Industrial Optimization Developments

Emerging Synergy between Topology Optimization, Manufacturing and Materials

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Legal Notices

3DEXPERIENCE®

Function-driven Generative Designer

Generative Design

Additive Manufacturing Programmer

Process Planning

Additive Manufacturing Researcher

Virtual Printing

Reverse Shape Optimizer

Post-processing

CATIA

DELMIA

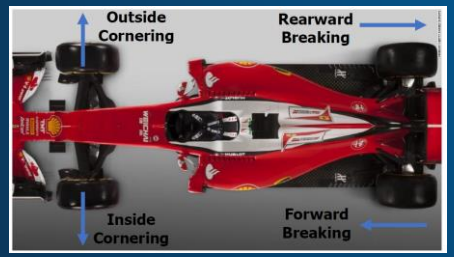
SIMULIA

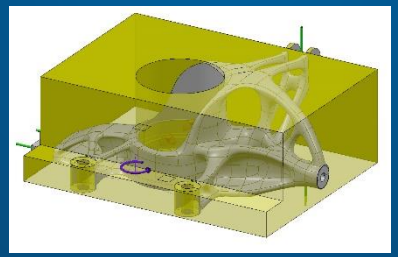
DS Wins First Place at Sandia Challenge!

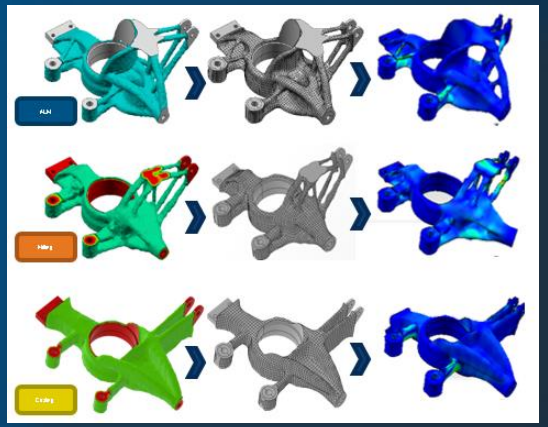
USACM Topology Optimization Round Table 2019

Hosted at Sandia National Labs

- <u>Challenge criteria:</u>
  - Component to optimize : Formula One suspension Upright
  - Objective : minimize mass while respecting the allowables
  - Three part versions : additive, cast, milled
  - Three materials : aluminum, titanium, steel





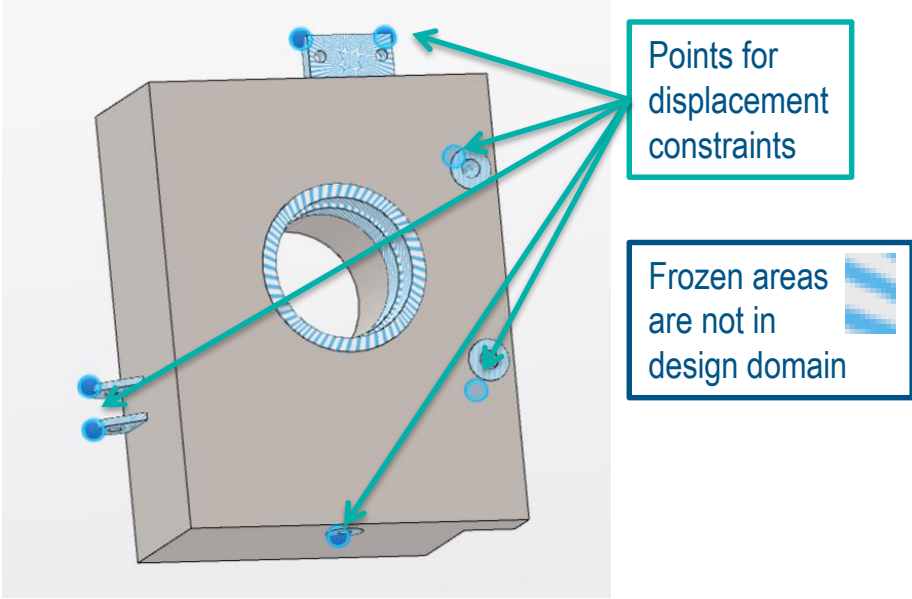


- All work was completed in less than **1** day
- All work was done in 3DX Functional Generative Design

Procedures Abaqus Static Perturbation and Frequency analysis

Optimization Model

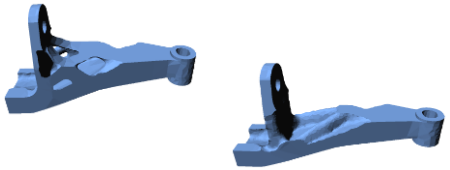
- **Objective**: Minimize mass
- **Constraints**: 72
  - 9 stress constraints < X MPa – Different materials
  - 9 load cases * 7 points of interest
    = 63 displacement constraints < 0.12 mm
- **Materials:** Aluminium, Titanium and Steel
- **Manufacturing constraints:**
  - ALM (None)
    - Minimum length scale
  - Milling
    - 3 axis: all surfaces reached from any of the main axes
  - Casting
    - Y-direction, no undercuts allowed in casting direction



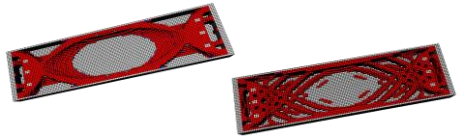
- Optimizer implementation
  - Tosca Structure solves a non-linear constrained optimization problem using first order adjoint sensitivities calculated directly in Abaqus using sparse direct solver

Manufacturing constraints

Casting restrictions



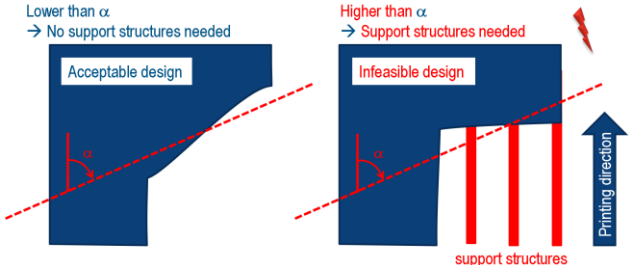
Minimum/Maximum member size



Symmetries

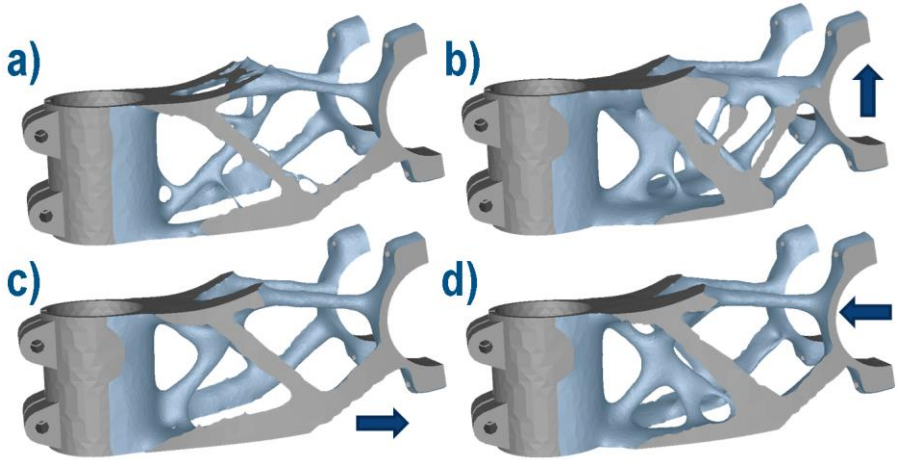
Including combinations of restrictions

Overhang



Design formulation:

- Minimize Mass
- Disp. Constraint
- Symmetry constraint

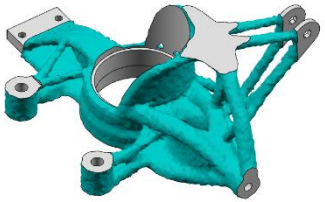


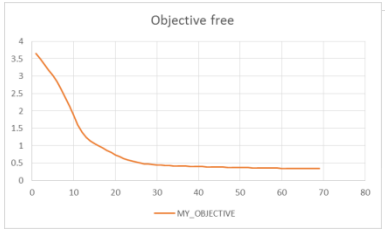
	Mass
a	22022 (1.00)
b	28063 (1.27)
c	25380 (1.15)
d	27043 (1.23)

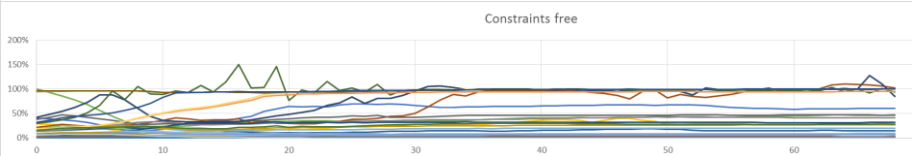
Optimization Results and Iteration Histories

Relative Constraints:
- Displacements
- Stresses

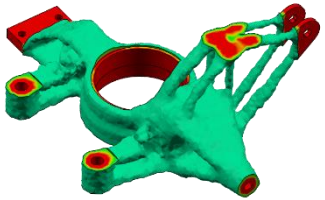
ALM

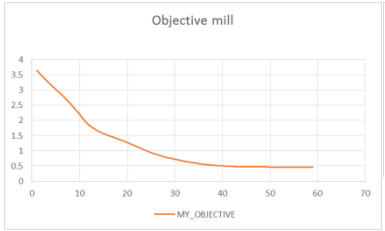


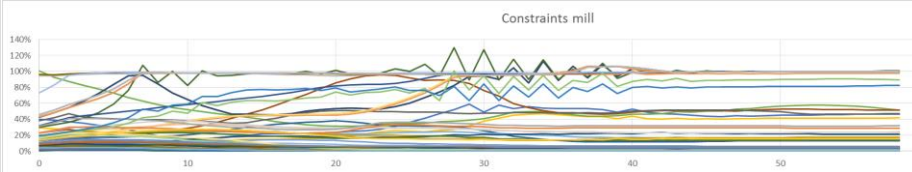




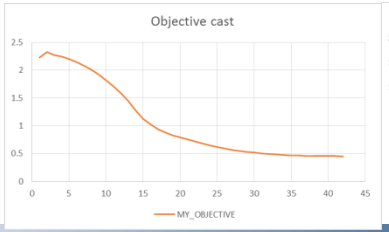
Milling

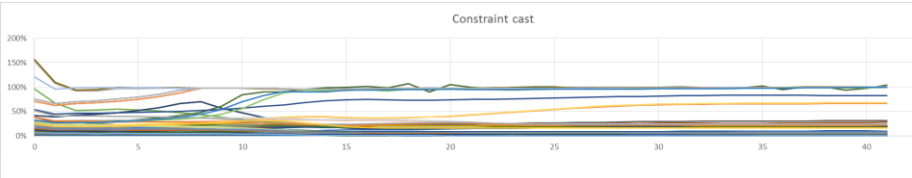




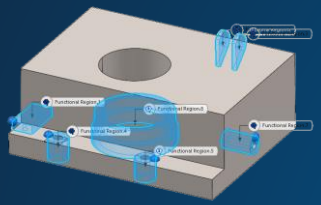


Casting



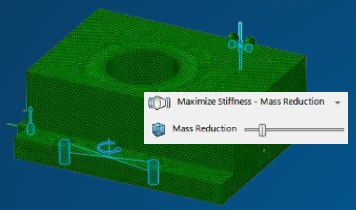


Generative Designs



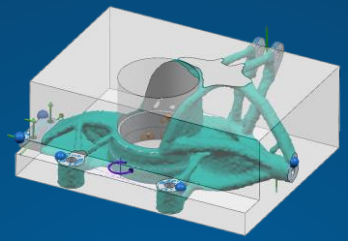
Geometry Specifications

Design Space, Interfaces

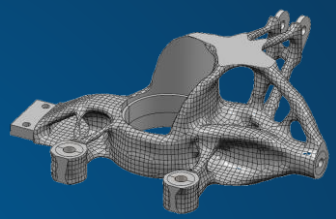


Functional Specifications

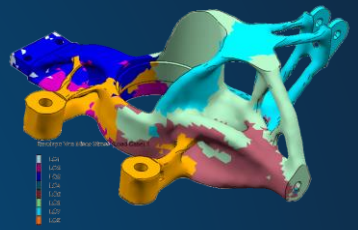
Load Cases, Mass Targets,..



Concept Generation

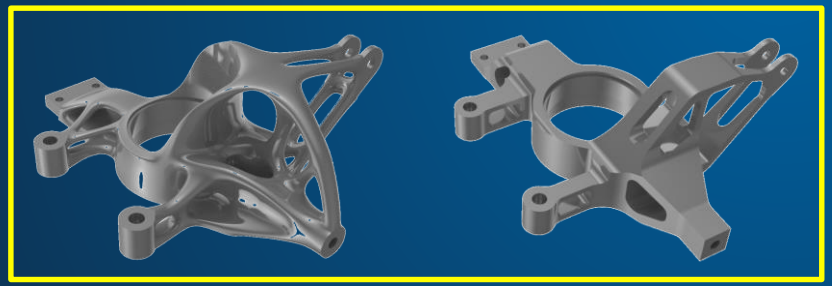


Exact Solid **Generation**

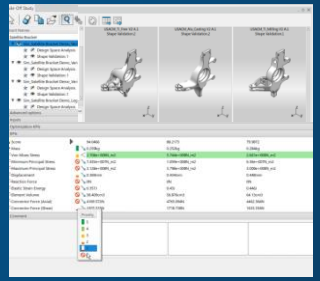


FEA Validation

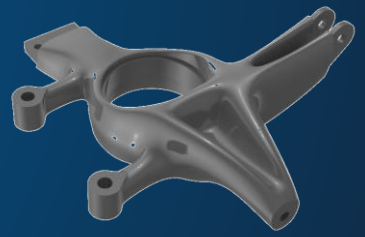
Review results per Load Cases or envelope



Detailed Design driven by Manufacturing Constraints (Additive Manufacturing or 3-Axis Milling)



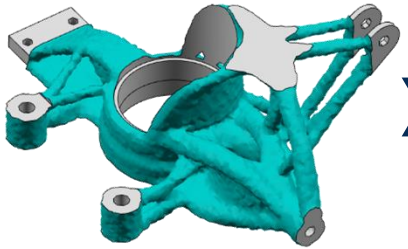
Trade-Off Study



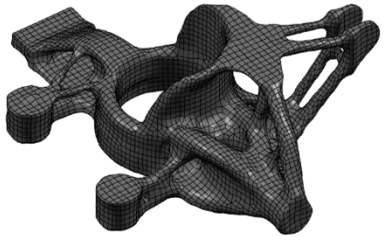
Variants Creation, here for casting

From Optimization Result Mesh to Concept Shape

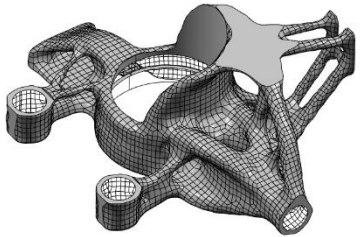
- Automatic reconstruction of the conceptual shape - no required user interaction



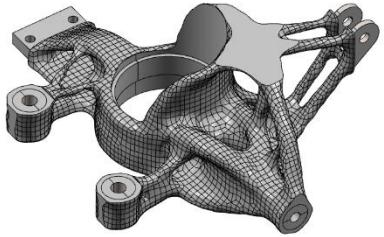
Optimization result mesh



Automatically computed subdivision surface

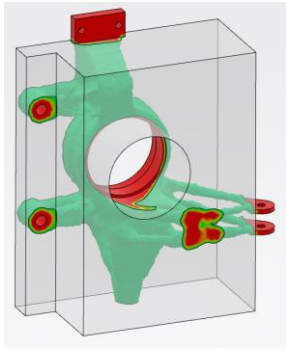


Split with split initial design space

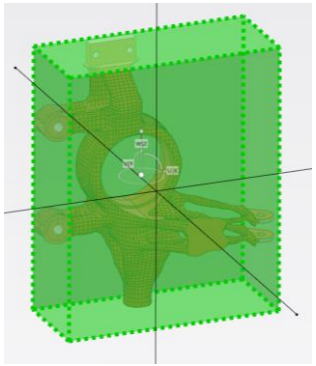


Union with initial frozen regions
(none-designable regions)
including full associativity transferring load cases from designing to validation

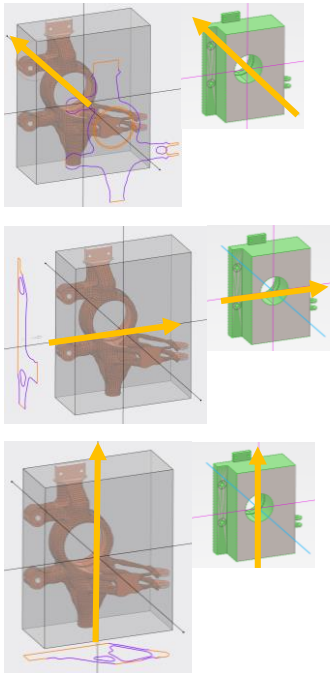
Shape generating for milling manufacturing



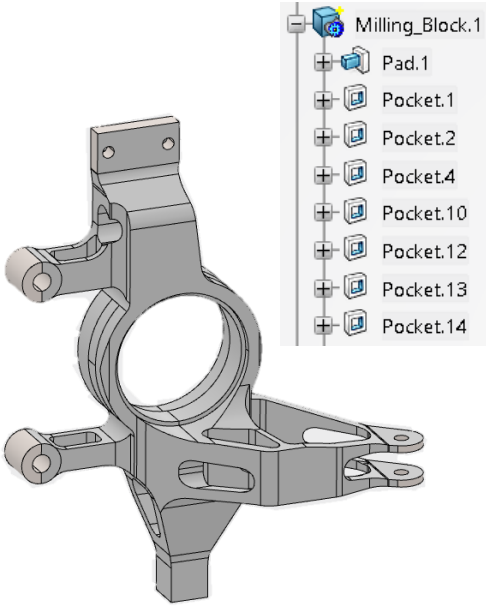
Optimization result



Milling Block



Cutting profiles in each milling direction



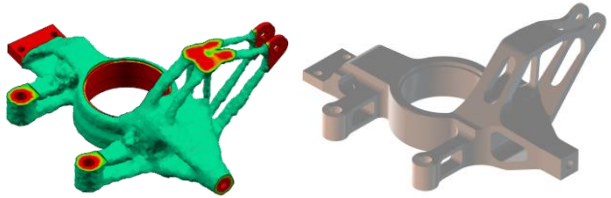
Model results created from standard modeling features

Turn Around Times

▶ Time format: HH:mm

ALM

Milling

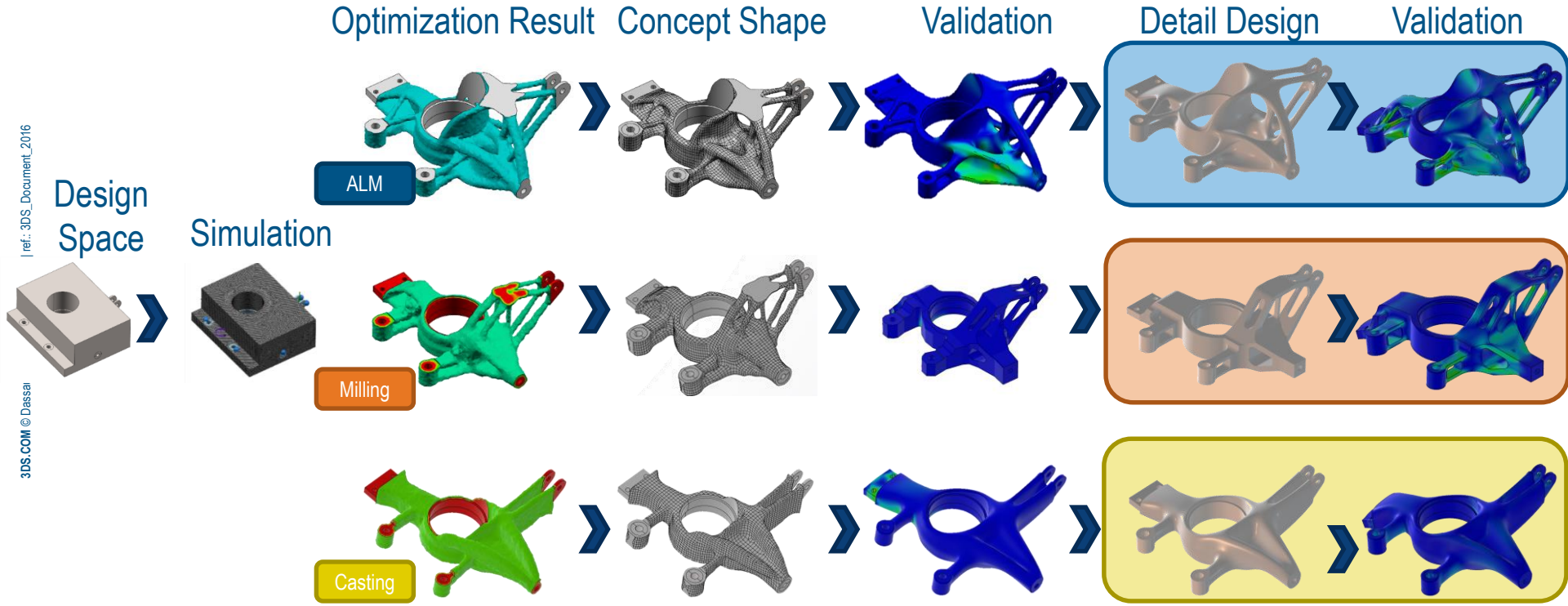


Casting

Simulation setup	Optimization setup	Compute time	Concept Shape Validation	Detail Design CAD construction time	Detail Design Validation	Total
02:00	00:15	03:10	00:15	00:45	00:15	**06:40**
* 02:00	00:15	03:32	00:15	01:00	00:15	**07:17**
* 02:00	00:15	01:46	00:15	01:00	00:15	**05:31**

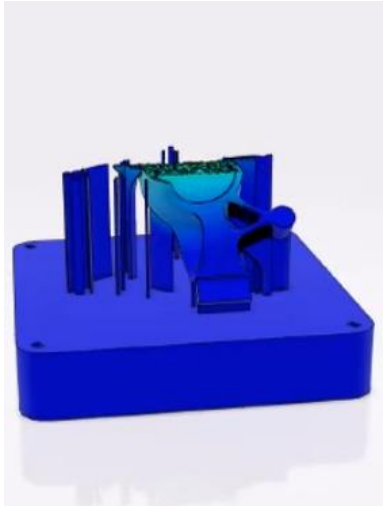
* Simulation was only setup once, then reused for all variants

Workflow



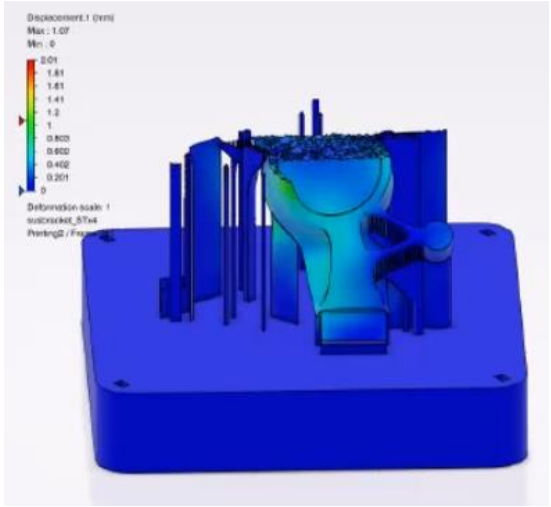
Process Simulation: Thermo-Mechanical Analysis

Thermal Analysis



- Laser scan path provides input for moving heat source
- Subsequent structural model applies the result of the thermal analysis

Mechanical Analysis



- Eigenstrain simulation is insufficient for accurate prediction of present application
- Thermo-mechanical analysis for robust failure detection and accurate buckling of thin-walled support members

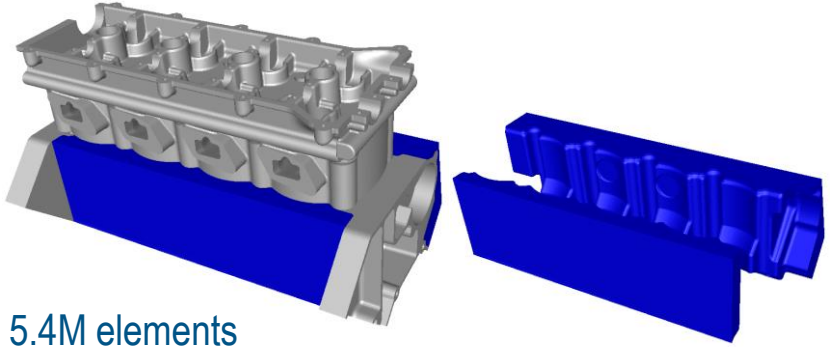
Printed successfully on a Renishaw AM Printer

3DEXPERIENCE®

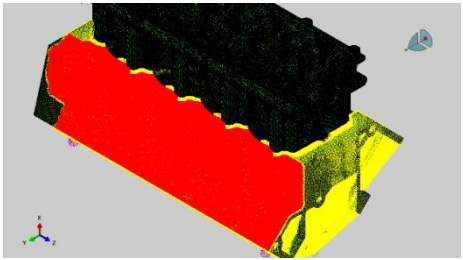
Iterative Solver for Industrial Large Scale Optimization

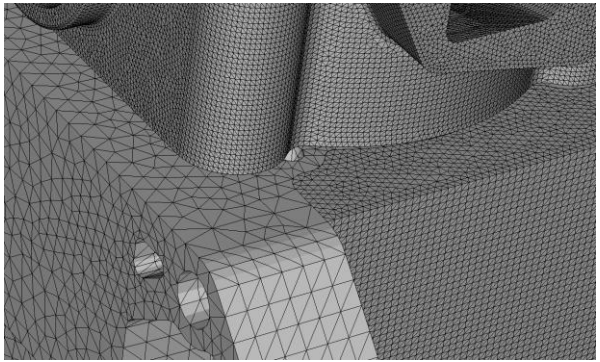
Powertrain: Two Design spaces → Total model + Ties

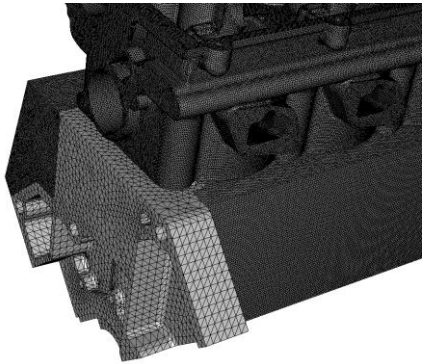
- Topology optimization with **AMG iterative solver**
- Mesh ~ 14.8M elements
  ~ 4.4M nodes ~12.7M DOFs
  - ▷ Two block design spaces
    ~ 2 mm **C3D4** mesh size = 5.4M elements
  - ▷ Block non-design ~ 6mm **C3D10** ~ 290k elements
- **Design spaces are connected to block sides through tied connections**
- **Min-Max Compliance s.t.**
  (Max-Min stiffness for the 3 load cases)
  - ▷ **30% mass on design space 1**
  - ▷ **10% mass on design space 2**



~ 68000 elements on tie surface block sides and design spaces

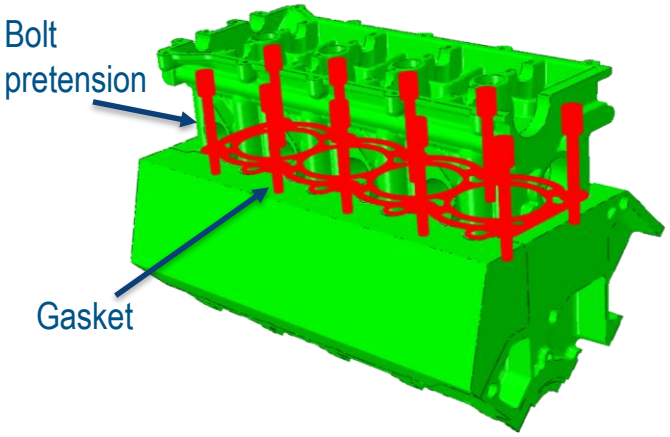




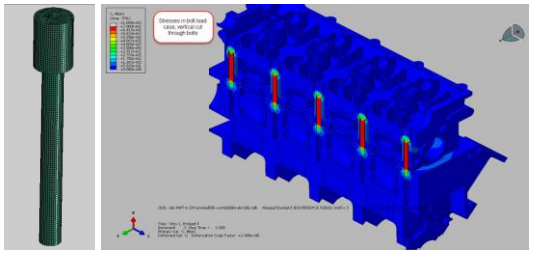


Powertrain: Assembly process → Bolts pretension + Contacts

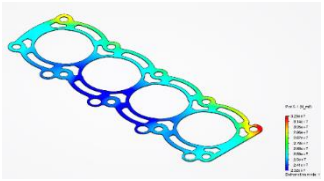
1 step: Bolt preloading + 2 step: Bolt clamping



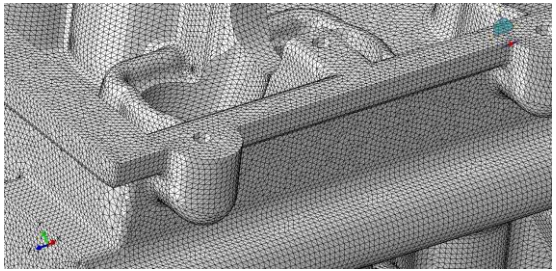
▷ 10 Bolts pretension ~ 197k elems C3D8I



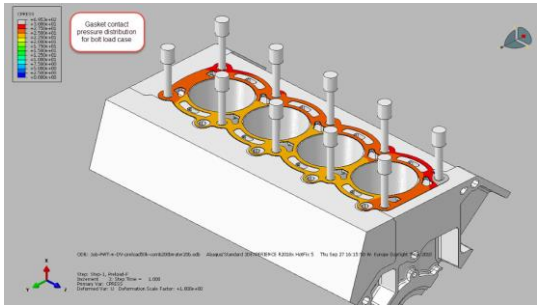
▷ Gasket ~ 47k elems GK3D8



▷ Head ~ 8.5M elems C3D4



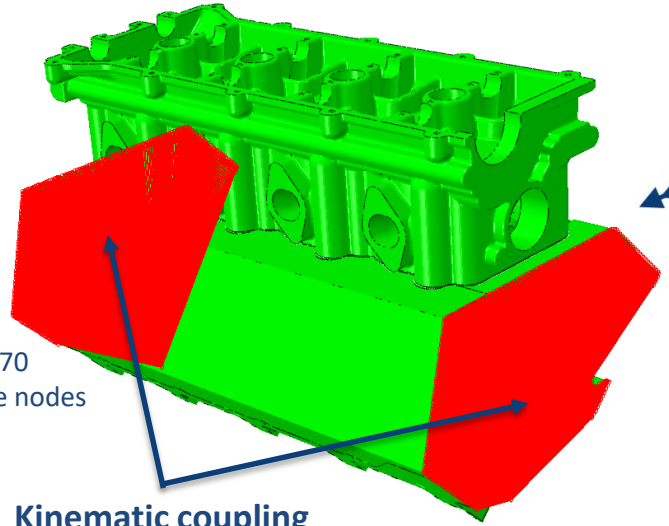
▷ Contact interaction: Penalty



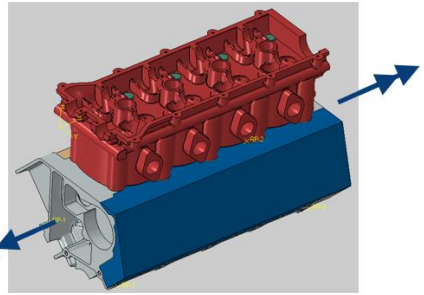
Powertrain: Service load cases → Industrial boundaries and loading

- Loading and restraint applied to control nodes in centerline of crankshaft
- **Control nodes are connected to end planes of the block through kinematic couplings**

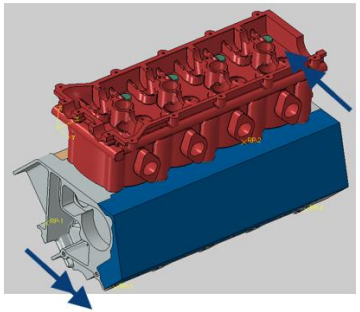
- Kinematic couplings



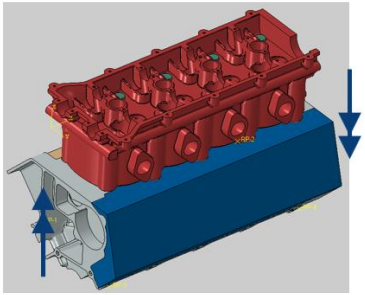
- LC1 – Torsional



- LC2 – Up/Down bending



- LC3 – Side bending

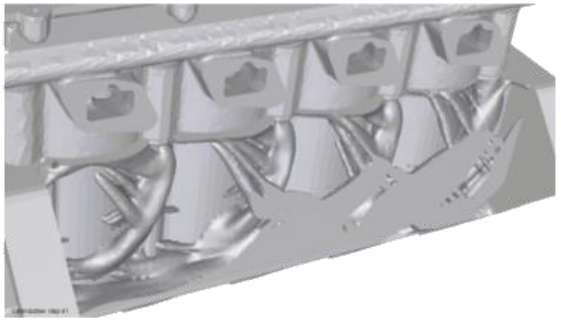


Optimization Iteration History – Additive Manufacturing

Iso-cuts for CAD reconstruction

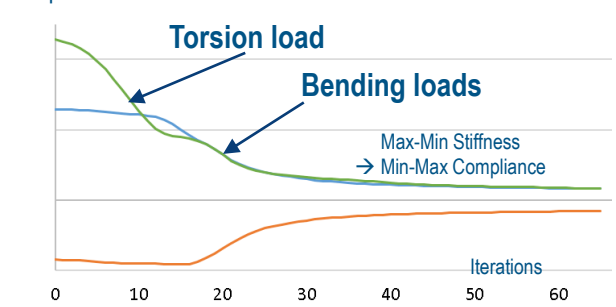
Design space 1

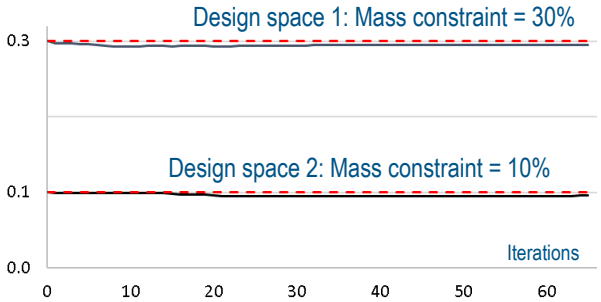
Top view



Side view – without engine block

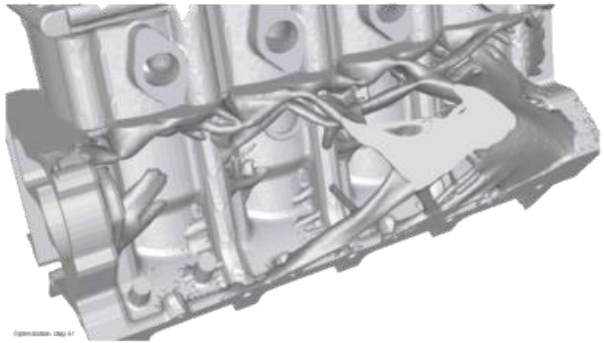
Two load cases contribute to max stiffness



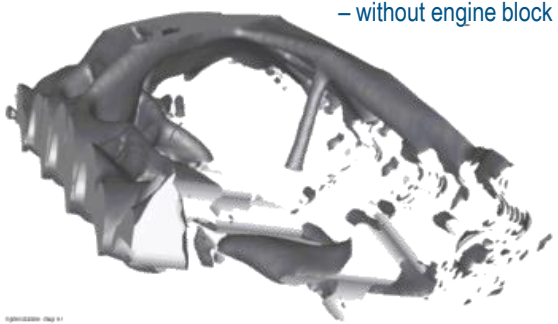


Design space 2

Top view



Side view – without engine block



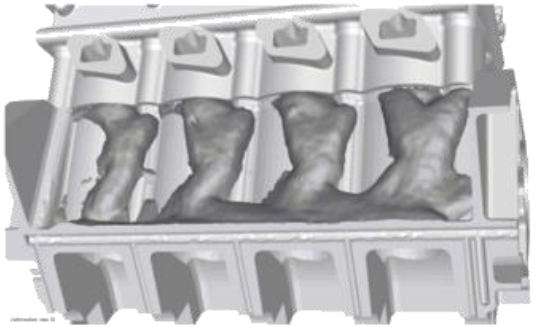
Optimization Iteration History – Casting Manufacturing

Iso-cuts for CAD reconstruction

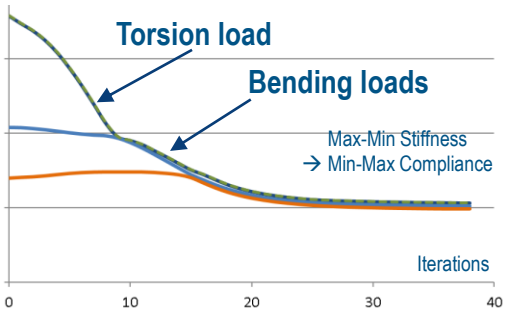
Design space 1

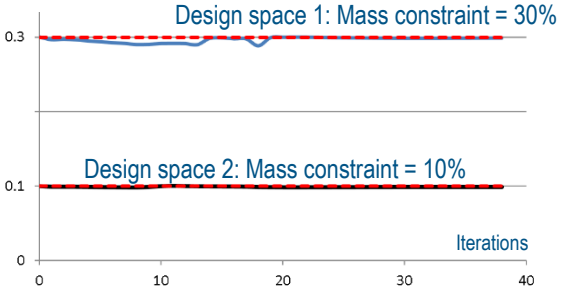
Top view

Bottom view



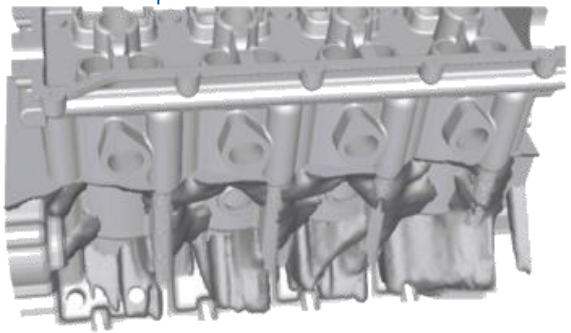
All three load cases contribute to max stiffness



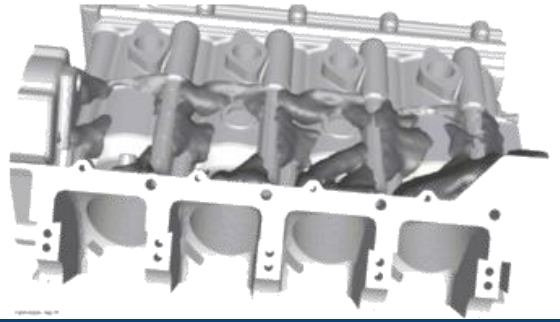


Design space 2

Top view



Bottom view

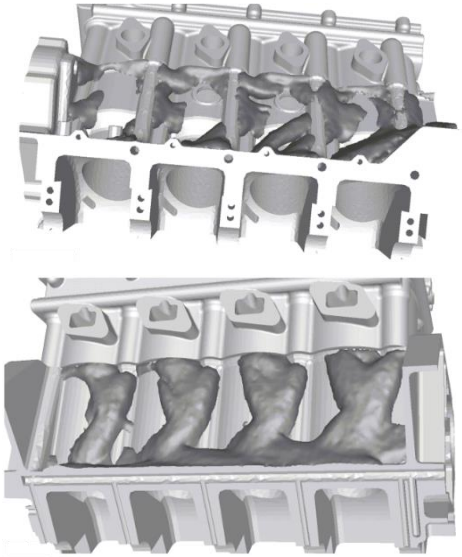


Stiffness: Casting / AM ~ 35%↓

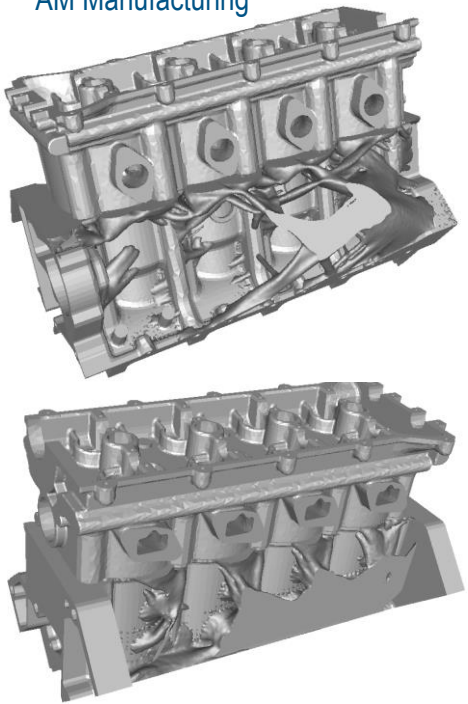
Industrial summary

- Optimization with **iterative AMG solver**
- **Typically, industrial models have:**
  - **Unstructured meshes**
    - Circular holes for preloaded bolts
  - **Different element types**
    - C3D4, C3D8I, C3D10
    - SPRING1
    - GK3D8
  - **Non-linear modelling - contact**
  - **Constraints inside or outside design space**
    - **Tie**
    - **Kinematic couplings**
    - **Bolt pre-tension sections**
  - **Preloading from assembling and three service load cases**

Casting Manufacturing



AM Manufacturing



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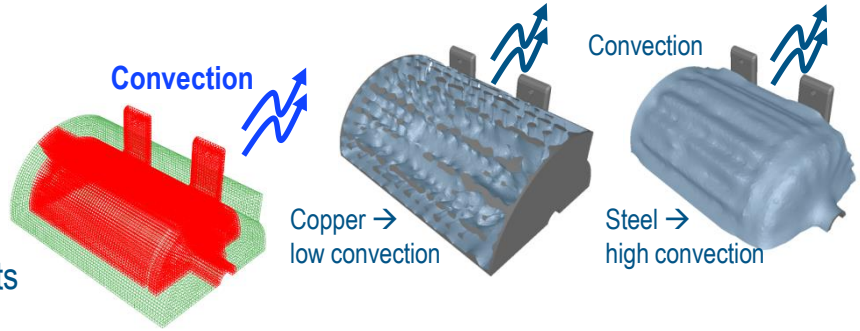
Multiphysics

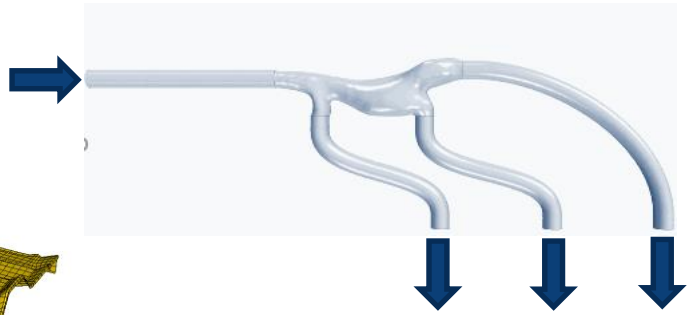
Multiphysics Optimization Examples

- **Finite element Thermal optimization**
  - Design variables are conductivity and convective coefficients



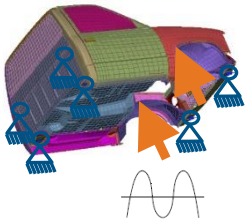
- **Integrated CFD + Tosca Fluid for designing fluid flow systems**

Minimize pressure drop of flow splitter

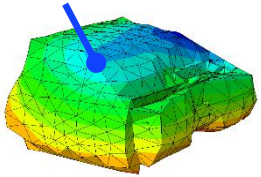


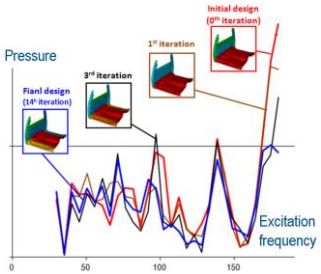
- **Vibro-acoustic models - Stead state dynamics**
  - Interaction between acoustic media and structural components

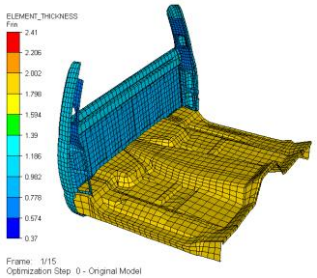
Structural continuum



Acoustic continuum
Pressure at ear position







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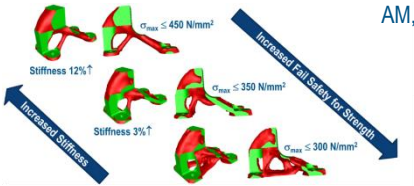
Conclusions

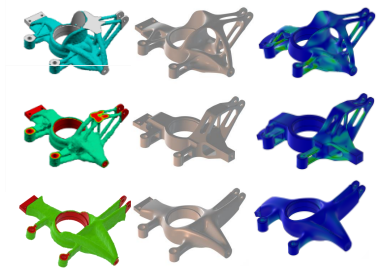
3DEXPERIENCE platform: Variations in Generative Designs

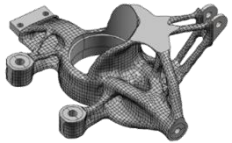
Function Driven Generative Design: CAD → CAE → CAD

Impact of mechanical constraints



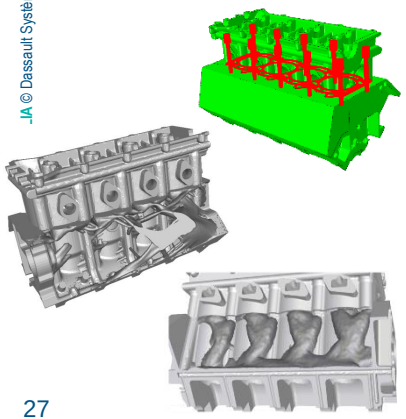
AM, Casting and Milling for constraints and CAD

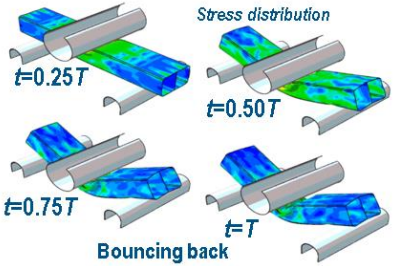




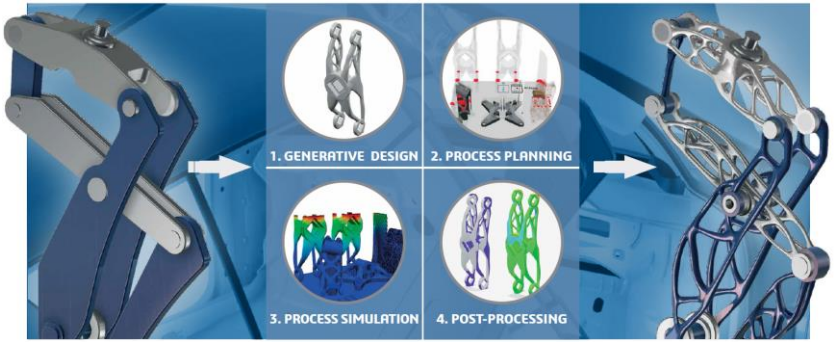
Automated transferring of load cases to CAD validation

Realistic BCs + Non-linear → Industrial designing





Topology Optimization in the Digital Thread



Digital trend: Continuity, Large sale and Design Workflow