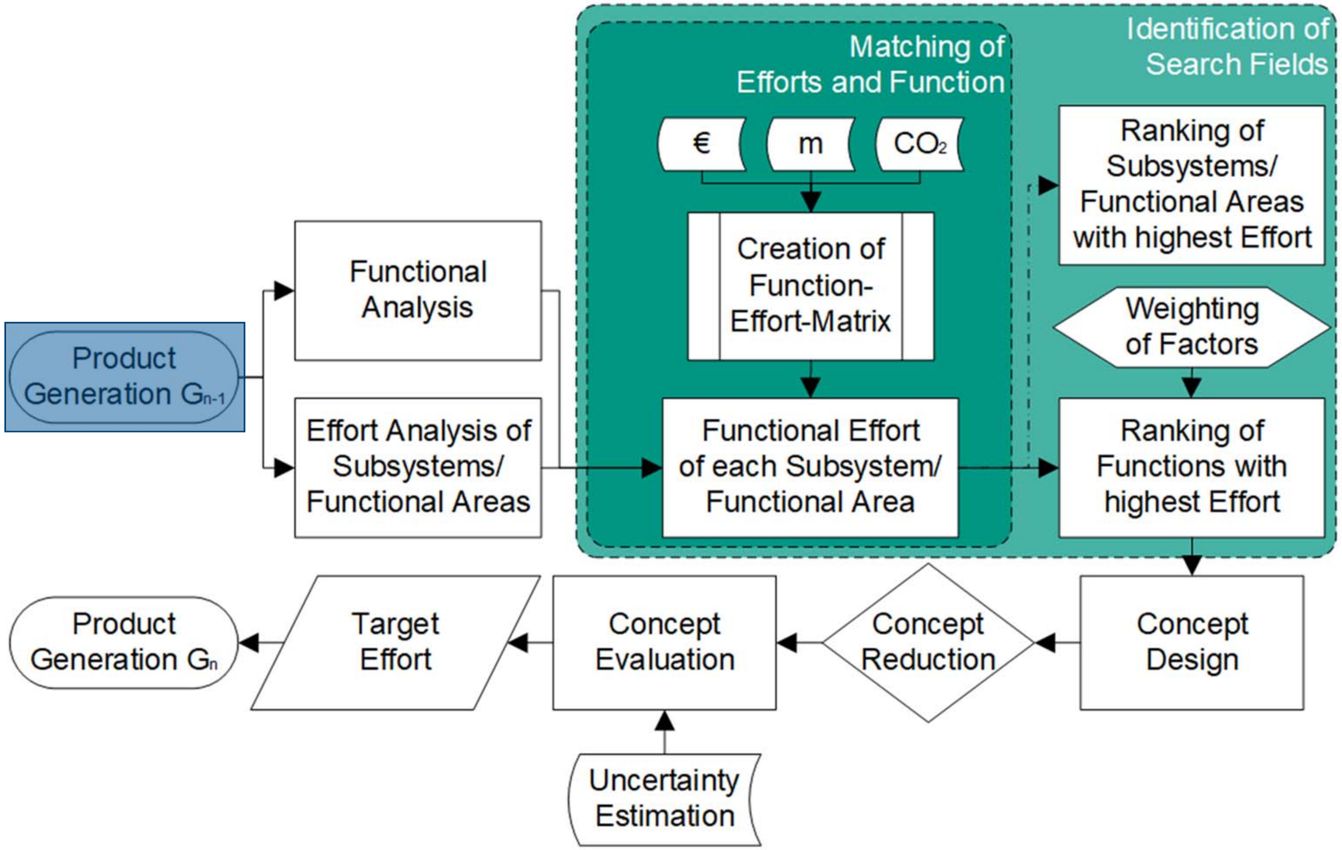
Extended Target Weighing Approach

Methodology – Product Generation G_{n-1}



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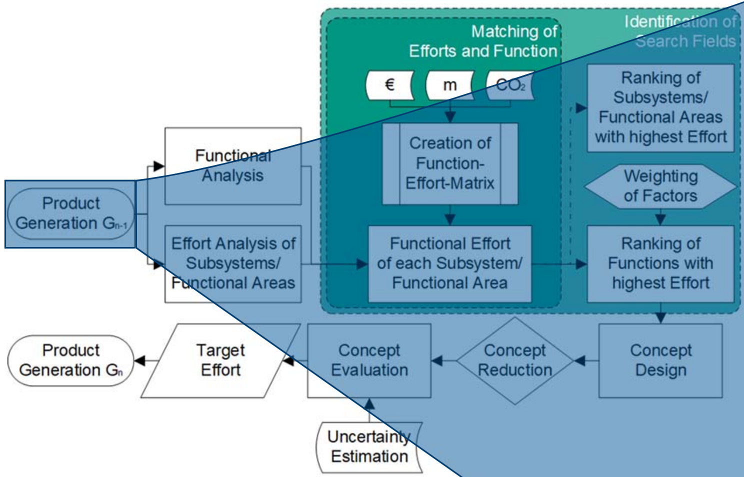
Extended Target Weighing Approach

ALLIANCE – Product Generation G_{n-1}



Ideally, the starting point for ETWA is a **reference product** in terms of **PGE – Product Generation Engineering** according to Albers whose mass has to be optimised.

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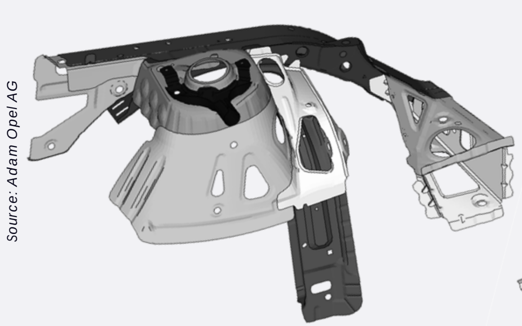
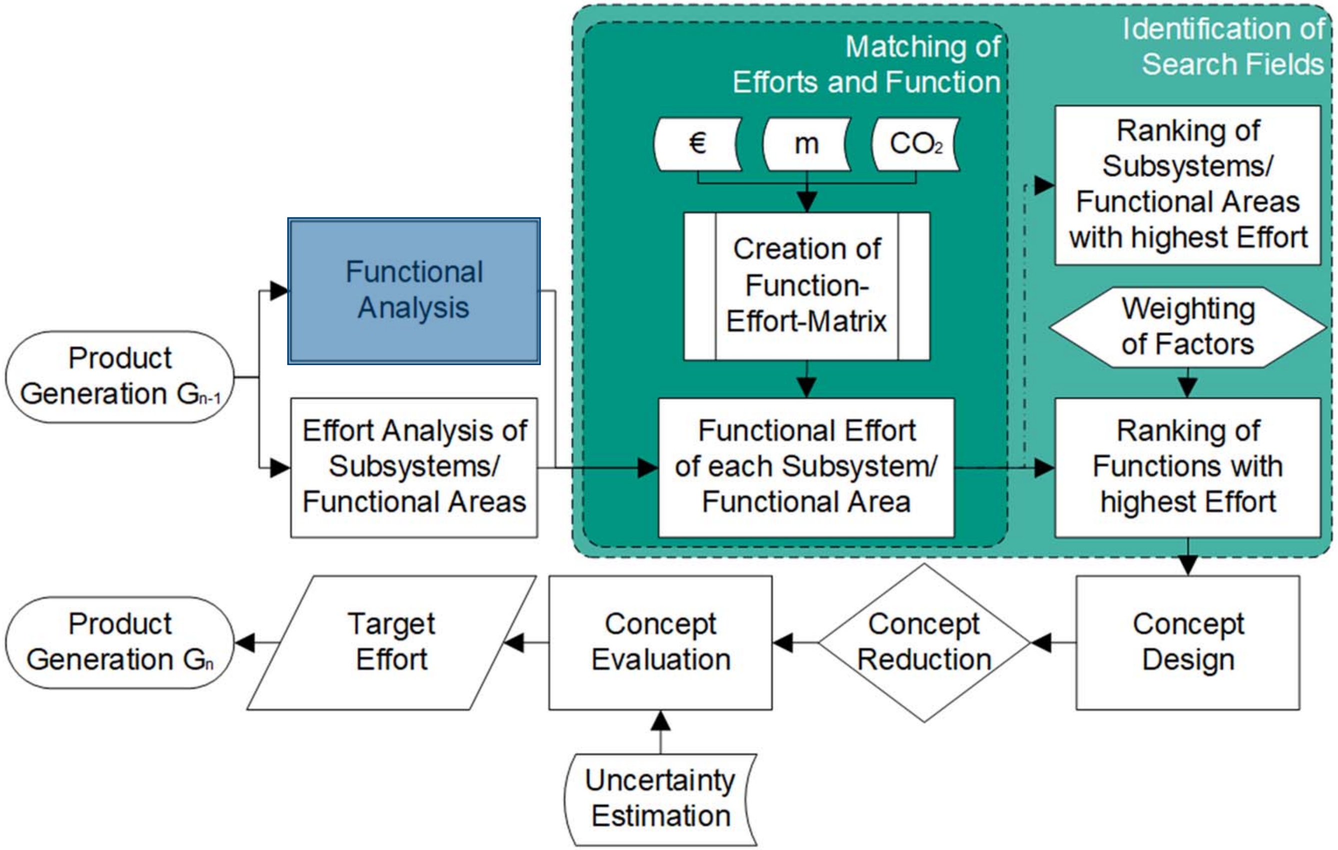


Strut Tower Opel Astra

Rail Opel Astra

Extended Target Weighing Approach

Methodology – Functional Analysis



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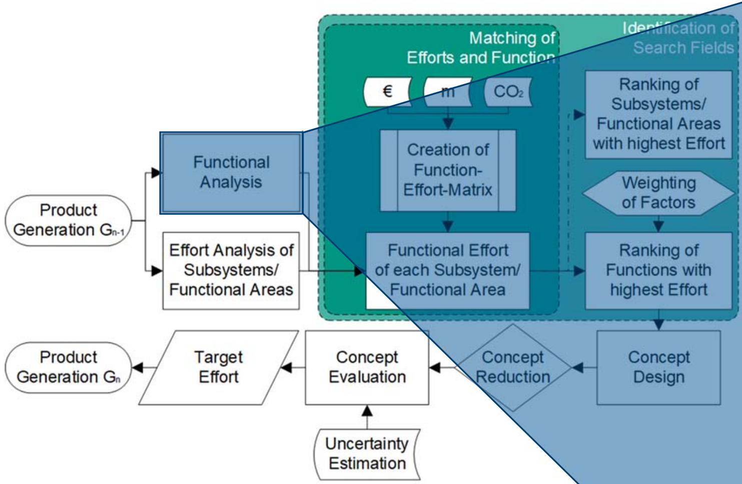
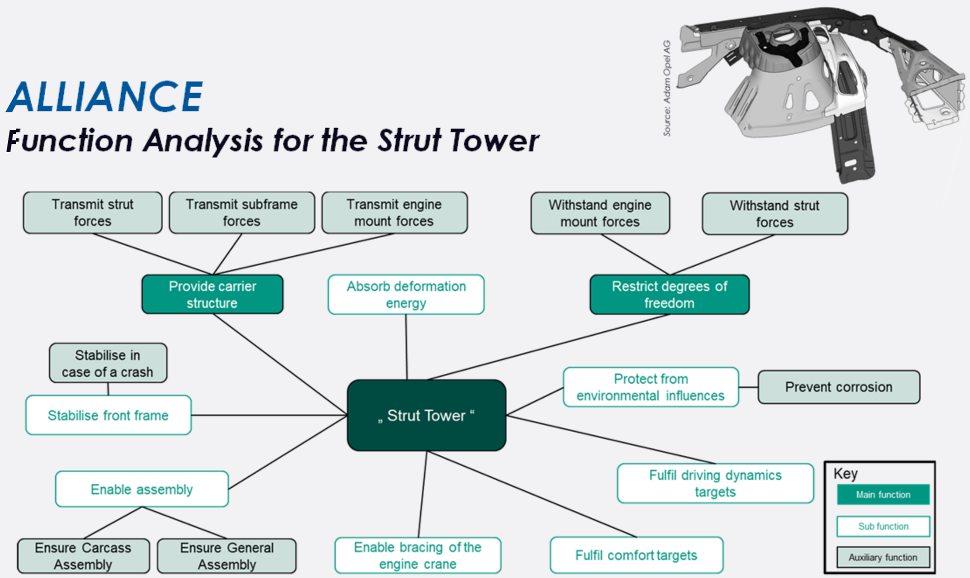
Extended Target Weighing Approach

ALLIANCE – Functional Analysis

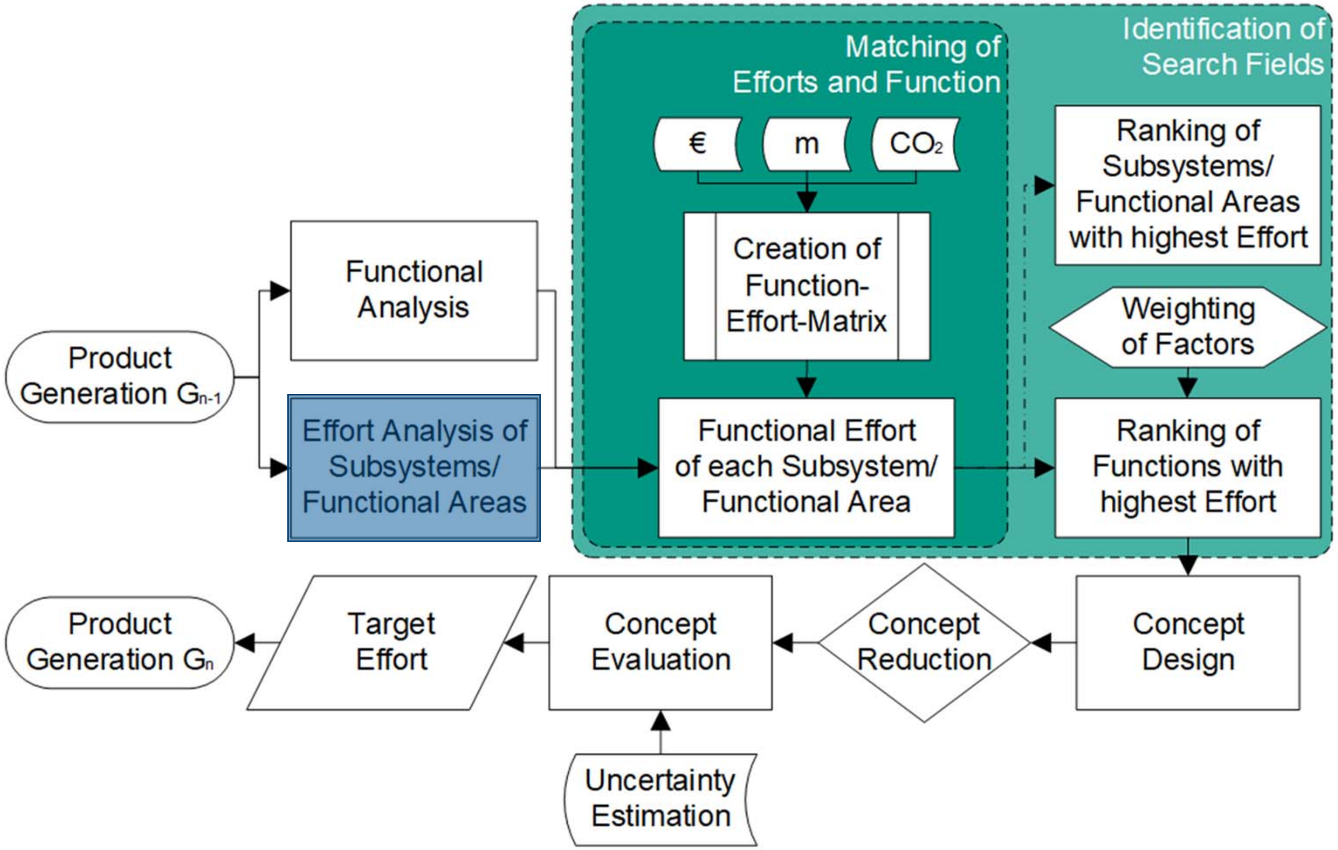


Analysis of the **functions** performed by the considered (part of the) **product/system**.



Extended Target Weighing Approach

Methodology – Effort Analysis



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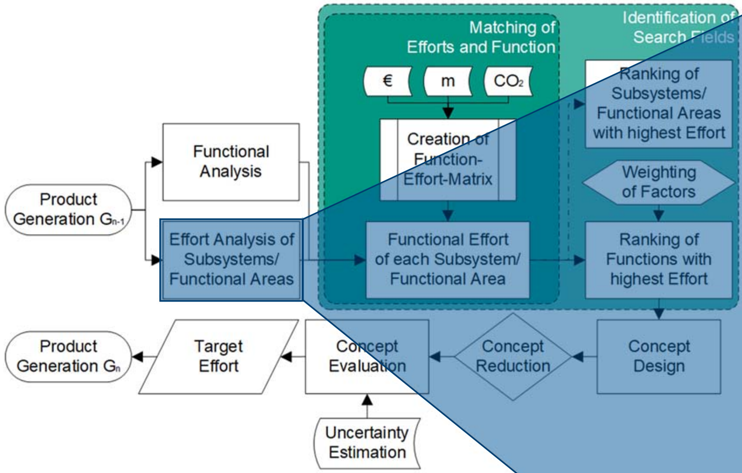
Extended Target Weighing Approach

ALLIANCE – Effort Analysis



Mass: **Volume** (CAD-data) and **density**

Costs: **Greenfield approach/Lifecycle Cost**

CO2 emissions: **Lifecycle Assessment** (Cradle-to-grave approach)

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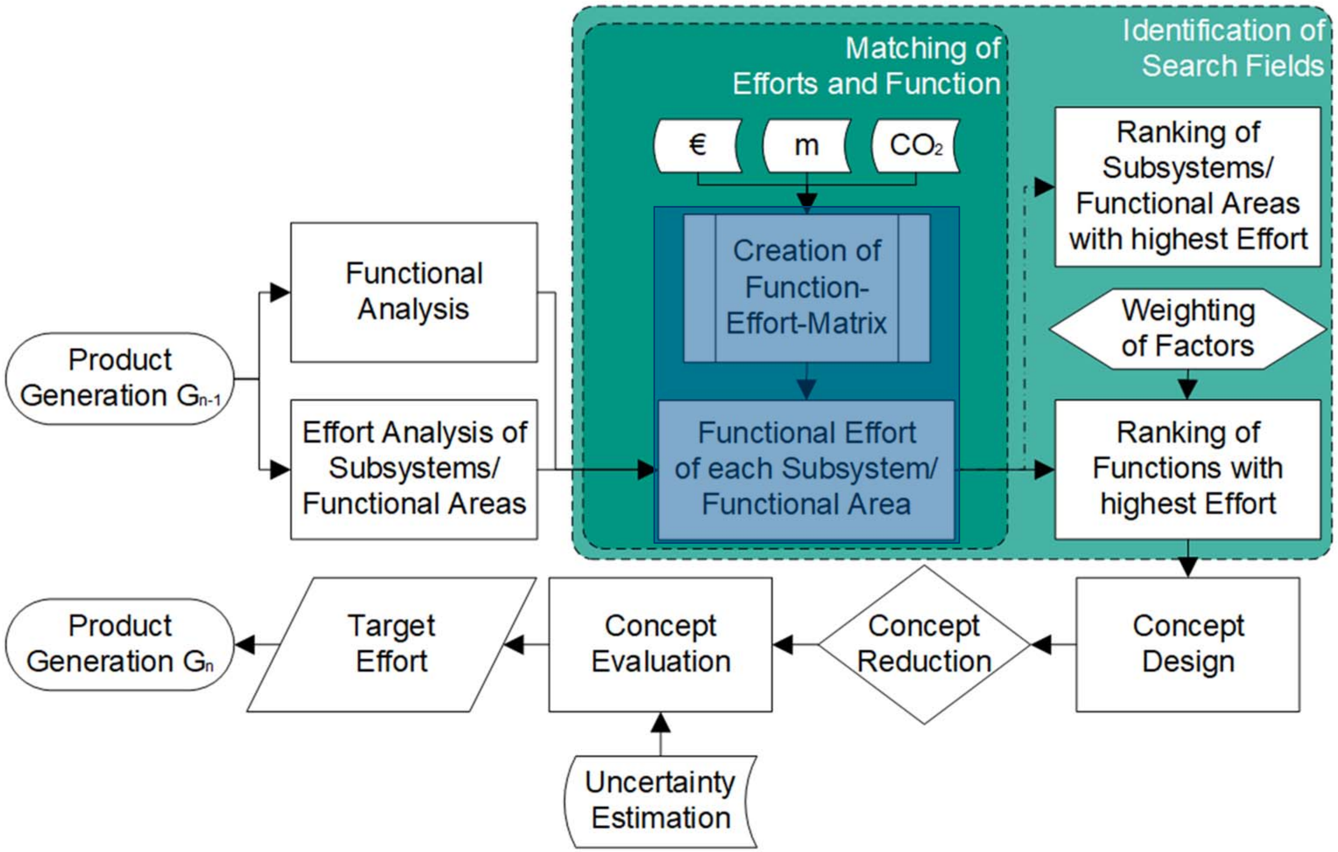
Effort Analysis for the Strut Tower

Part	Mass [kg]	Costs [€]	CO2 [kg]
13375206	0,86	2,40	11,20
13375208	0,68	2,60	7,93
13375212	0,69	2,20	7,96
13375218	0,21	1,60	2,49
13418959	0,57	2,20	7,91
13464655	1,59	3,10	17,50
13469891	1,02	2,50	12,00
13473417	0,22	1,60	2,86
13473521	0,48	1,90	5,19
OPS27890	0,48	1,90	5,12
13377812	0,38	1,80	6,15

Extended Target Weighing Approach

Methodology – Function-Effort-Matrix



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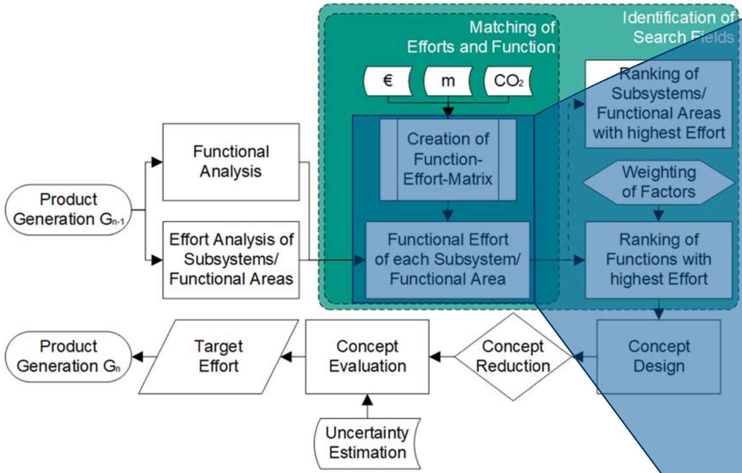
Extended Target Weighing Approach

Methodology – Function-Effort-Matrix

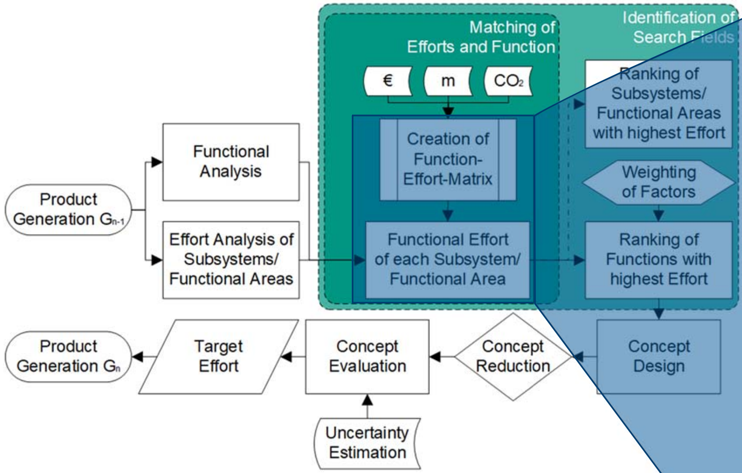


	Mass [kg]	Costs [€]	CO2 [kg]	Function 1	Function 2	Function 3	…	Function n
Subsystem 1	0,1	100	0,1	50%				50%
Subsystem 2	0,5	500	0,5		100%			
Subsystem 3	0,4	60	0,4	25%	25%	25%		25%
…	…	…	…				100%	
Subsystem n	0,2	350	0,1	10%		10%		80%
Mass per Function				0,17	0,6	0,12	…	0,31
Costs per Function				100	515	50	…	345
CO2 per Function				0,16	0,6	0,11	…	0,23

Result: **Functional Effort**

Extended Target Weighing Approach

ALLIANCE – Function-Effort-Matrix



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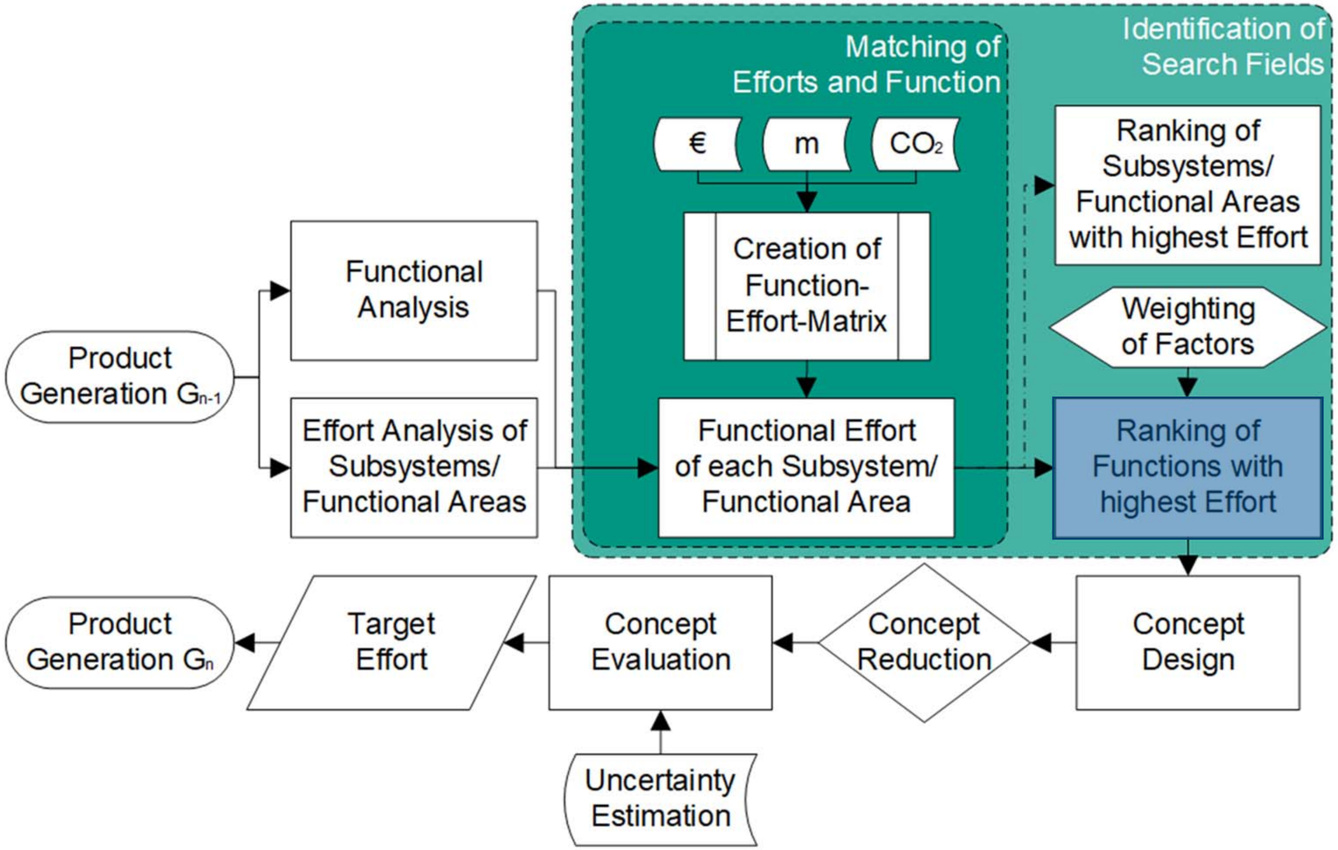
Function-Effort-Matrix for the Strut Tower

Part number	Mass in kg	LCA in kgCO2-eq	Costs in %	Provide carrier structure: Transmit strut forces	Provide carrier structure: Transmit subframe forces	Provide carrier structure: Transmit engine mount forces	Restrict degrees of freedom: Withstand engine mount forces	Restrict degrees of freedom: Withstand strut forces	Stabilise front frame: Stabilise in case of a crash	Enable assembly: Ensure Carcass Assembly	Enable assembly: Ensure General Assembly	Enable bracing of the engine crane: Enable bracing of the engine cr	Fulfill comfort targets: Fulfill comfort targets	Fulfill driving dynamics targets: Fulfill driving dynamics targets	Absorb deformation energy: Absorb deformation energy	Protect from environmental influences: Prevent corrosion
13375206	0,86	11,20	4,47%	40,0%	10,0%	10,0%			5,0%	7,5%	7,5%		10,0%	10,0%		
13375208	0,68	7,93	3,60%	15,0%	30,0%	15,0%			5,0%	7,5%	7,5%		10,0%	10,0%		
13375212	0,69	7,96	2,45%	30,0%	5,0%	5,0%			15,0%	10,0%	5,0%	10,0%	5,0%	5,0%	10,0%	
13375218	0,21	2,49	1,42%	15,0%	10,0%	5,0%			25,0%	10,0%	5,0%	5,0%	10,0%	10,0%	5,0%	
13418959	0,57	7,91	3,42%	25,0%	5,0%	5,0%			20,0%	10,0%		15,0%	5,0%	5,0%	10,0%	
13464655	1,59	17,50	5,01%	40,0%					10,0%	5,0%	5,0%	10,0%	15,0%	15,0%		
13469891	1,02	12,00	4,06%	25,0%	5,0%	5,0%			20,0%	10,0%	5,0%	5,0%	10,0%	10,0%	5,0%	
13473417	0,22	2,86	2,30%	30,0%						10,0%	15,0%		20,0%	25,0%		
13473521	0,48	5,19	1,95%	15,0%	10,0%	5,0%			30,0%	5,0%	5,0%	5,0%	10,0%	10,0%	5,0%	
OP527890	0,40	5,12	2,70%	10,0%	5,0%	20,0%	30,0%		5,0%	5,0%	5,0%	5,0%	10,0%	5,0%		
13377812	0,30	6,15	5,74%	25,0%				25,0%		10,0%	10,0%		15,0%	15,0%		
xxx	0,02		2,08%													100,0%
yyy	0,03		2,84%													100,0%
Funktionsmasse in kg	7,24	86,31	42,23%	2,00	0,50	0,43	0,14	0,10	0,88	0,55	0,41	0,42	0,78	0,76	0,21	0,05
	relative Massenanteile			27,66%	6,88%	5,97%	1,90%	1,33%	12,13%	7,63%	5,68%	5,84%	10,74%	10,57%	2,92%	0,68%
Funktionsemissionen in kg				24,09	5,92	5,11	1,54	1,54	10,32	6,76	4,99	4,97	9,31	9,19	2,57	0,00
	relative Emissionsanteile			27,92%	6,85%	5,92%	1,78%	1,78%	11,95%	7,83%	5,78%	5,76%	10,78%	10,65%	2,98%	0,00%
Funktionskosten in %				9,87%	2,55%	2,22%	0,81%	1,44%	3,85%	3,04%	2,42%	1,77%	4,21%	4,19%	0,96%	4,92%
	relative Kostenanteile			23,37%	6,05%	5,26%	1,92%	3,40%	9,12%	7,20%	5,73%	4,18%	9,96%	9,91%	2,27%	11,64%

Extended Target Weighing Approach

Methodology – Ranking of Functions



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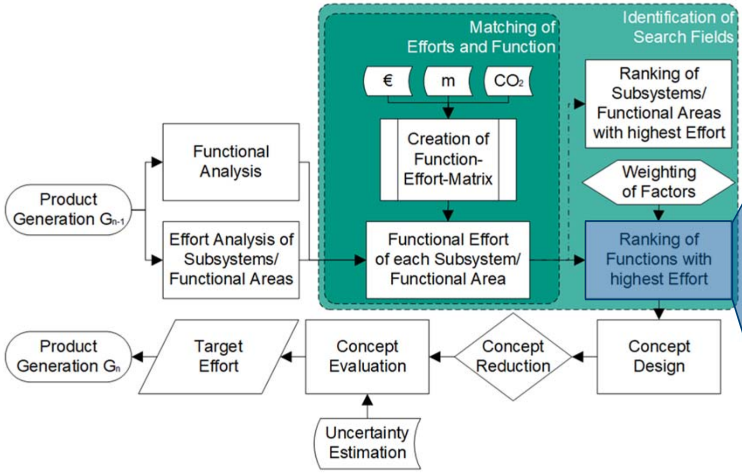
Extended Target Weighing Approach

ALLIANCE – Ranking of Functions



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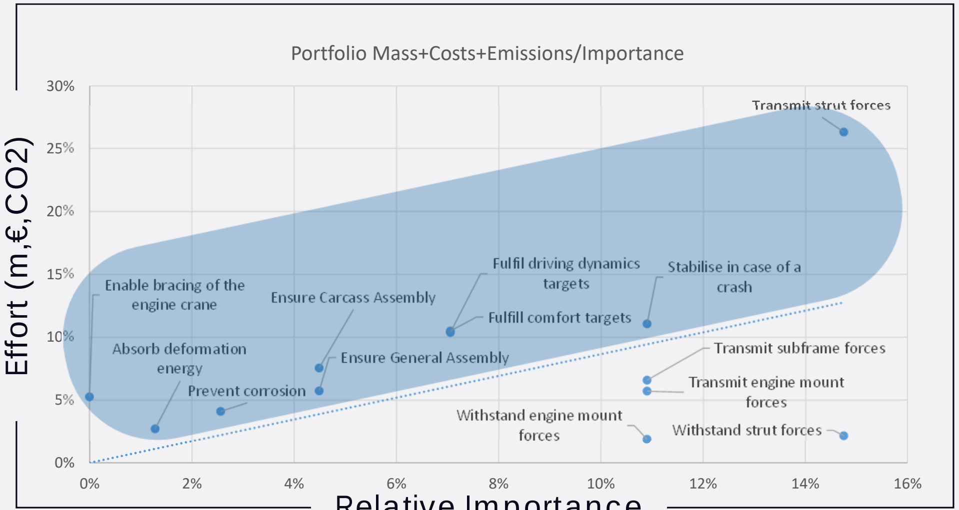
Function Portfolio for the Strut Tower



$$E = \mathbf{0,33} \cdot m + \mathbf{0,33} \cdot € + \mathbf{0,33} \cdot CO2$$

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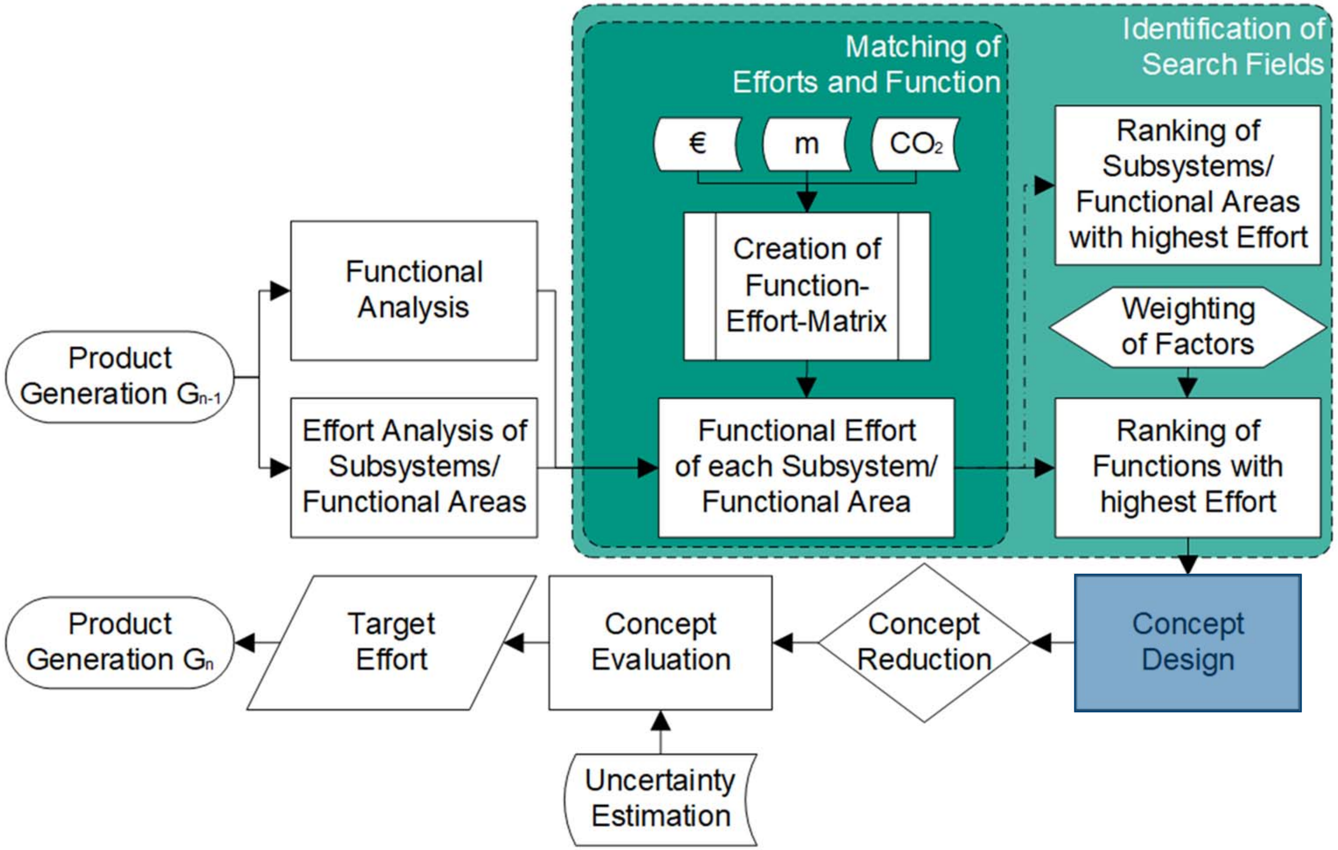
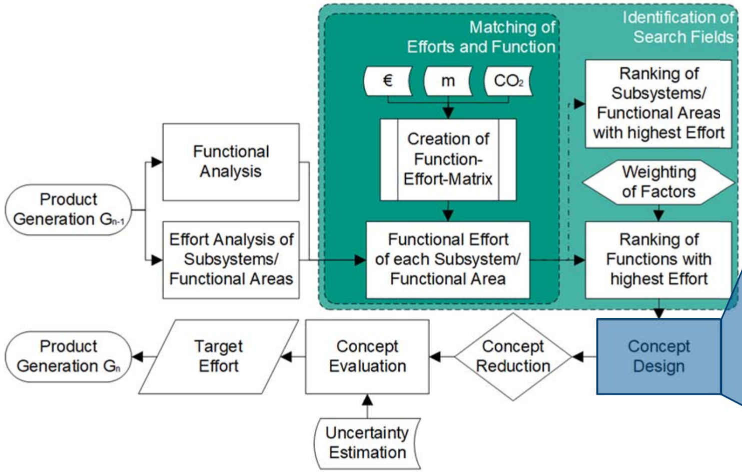
Extended Target Weighing Approach

Methodology – Concept Design



Extended Target Weighing Approach

Methodology – Concept Design

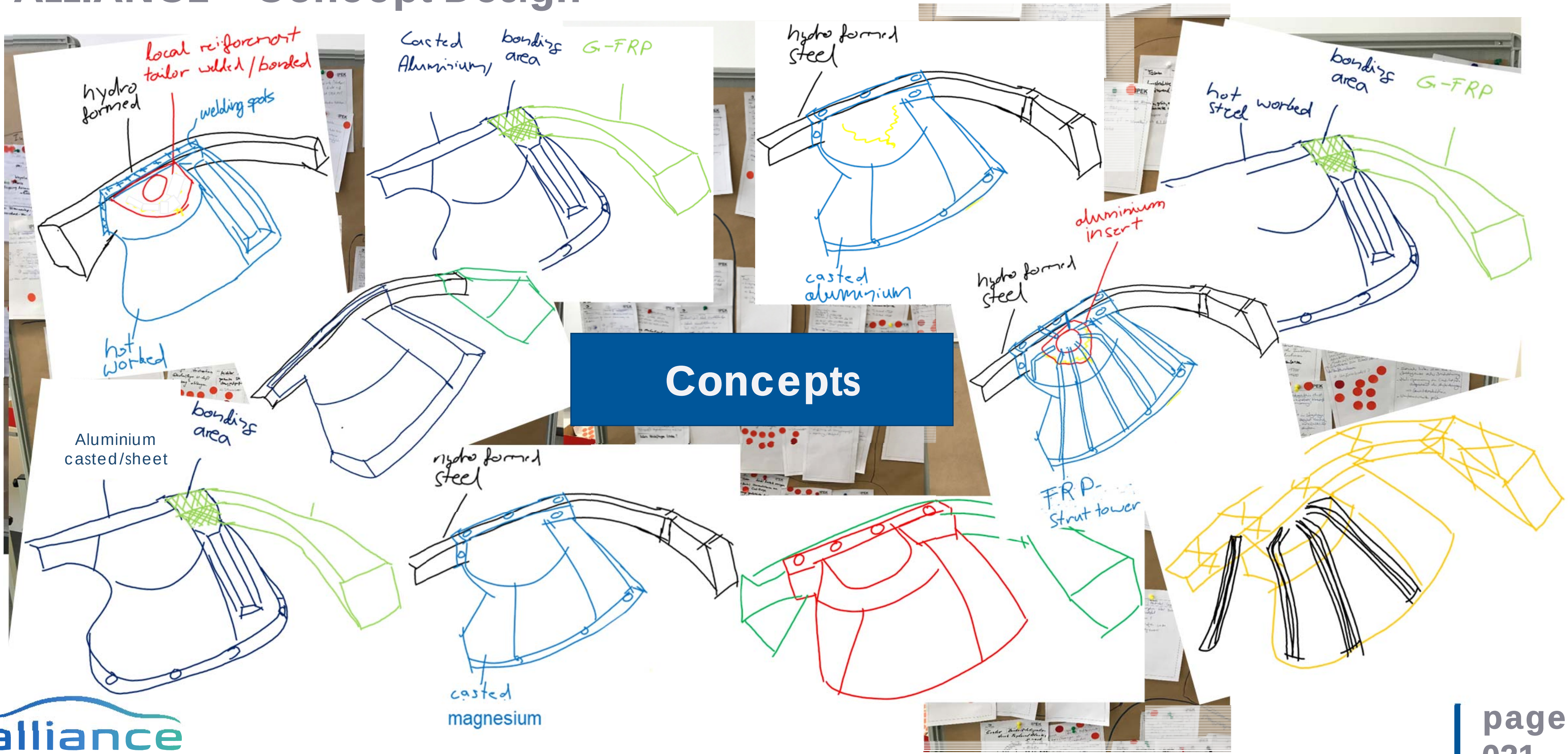


Method-supported

- Creativity Methods
  - 6-3-5 Method
  - Brainstorming/Brainwriting Pool
  - TRIZ
- Design Guidelines
- Ashby-supported
- Benchmark-based

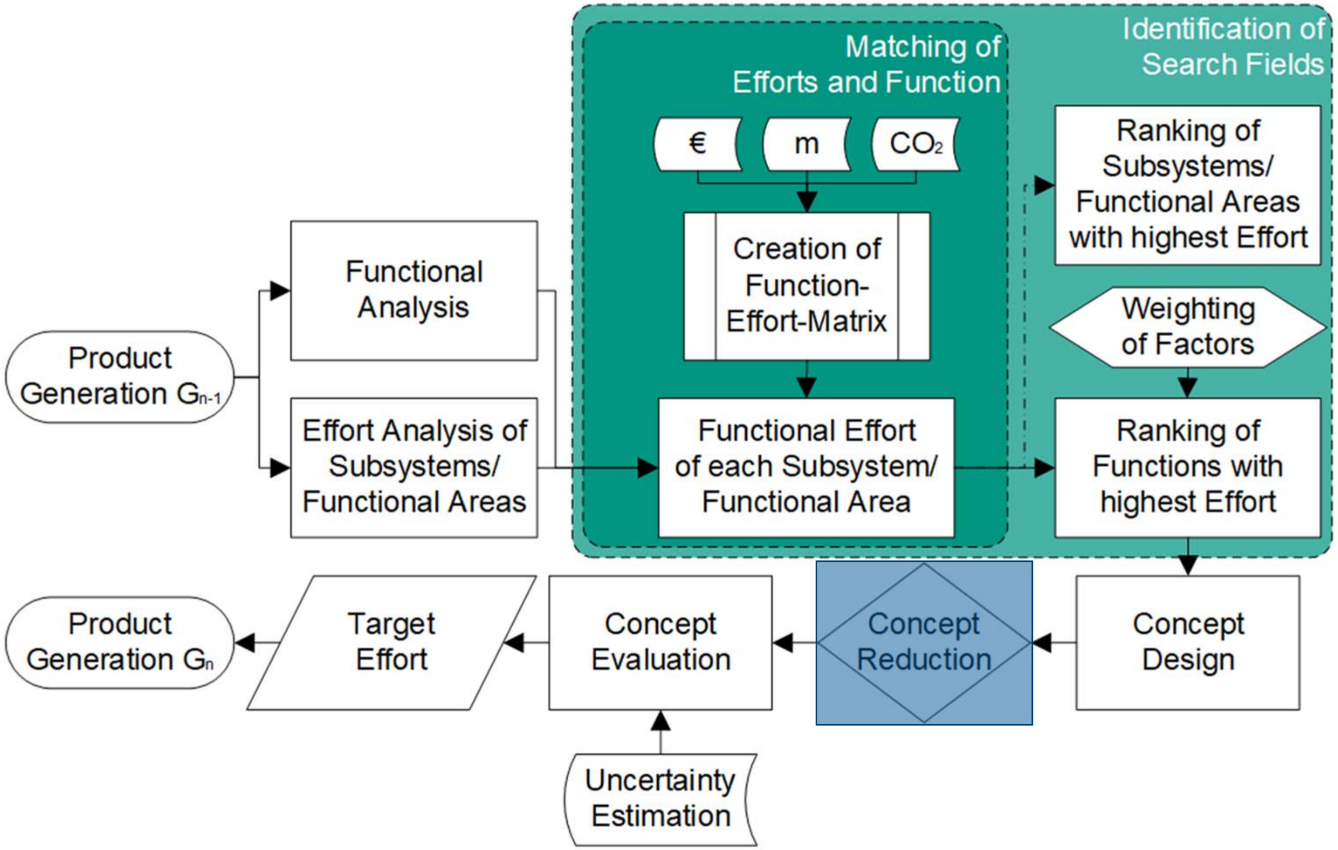
Extended Target Weighing Approach

ALLIANCE – Concept Design



Extended Target Weighing Approach

Methodology – Concept Reduction



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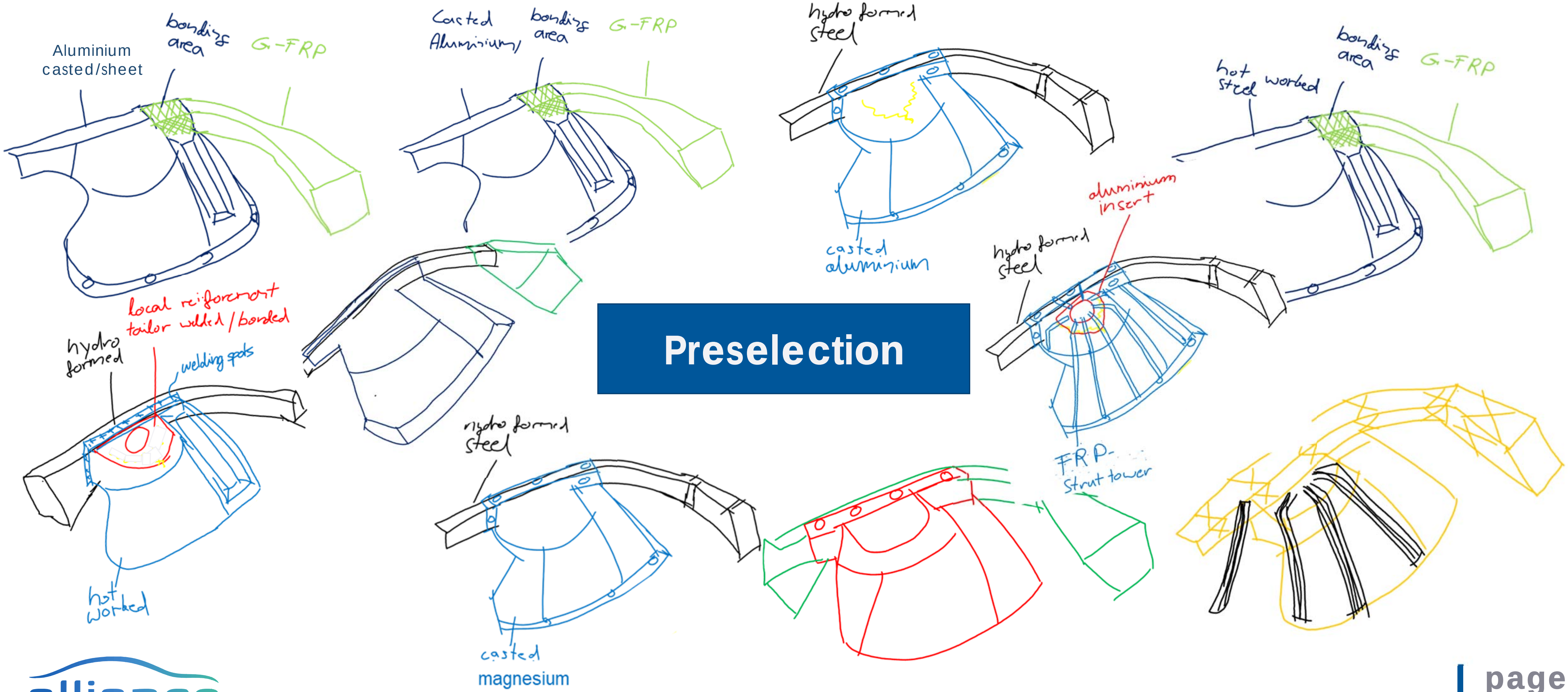
Extended Target Weighing Approach

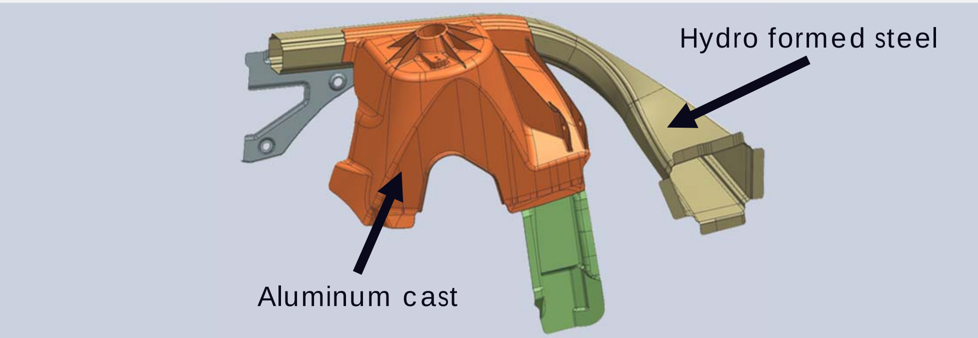
ALLIANCE – Concept Reduction



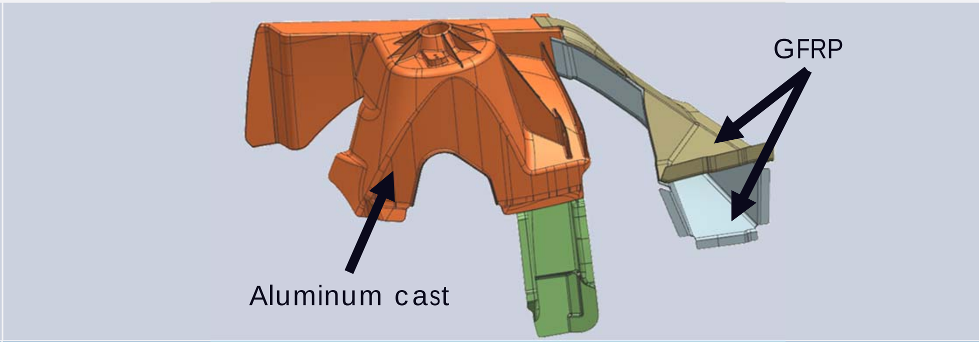
Extended Target Weighing Approach

ALLIANCE – Concept Reduction

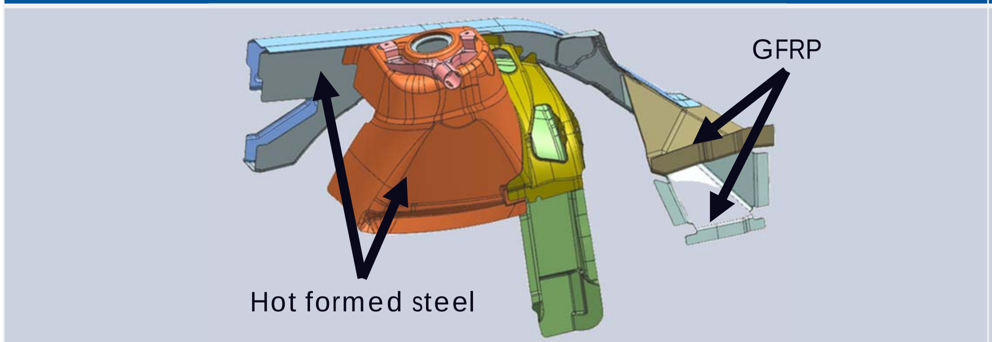
Multi-Material-Design 1 (MMD 1)



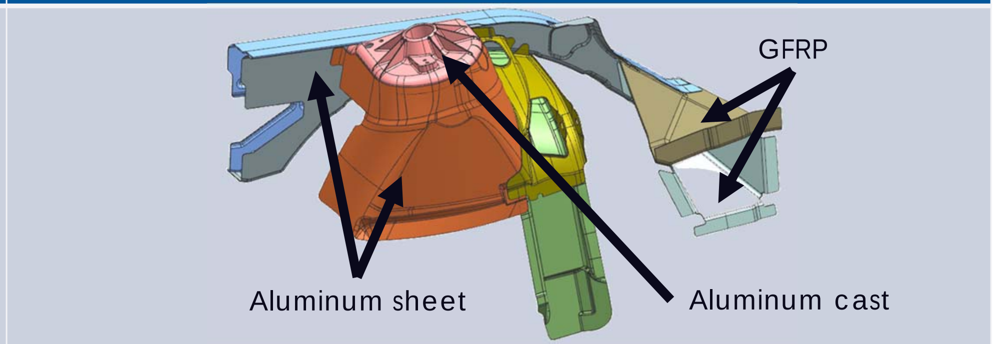
Multi-Material-Design 4 (MMD 4)



Multi-Material-Design 5 (MMD 5)

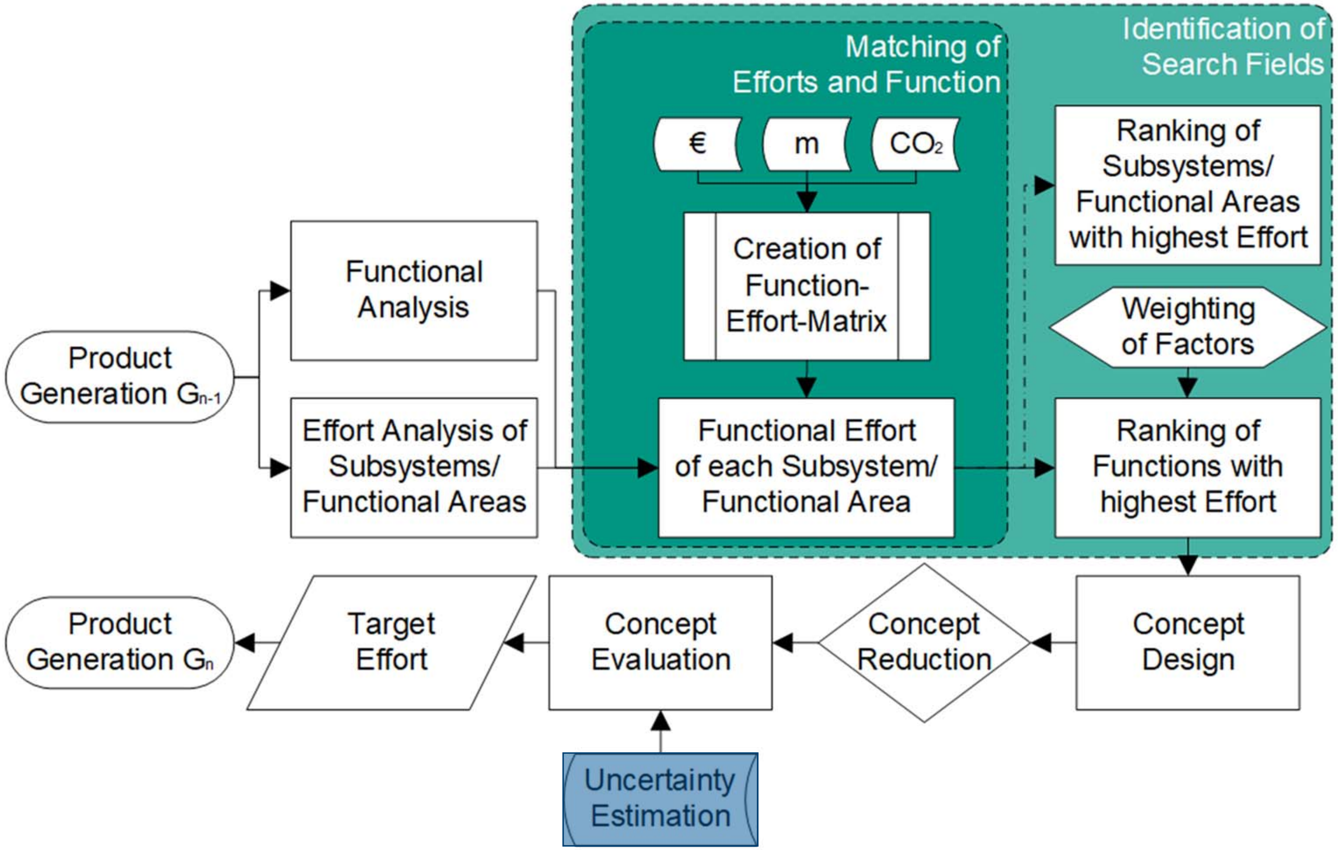


Multi-Material-Design 8 (MMD 8)



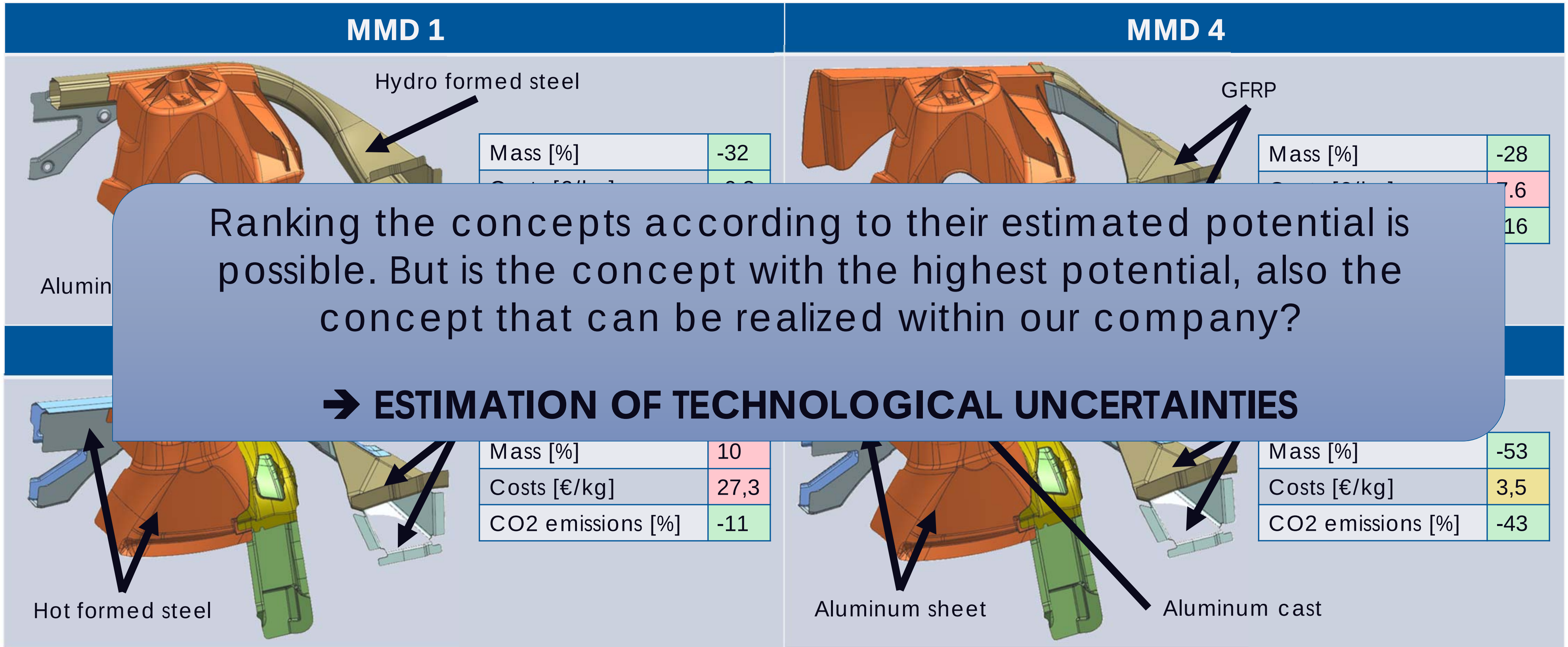
Extended Target Weighing Approach

Methodology – Uncertainty Estimation



Extended Target Weighing Approach

ALLIANCE – Uncertainty Estimation



Ranking the concepts according to their estimated potential is possible. But is the concept with the highest potential, also the concept that can be realized within our company?

➔ **ESTIMATION OF TECHNOLOGICAL UNCERTAINTIES**

Extended Target Weighing Approach

Methodology – Uncertainty Estimation

Carryover Variation Share ...

... displays how many subsystems from the reference product can be transferred as a Carryover Variation

Impact ...

... describes the percentage share of the functions changed by the new concept idea with regard to their importance

Reference Product – Technology ...

... describes the active principle, the used materials and the associated production technology used for the new concept

Reference Product – Application Scenario ...

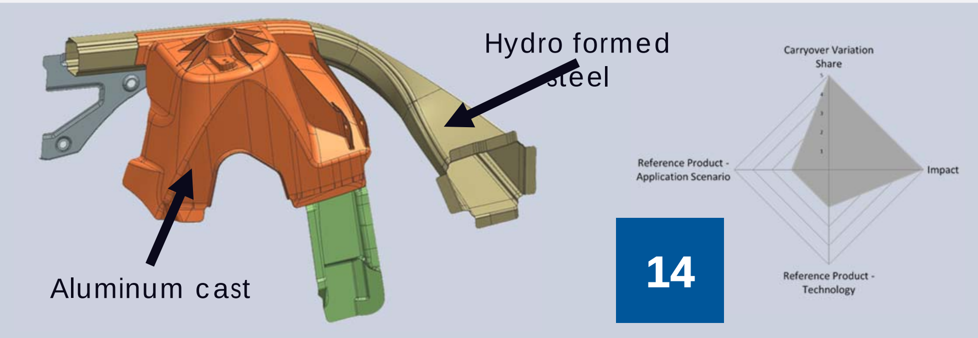
... describes the functions that a subsystem has to fulfil together with all its boundary conditions and the use of the active principle in the same context

Total technological uncertainty: **Summation of these four influencing factors**

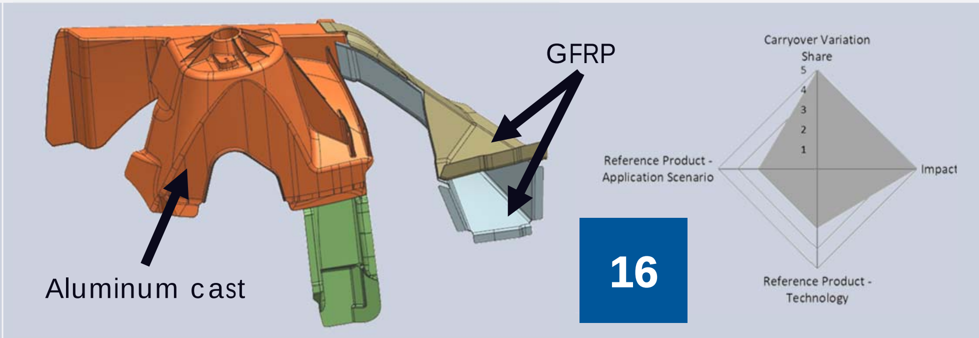
Extended Target Weighing Approach

ALLIANCE – Uncertainty Estimation

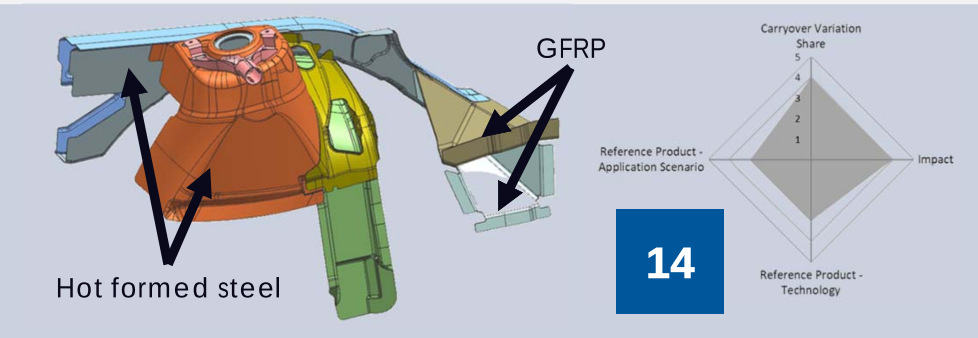
MMD 1



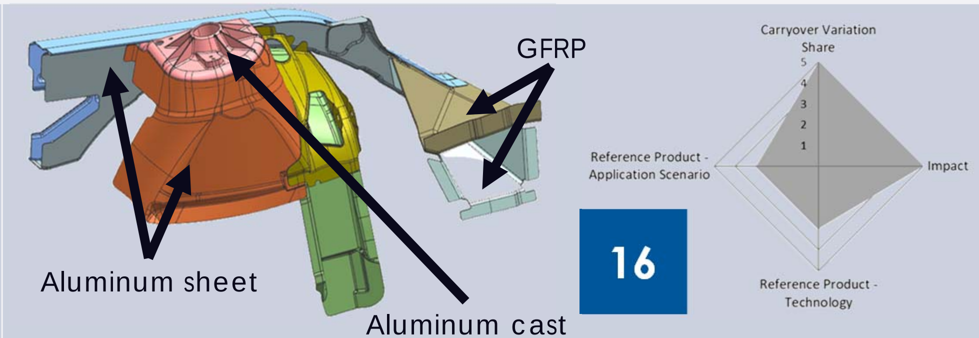
MMD 4



MMD 5

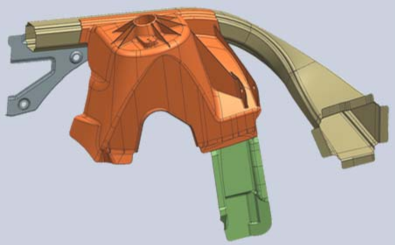
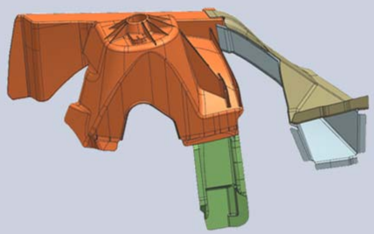
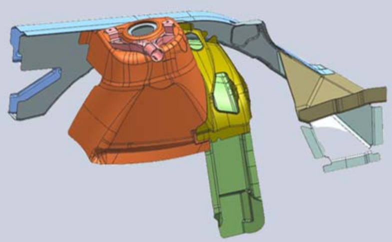
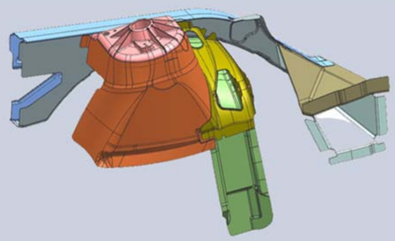


MMD 8



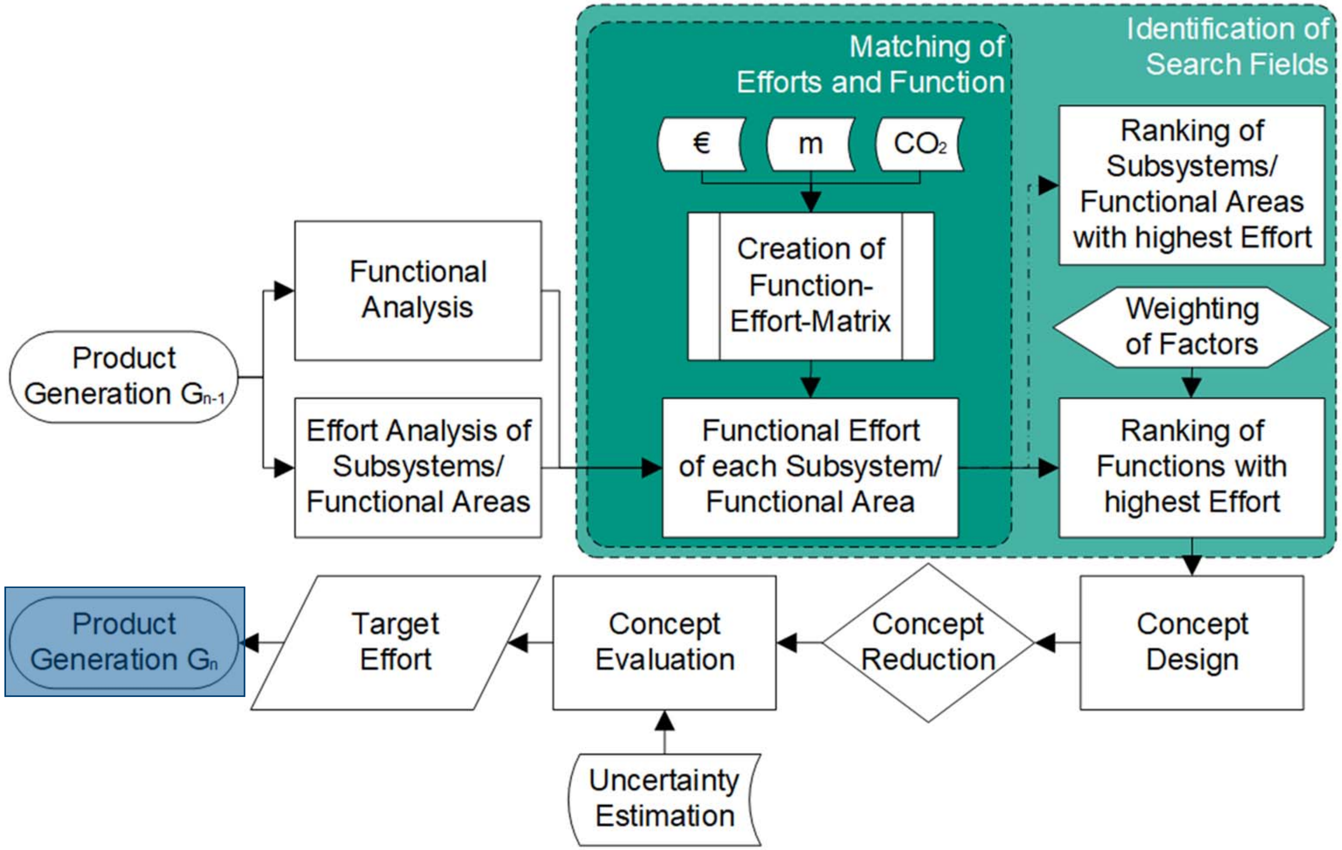
Extended Target Weighing Approach

ALLIANCE – Concept Evaluation

Concept	MMD 1	MMD 4	MMD 5	MMD 8
				
Mass [%]	-32	-28	10	-53
Costs [€/kg]	-0,3	7,6	27,3	3,5
CO_2 emissions [%]	-27	-16	-11	-43
Technological Uncertainty	14	16	14	16

Extended Target Weighing Approach

Methodology – Product Generation G_n



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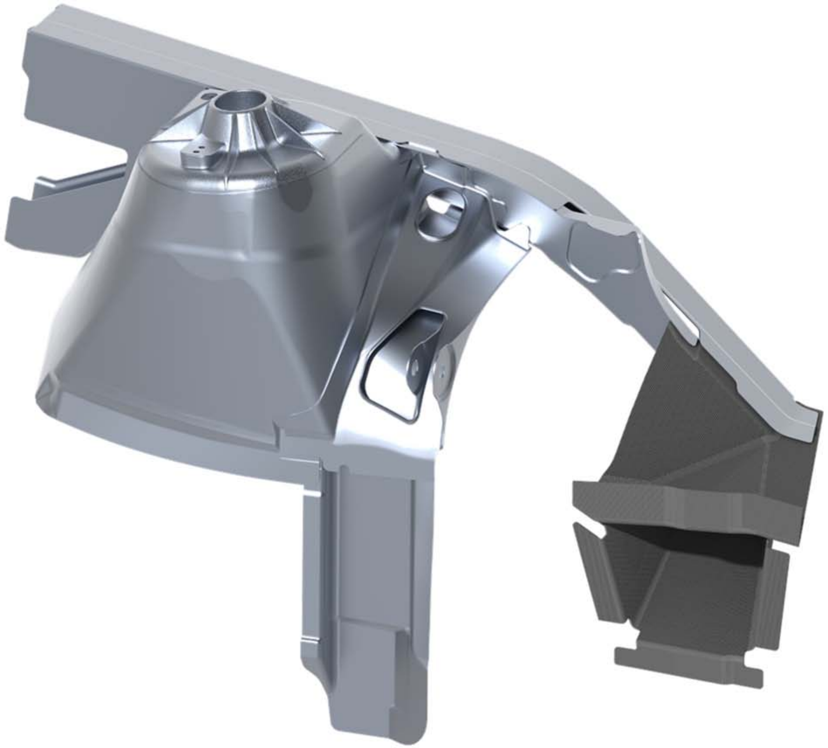
Extended Target Weighing Approach

ALLIANCE – Product Generation G_n



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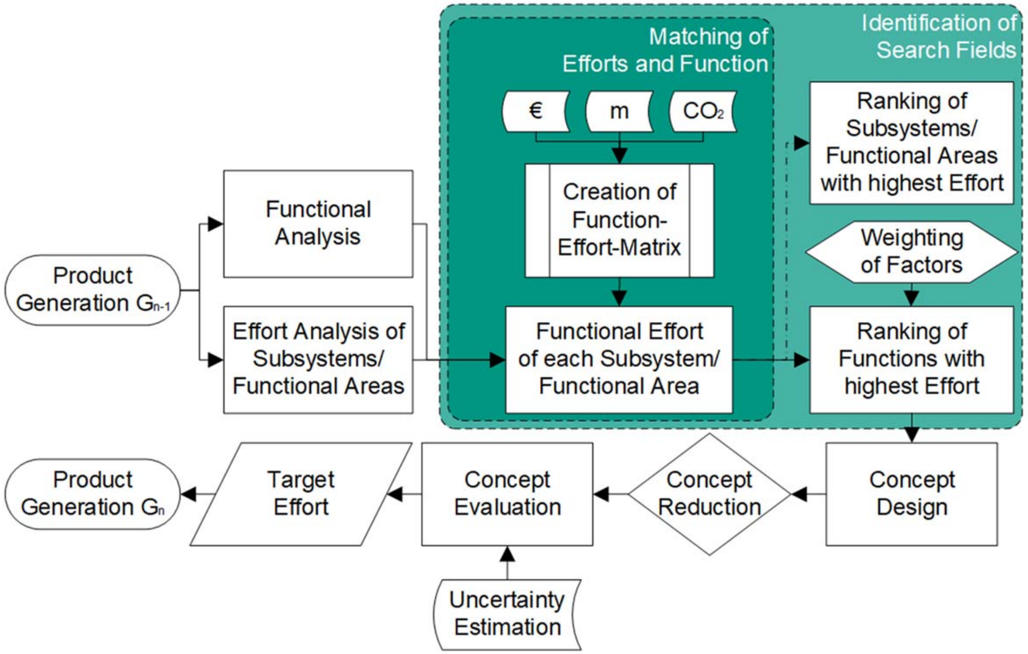
Extended Target Weighing Approach
Conclusion

The Extended Target Weighing Approach is a **holistic, cross-subsystem, function-based lightweight design method** for the **systematic identification and evaluation** of **lightweight design potentials** in early phases of product development which takes into account:

- **Mass**
- **Costs**
- **CO2 emissions**
- **uncertainty estimations**



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European Commission | Horizon 2020 European Union funding for Research & Innovation

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The Extended Target Weighing Approach

Identification and Evaluation of Lightweight Design Potentials

Future of Automotive Lightweighting Day, 19.09.2019, Aachen

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723893