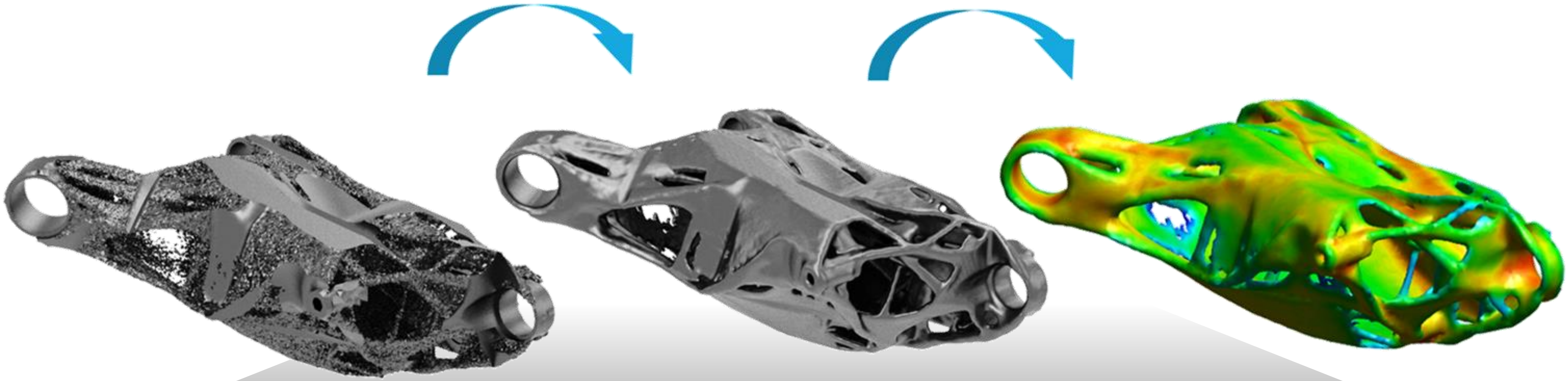
MASTER THESIS PRESENTATION

Development Process of Topology Optimized Casted Components

By Eetu Autio based on thesis by Nadine Kåmark



Altair

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Agenda

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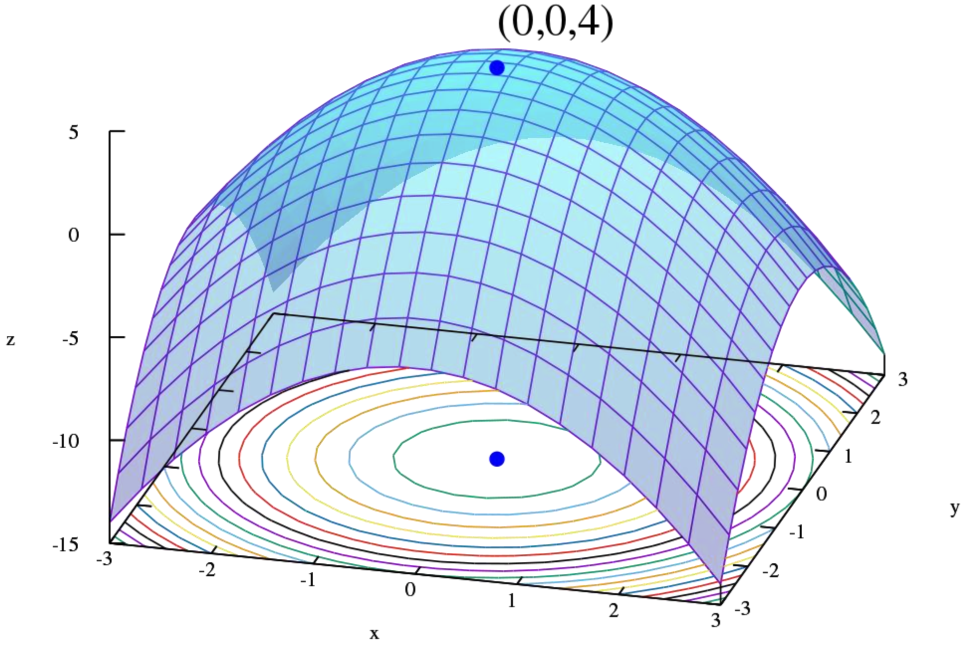
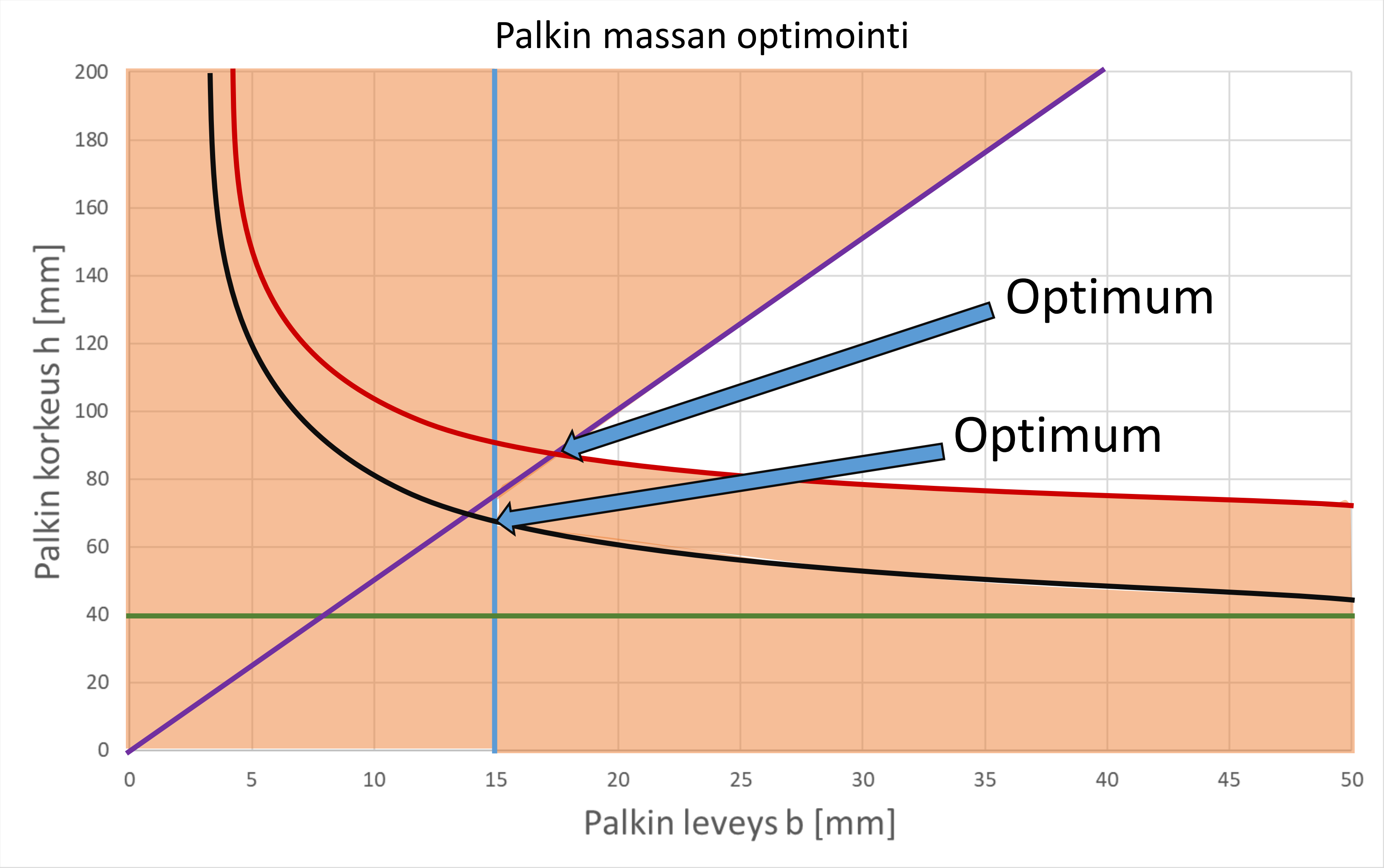
- Optimization theory
- Background
- Aim
- Theory / Methods
- Results
  1. Topology Optimization
  2. Topology Optimization result into casting simulation
  3. Evaluate Castability
- Summary / Conclusions

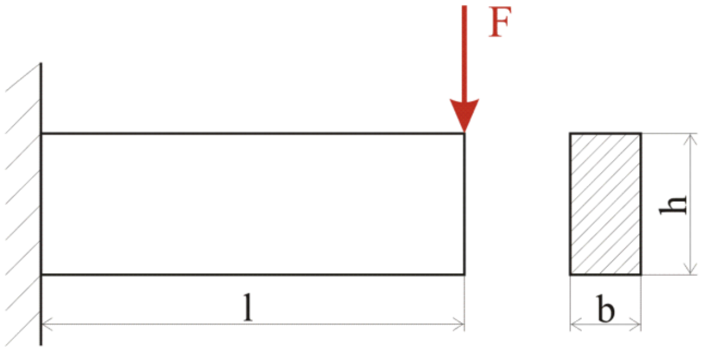
Optimization theory

- A problem or solution procedure which aims to find the optimal solutions to the objective function or functions under constraints. Typically this means of maximizing or minimizing a real function
- In day-to-day life optimization means of finding the best possible solution to a certain problem
- Iteration and optimization are not the same thing



Graphical beam mass optimization example





Constraints:

15 mm ≤ b

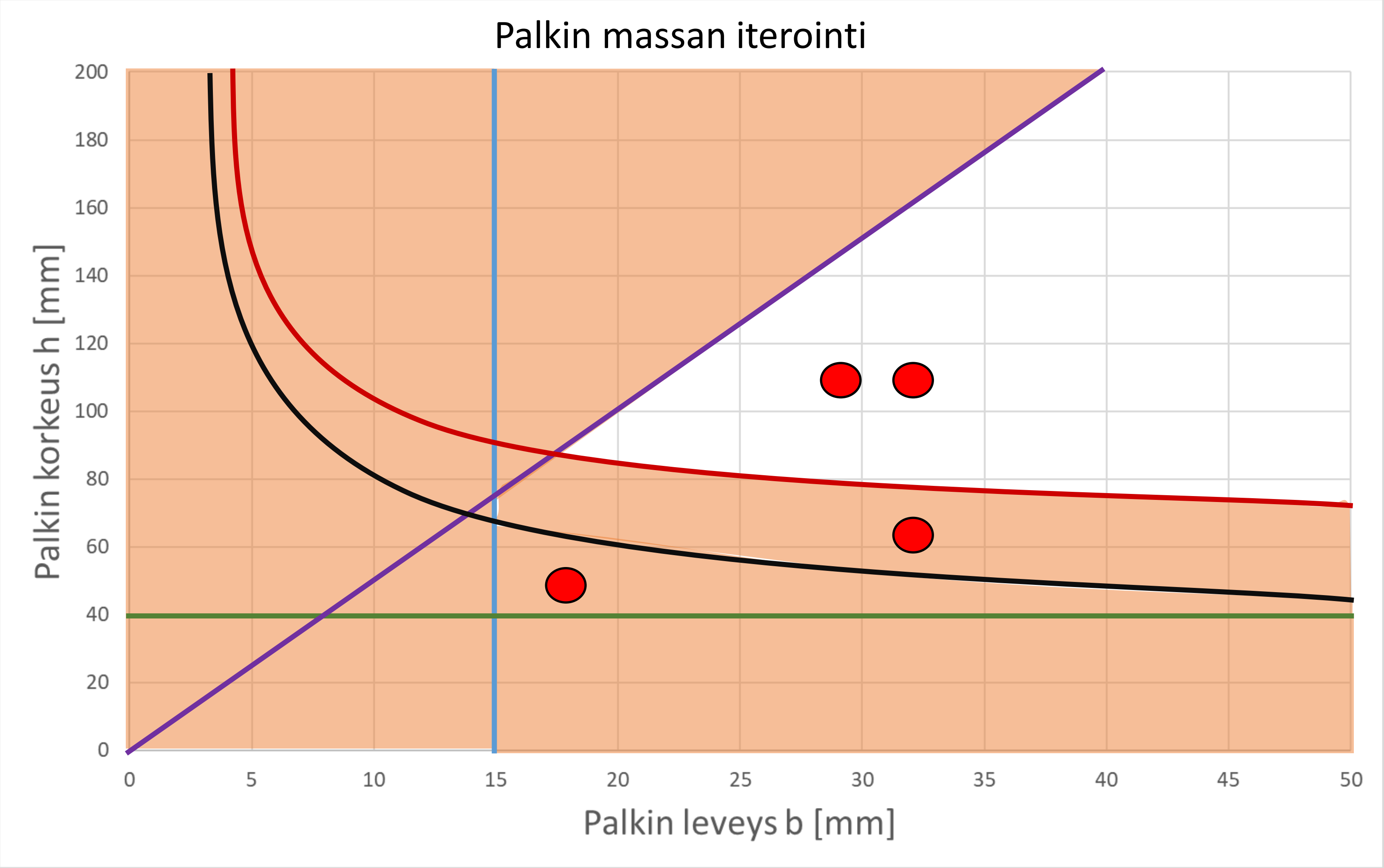
40 mm ≤ h

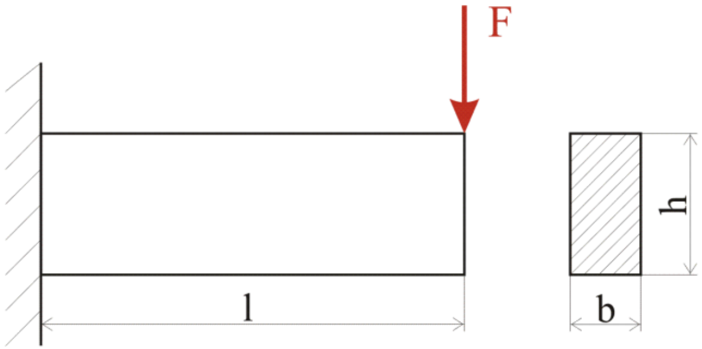
h ≤ 5*b

σ(b,h) ≤ 160 Mpa

v (b,h) ≤ 15 mm

Beam design iteration example





Constraints:

15 mm ≤ b

40 mm ≤ h

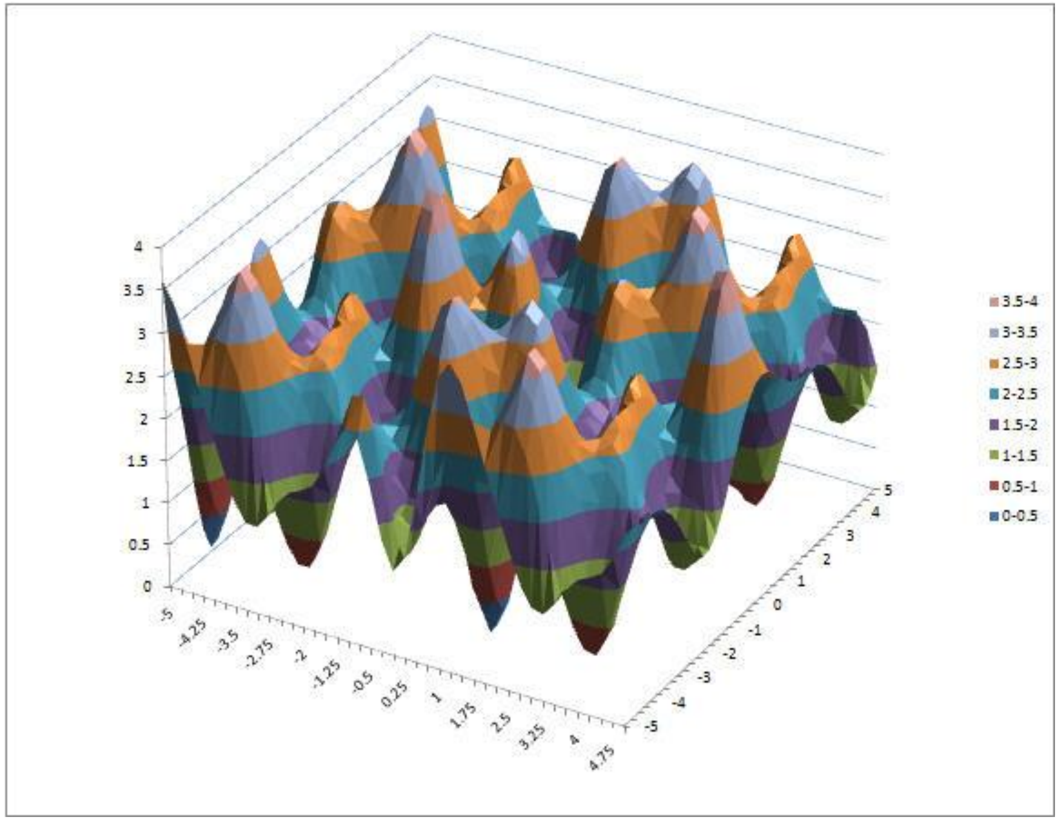
h ≤ 5*b

σ(b,h) ≤ 160 Mpa

v (b,h) ≤ 15 mm

Interpreting the results

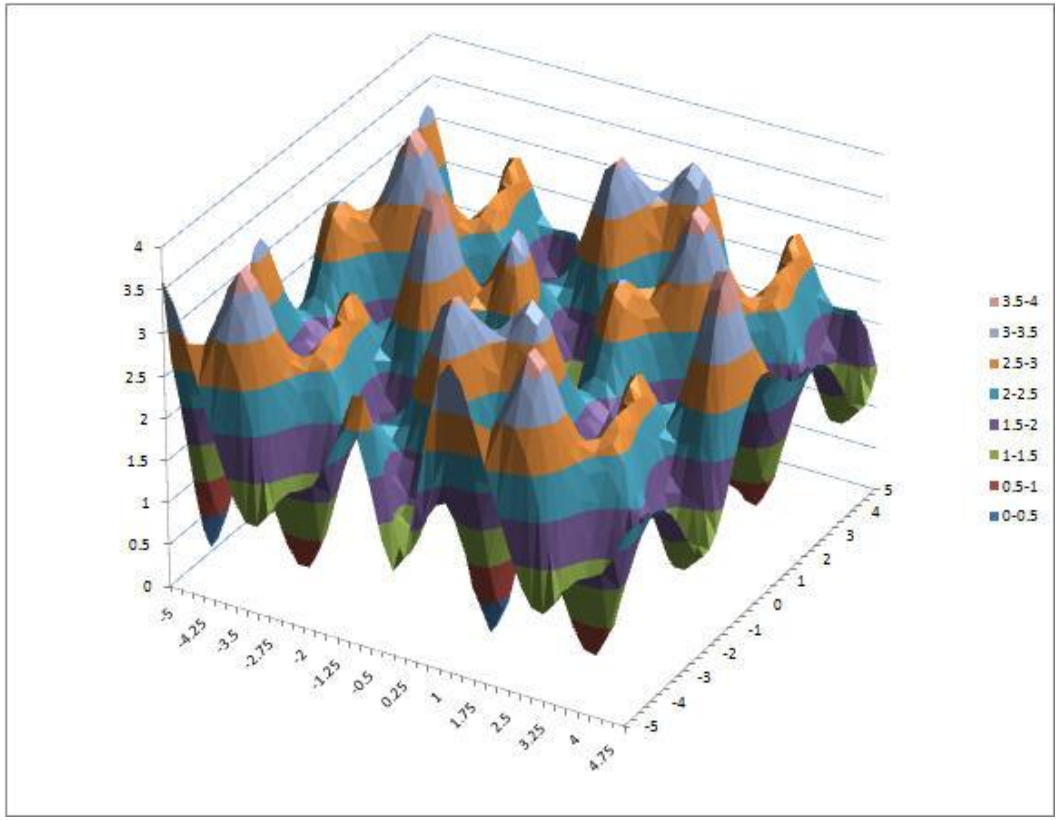
- Objective
  - Did we reach our objective?
  - How much did the objective improve?
- Design variables
  - Did we get values of variables for the improved design?
- Constraints
  - Did we violate any constraints?



Interpreting the results

Things to consider

- Local minimum vs. global minimum
- Solution might not be available
  - Objective, constraints and design variables overconstrained
- Efficiency of optimization
  - Number of design variables and constraints
- Unconstrained optimization problem
- Issues related to FEA modelling



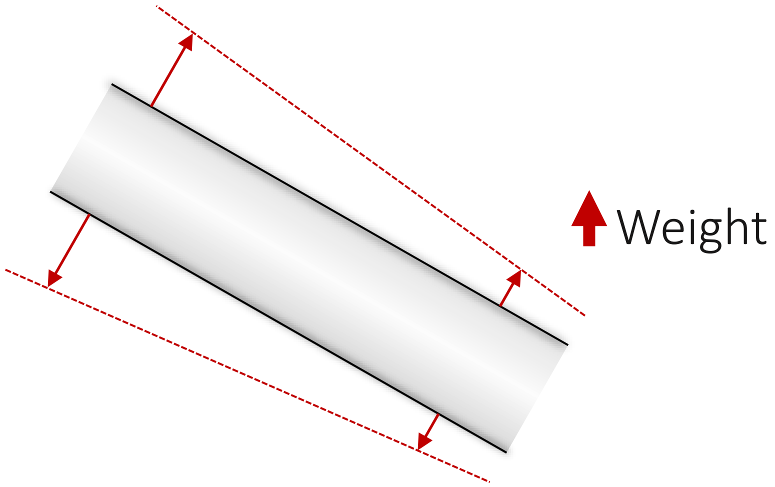
Background

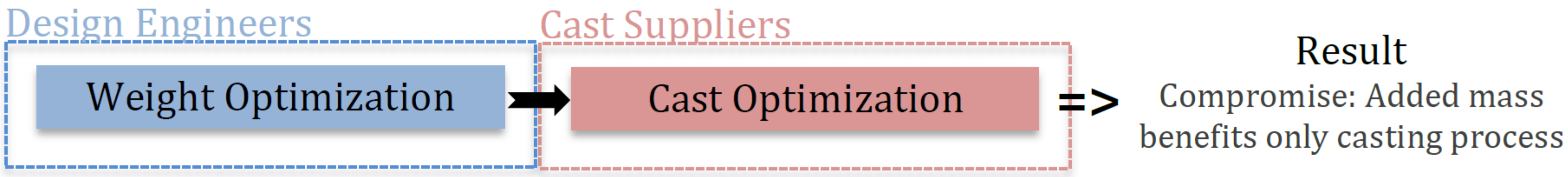
Topology Optimization

Casting

Background

- Today castability is not taken into account until the end of the development process.
- Usually the weight increases when a design is adjusted to become feasible to cast.
- Today there is no iterations between the weight and casting optimization processes.

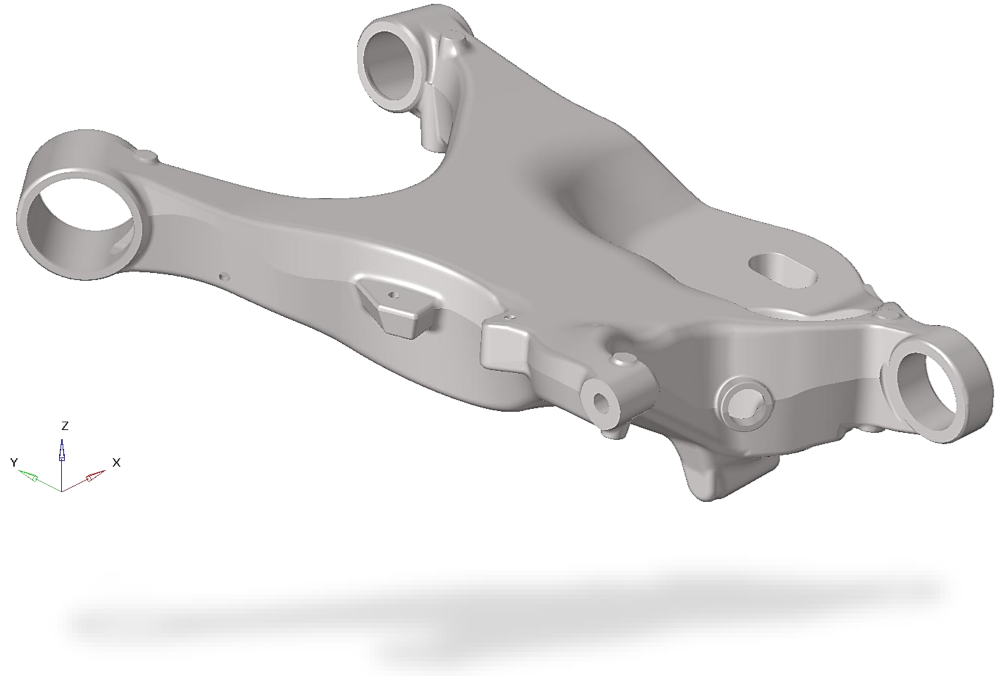




Background

Rear Lower Control Arm (RLCA)

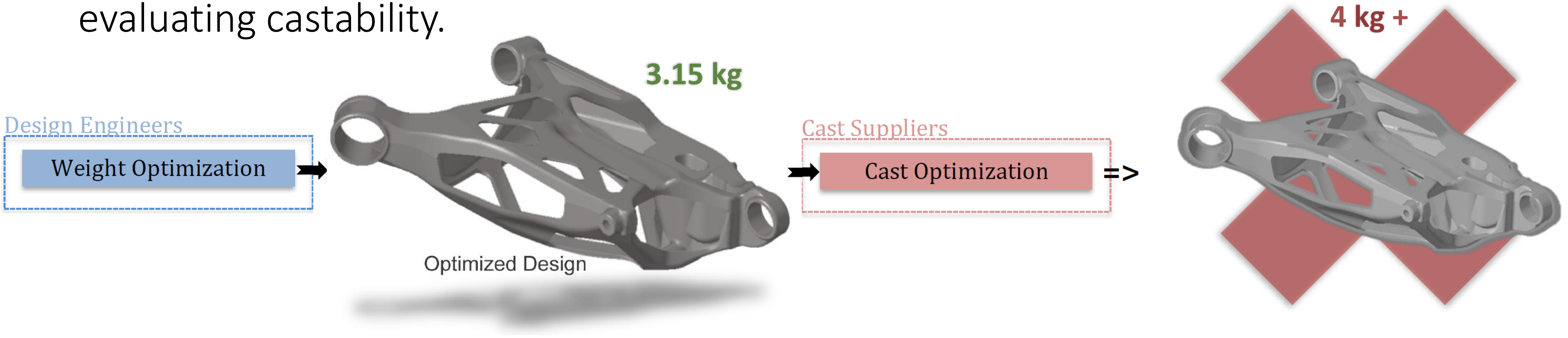
- Based on a previous thesis.
- Parts in the rear wheel suspension of a Volvo car.
- Today manufactured using casting with a sand core.
- Made in aluminum.
- 4.07 kg



Background

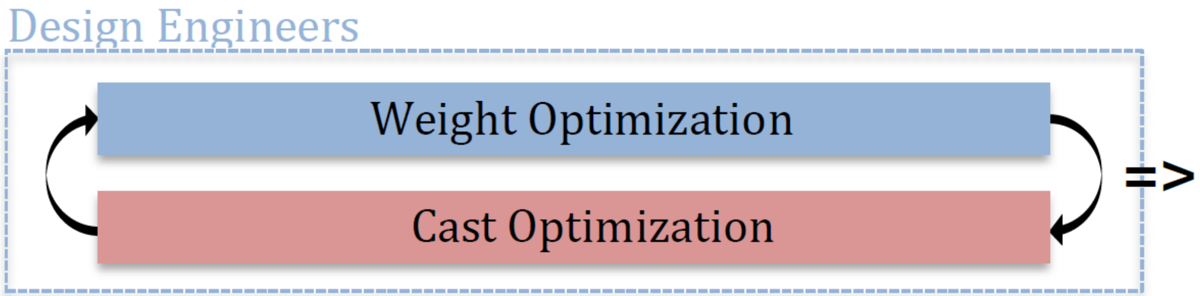
Previous Master Thesis:

- Topology Optimized and Shape Optimized RLCA.
- Later be used as reference model when evaluating castability.



Aim

- Find a way of evaluating castability already in the early phase of the development process
- Casting simulations
- Numerically
  - Evaluate castability in a consistent manner.
  - Evaluate a large range of different design concepts.



Result

Compromise: Added mass benefits both structural strength and casting

Aim

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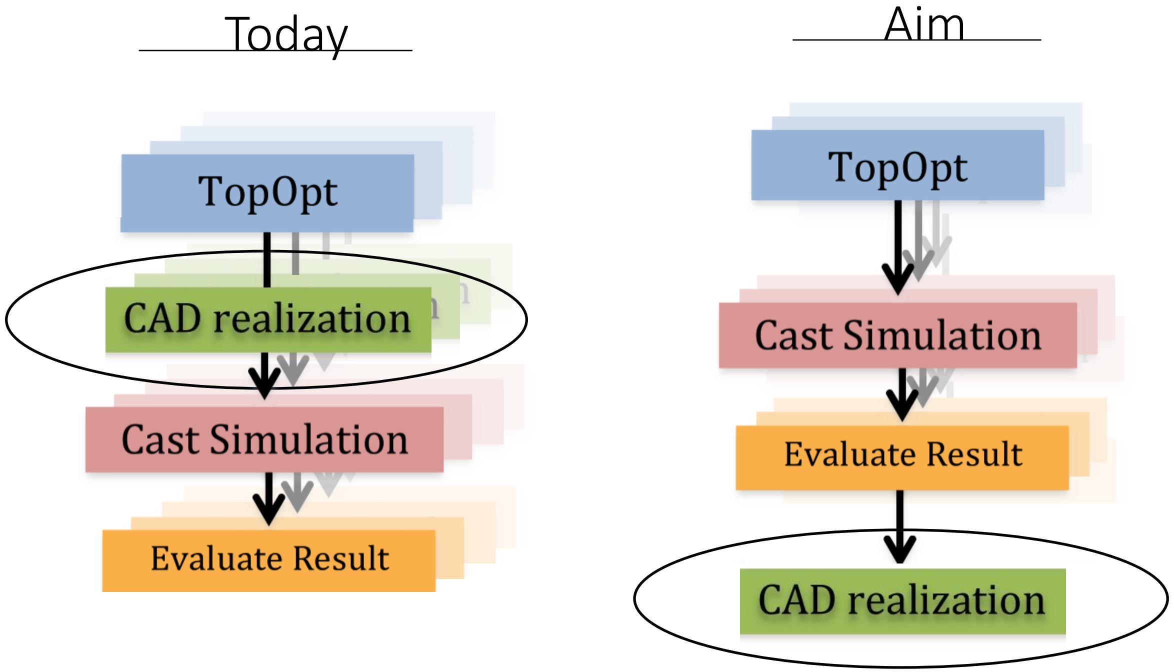
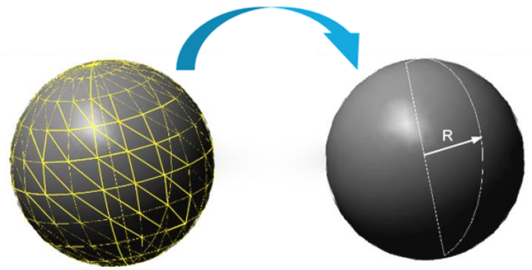
CAD realization

- CAD realization of the topology optimization result has today be done in order to use it in a casting simulation.
- Time consuming!
    - Done manually by design engineers
    - Iterative process
    - Large range of design concepts
- Move it to the end of the development process.





Mesh (TopOpt)

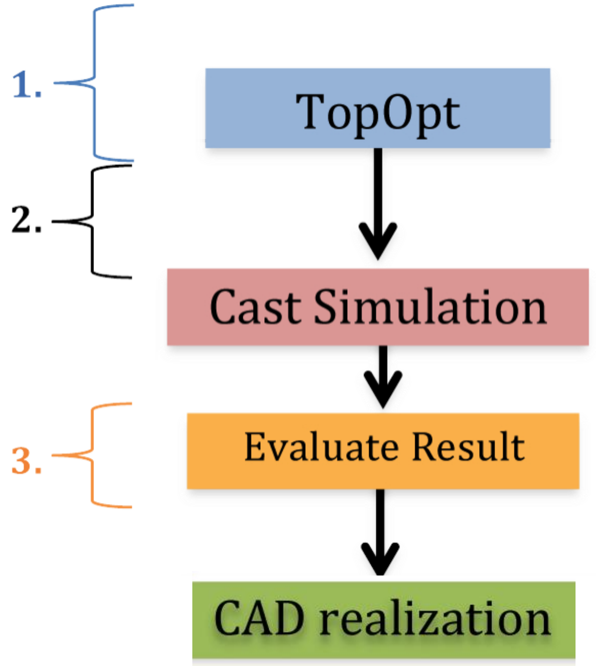
CAD

Method

1. Topology optimization

2. Topology result into cast simulation

3. Evaluating castability



Method

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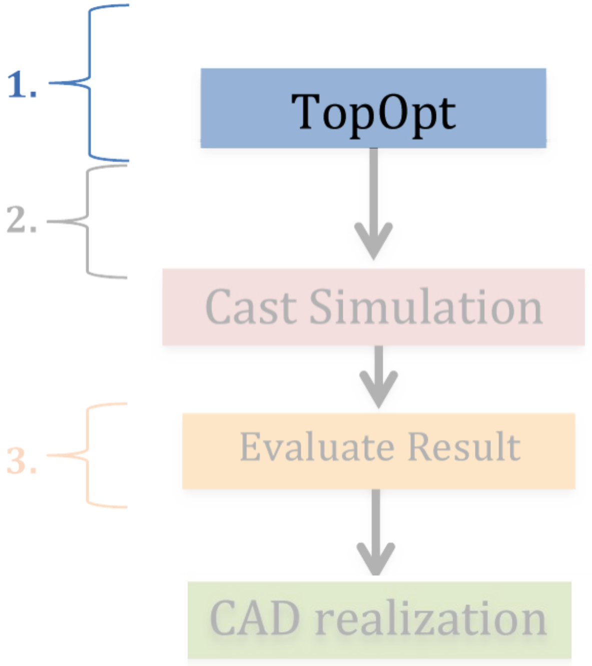
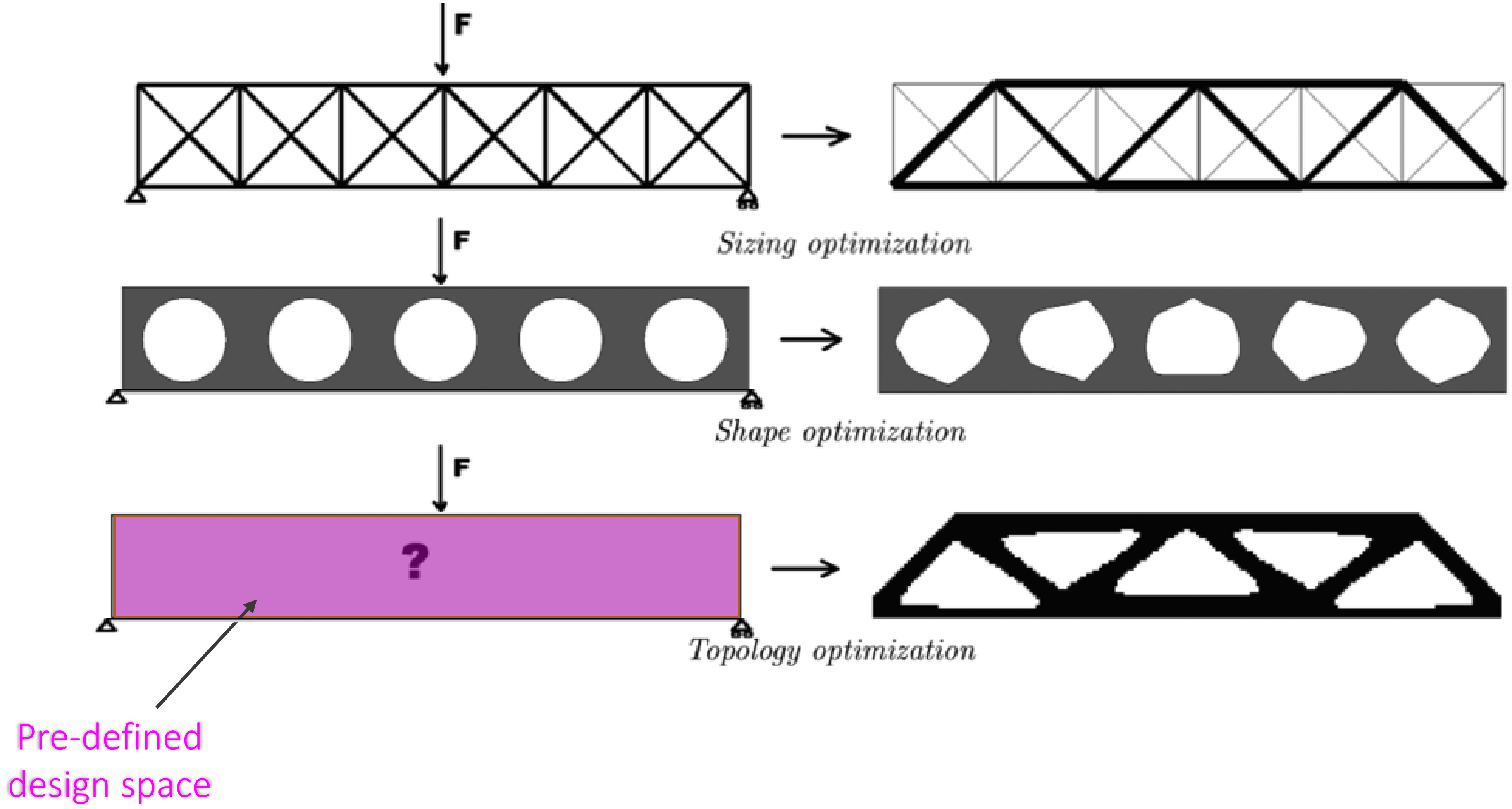
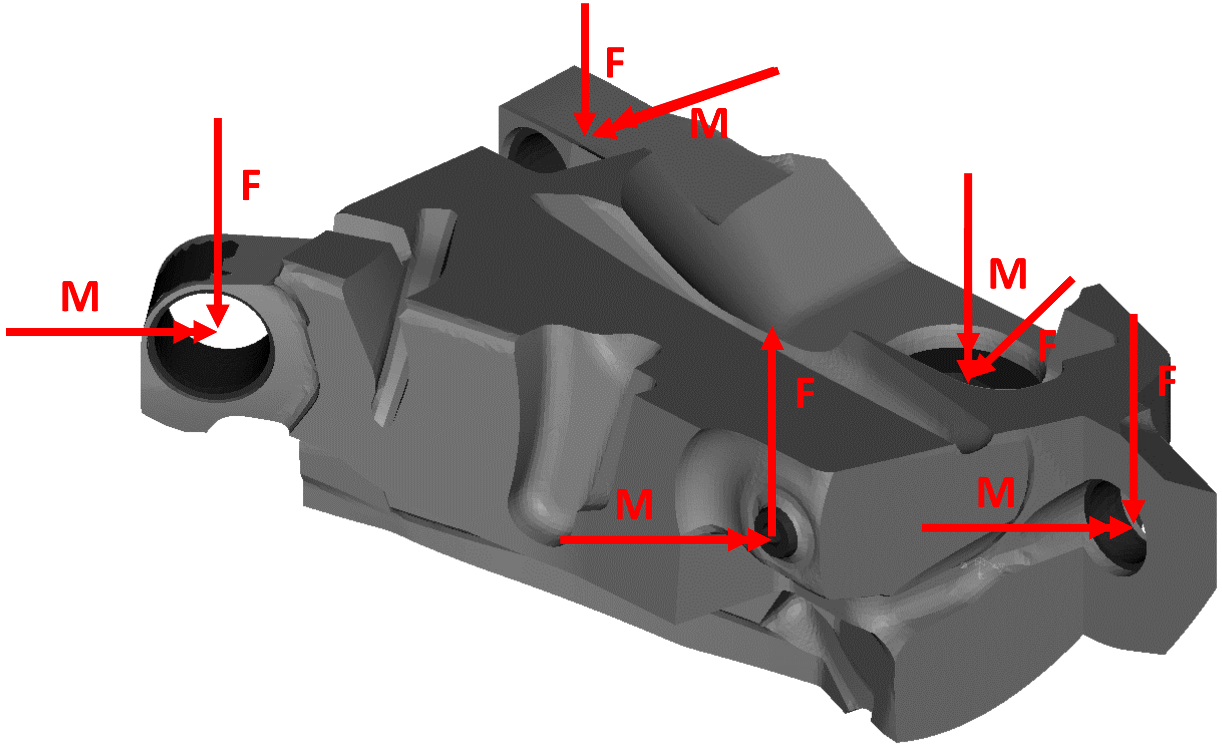


Topology Optimization

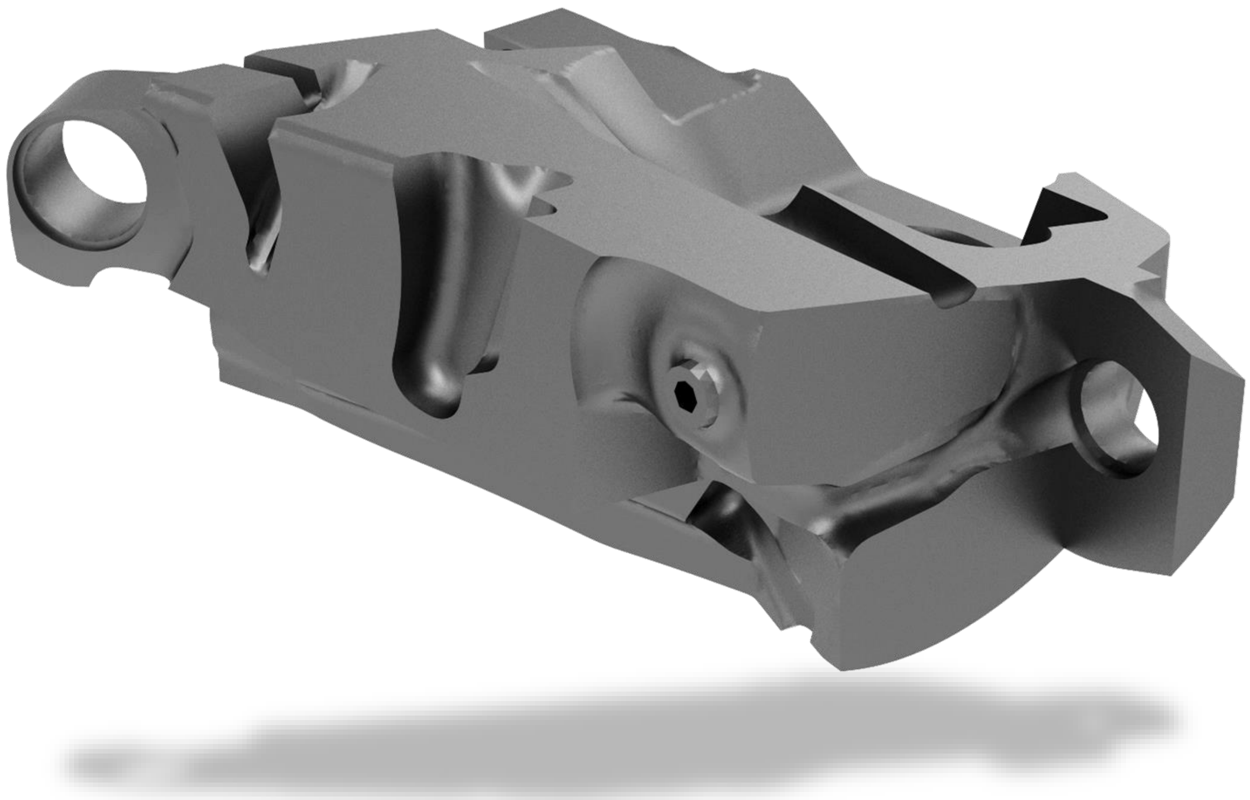
Three common structural optimization problems:
sizing- , shape- and topology optimization.



Design Space (DS)



Topology Optimization



Method - Topology optimization

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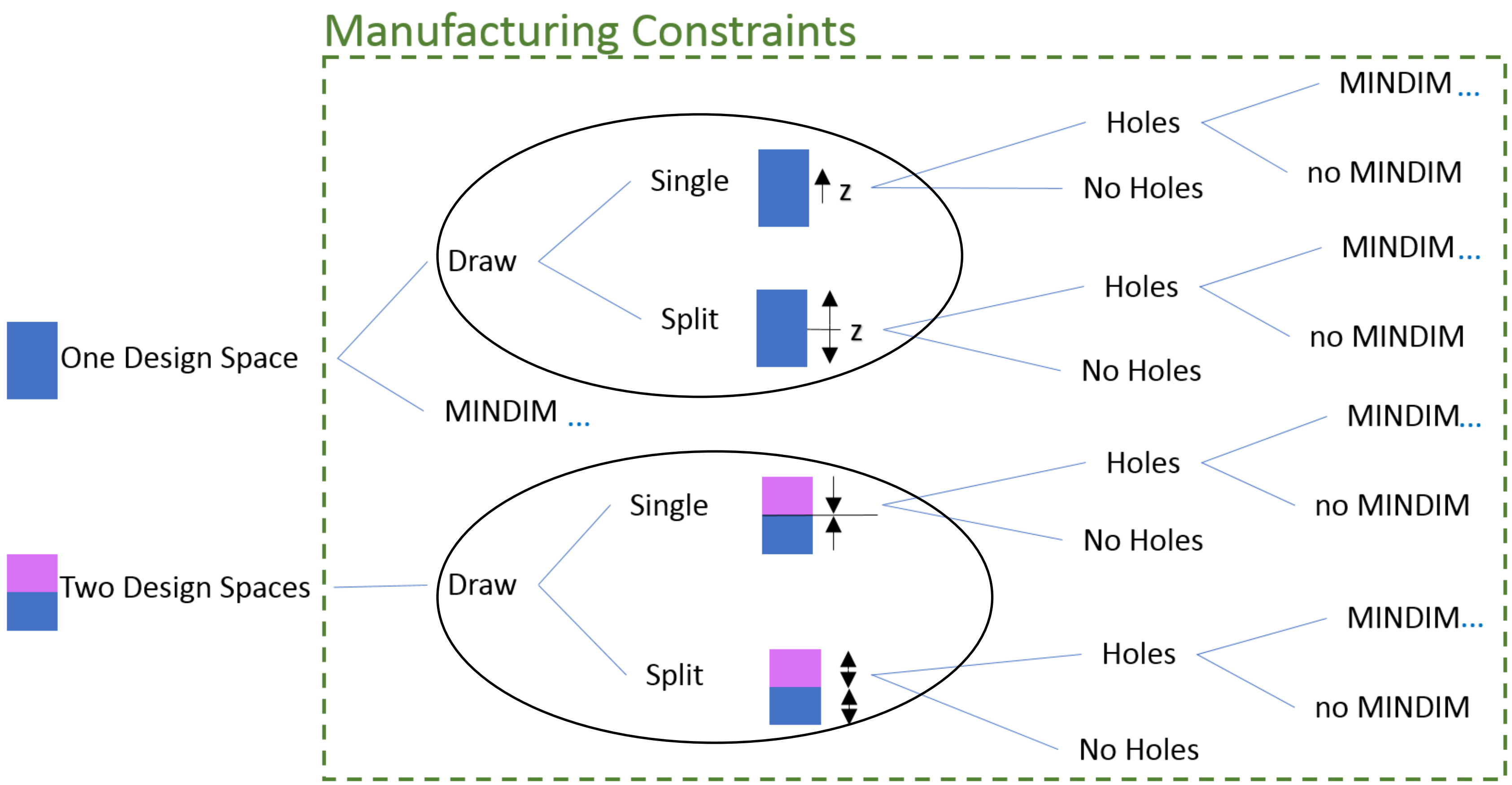
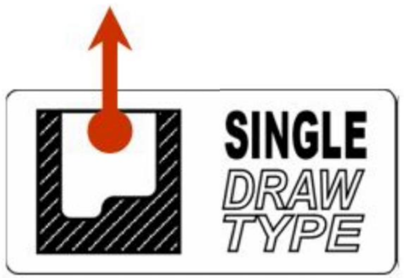
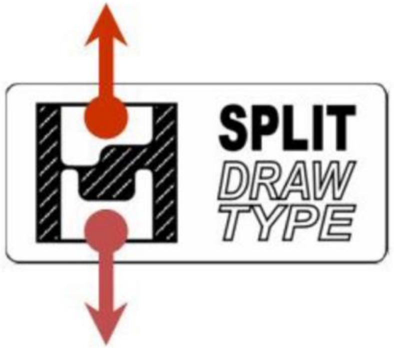


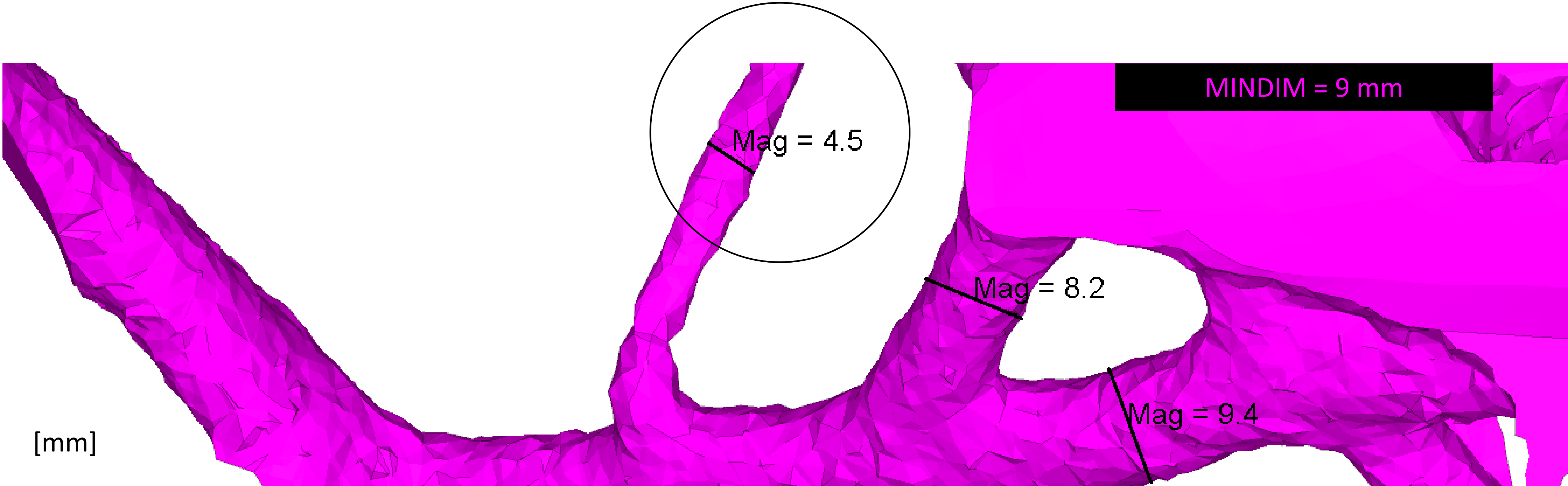




Results - Topology optimization

Member size control - MINDIM

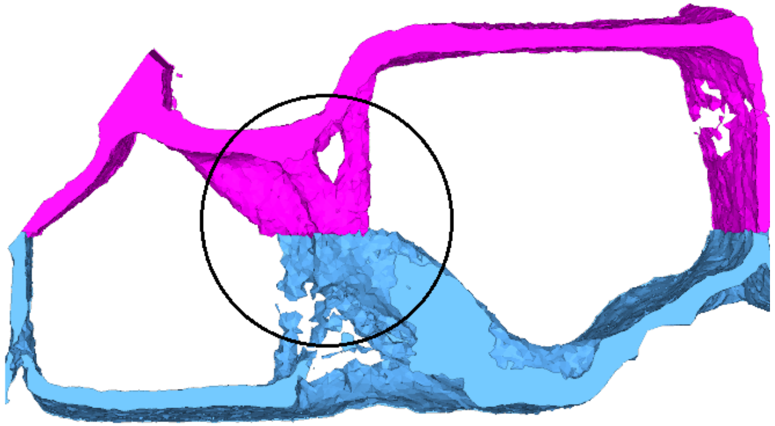
- Manufacturing restrictions: MINDIM > 5 mm
- If a small member is very important to the load transmission, it may not be removed by penalization
  even if it is significantly under the prescribed minimum member size.

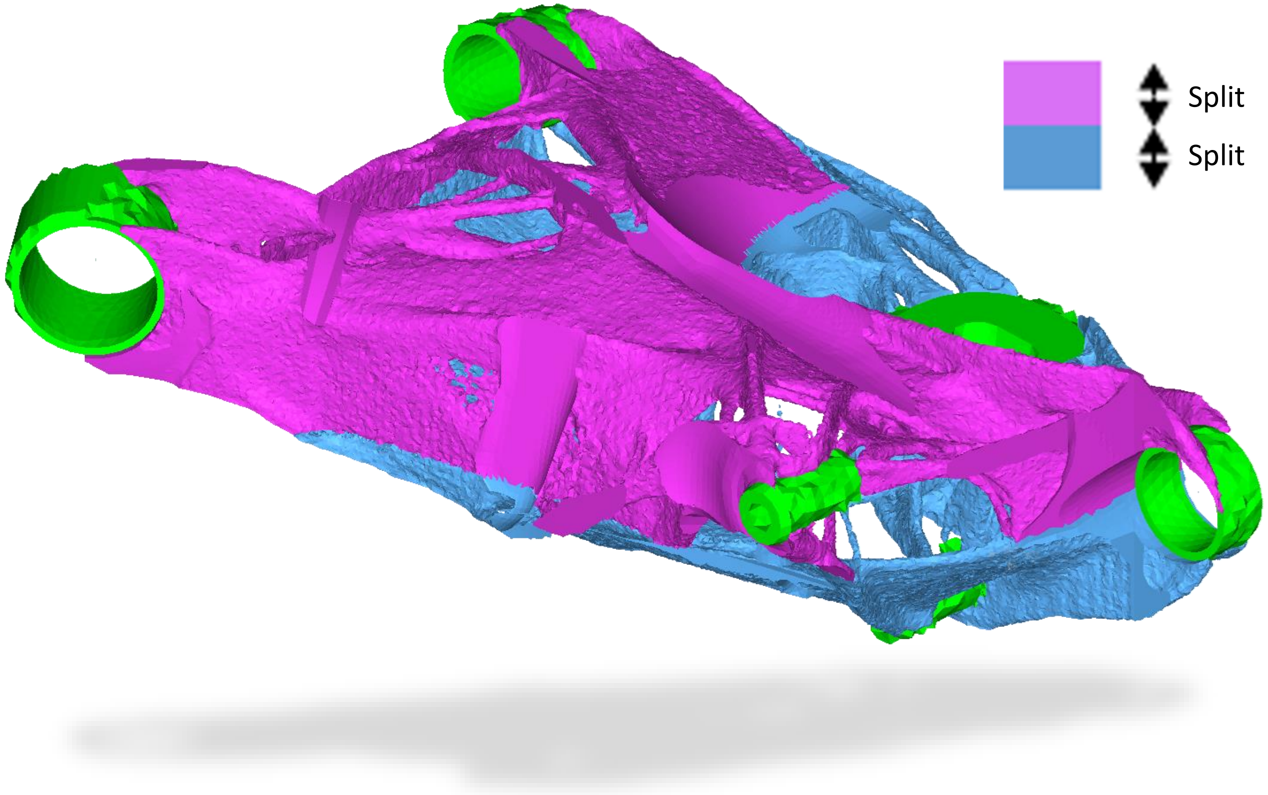


Results - Topology optimization

Two Design Spaces

- Used to illustrate a core, i.e to get a cavity in the middle of the casting.





Results - Topology optimization

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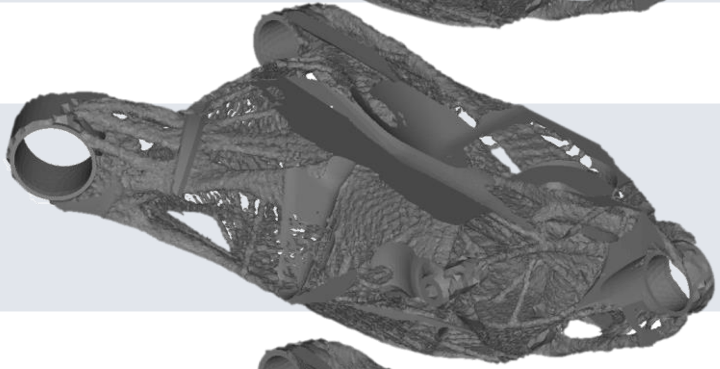
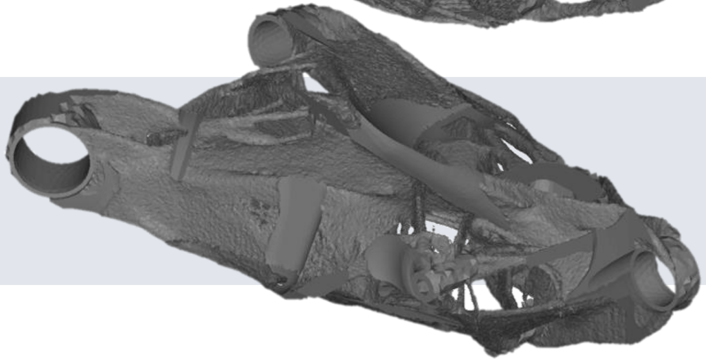
	Weight	
Unconstrained	3.38 kg	
One Design Space — MINDIM 5mm	3.04 kg	
Two Design Spaces — Draw — Split — Holes — MINDIM 5mm	3.90 kg	

Results - Topology optimization

	Weight	
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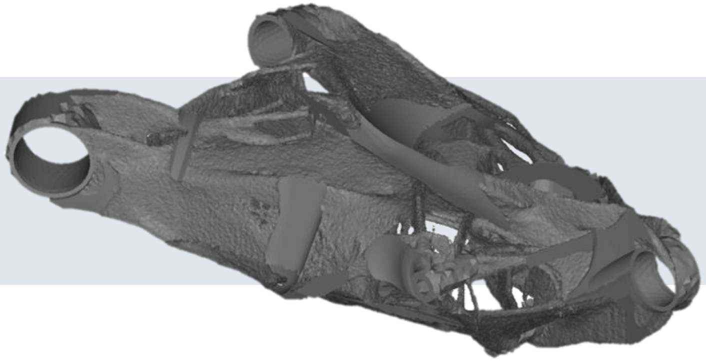
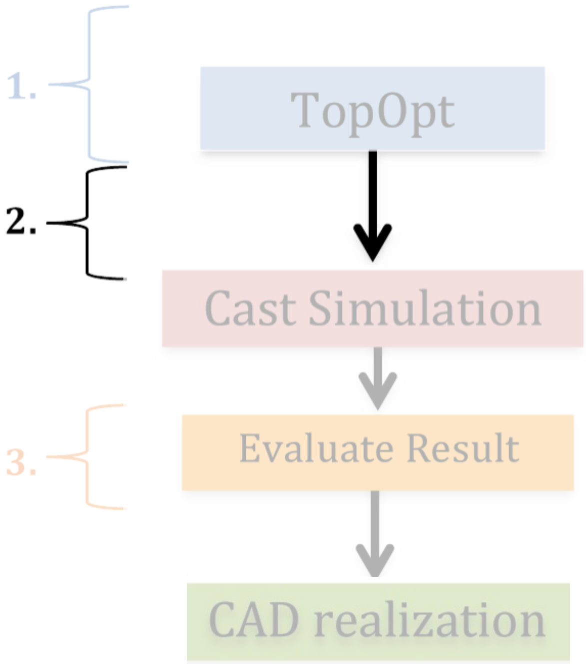
Two Design Spaces — Draw — Split — Holes — MINDIM 5mm	3.90 kg	

Method

1. Topology optimization

2. Topology result into cast simulation

3. Evaluating castability



Results – Topology result into cast simulation

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- Topology optimization result is represented by volume elements and a rough surface.
- Casting simulations requirements:
  - Surface mesh
  - Enclosed volume
  - Smooth

Topology optimization result

Averaged iso surface
+
Shrink Wrap

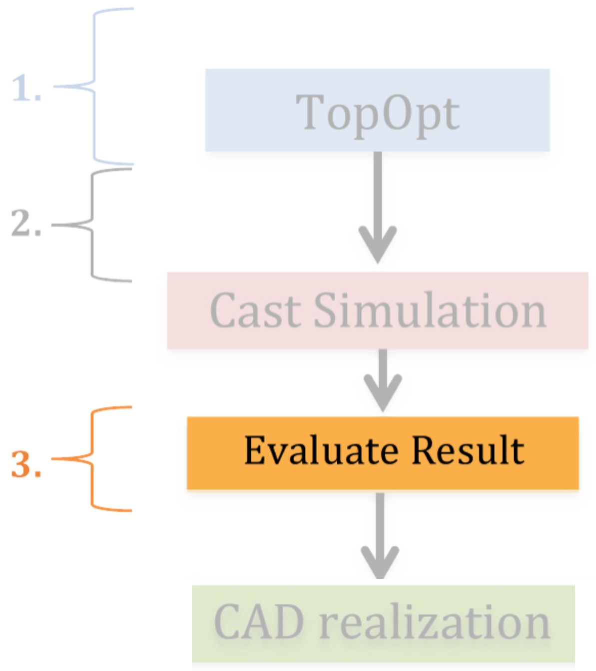
Casting simulation

Method

1. Topology optimization

2. Topology result into cast simulation

3. Evaluating castability

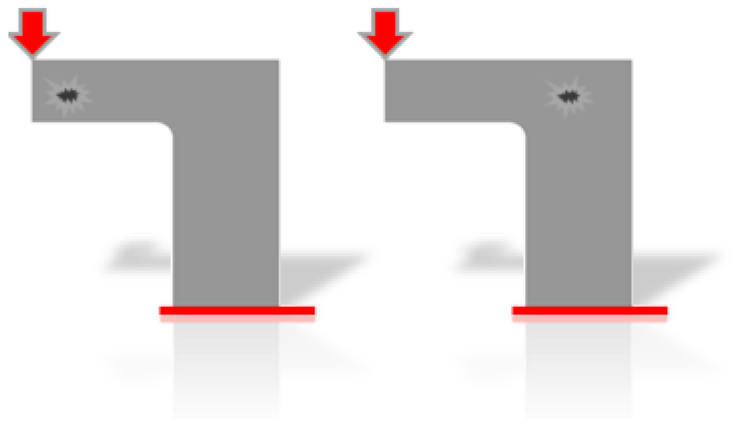


Method - Evaluating castability

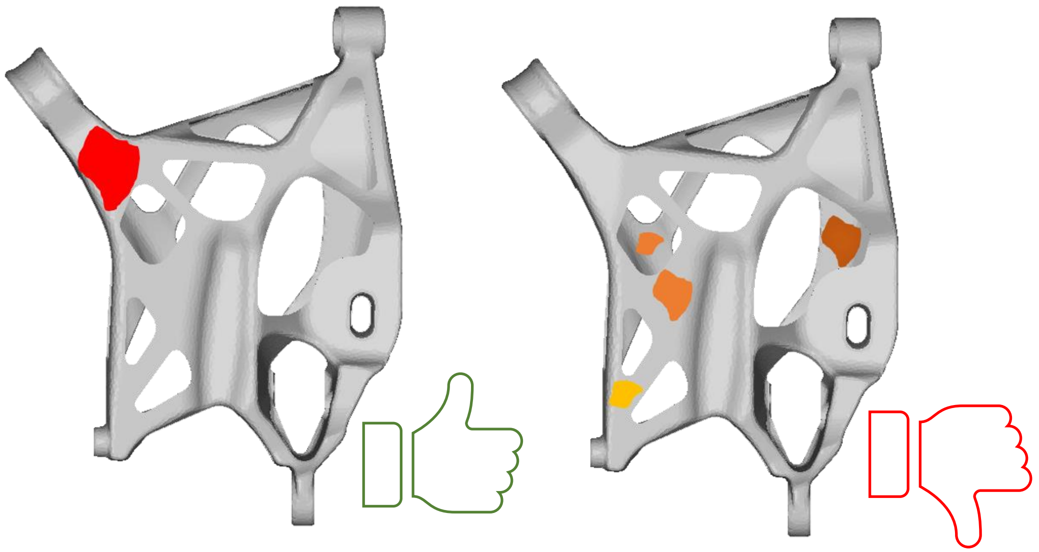
- Only considering solidification simulation
- Casting defects – shrinkage porosity
- Hot spots

Method - Evaluating castability

- Max/Min values are not that much of importance.
  More importance:
  - where different values occur
  - how values changes over the structure



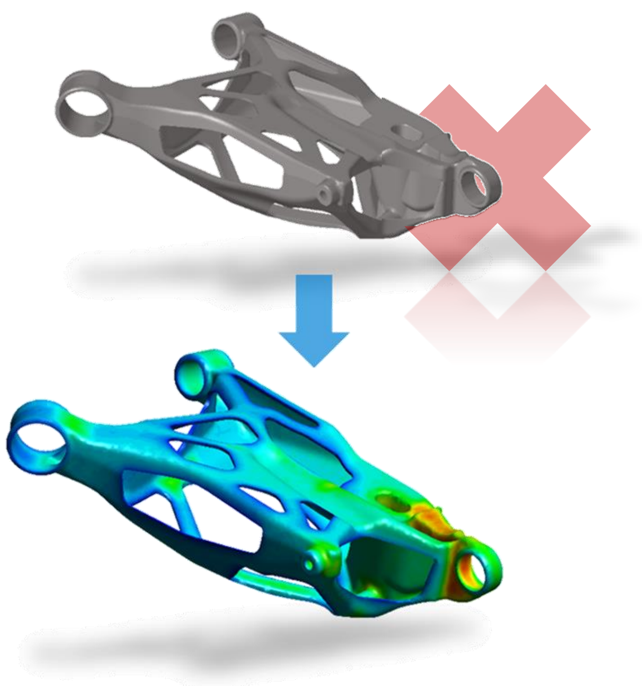
- The **amount** of critical areas are of bigger importance compared to the **magnitude** of the most critical value.



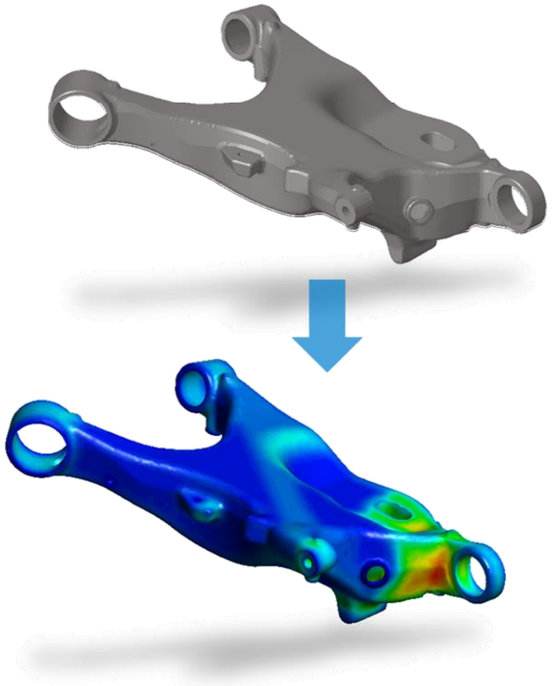
- Casting defects can be avoided by applying additional casting tools.

Method - Evaluating castability

Reference Models



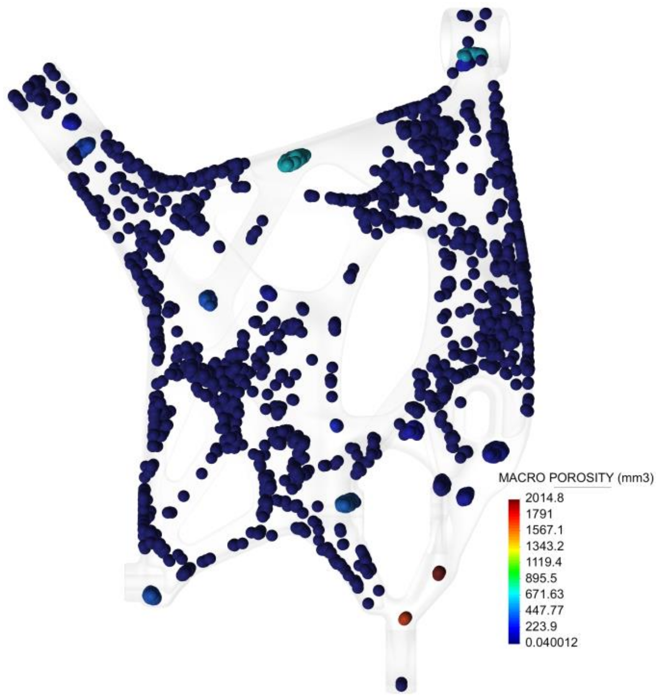
Optimized Design



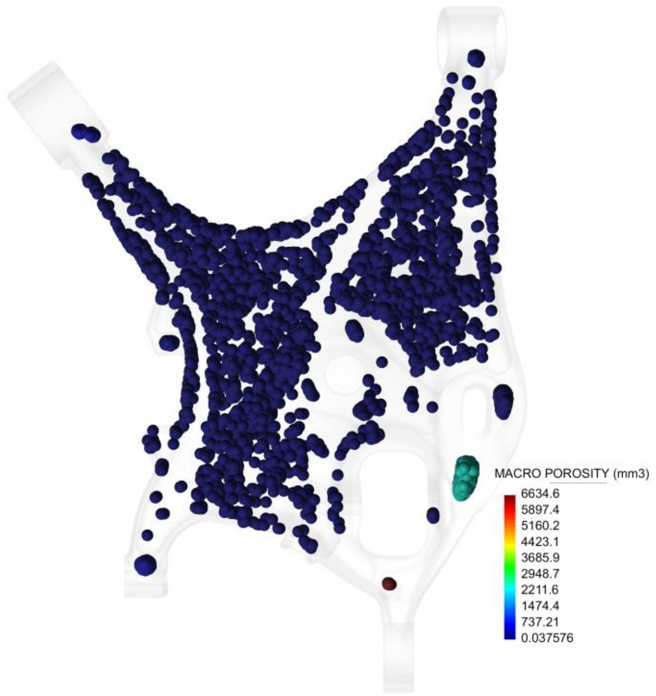
Current Design

Results - Evaluating castability

Numerical results presented in the casting simulation showed that Optimized Design performed better than the Current Design.



Optimized Design



Current Design

Results - Evaluating castability

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Liquid Fraction

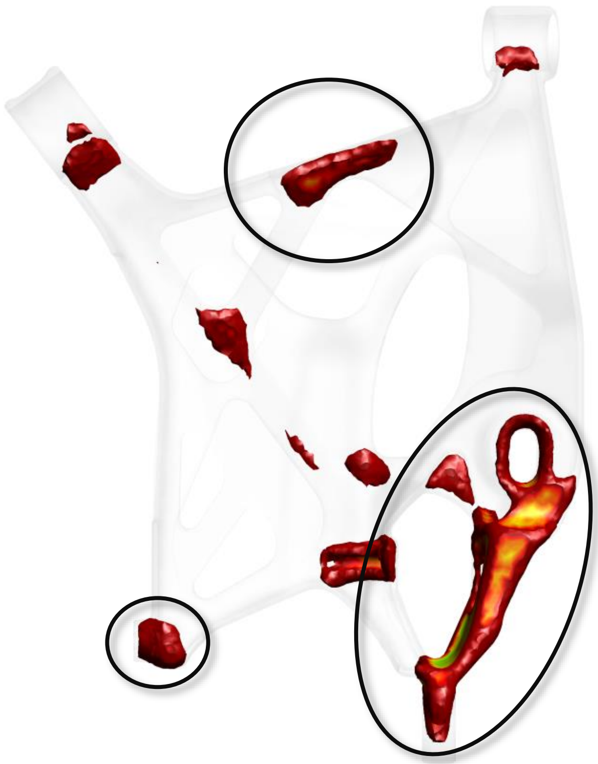
- Animation of how the temperature change during the solidification process.
- The purpose is to give an idea of where shrinkage porosity likely will occur.
- Want to evaluate castability numerically.
- Liquid fraction is based on temperature gradients.

Optimized Design

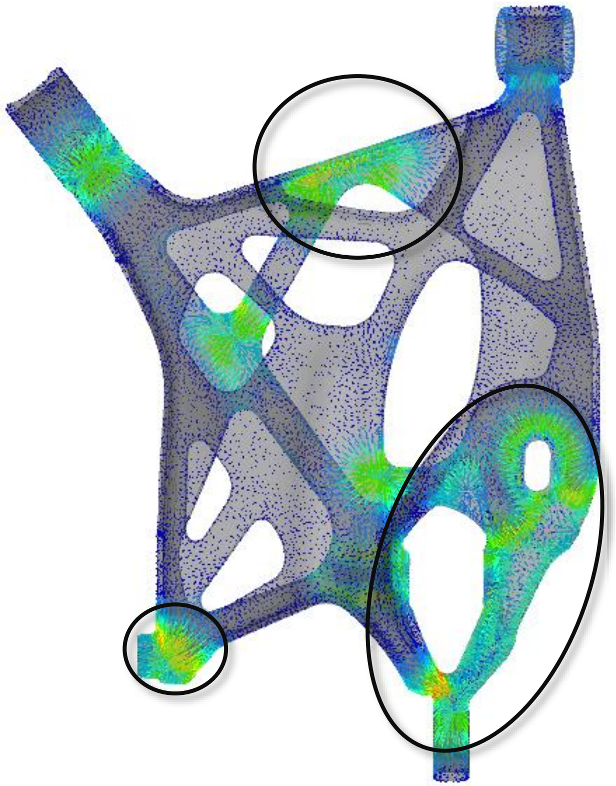
Current Design

Results - Evaluating castability

- Liquid fraction correlates to the temperature gradients.
- Previous studies: The occurrence of porosity can be minimized by maintaining a minimum temperature gradient in the casting.
- Higher temperature gradients were detected in the Optimized Design compared to the Current Design.



Liquid Fraction

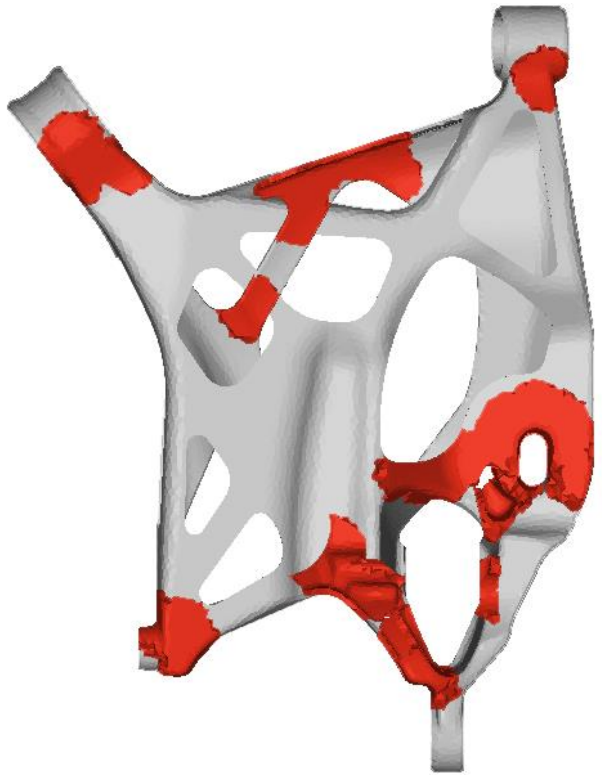


Temperature Gradient

Results - Evaluating castability

- Trace hot spots
- Count the number of hot spots.
- Number of hotspots is dependet on the seaching distance.

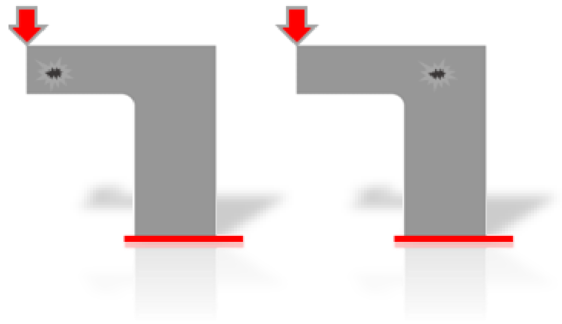
Liquid Fraction



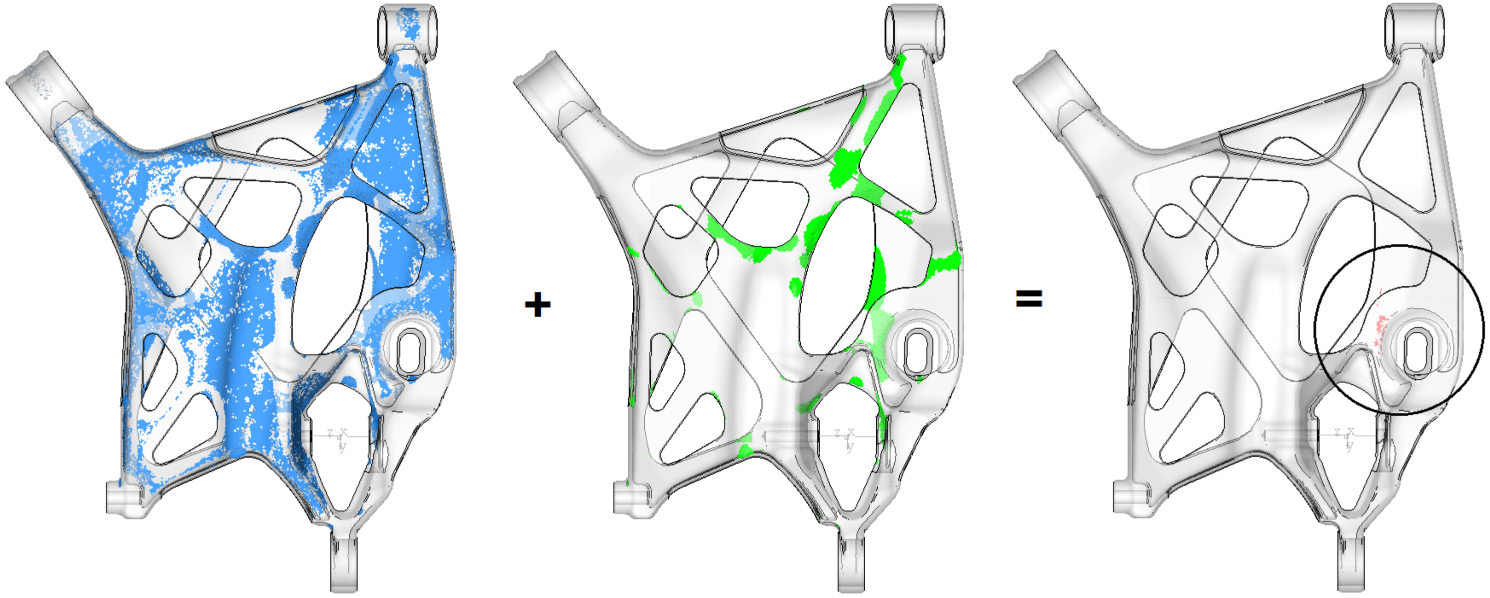
Number of hot spots

Results - Evaluating castability

- How critical a certain amount of porosity is depends on where it occurs in relation to stress concentrations.
- Searched for correlations between the stress concentrations and critical casting results.



Stress-Mapping



Results - Evaluating castability

Criteria

Niyama:
Niyama ≤ 0.3

Porosity:
Porosity $\geq 20\%$
Max Porosity [mm^3]
Porosity $\geq 100\ mm^3$

Temperature gradients:
G_{max}
$G \geq G_{crit}$

Stress mapping:
$\sigma \geq \sigma_{crit}$ & Niyama ≤ 0.3
$\sigma \geq \sigma_{crit}$ & $G \geq G_{crit}$
$\sigma \geq \sigma_{crit}$ & Porosity $\geq 10\%$
$\sigma \geq \sigma_{crit}$ & Porosity $\geq 100\ mm^3$

Additional properties:
Weight
V_b/V_c
$A_c/(6 * V_c^{2/3})$

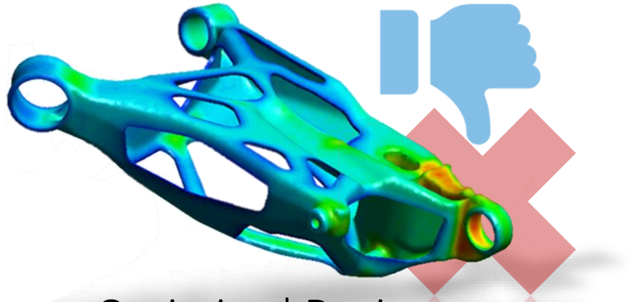
Weighting

$$w_{i,j} = K_{i,j}/K_{i,max}$$

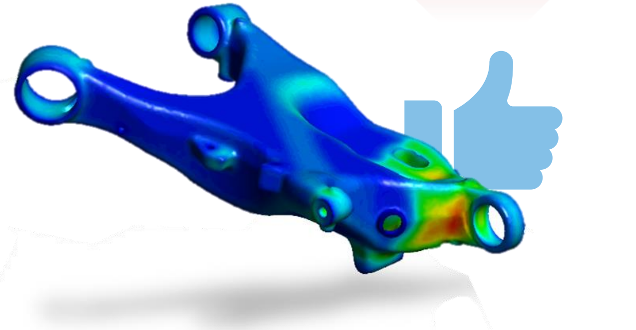
$$W_j = \sum_i w_{i,j}$$

i \ j	DC 1	DC 2	...	max
K1	$K_{1,1}$	$K_{1,2}$	$\cdots$	$K_{1,max}$
K2	$K_{2,1}$	$K_{2,2}$	$\cdots$	$K_{2,max}$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$

DC 1	DC 2	...
$w_{1,1}$	$w_{1,2}$	$\cdots$
$w_{2,1}$	$w_{2,2}$	$\cdots$
$\vdots$	$\vdots$	$\ddots$
W_1	W_2	



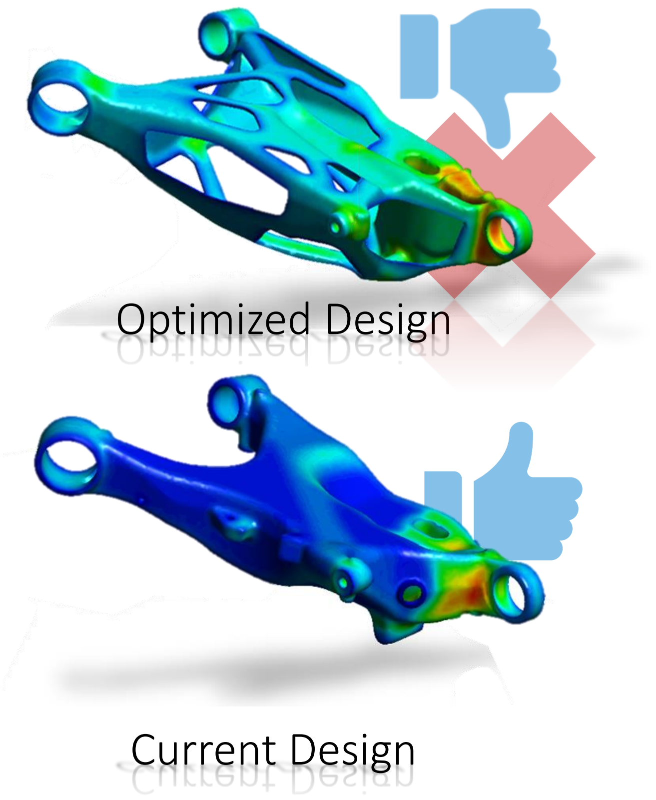
Optimized Design



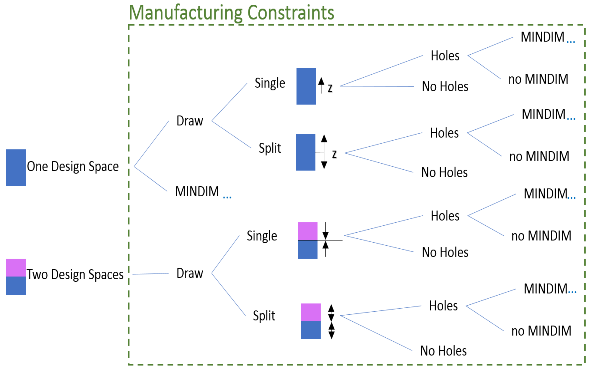
Current Design

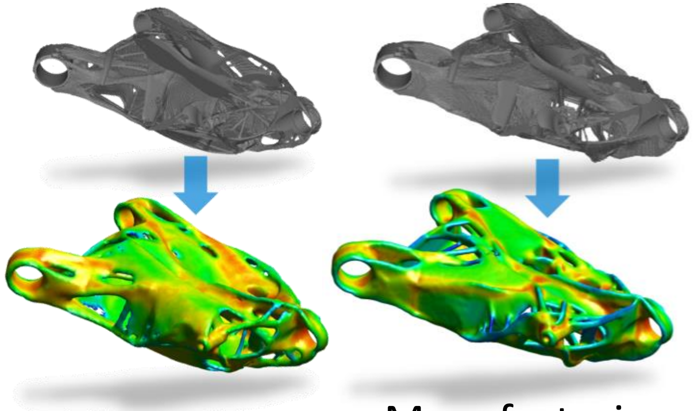
Results - Evaluating castability

This new method captures much more information
about the castability of a design
and the ratings now shows that
the Optimized Design is **not** as beneficial to cast
compared to the Current Design



Results - Evaluating castability





Unconstrained

Manufacturing constraints

Criteria

Niyama:
- Niyama ≤ 0.3

Porosity:
- Porosity ≥ 20%
- Max Porosity [mm^3]
- Porosity ≥ 100 mm^3

Temperature gradients:
- G_{max}
- $G \geq G_{crit}$

Stress mapping:
- $\sigma \geq \sigma_{crit}$ & Niyama ≤ 0.3
- $\sigma \geq \sigma_{crit}$ & $G \geq G_{crit}$
- $\sigma \geq \sigma_{crit}$ & Porosity ≥ 10%
- $\sigma \geq \sigma_{crit}$ & Porosity ≥ 100 mm^3

Additional properties:
- Weight
- V_b/V_c
- $A_c/(6 * V_c^{2/3})$

Weighting

$$w_{i,j} = K_{i,j}/K_{i,max}$$

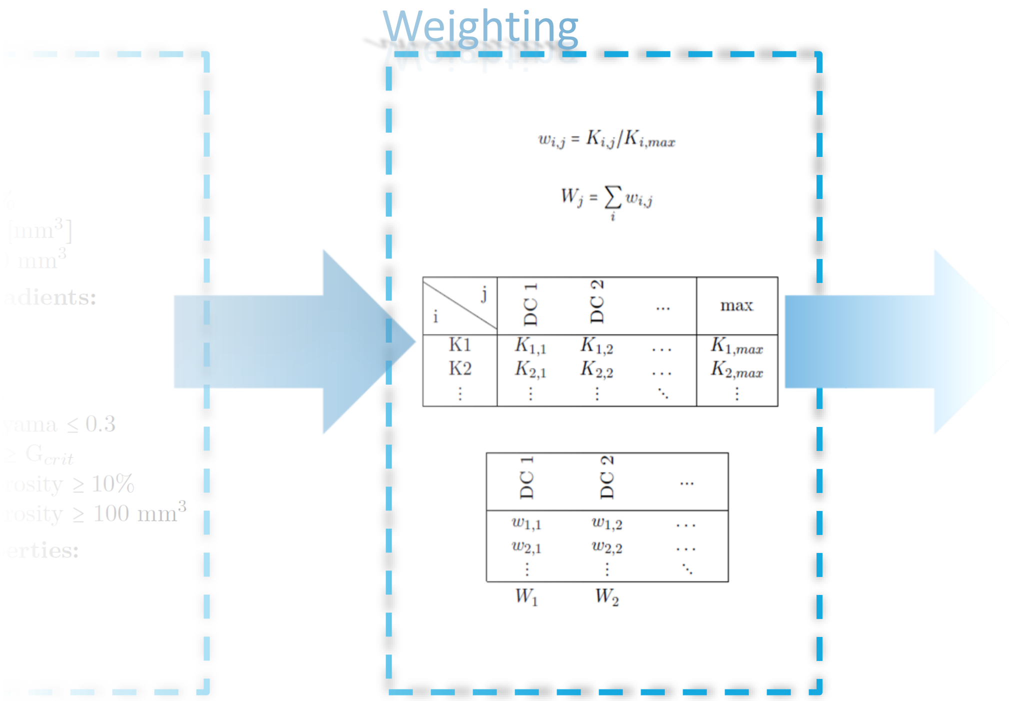
$$W_j = \sum_i w_{i,j}$$

i \ j	DC 1	DC 2	...	max
K1	$K_{1,1}$	$K_{1,2}$	...	$K_{1,max}$
K2	$K_{2,1}$	$K_{2,2}$	...	$K_{2,max}$
⋮	⋮	⋮	⋱	⋮

DC 1	DC 2	...
$w_{1,1}$	$w_{1,2}$	...
$w_{2,1}$	$w_{2,2}$	...
⋮	⋮	⋱
W_1	W_2	

Results - Evaluating castability

- The rating value can be derived in several different ways.
- The rating value is strongly dependent on which method that are used.
- Two simple methods has been used.



Every single criterion equally important

100%

Niyama:
Niyama ≤ 0.3
Porosity:
Porosity ≥ 20%
Max Porosity [mm^3]
Porosity ≥ 100 mm^3
Temperature gradients:
G_{max}
$G \geq G_{crit}$
Stress mapping:
$\sigma \geq \sigma_{crit}$ & Niyama ≤ 0.3
$\sigma \geq \sigma_{crit}$ & $G \geq G_{crit}$
$\sigma \geq \sigma_{crit}$ & Porosity ≥ 10%
$\sigma \geq \sigma_{crit}$ & Porosity ≥ 100 mm^3
Additional properties:
Weight
V_b/V_c
$A_c/(6 * V_c^{2/3})$

Mass equally important as the other criterias together

50%

Niyama:
Niyama ≤ 0.3
Porosity:
Porosity ≥ 20%
Max Porosity [mm^3]
Porosity ≥ 100 mm^3
Temperature gradients:
G_{max}
$G \geq G_{crit}$
Stress mapping:
$\sigma \geq \sigma_{crit}$ & Niyama ≤ 0.3
$\sigma \geq \sigma_{crit}$ & $G \geq G_{crit}$
$\sigma \geq \sigma_{crit}$ & Porosity ≥ 10%
$\sigma \geq \sigma_{crit}$ & Porosity ≥ 100 mm^3
Additional properties:
~~Weight~~
V_b/V_c
$A_c/(6 * V_c^{2/3})$

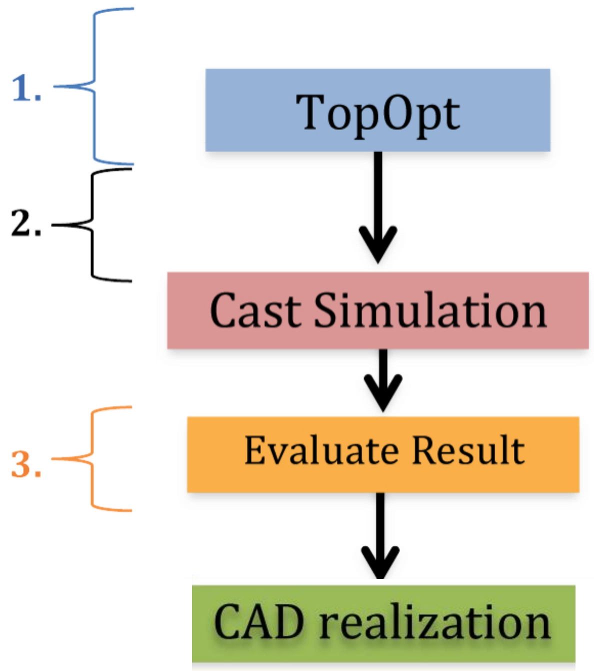
\+

50%

Mass

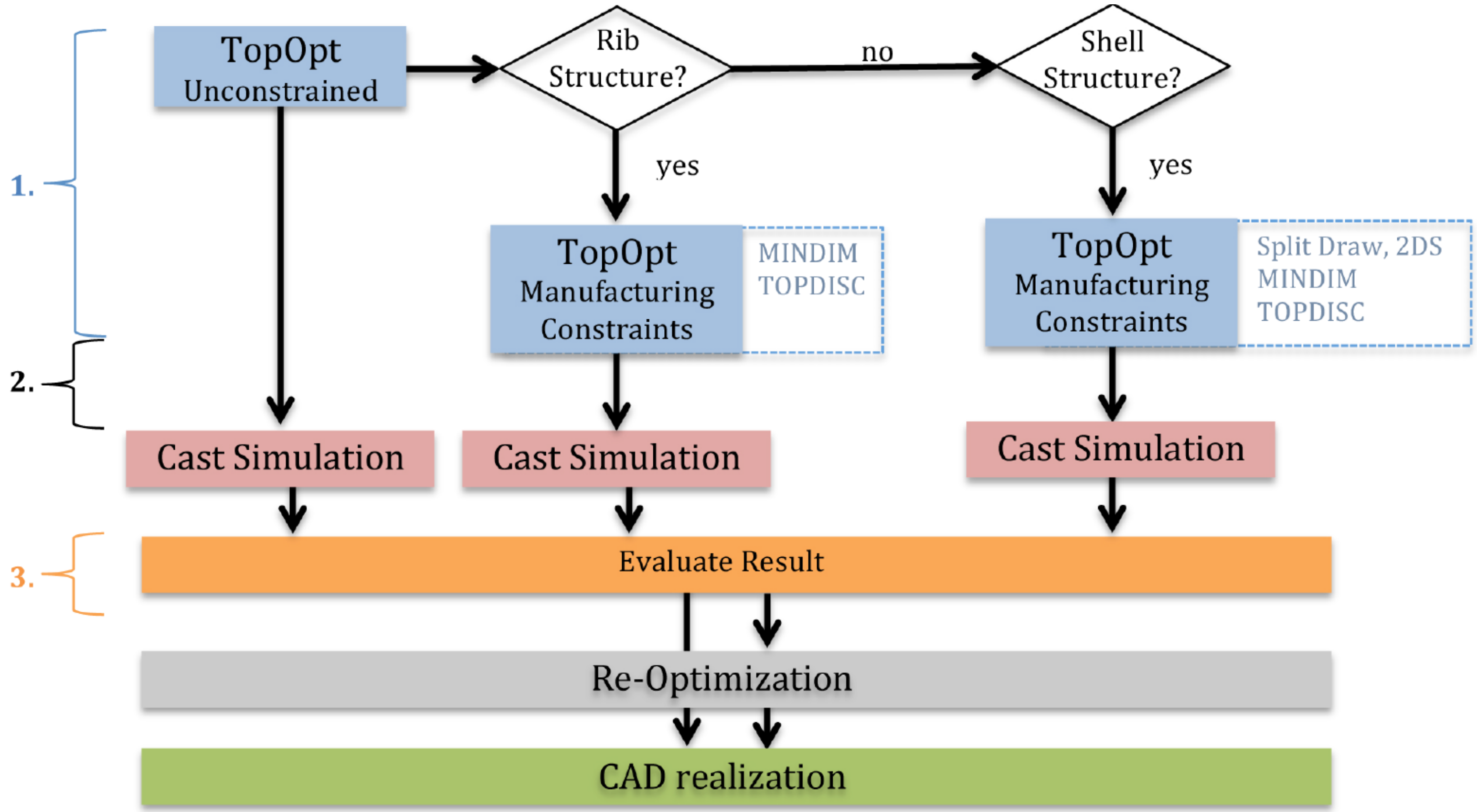
Results

1. Topology optimization
2. Topology result into cast simulation
3. Evaluating castability



Results – Development process

A suggested work flow has been formed based on the outcomes in this project, including recommendations within each part 1 – 3 in the development process.



Conclusions

- Topology optimization results can be casting simulated without first being manually realized using CAD.

- Casting properties can be evaluated numerically.

- Optimization results can be eliminated based on castability already in the early phase of the development process.

- No general castability score ⇒ Design concept can not be graded separately.

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