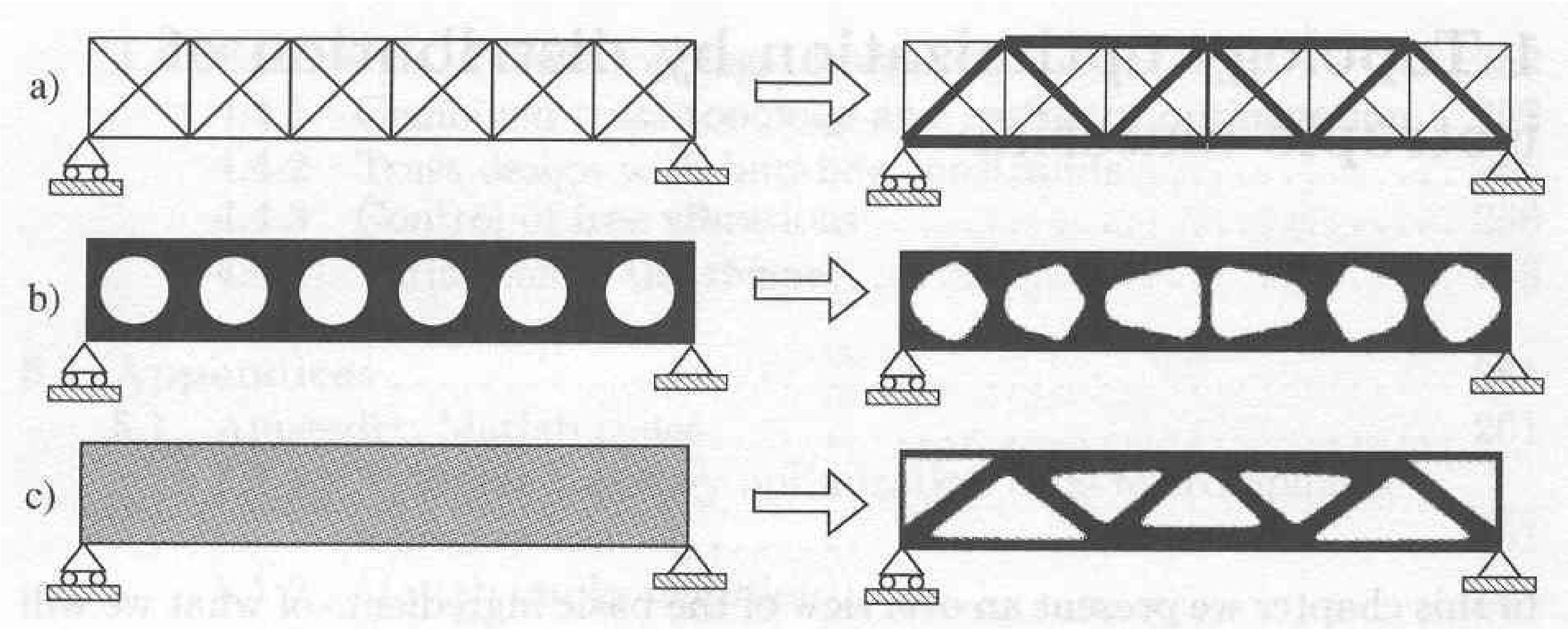
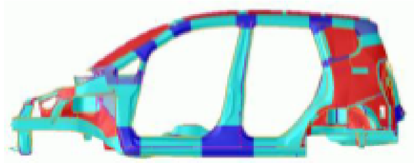
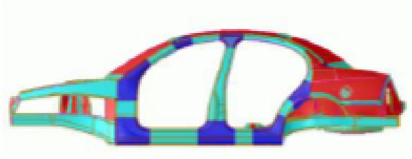
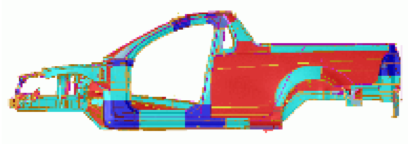
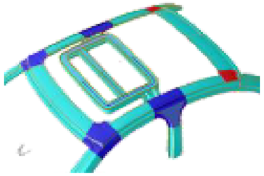
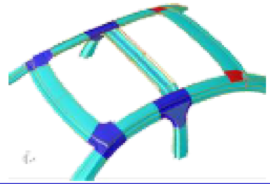
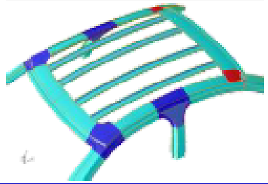
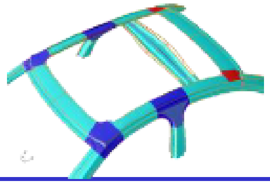
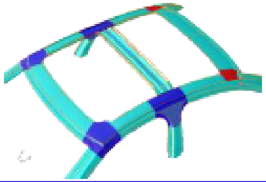
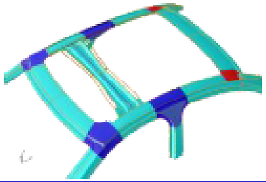
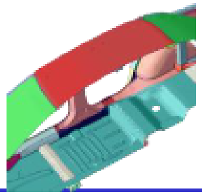
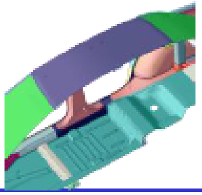
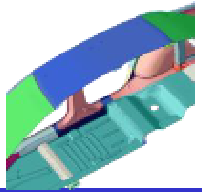
# Categories of Structural Optimization

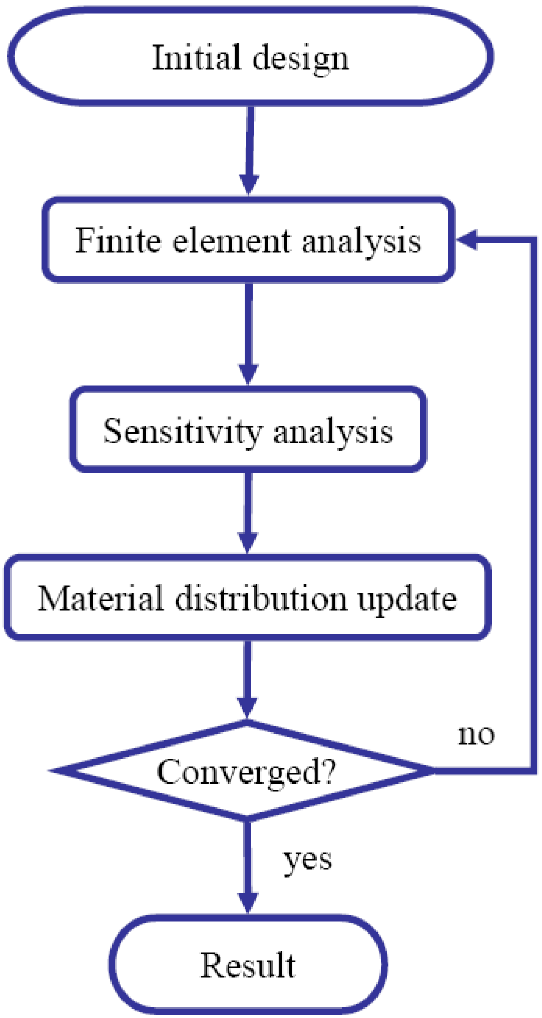


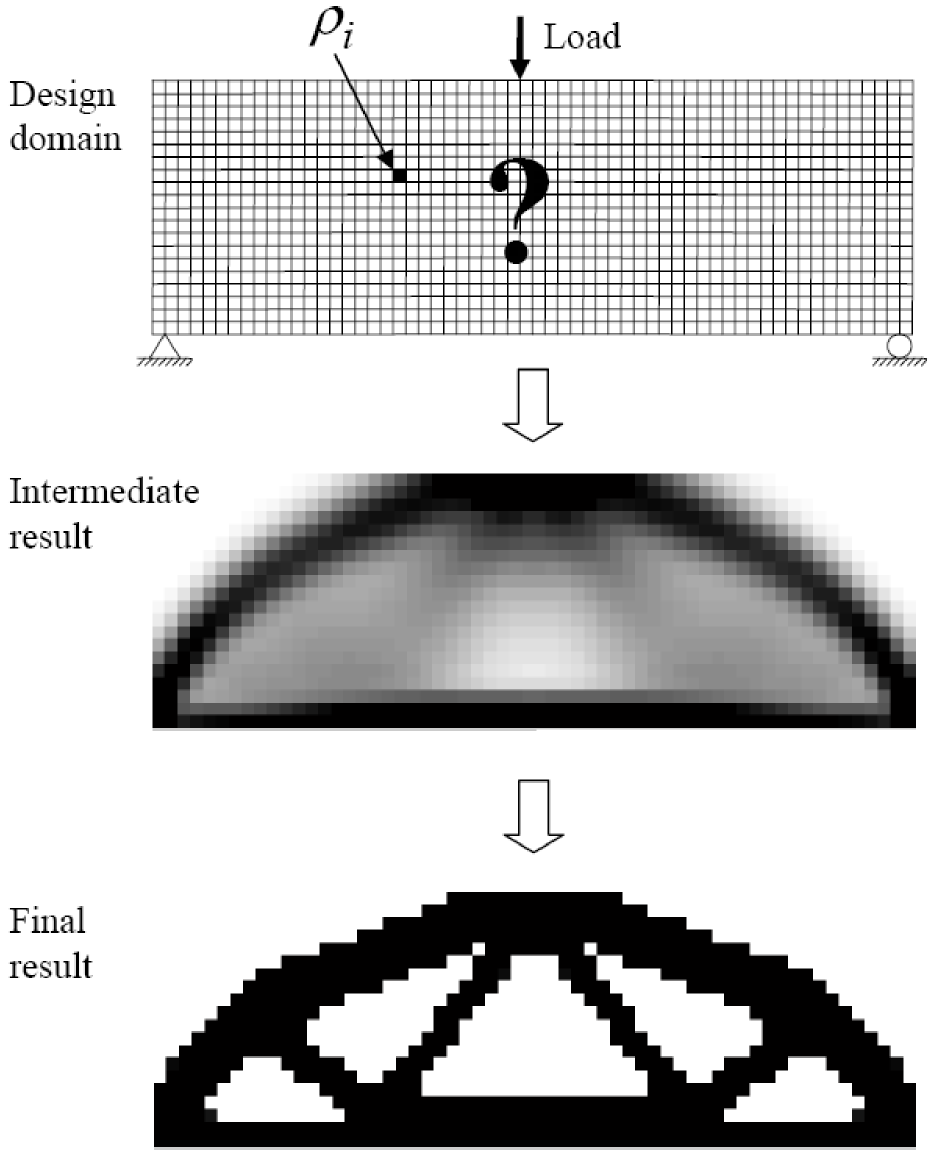

M.P.Bendsoe and O. Sigmund, Topology Optimization: Theory, Methods and Applications, Springer, 2003

# Shape and Topology Optimization for Crash

| | | | |
|---|---|---|---|
| **Concept** |  |  |  |
| **Material** | Steel | Aluminium | Composites |
| **Topology** |  |  |  |
| **Shape** |  |  |  |
| **Size (thickness)** |  |  |  |

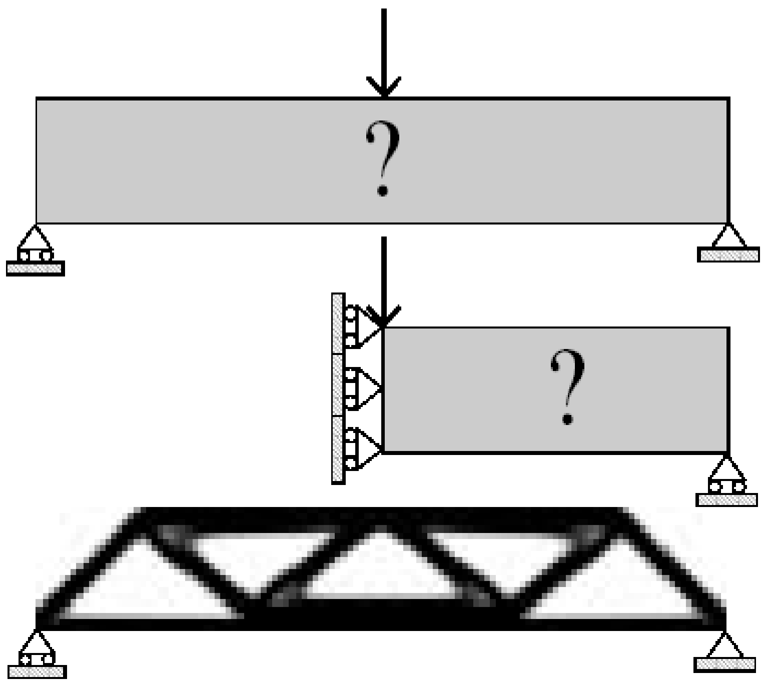
# Topology Optimization Process

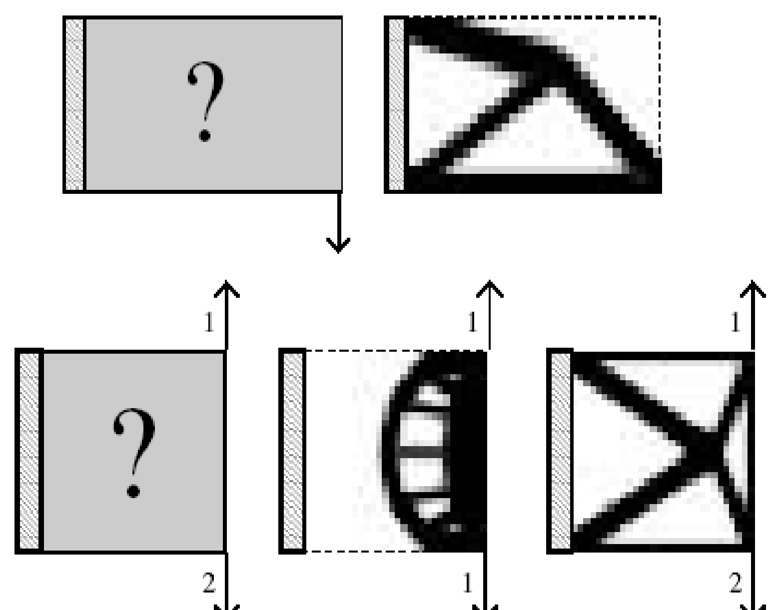


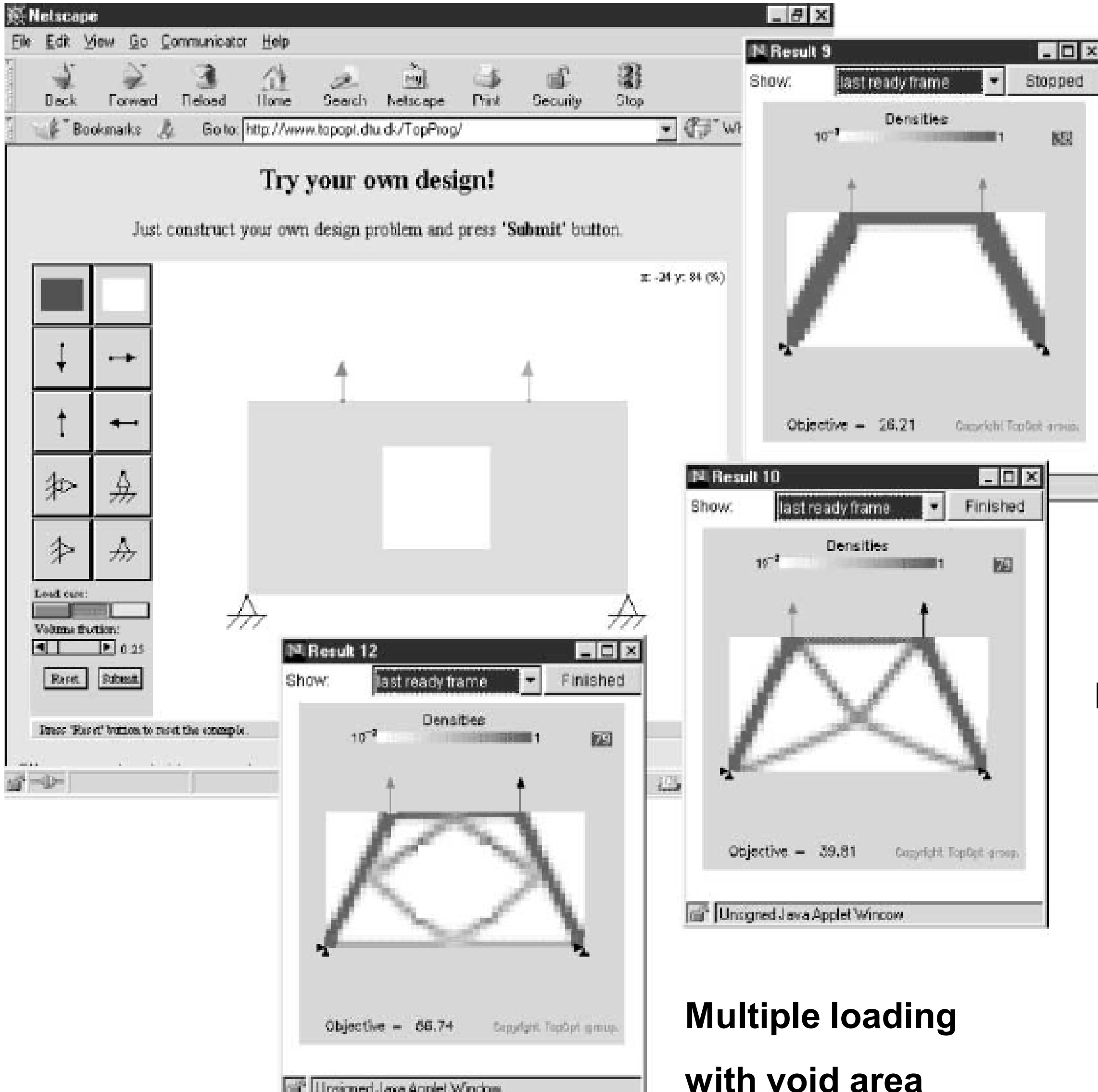
# Educational Design Tool (1)

- TOPOPT (www.topopt.dtu.dk)
  - O. Sigmund, A 99 line topology optimization code written in Matlab, Struct Multidisc Optim 21, pp.120-127, 2001
  - D. Techerniak and O. Sigmund, A web-based topology optimization program, Struct Multidisc Optim 22, pp.179-187, 2001





# Educational Design Tool (2)



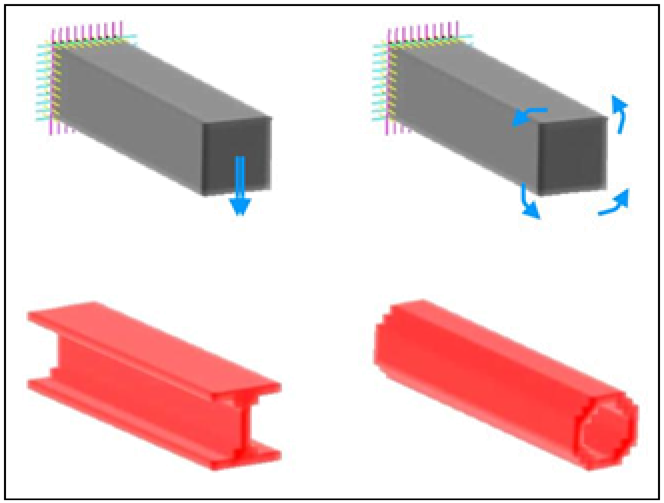

**Single loading**

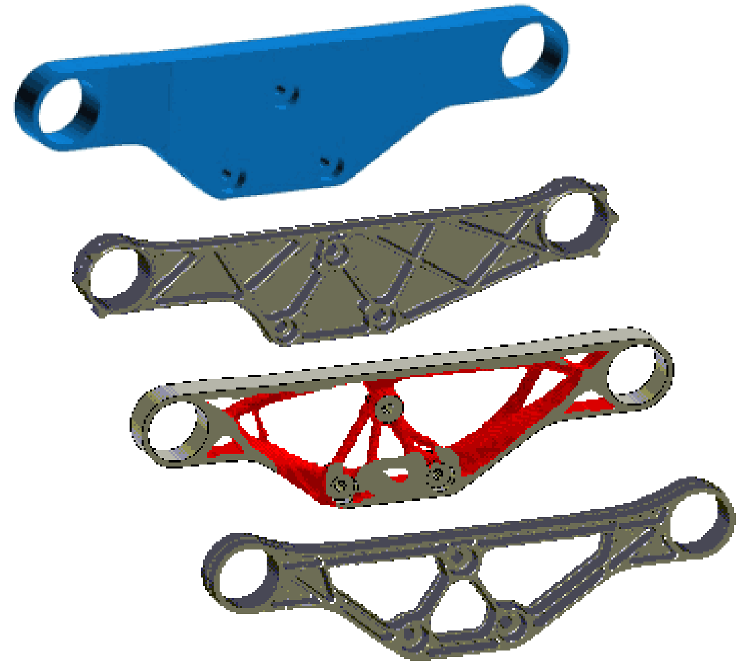
**Multiple loading**

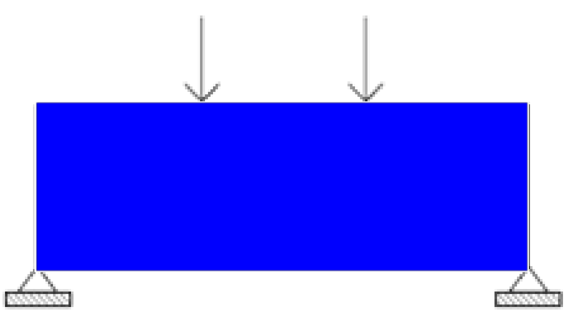
**Multiple loading with void area**

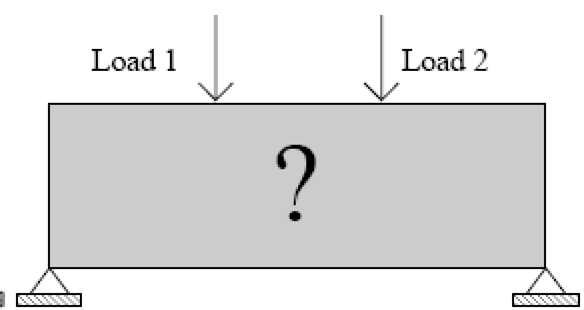
# Linear Static Problem (1)

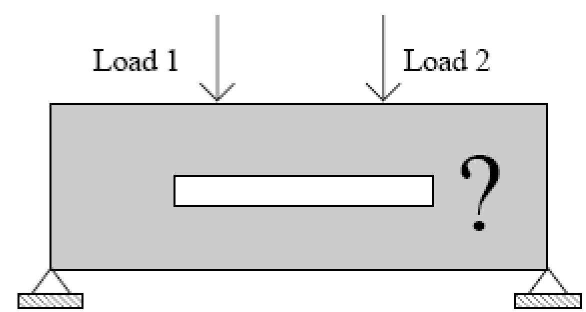
## Solid Mechanics: Load Path





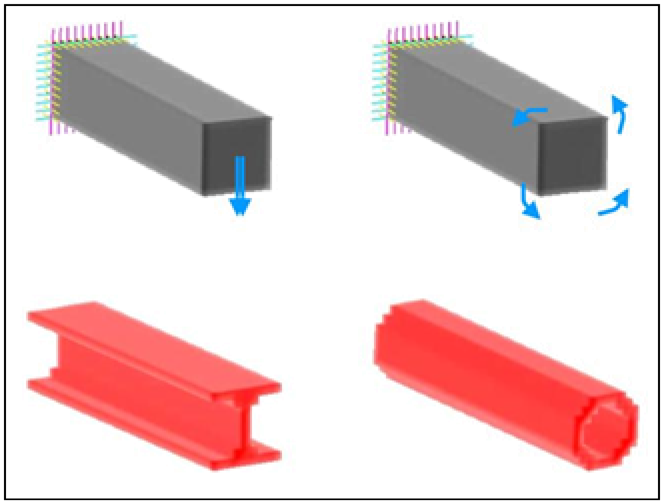


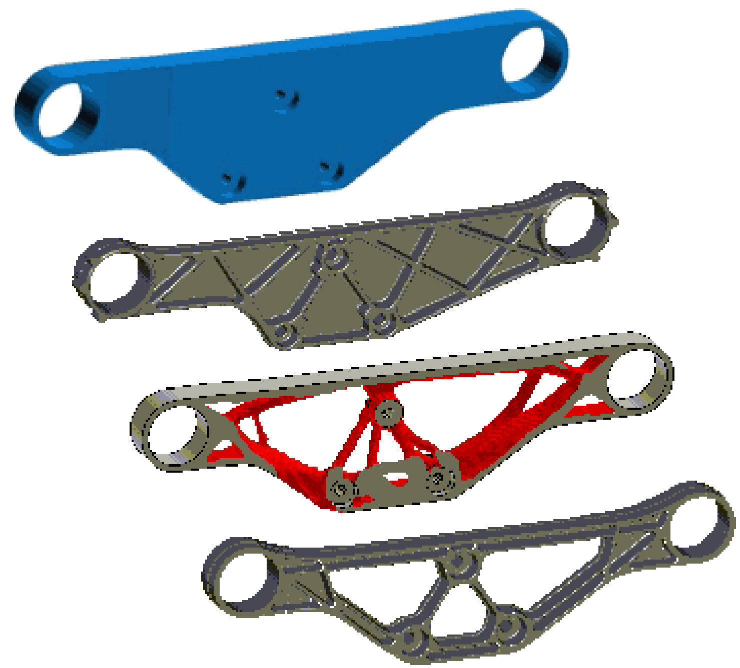


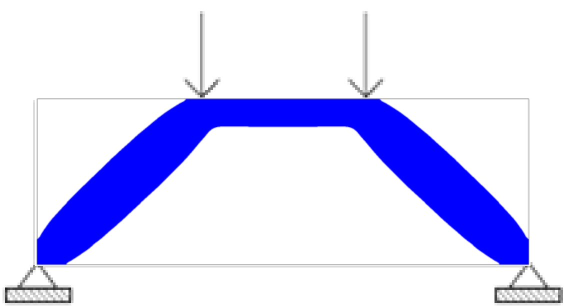



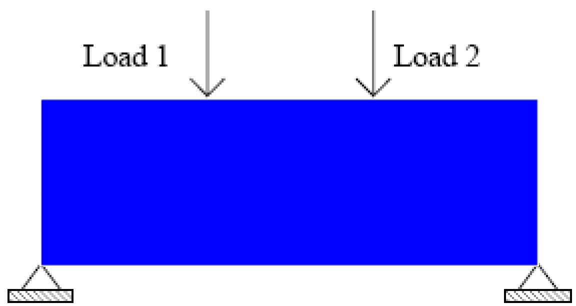
# Linear Static Problem (2)

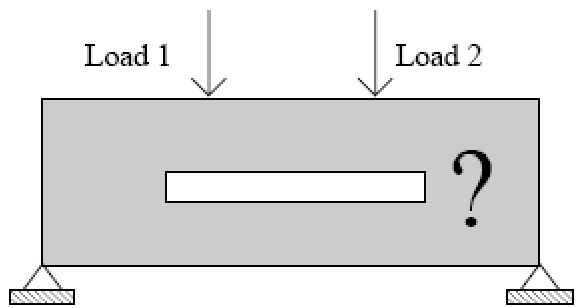
- **Solid Mechanics: Load Path**





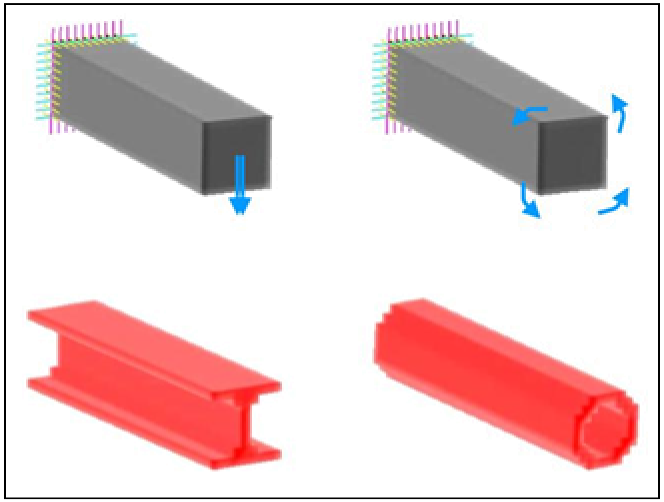


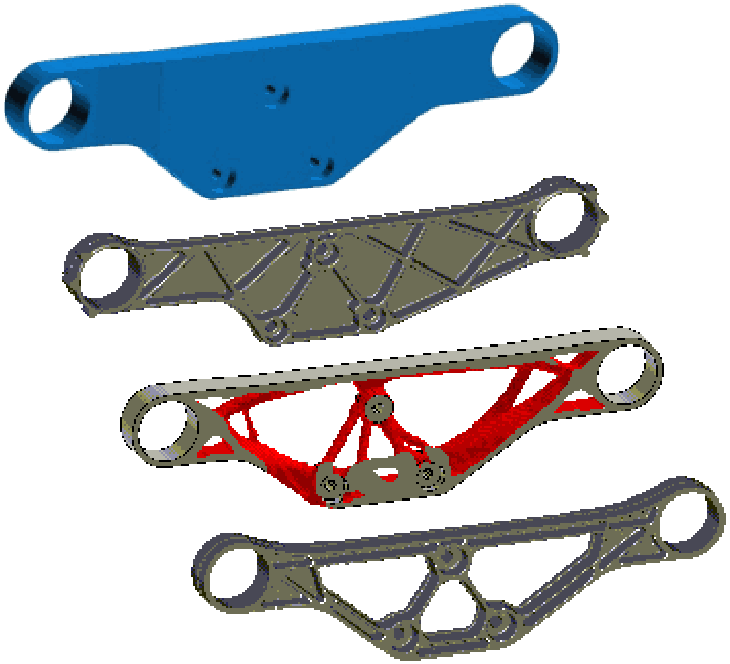


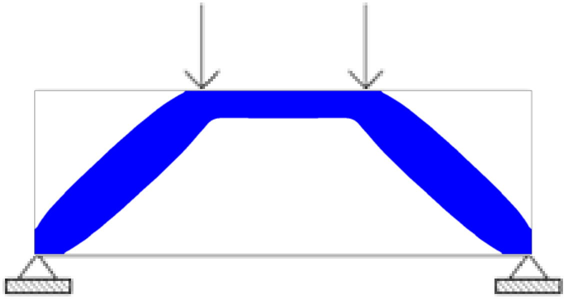



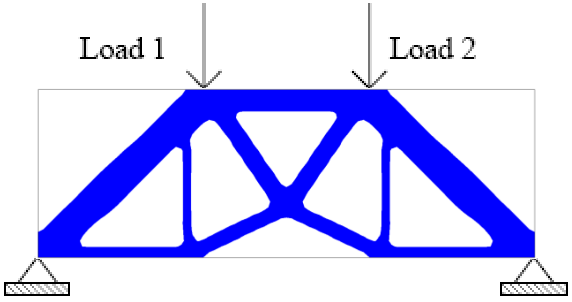
# Linear Static Problem (3)

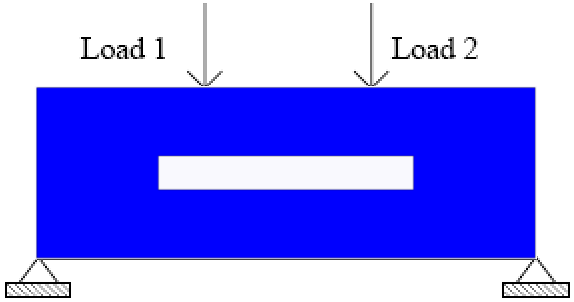
## Solid Mechanics: Load Path



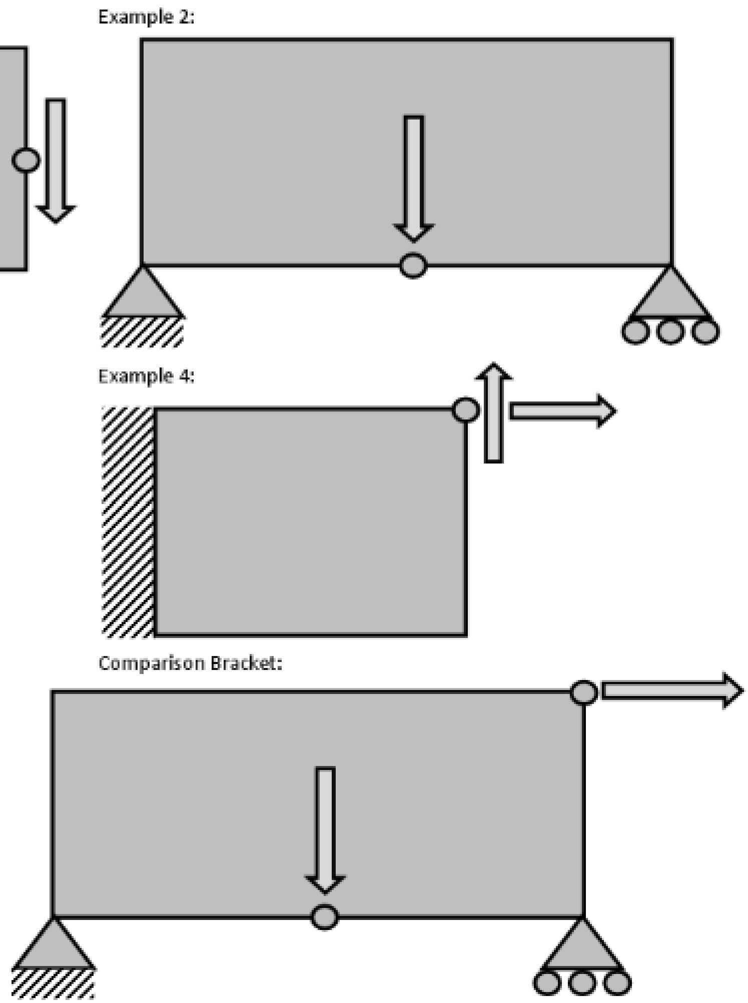






# Test Your Intuition



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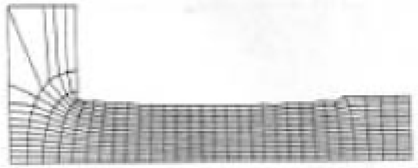
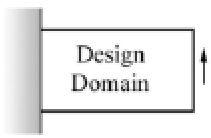
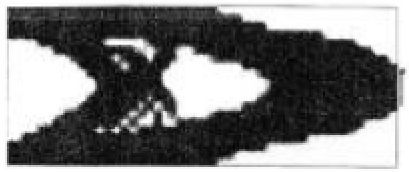
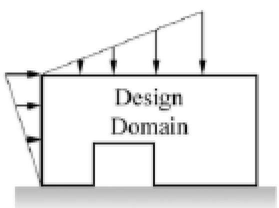
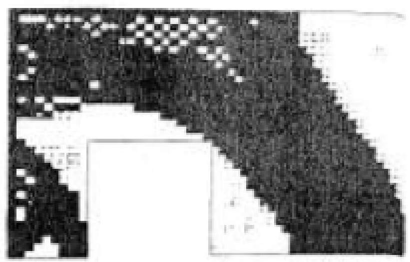
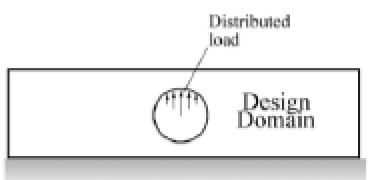
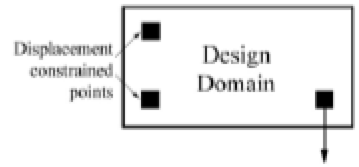
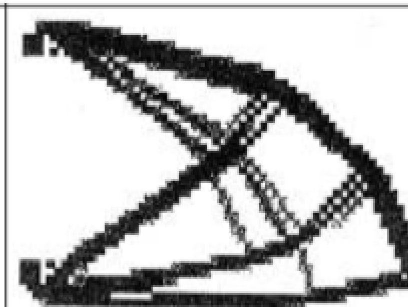
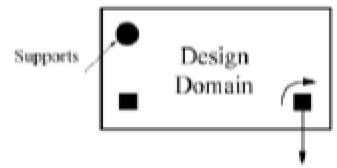
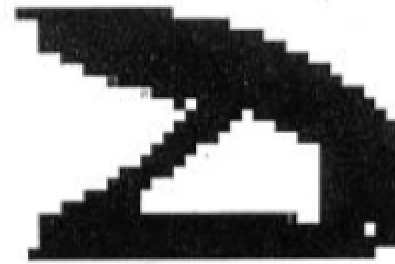
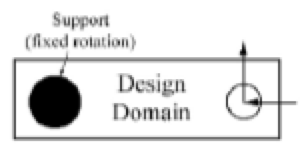
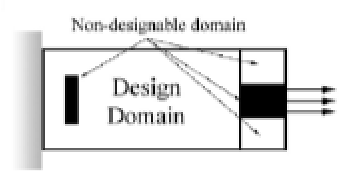
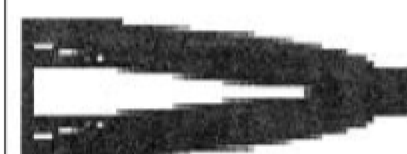
| 1 |   |  Bendsøe and Rodrigues (1991) |
| 2 |   |  Bendsøe and Rodrigues (1991) |
| 3 |   |  Bendsøe and Rodrigues (1991) |
| 4 |   |  Olhoff *et al.* (1991) |
| 5 |   |  Bremicker *et al.* (1991) |
| 6 |   |  Bremicker *et al.* (1991) |
| 7 |   |  Bremicker *et al.* (1991) |
| 8 |   |  Chirehdast *et al.* (1994) |

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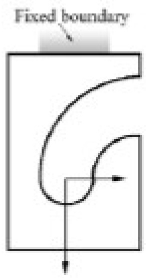
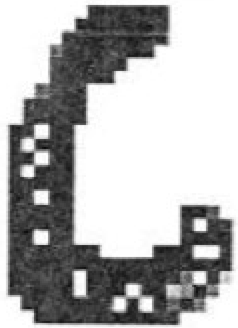
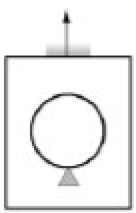
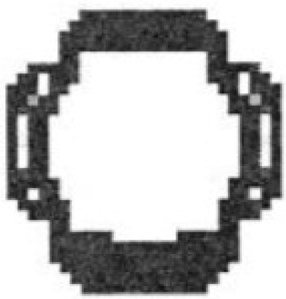
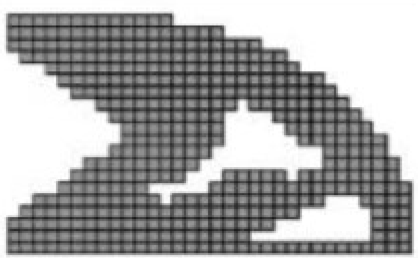
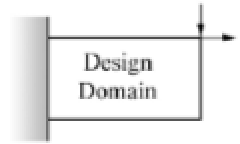
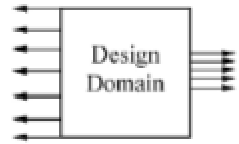
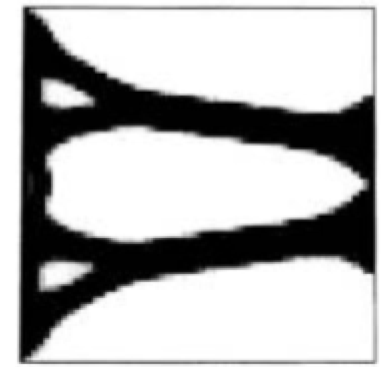
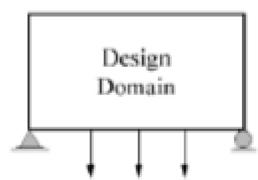
| 9 |  |  Chirehdast *et al*. (1994) |
| 10 |  |  Chirehdast *et al*. (1994) |
| 11 |  |  Tang and Chang (2001) |
| 12 |  |  Youn and Park (1997) |
| 13 |  |  Youn and Park (1997) |
| 14 |  |  Youn and Park (1997) |

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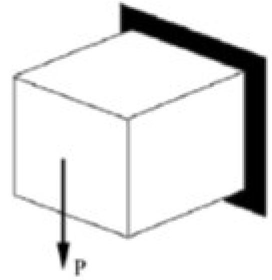
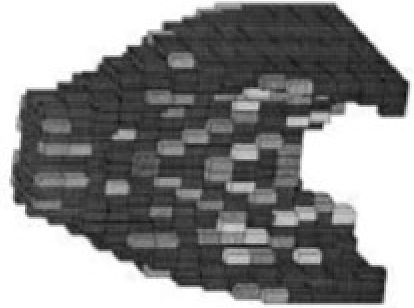
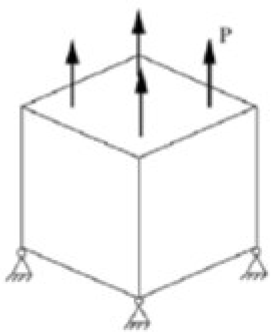
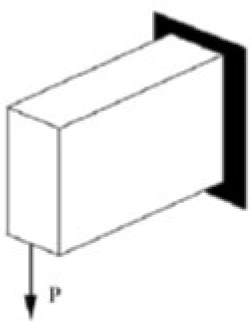
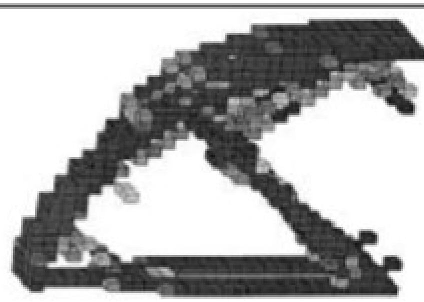
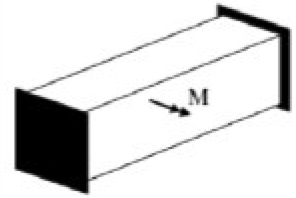
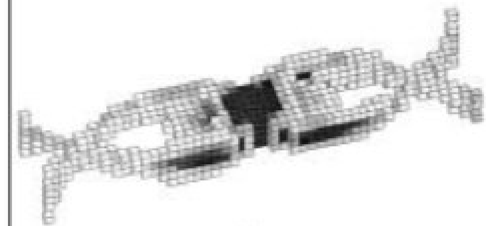
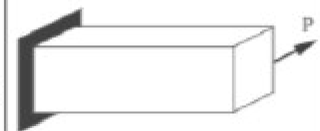
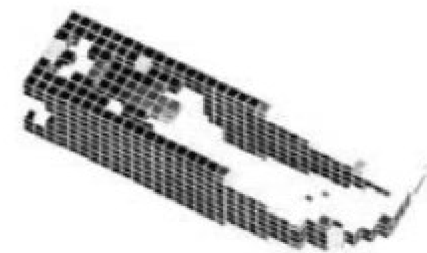
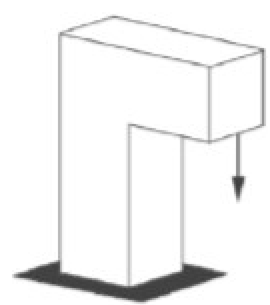
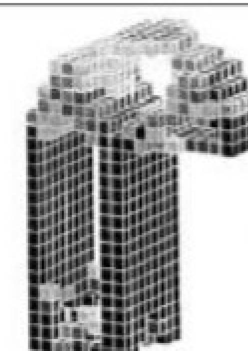
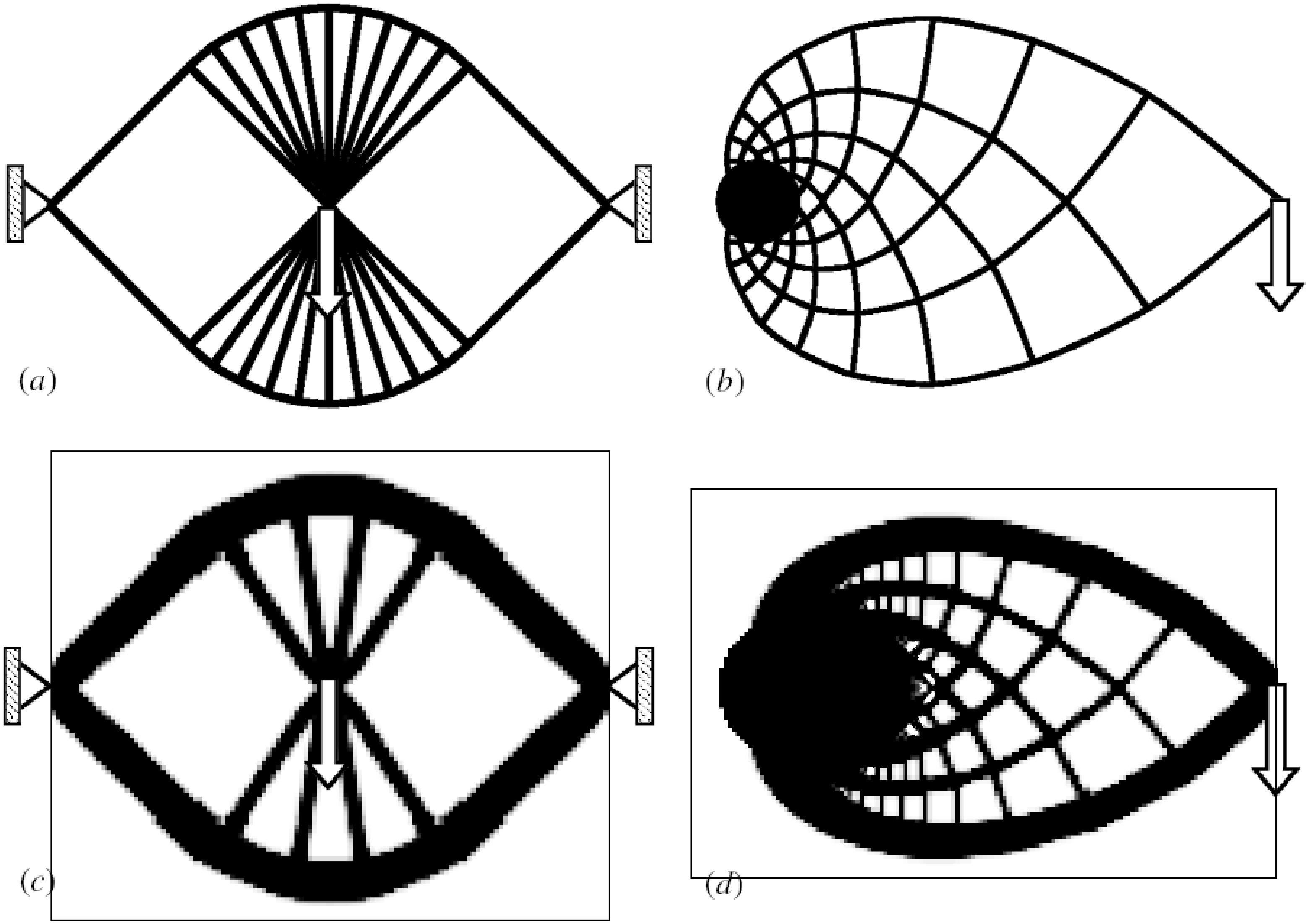
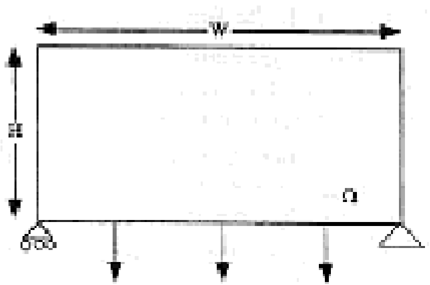
| 1 |  |  Olhoff *et al.* (1998), Jacobsen *et al.* (1998), Beckers (1999) |
| 2 |  |  Olhoff *et al.* (1998), Jacobsen *et al.* (1998) |
| 3 |  |  Olhoff *et al.* (1998), Jacobsen *et al.* (1998) |
| 4 |  |  Olhoff *et al.* (1998), Jacobsen *et al.* (1998), Beckers (1999) |
| 5 |  |  Díaz and Lipton (1997) |
| 6 |  |  Díaz and Lipton (1997) |

# Optimal Michell Type Structures

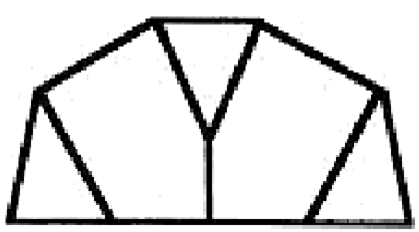


# Design Tool

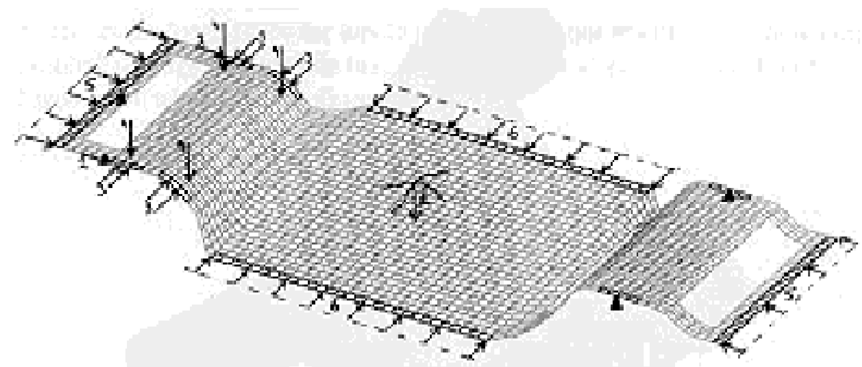
**Conceptual Design**



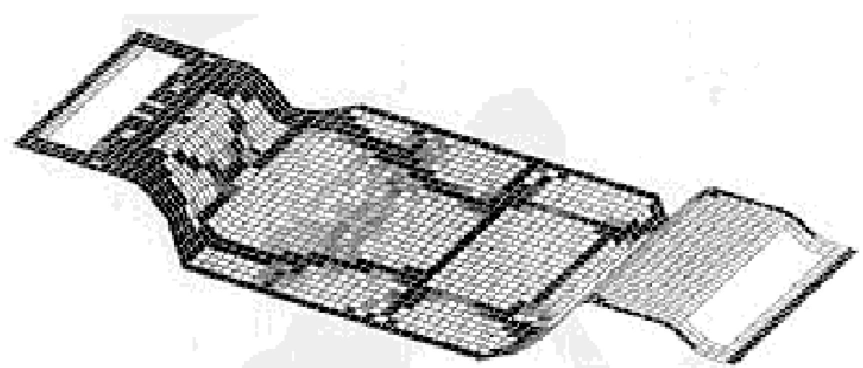

bridge design



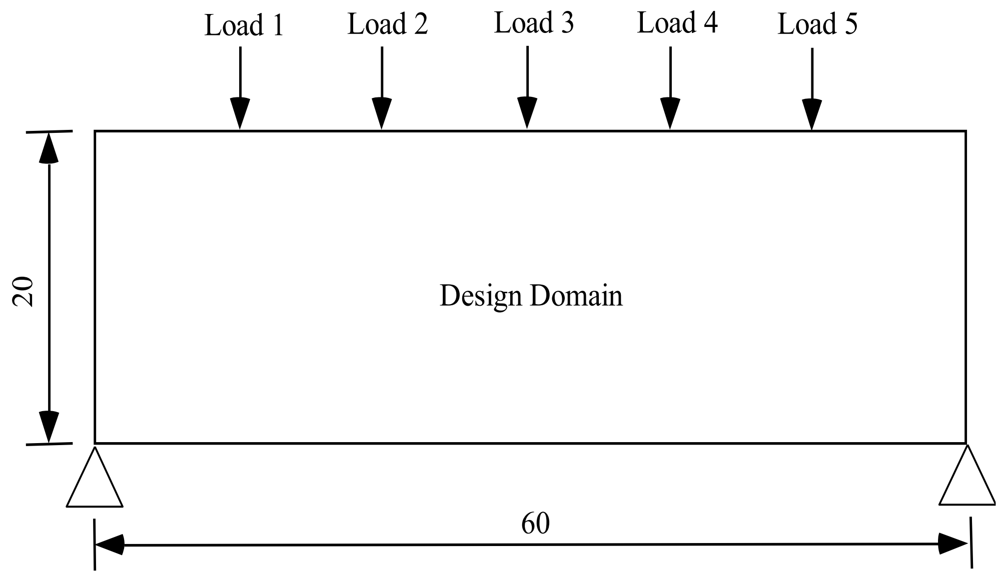
**Reinforcement Design**

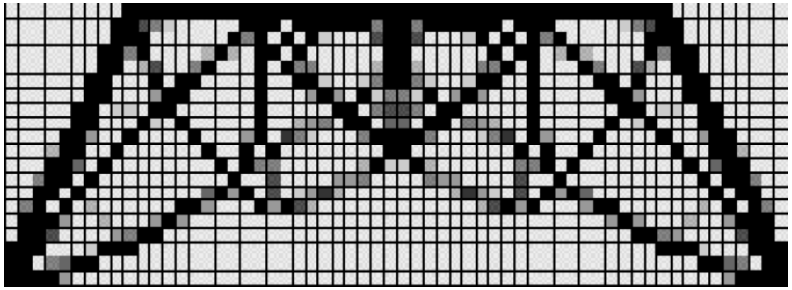


floor panel reinforcement

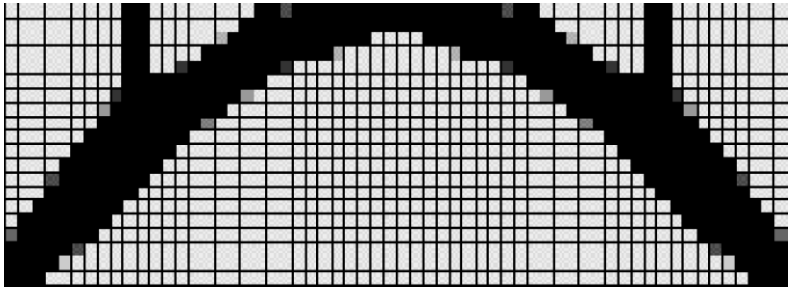


# Bridge Structure



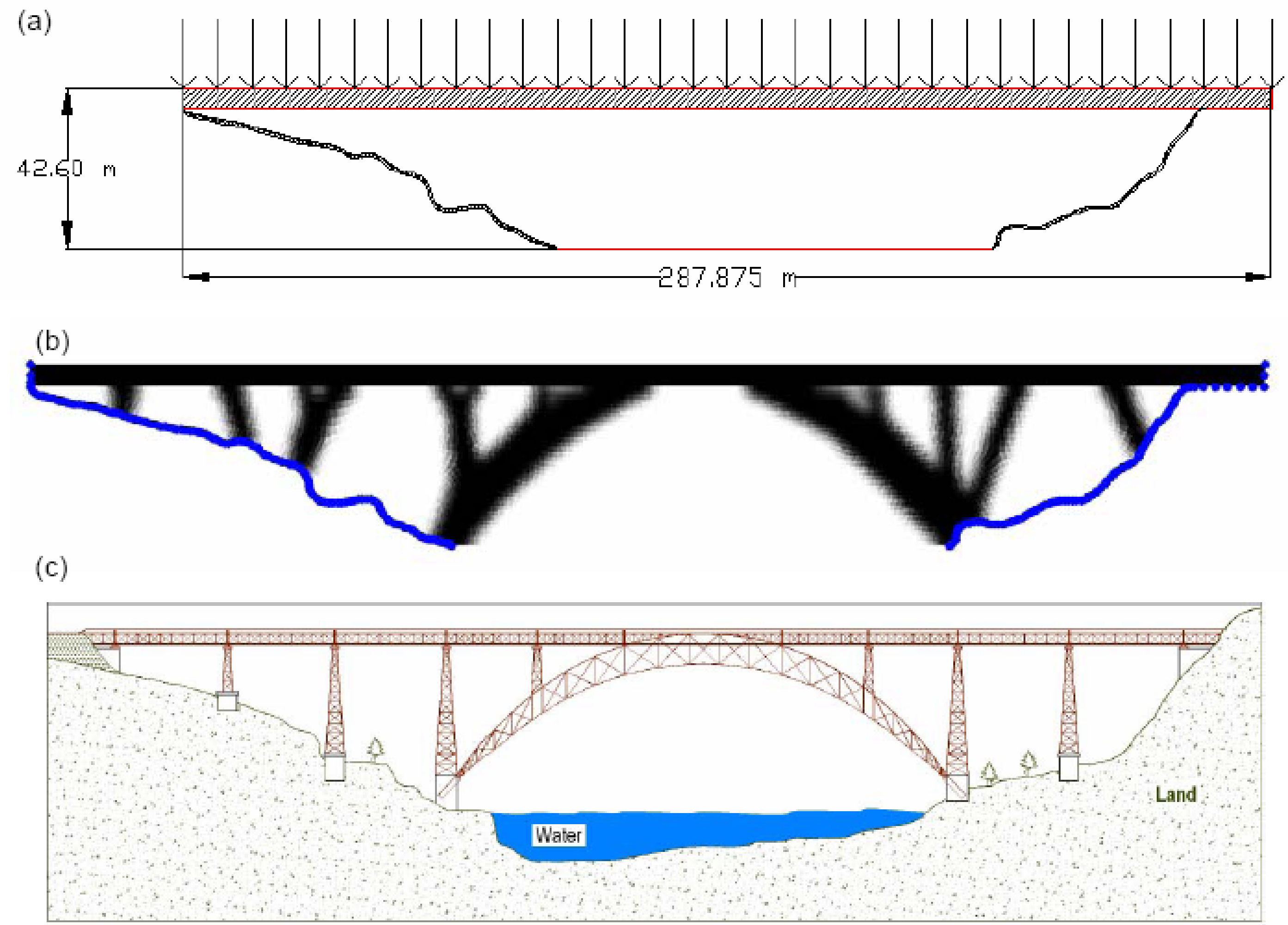



Multiple loadings



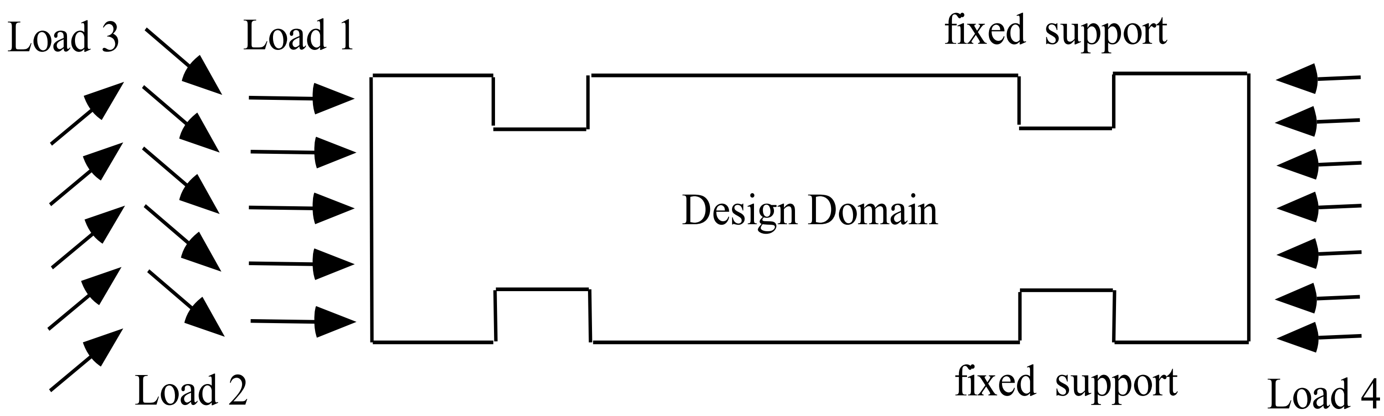
Single loading

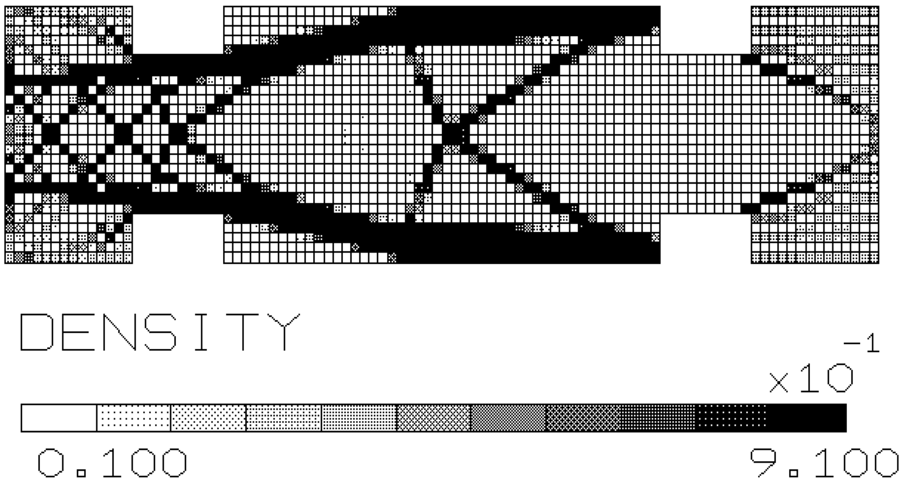
# Bridge



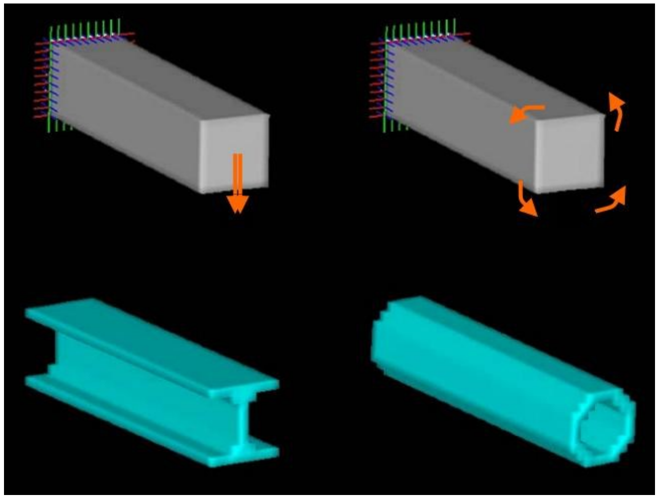

Maria Pia bridge

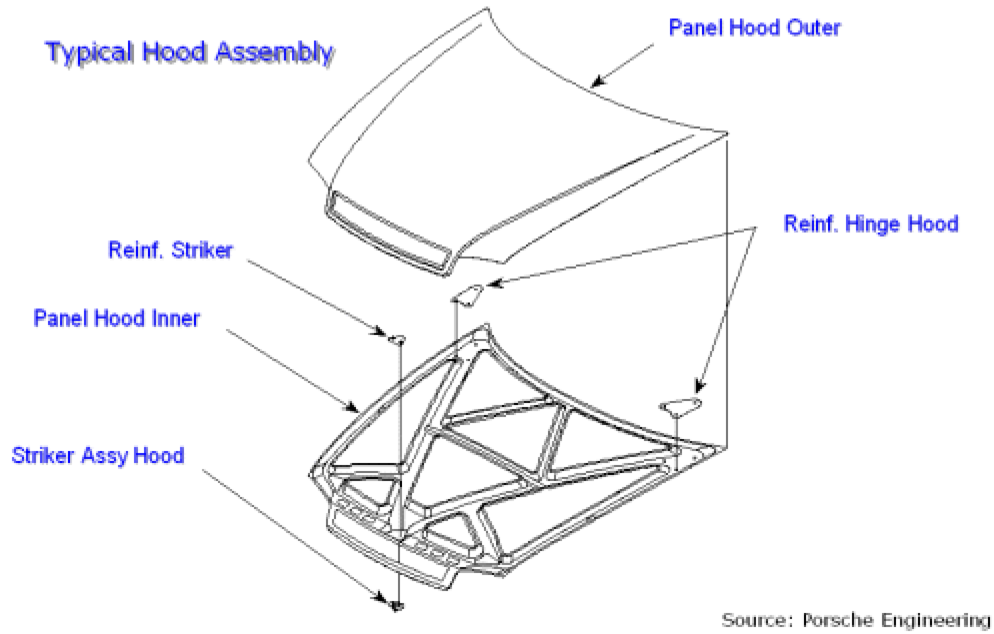
# Floor Panel Reinforcement

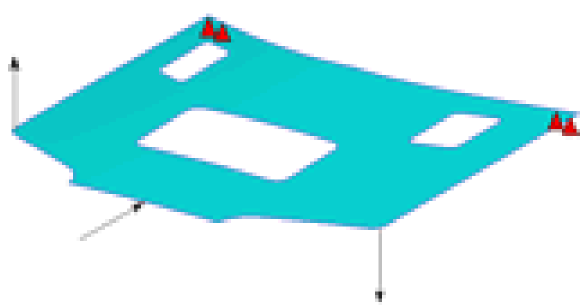


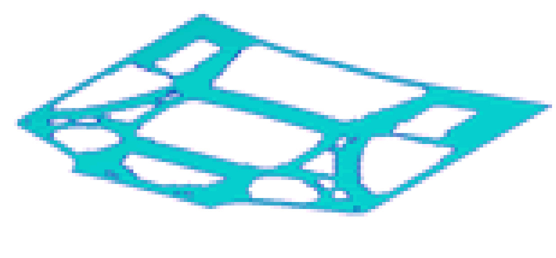



# Hood Panel Reinforcement



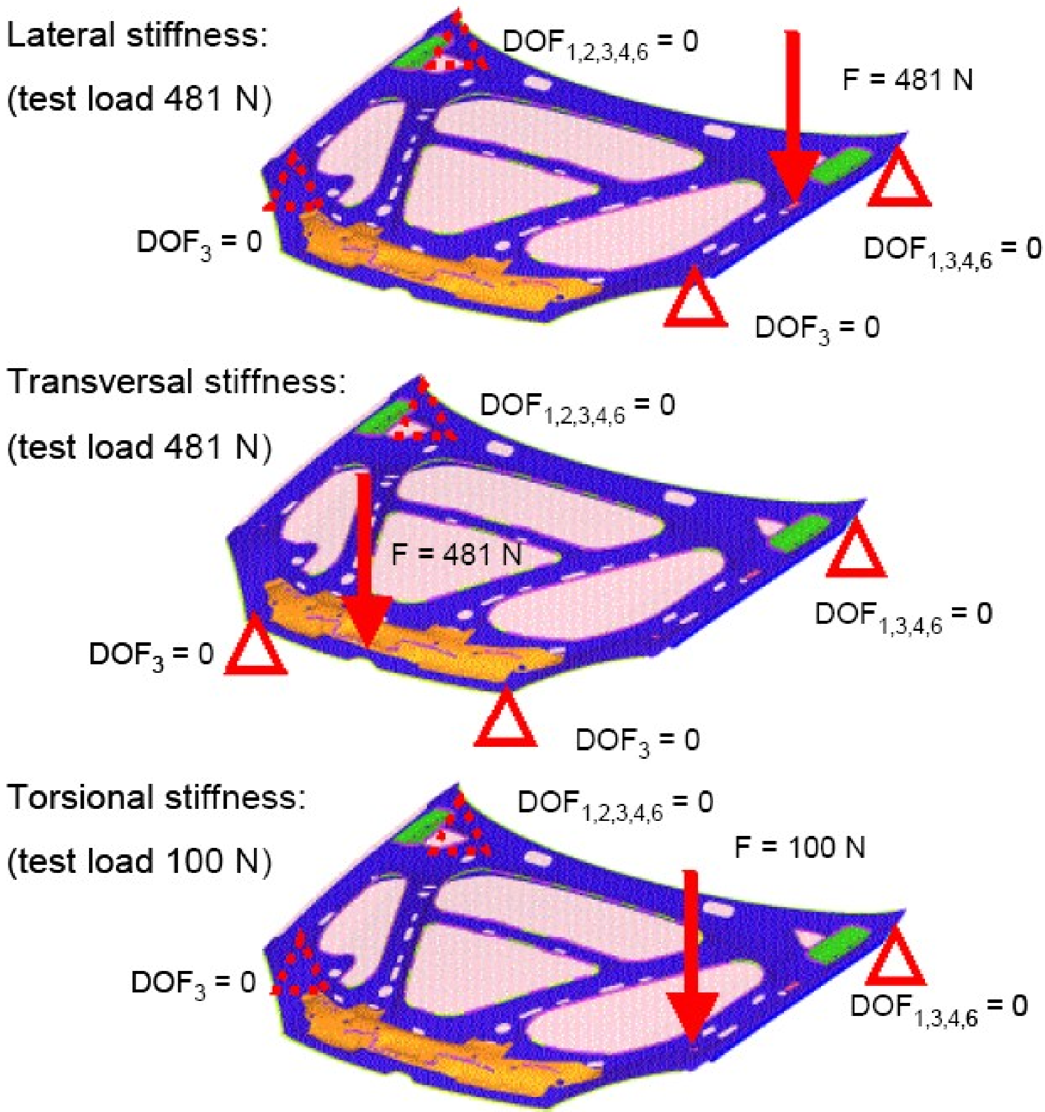


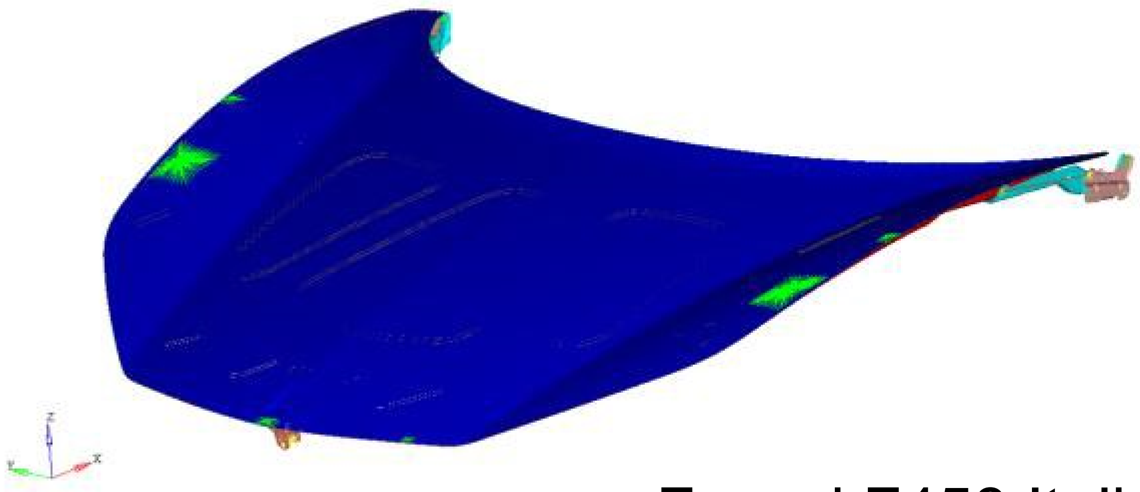


# Load Cases for Hoods

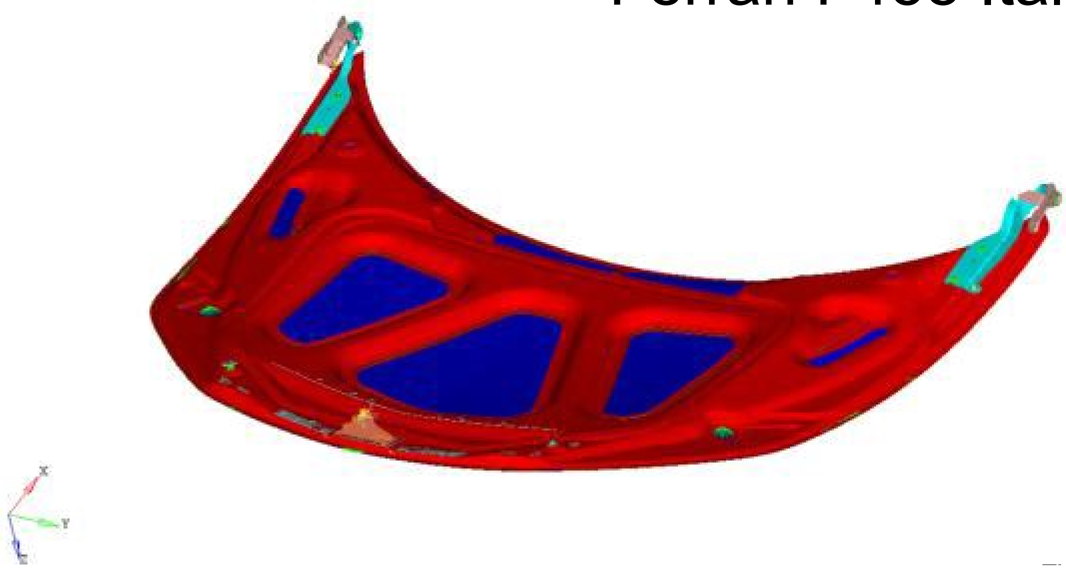
- Steel
  - 12.62 kg
  - 8.89 euro
- Aluminum
  - 8.10 kg (36% reduction)
  - 16.63 euro (87% increase)



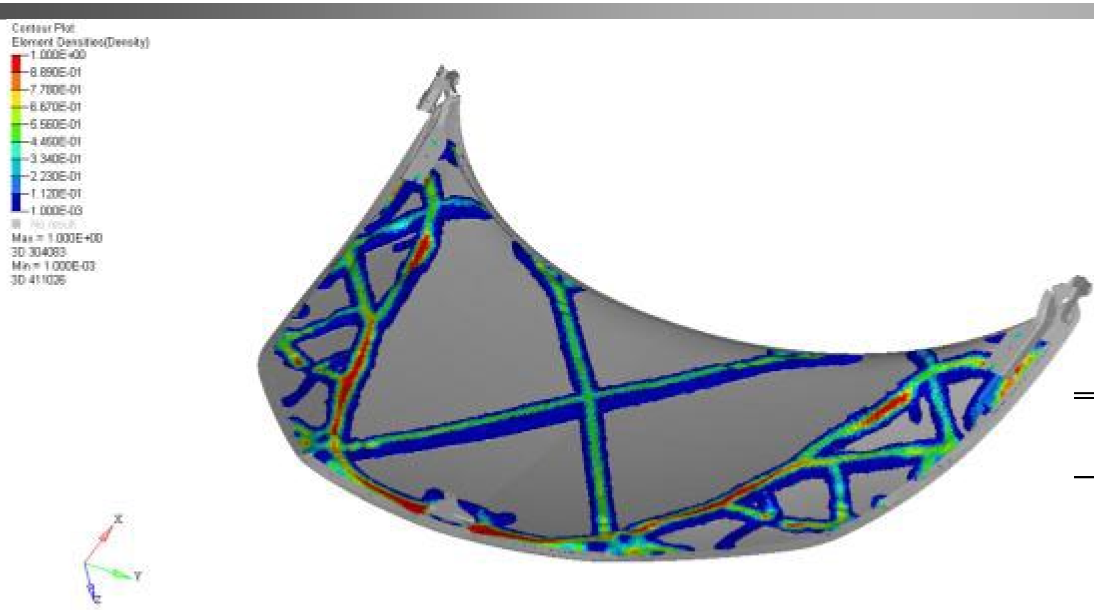
# Automotive Hood Substructure (Inner Panel)



Ferrari F458 Italia front hood



# Results

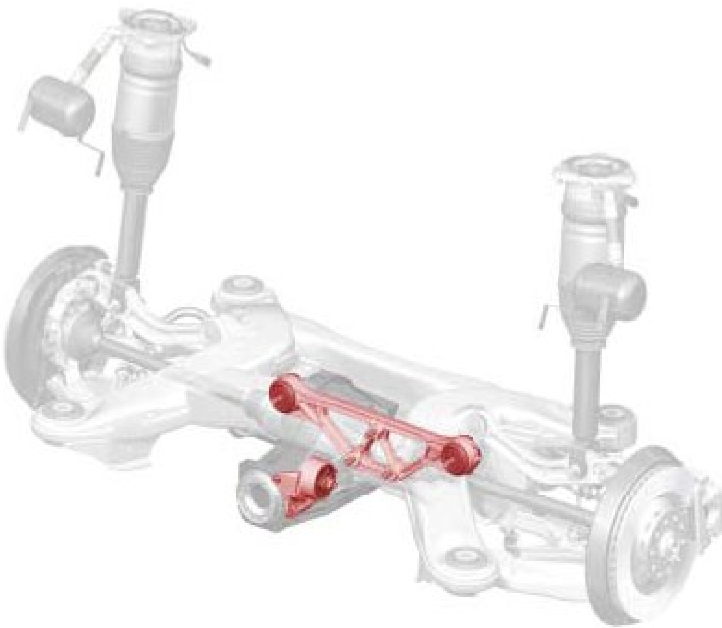


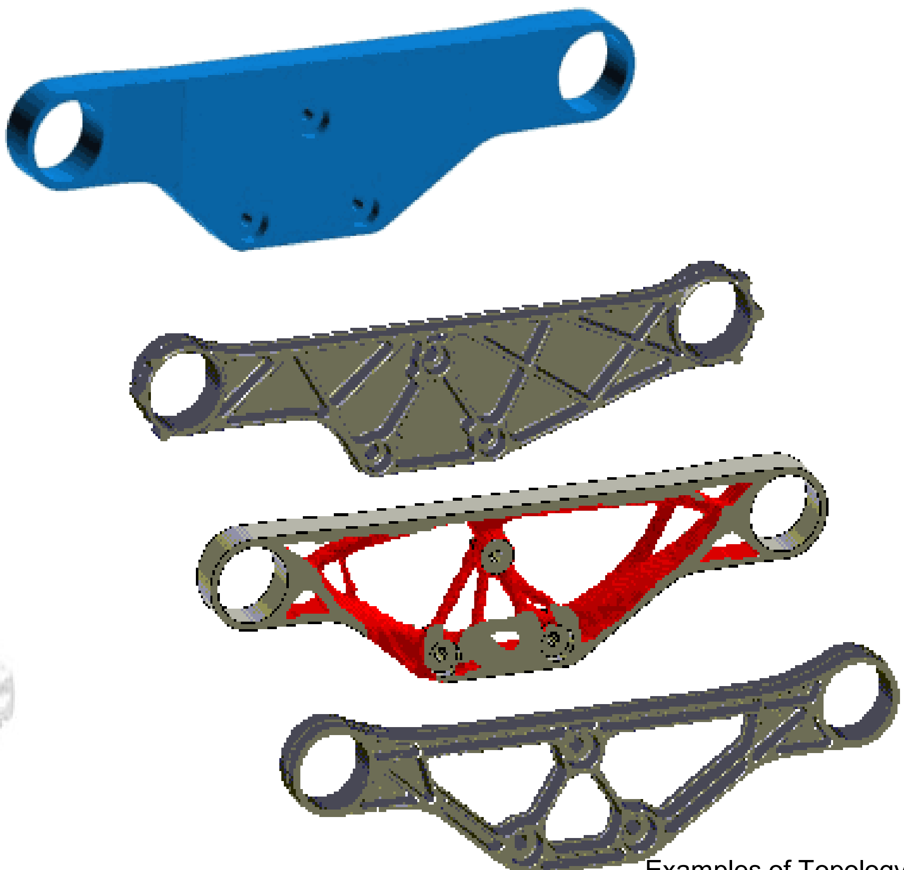

STIFFNESS OF THE MODEL IN EACH LOADCASE

| Loadstep | Initial Model[a] | Final Model[a] |
|---|---|---|
| Torsion | 100.00% | 99.78% |
| Bending | 100.00% | 102.45% |
| Flap's Bending | 100.00% | 101.21% |
| Closure hand STD | 100.00% | 101.23% |
| Closure hand Central | 100.00% | 105.47% |
| Closure hand Lateral | 100.00% | 110.88% |
| **Total Mass** | **100.00%** | **87.56%** |

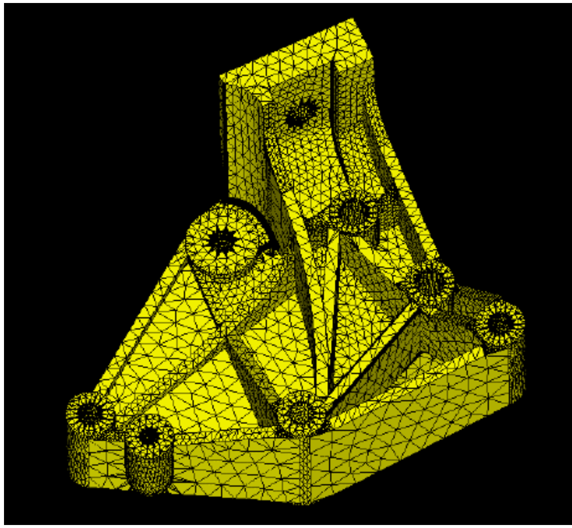
# Transverse Link of Audi A8

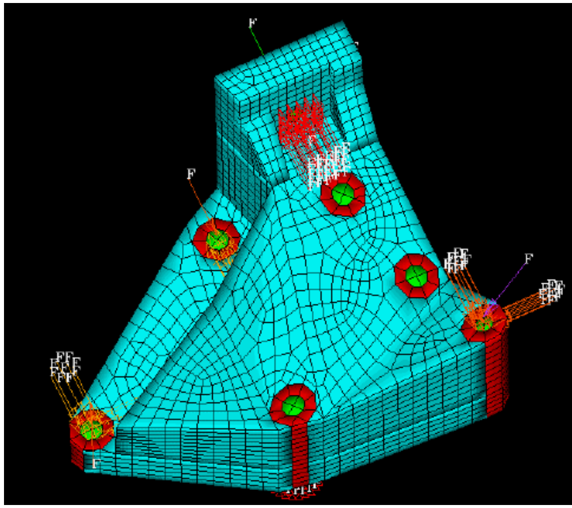
- 45% stress reduction
- 10% weight reduction
- 1$^{st}$ prototype passed all mechanical tests !





# Engine Mounting Bracket (1)

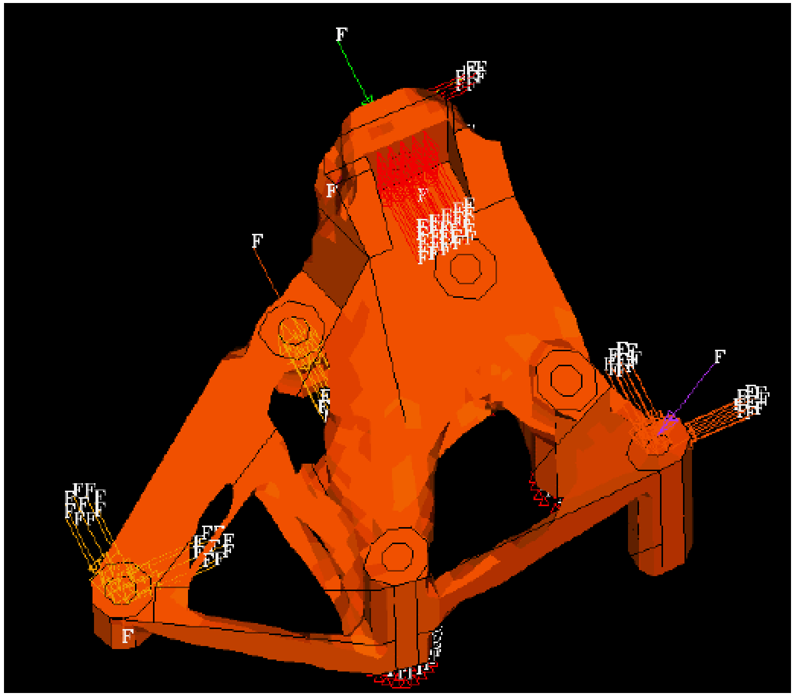


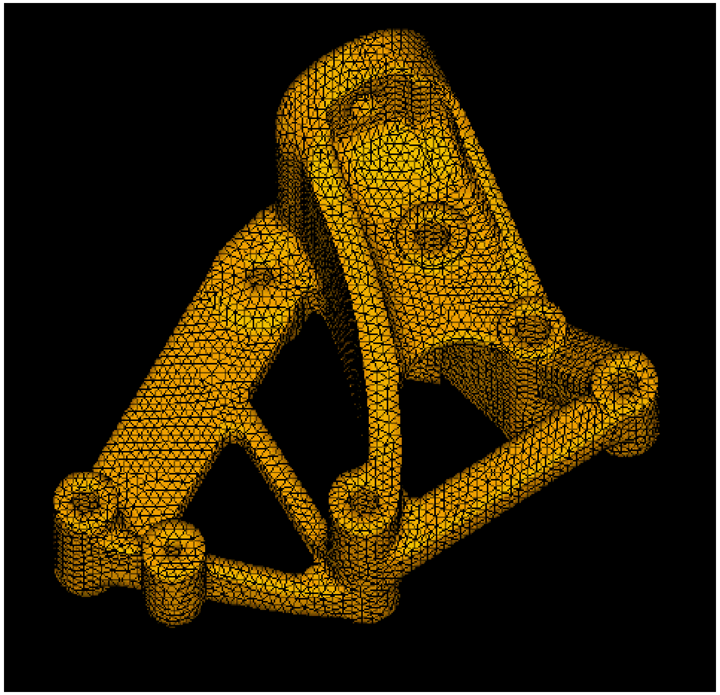


- Minimize mass of engine bracket
  - Subject to stiffness/frequency constraint
- (a) Initial mass = 950 g
- (b) 20,000 solid elements, 30% material
  - Bolted joints: non-design domain
  - Loading conditions
    - Drive-off forward
    - Drive-off backwards
    - Driving into a pot hole
    - Driving out of a pot hole
    - Transmission loads
    - Assembly

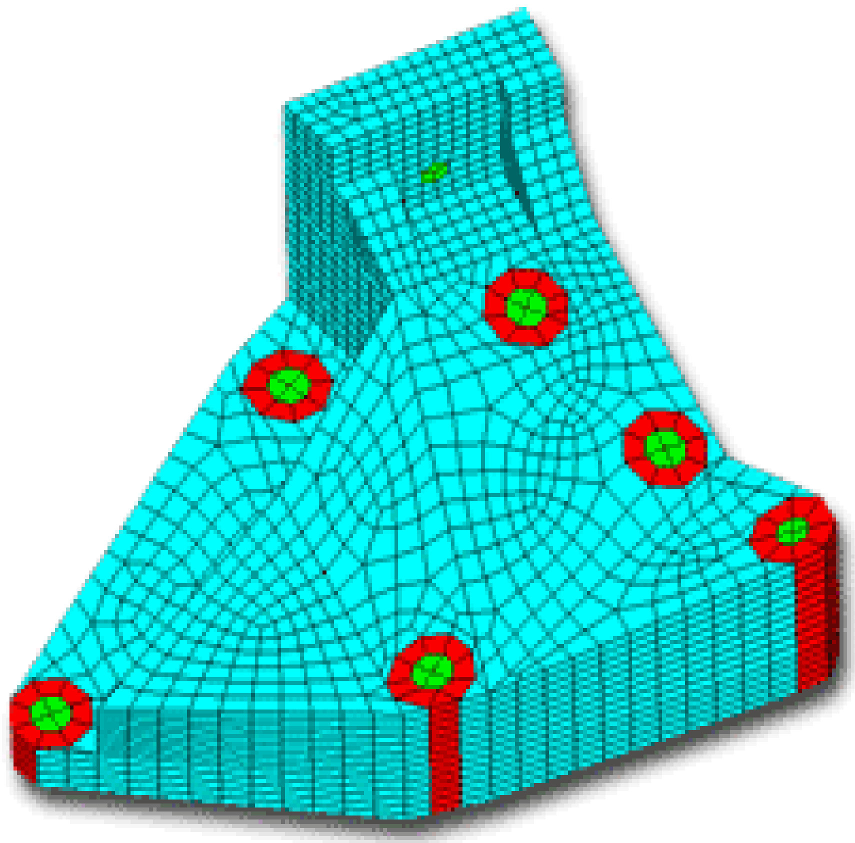
# Engine Mounting Bracket (2)

- (c) 3D features of the optimal configuration
- (d) isodensity surface (density > 0.4)
  - Starting point for developing a production-ready engine bracket
- (e) shape optimization, final mass = 730 g (23%↓)





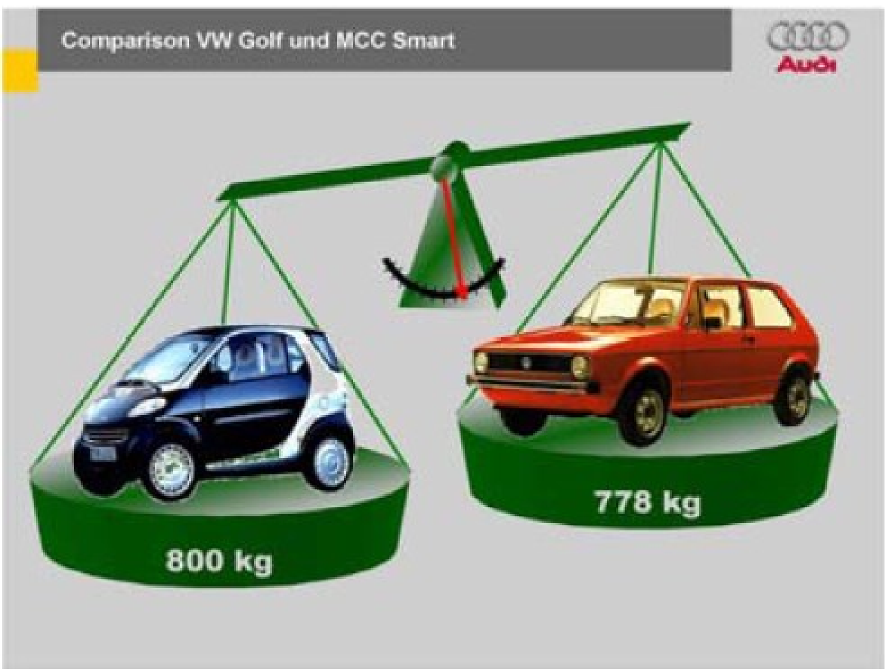
# Engine Mounting Bracket (3)

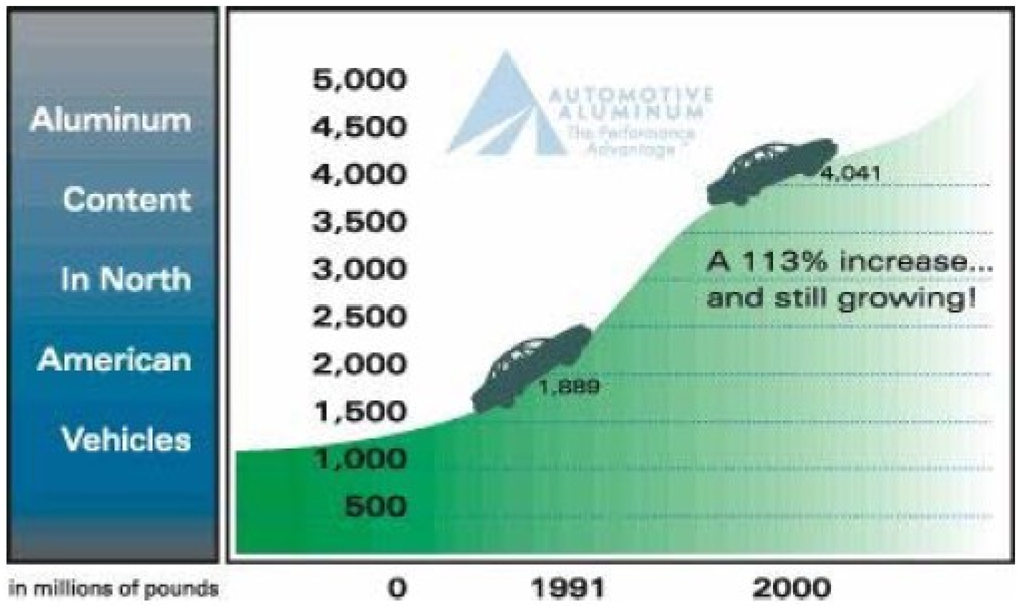


Courtesy of Volkswagen AG, Wolfsburg via Altair Engineering

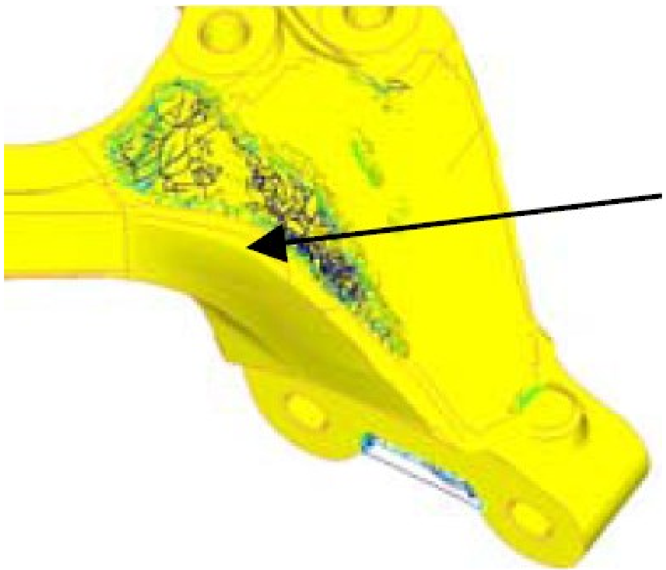
# Vehicle Weight Trend

- VW GTI: 1804 lb (1976) → 2939 lb (2004)
- Aluminum casting component: 92.3 lb (1978) → 240 lb (2002)

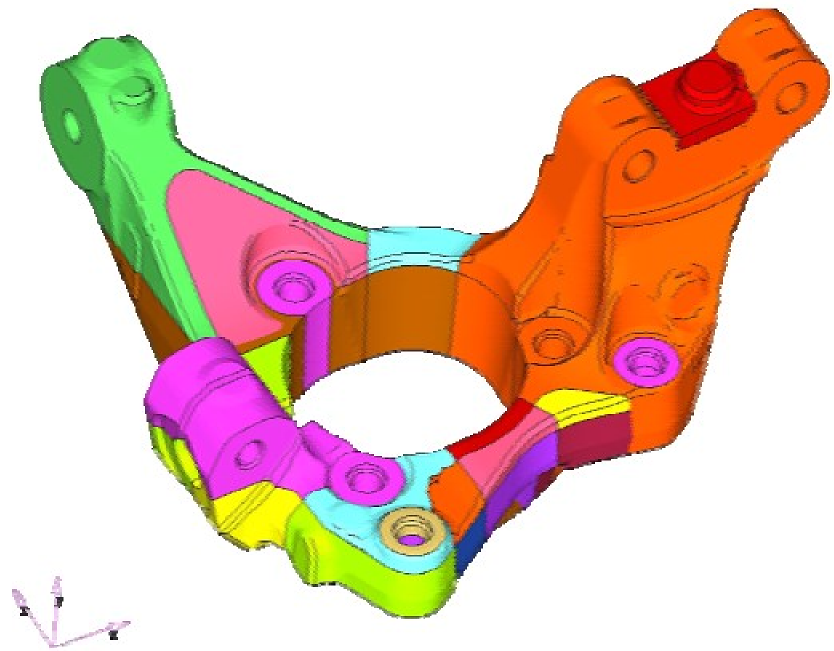


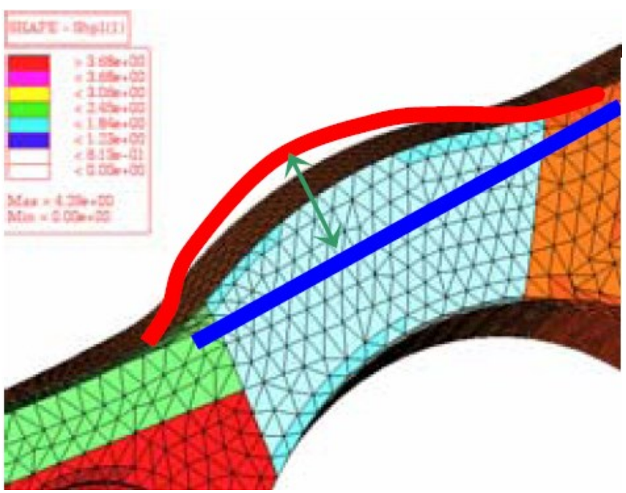



# Aluminum Front Knuckle Design (1)



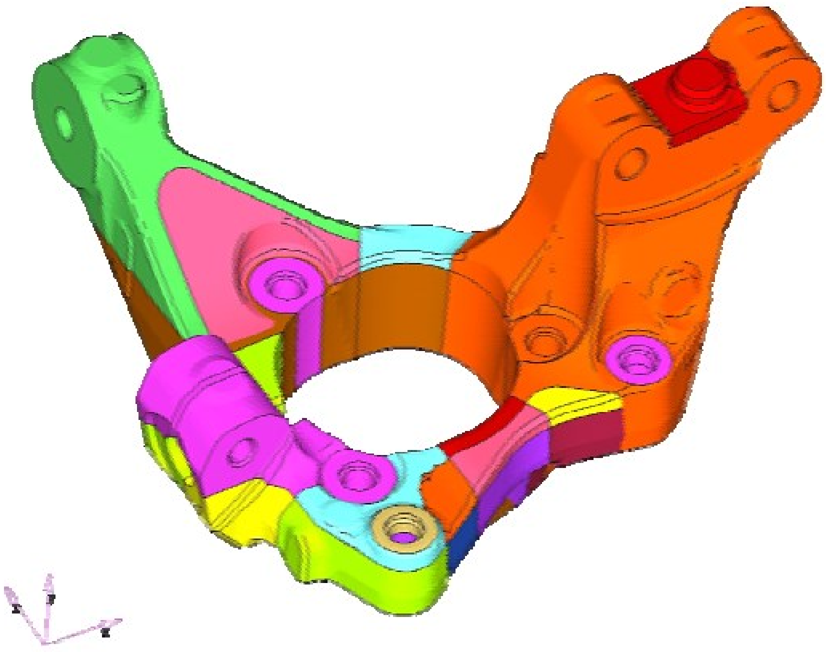
Example of results in a topology optimization zone

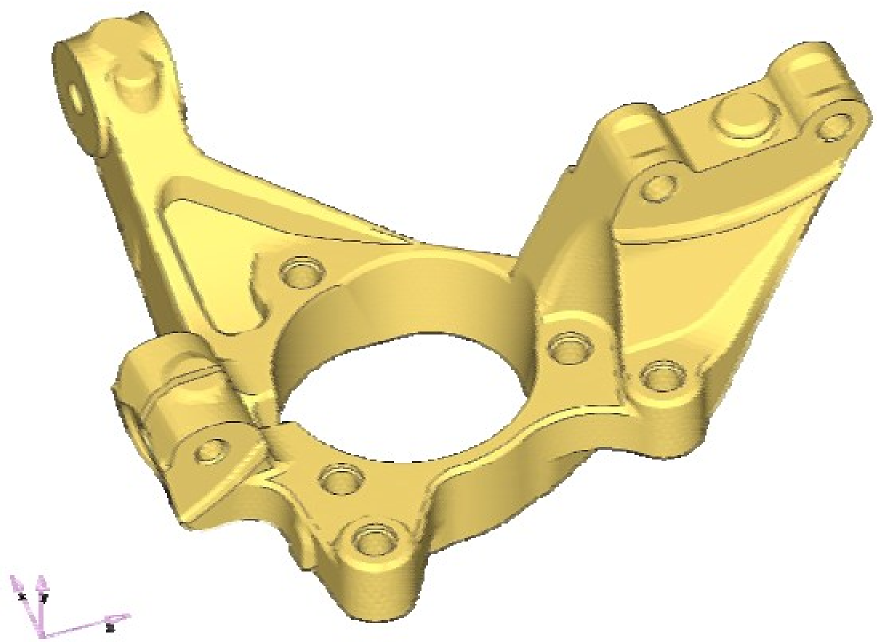




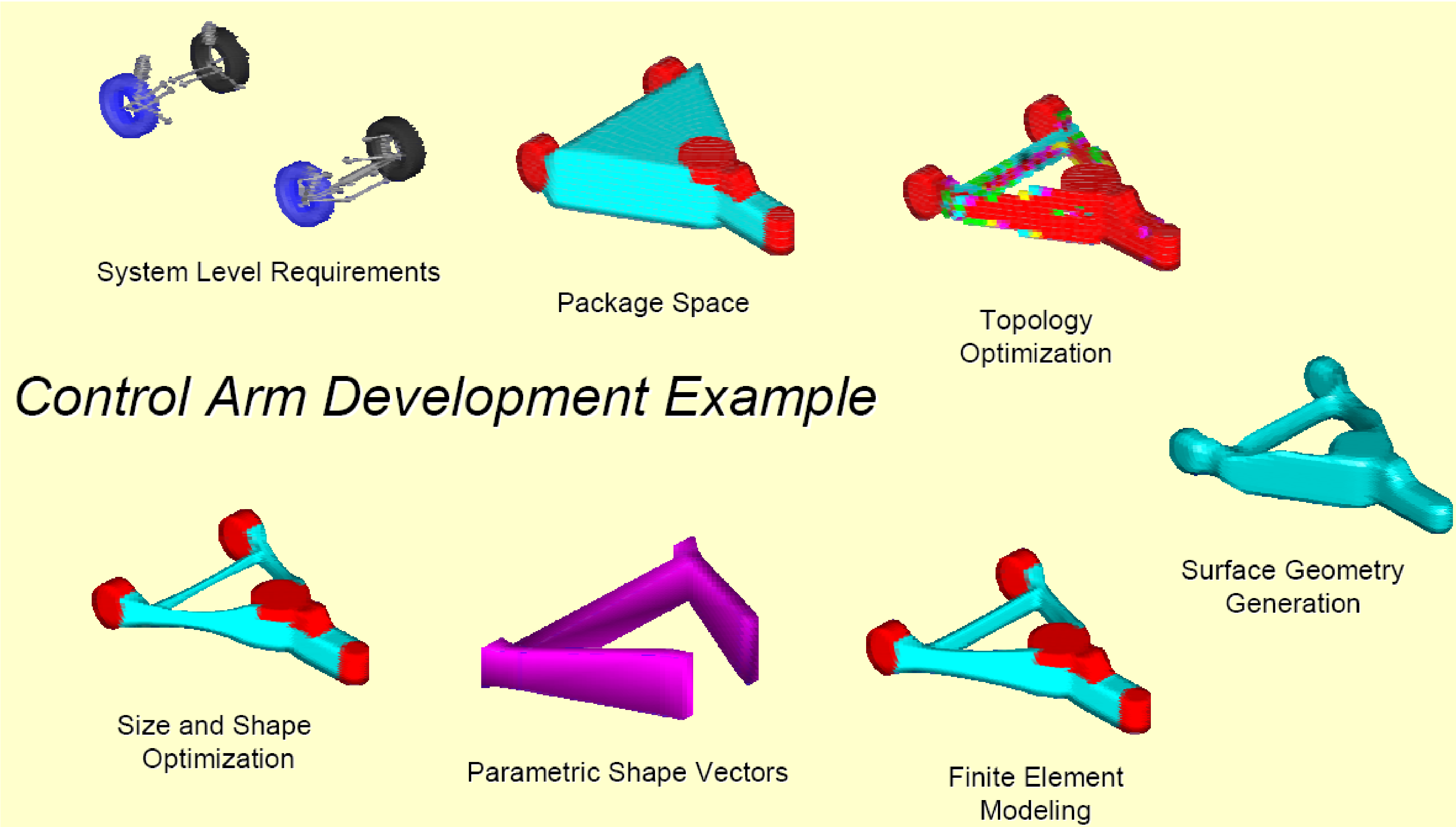
Example of a shape optimization zone: shape function allows FE mesh to “morph” between red and blue lines

# Aluminum Front Knuckle Design (2)

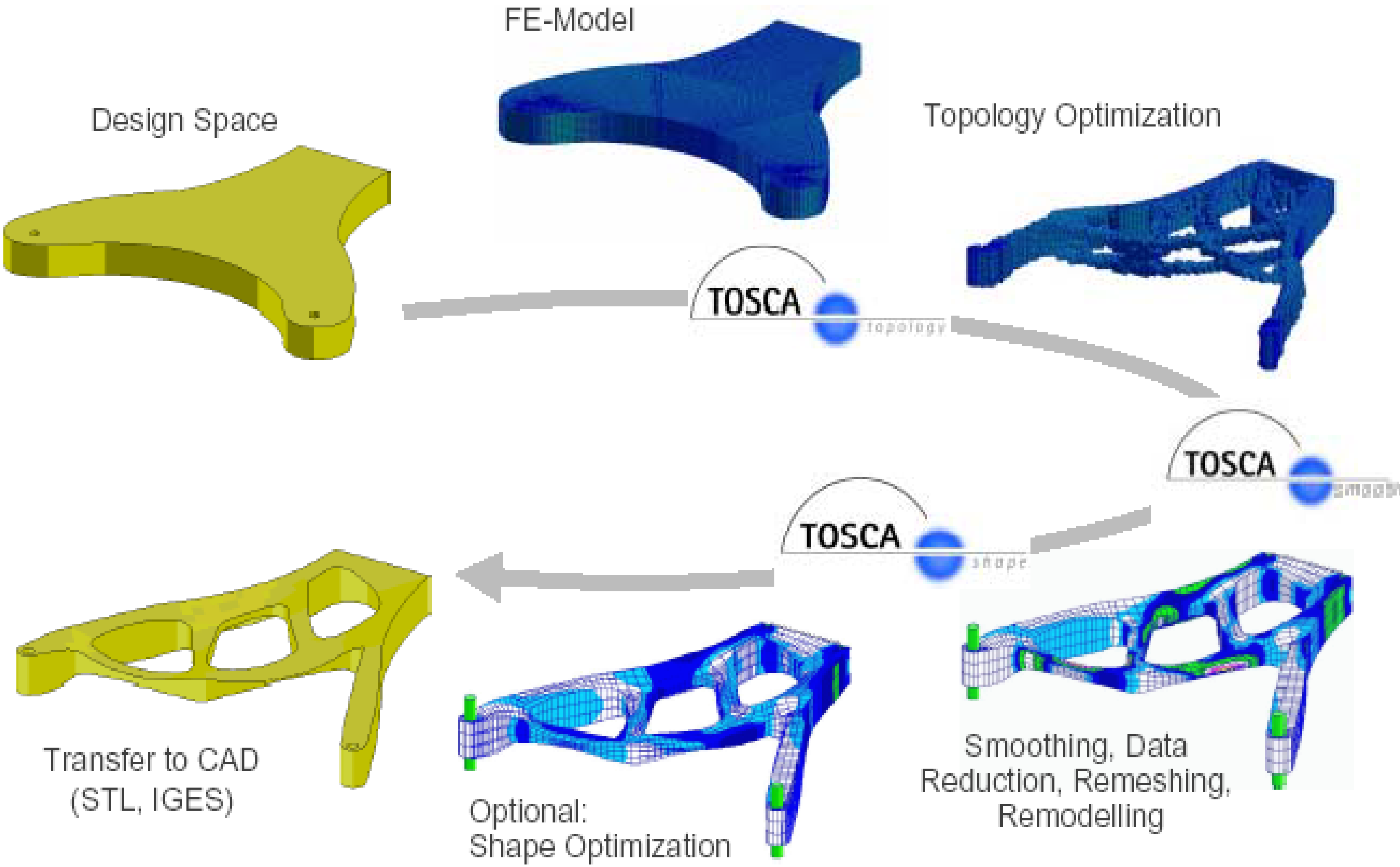




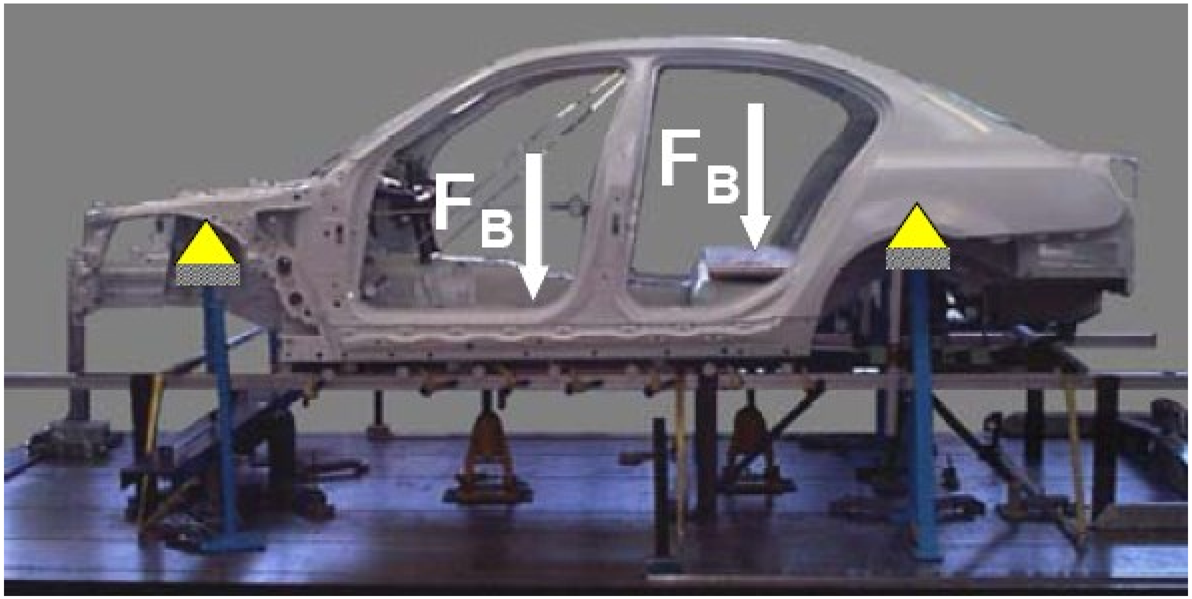
# Concept Design Environment

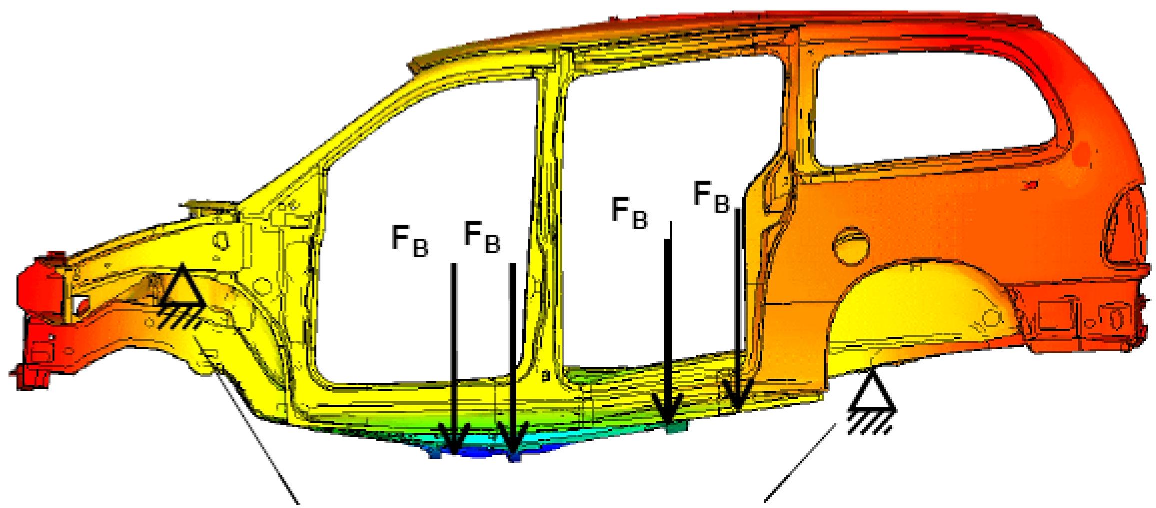


# Integrated Topology and Shape Optimization into Product Development Process



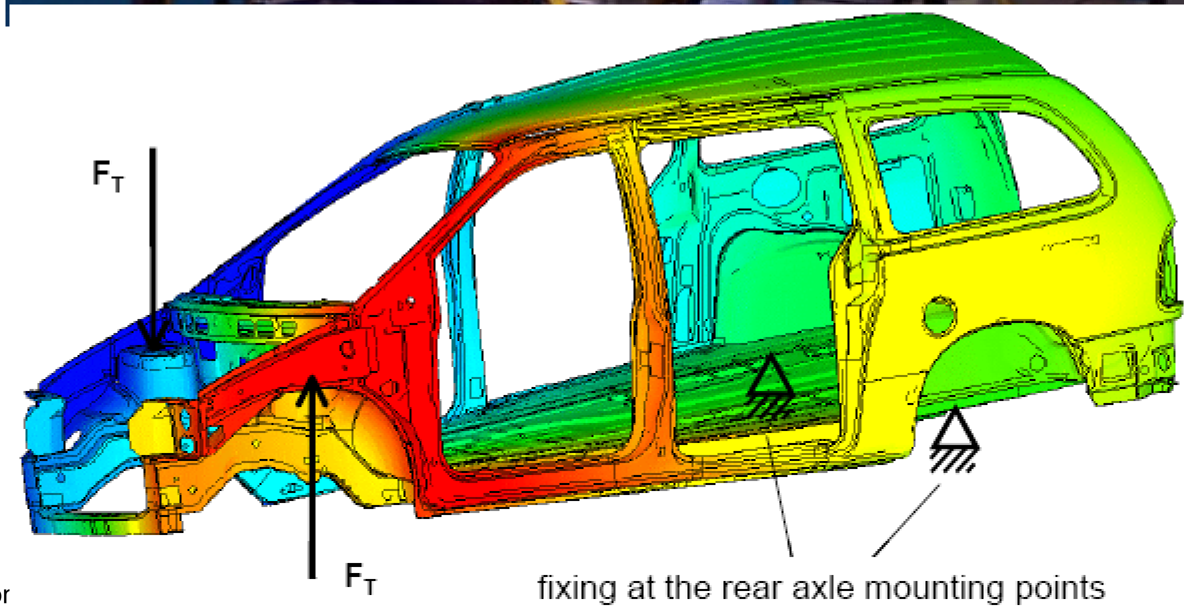
# Bending Test



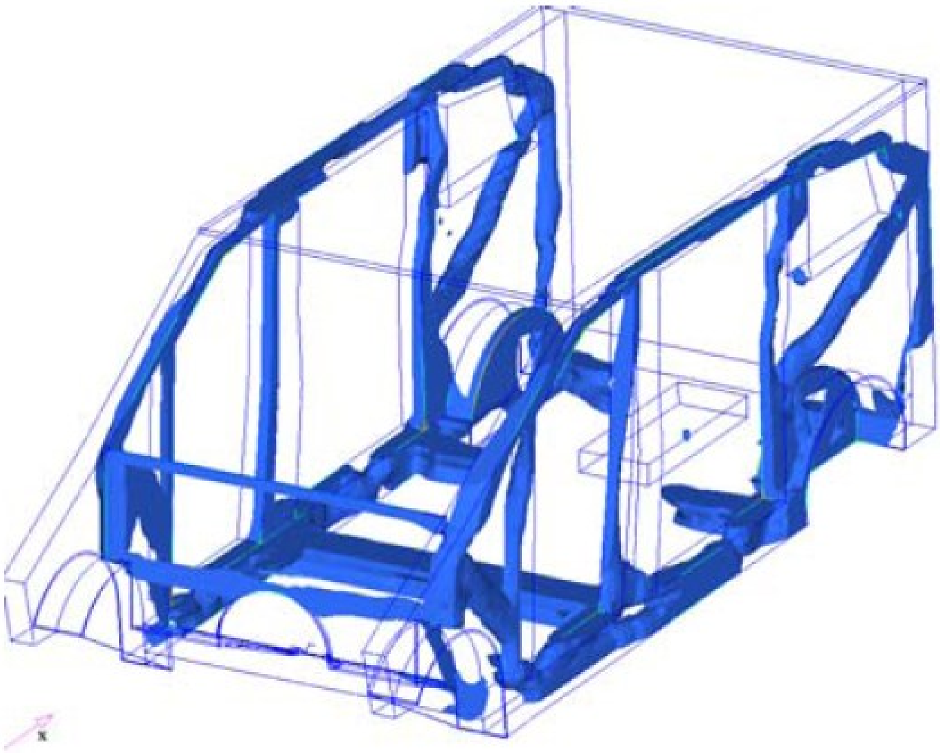

fixing at the axle mounting points

# Torsional Test

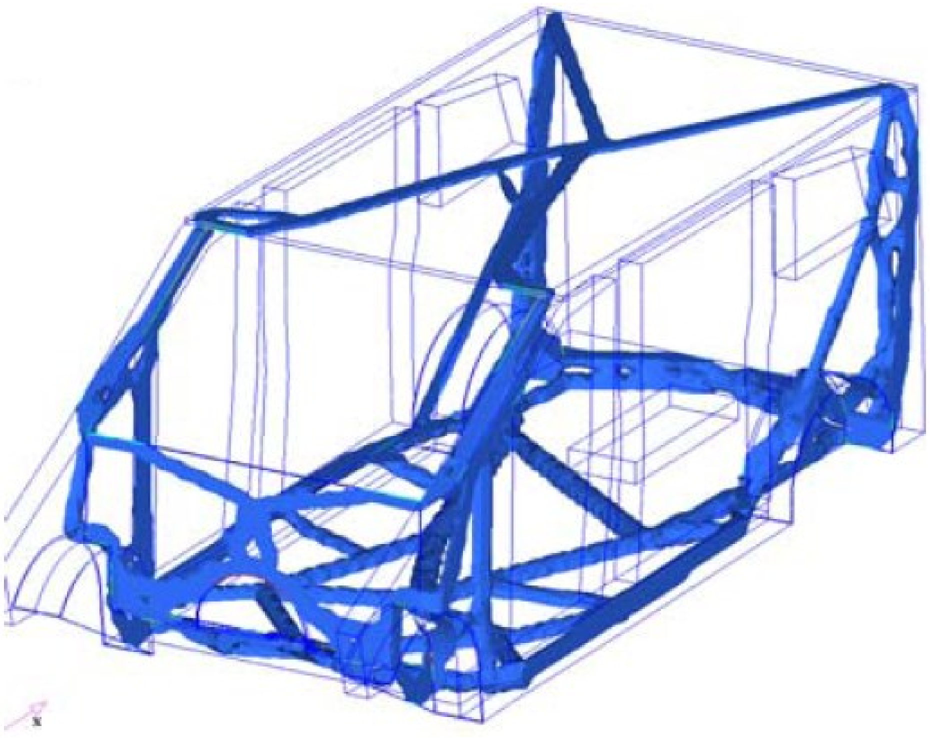



# Result of Topology Optimization (1)

- Bending

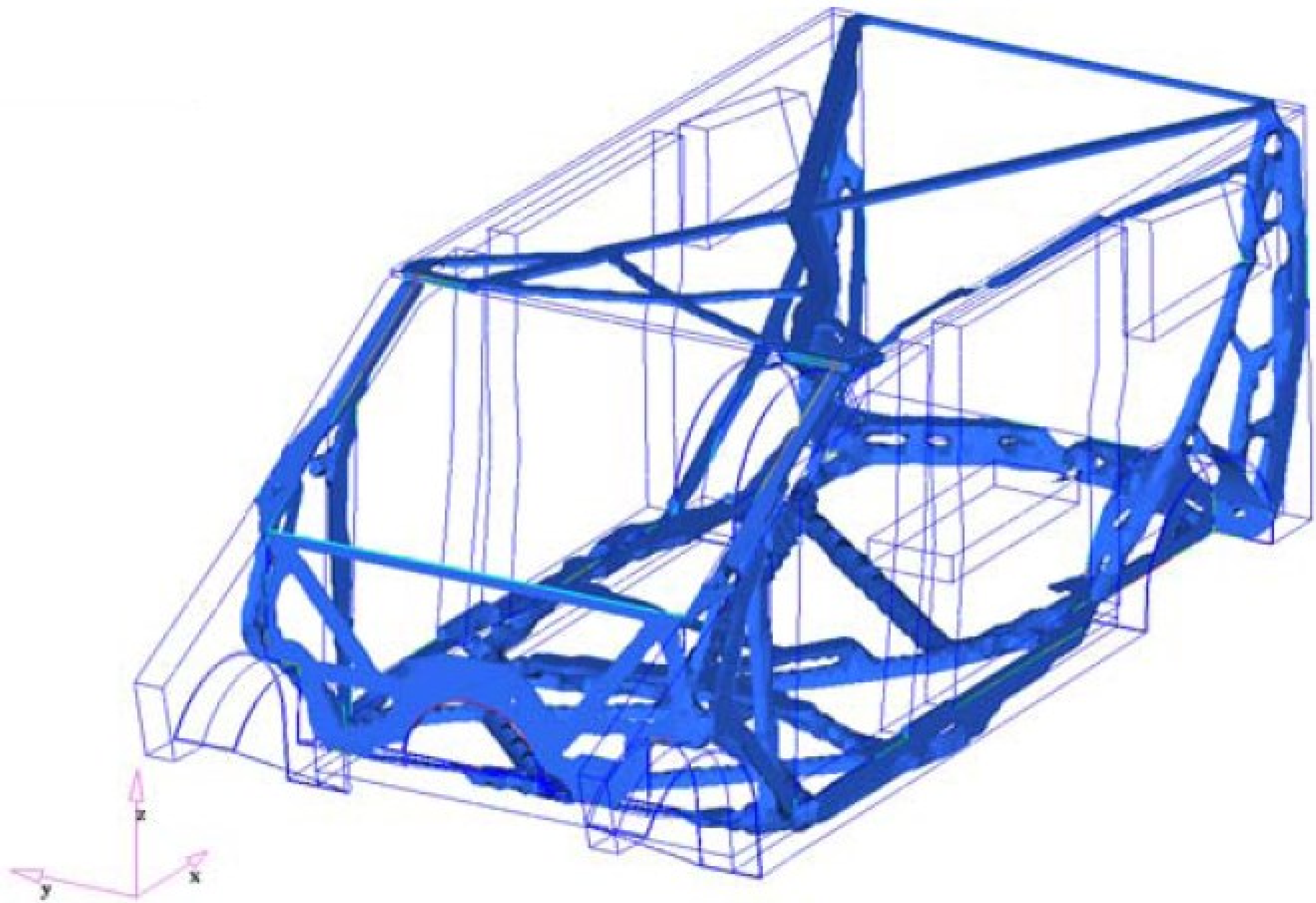


- Torsion



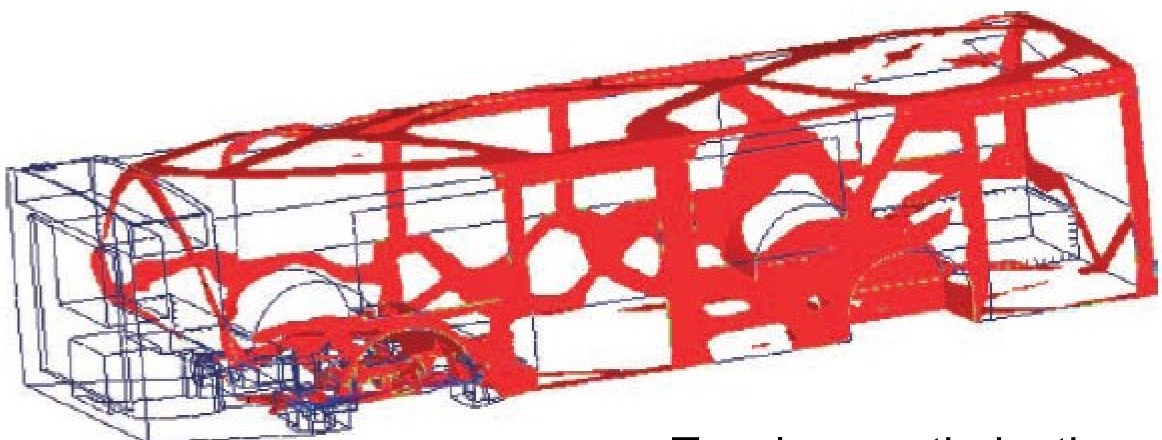
# Result of Topology Optimization (2)

- Combination of bending and torsion



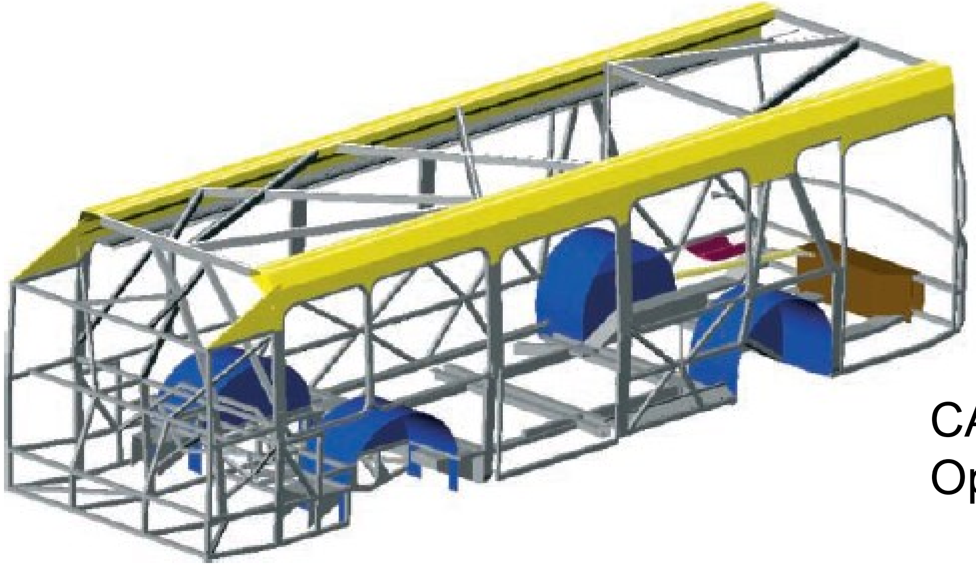
# Lightweight City Bus (1)

Bus design package space (in gray)

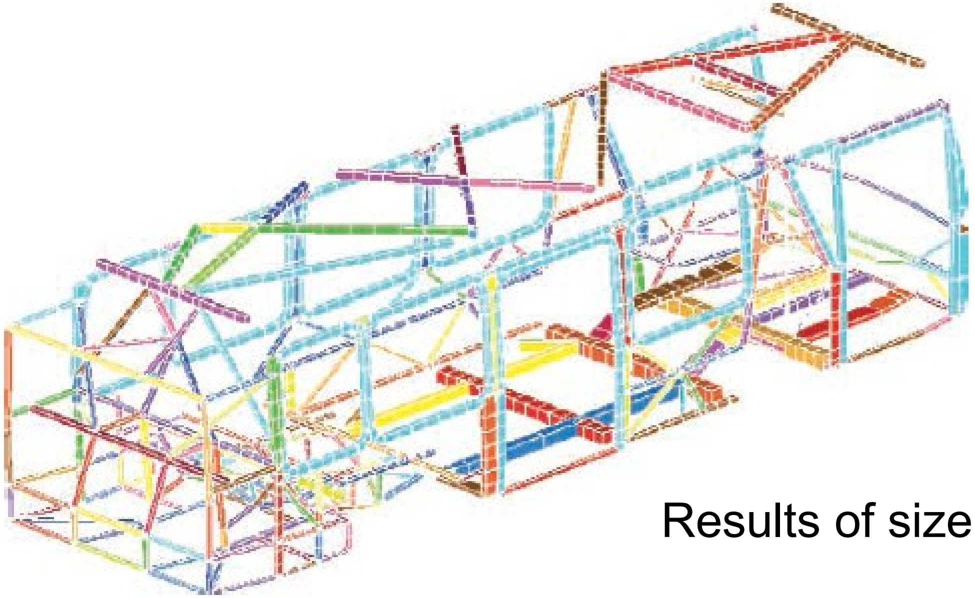


Topology optimization result

# Lightweight City Bus (2)



CAD model interpretation of topology Optimization design proposal

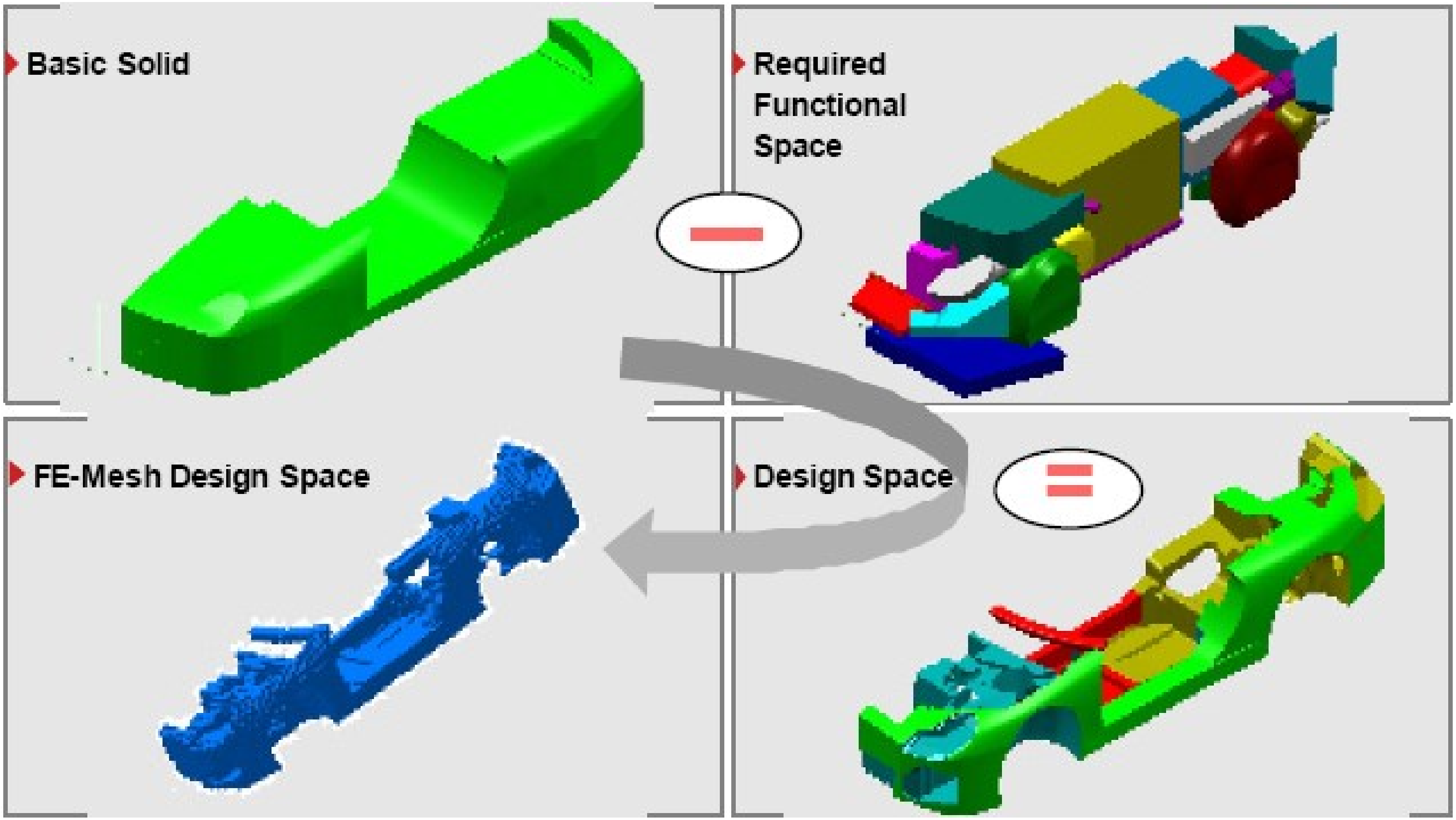


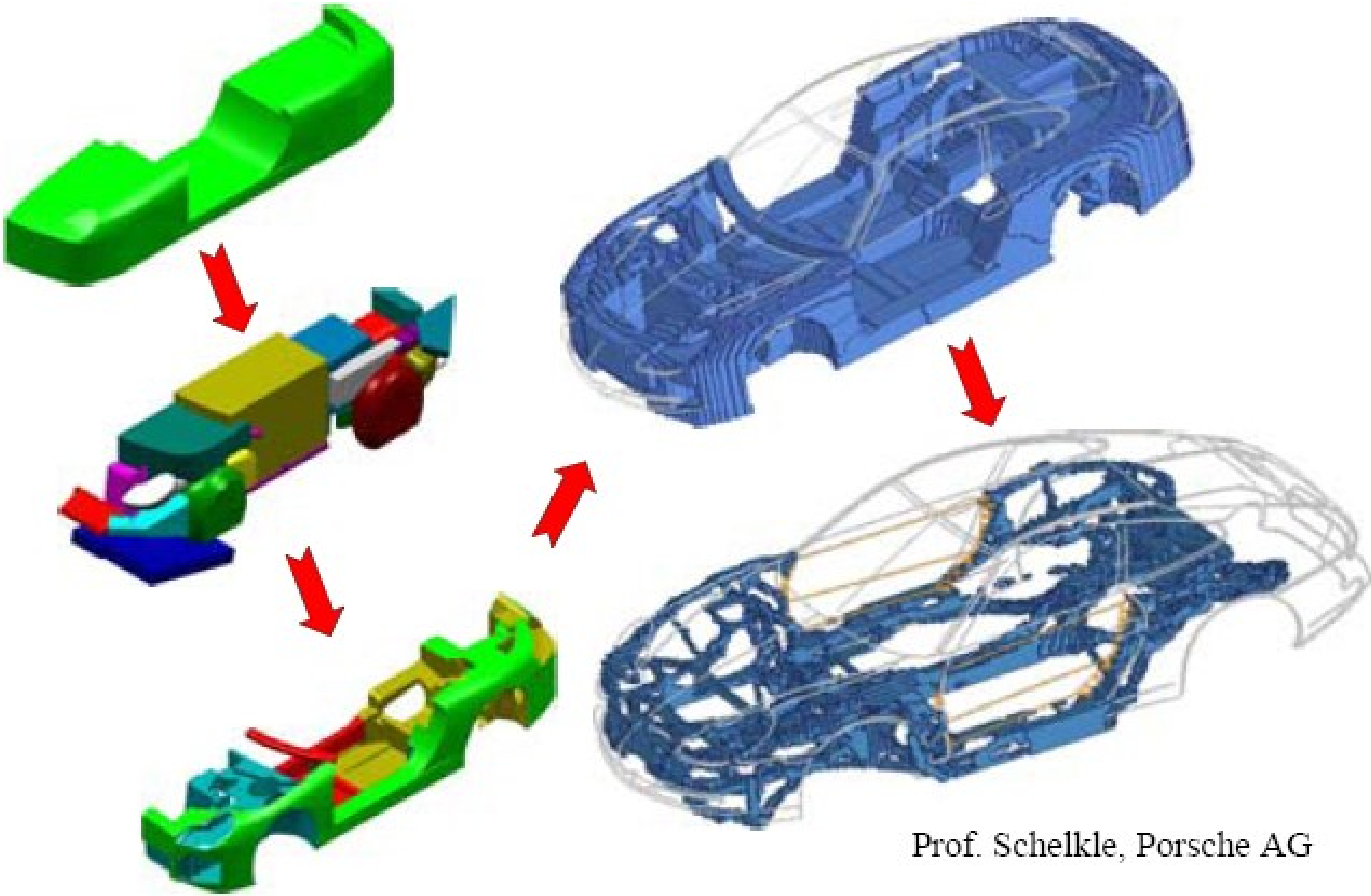
Results of size optimization

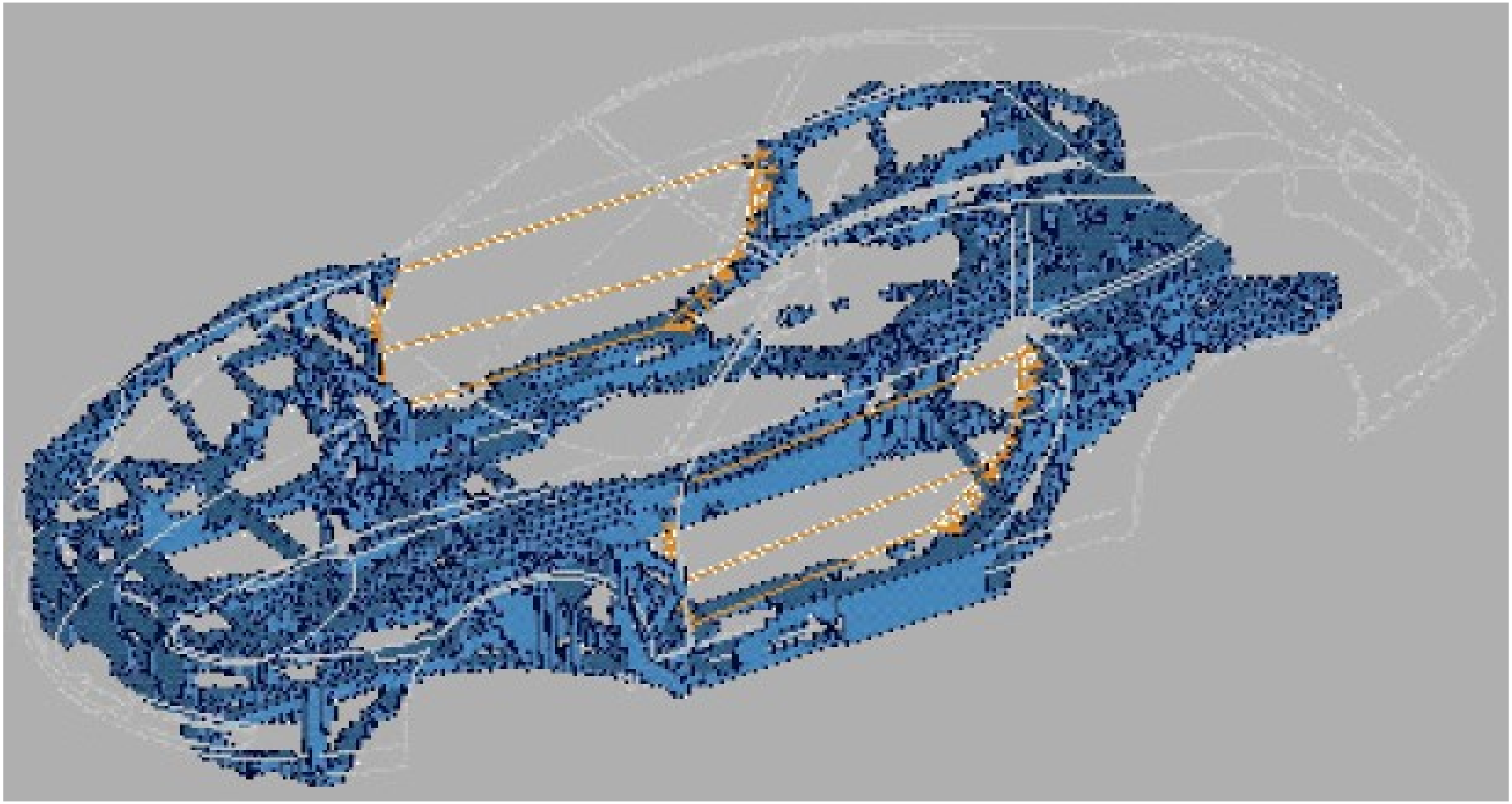
# Lightweight City Bus (3)


Final bus design

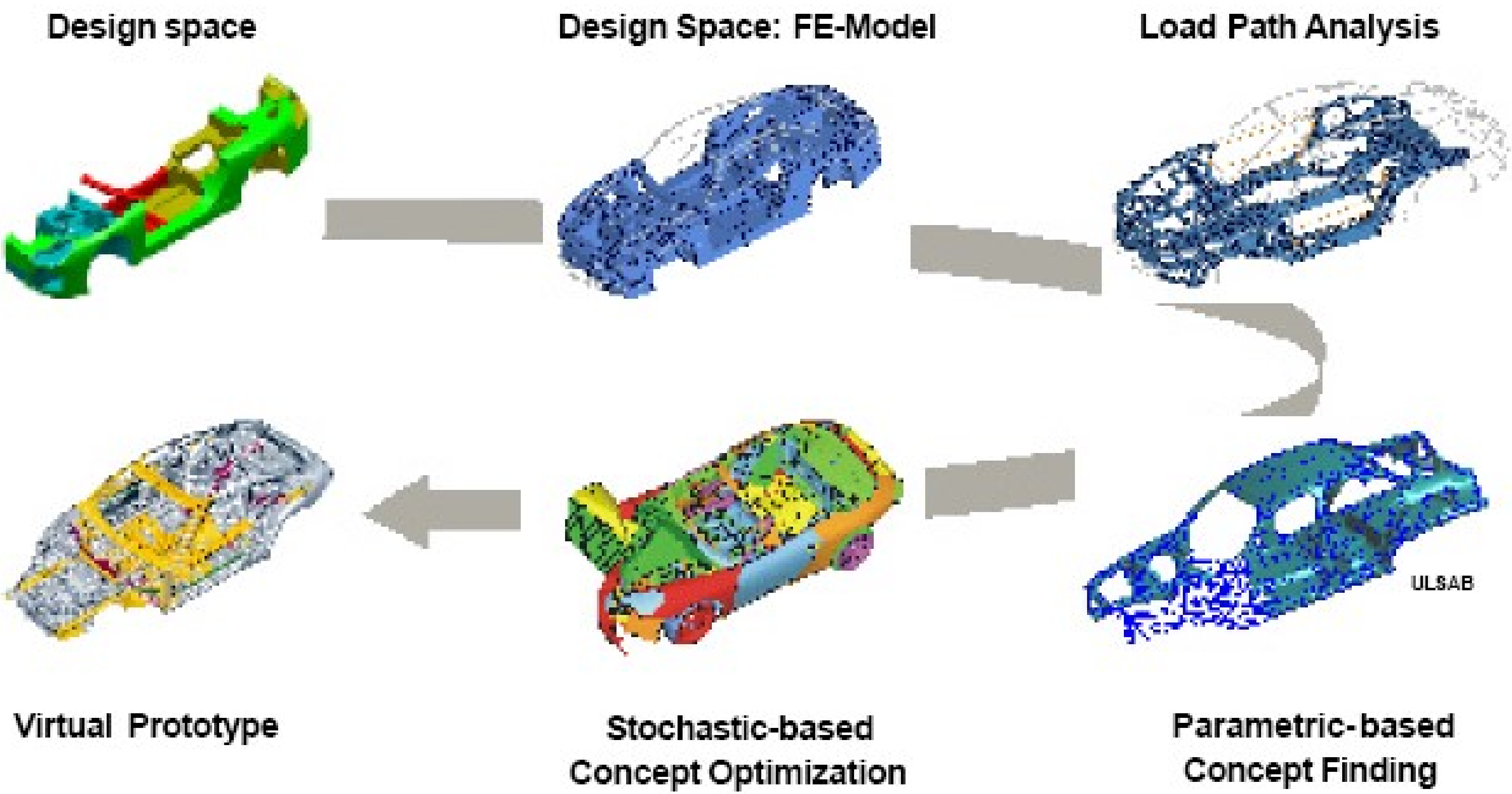
# Load Path Analysis Sequence




Prof. Schelkle, Porsche AG

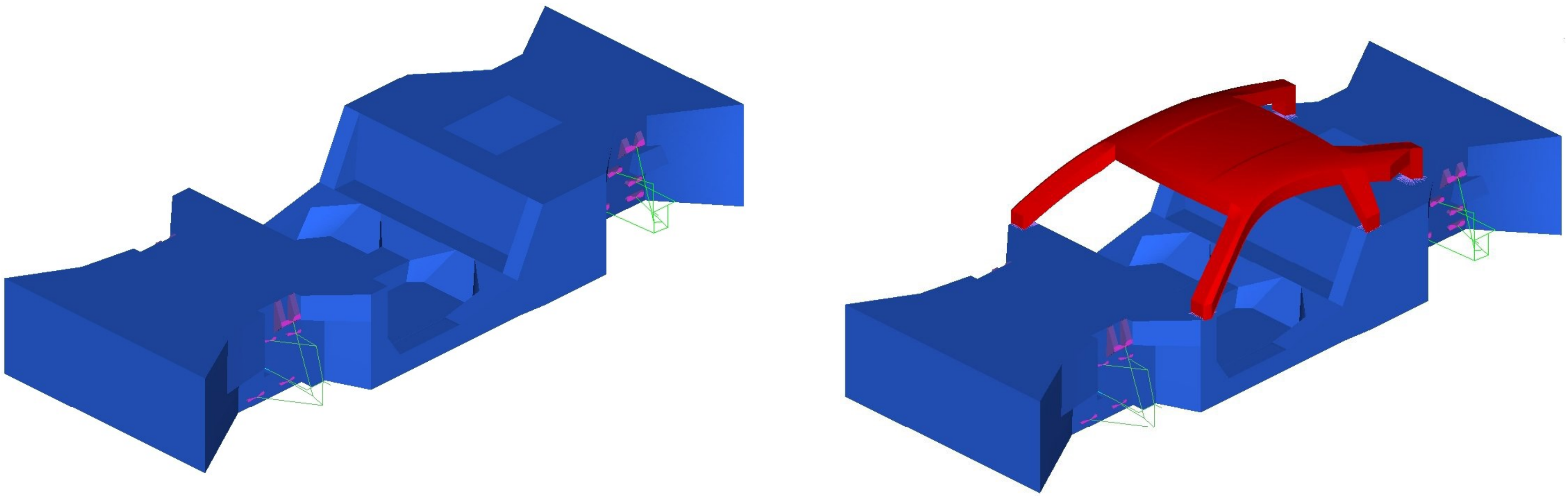


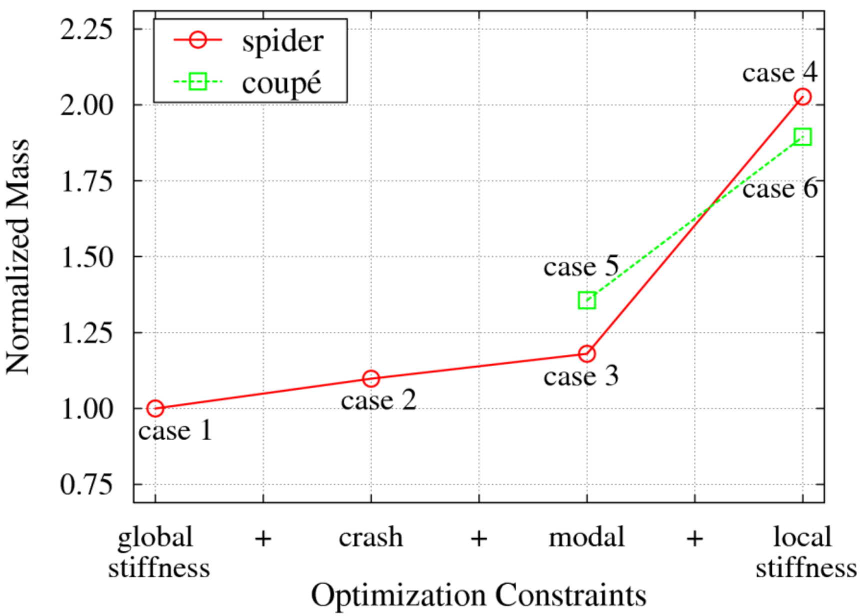
# Concept Stage of Vehicle Development



# Automotive Chassis

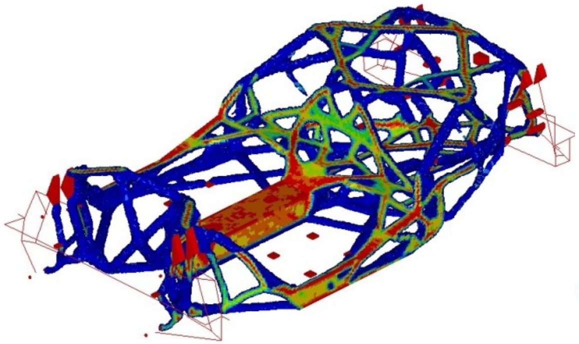
- Comparison Between Spider and Coup´e Designs



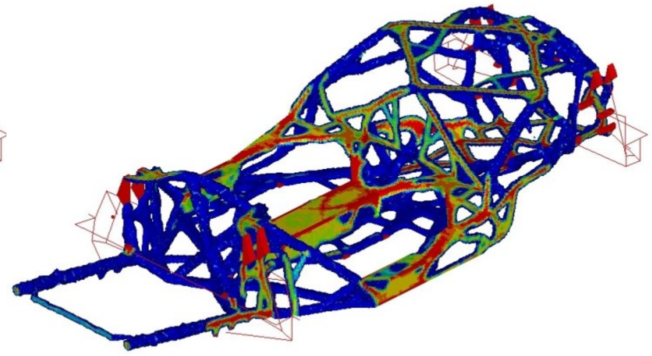



| Active Optimization Constraints | Cases | | | | | |
|---|---|---|---|---|---|---|
| | Spider | | | | Coupé | |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Global bending stiffness | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Global torsion stiffness | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Crash seat joints displacement | – | ✗ | ✗ | ✗ | ✓ | ✗ |
| Crash engine joints displacement | – | ✓ | ✓ | ✗ | ✓ | ✓ |
| Crash A-pillar displacement | – | ✓ | ✓ | ✓ | ✓ | ✓ |
| Crash pedal displacement | – | ✗ | ✓ | ✗ | ✗ | ✗ |
| Crash flame shield displacement | – | ✓ | ✓ | ✗ | ✗ | ✗ |
| Crash dashboard joints displacement | – | ✗ | ✗ | ✗ | ✗ | ✓ |
| Crash compliance | – | ✓ | ✓ | ✓ | ✓ | ✓ |
| First natural mode | – | – | ✓ | ✓ | ✓ | ✓ |
| Local front wheel stiffness along $x$ | – | – | – | ✓ | – | ✓ |
| Local front wheel stiffness along $y$ | – | – | – | ✓ | – | ✓ |
| Local front wheel stiffness along $z$ | – | – | – | ✓ | – | ✓ |
| Local rear wheel stiffness along $x$ | – | – | – | ✓ | – | ✓ |
| Local rear wheel stiffness along $y$ | – | – | – | ✓ | – | ✓ |
| Local rear wheel stiffness along $z$ | – | – | – | ✗ | – | ✗ |
| Local engine joint stiffness along $z$ | – | – | – | ✓ | – | ✓ |
| Local gearbox joint stiffness along $z$ | – | – | – | ✓ | – | ✗ |
| Total | $\frac{2}{2}$ | $\frac{5}{9}$ | $\frac{8}{10}$ | $\frac{12}{18}$ | $\frac{7}{10}$ | $\frac{12}{18}$ |

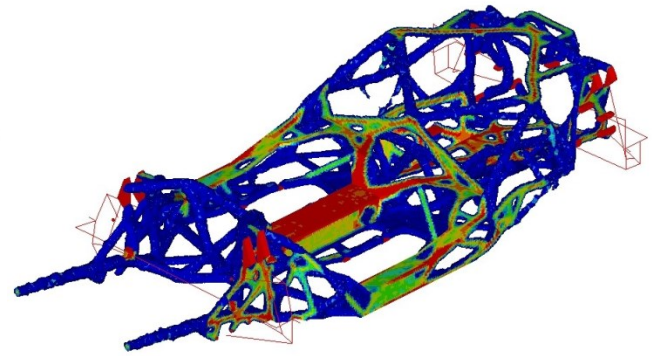
# Results (1)



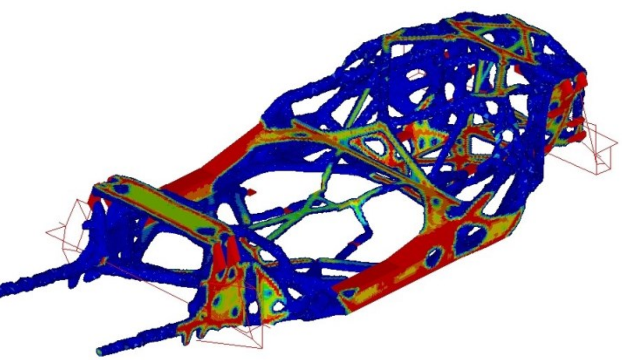
Case 1



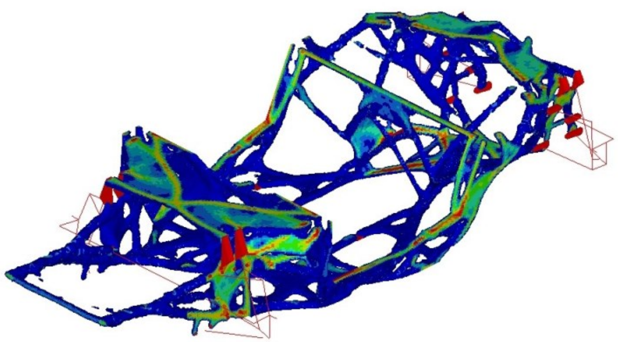
Case 2



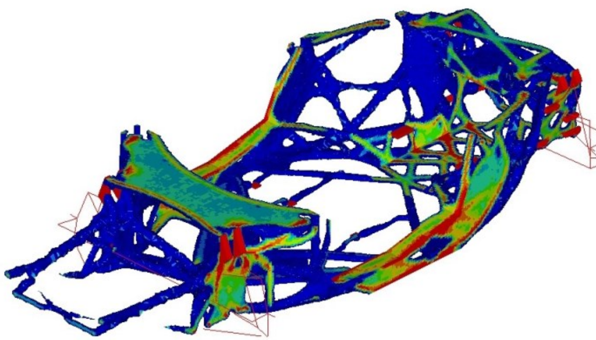
Case 3



Case 4

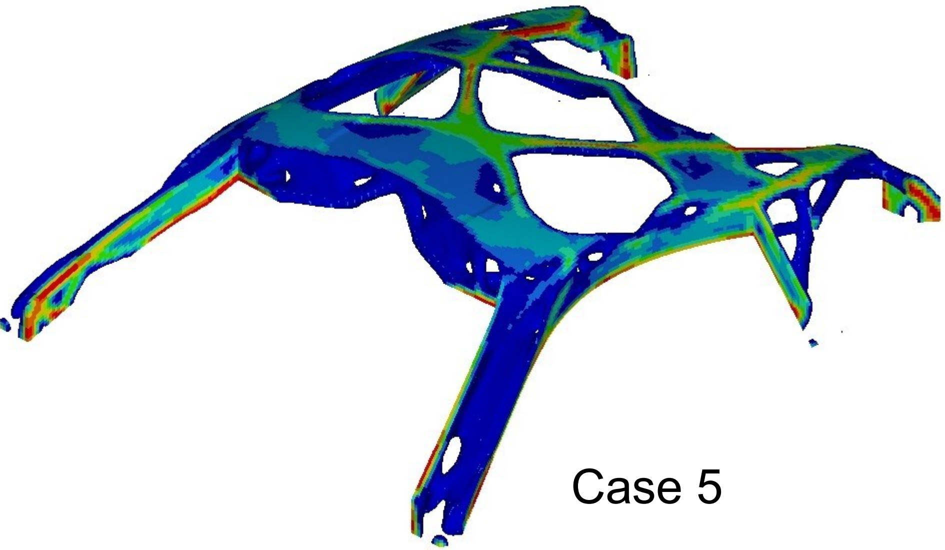


Case 5

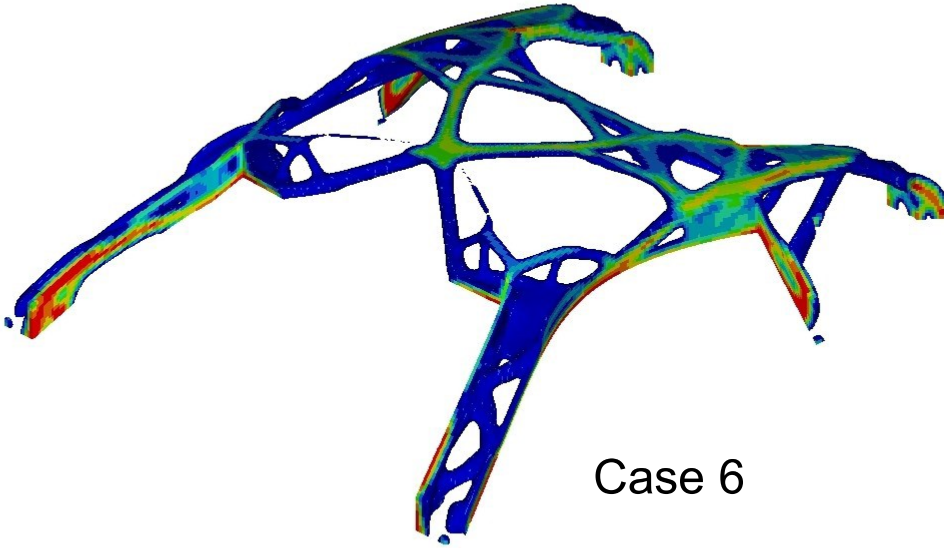


Case 6

# Results (2)

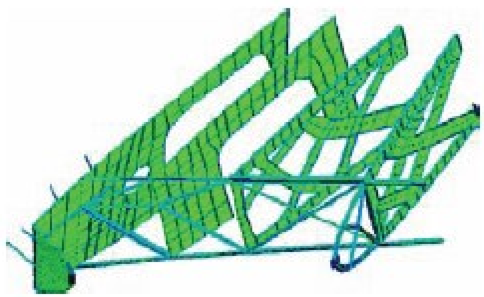


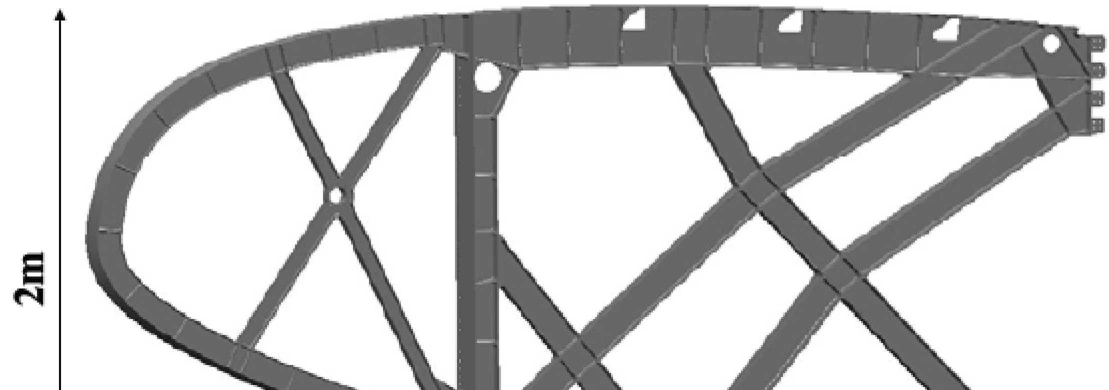
Case 5

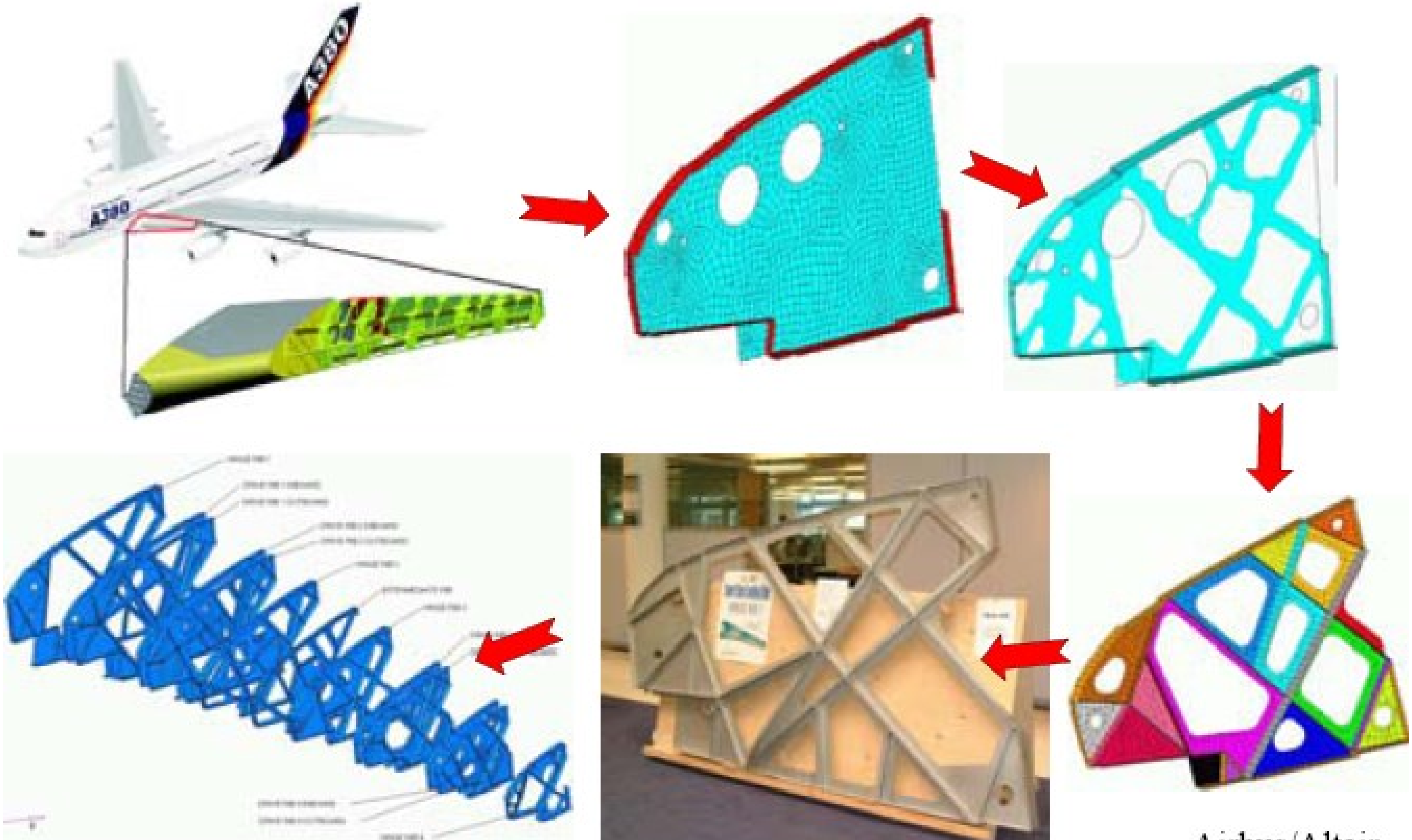


Case 6

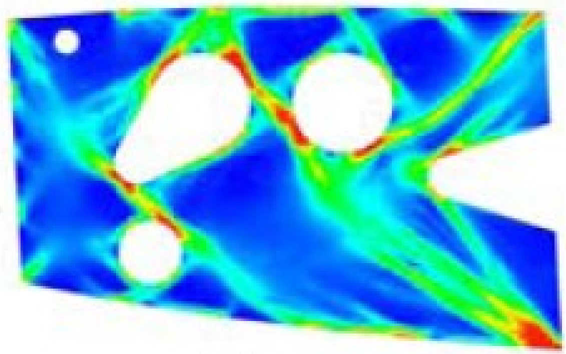
# A380 Leading Edge Droop Nose Ribs

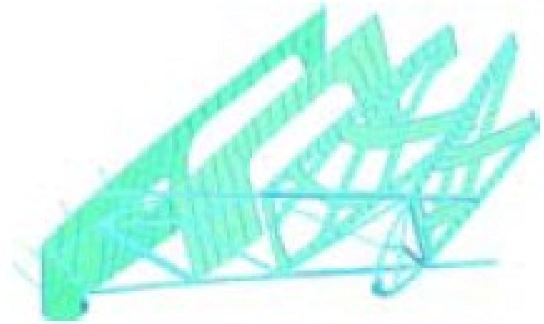






Airbus/Altair





Kochvara/Airbus

# Ultra-lightweight Hub-Bearing

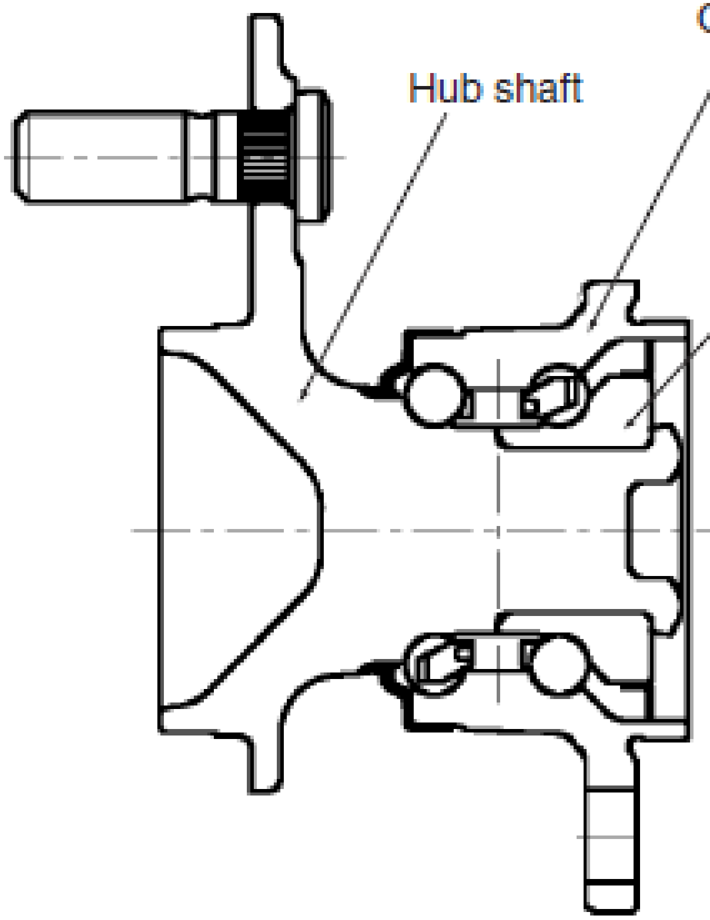
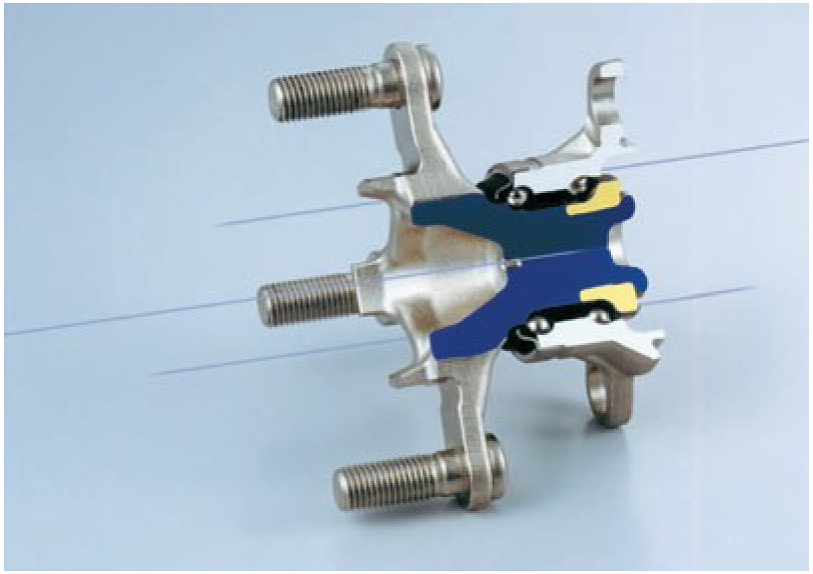
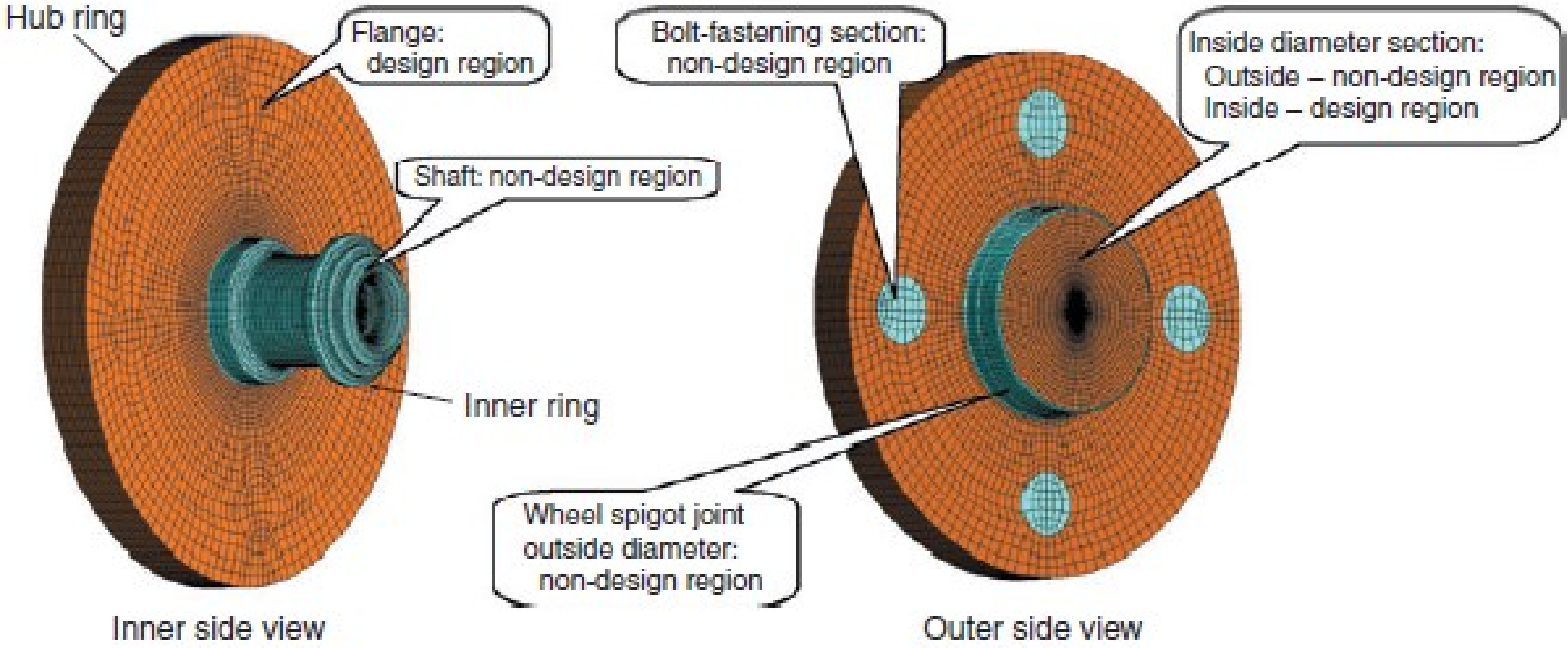



**Fig.1** Hub-Bearing original design

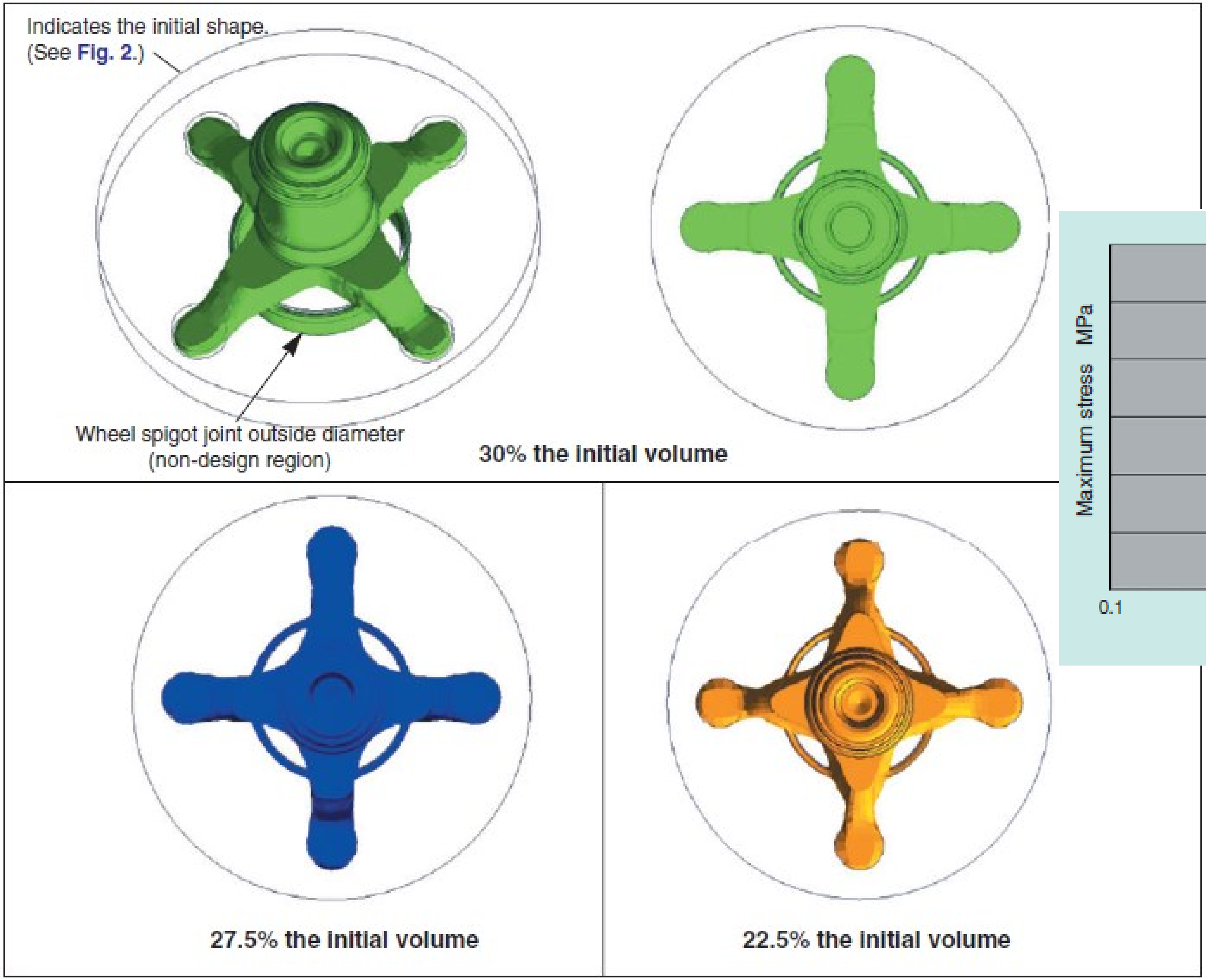


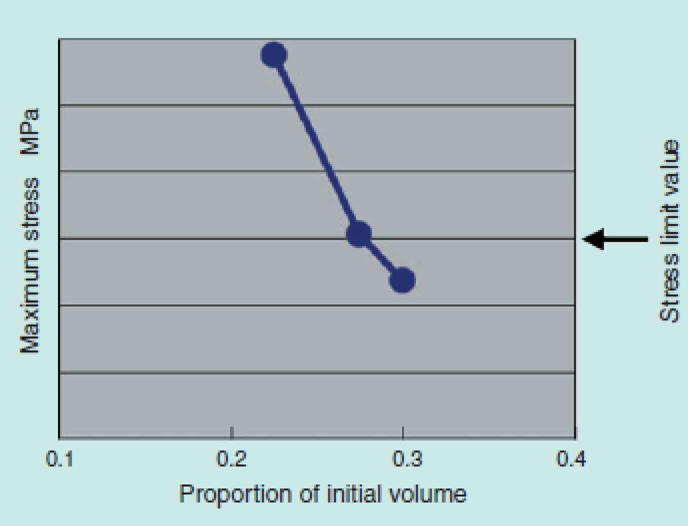
1.4 kg → 1.0 kg
(strength, durability, rigidity)

# Topology Optimization Model

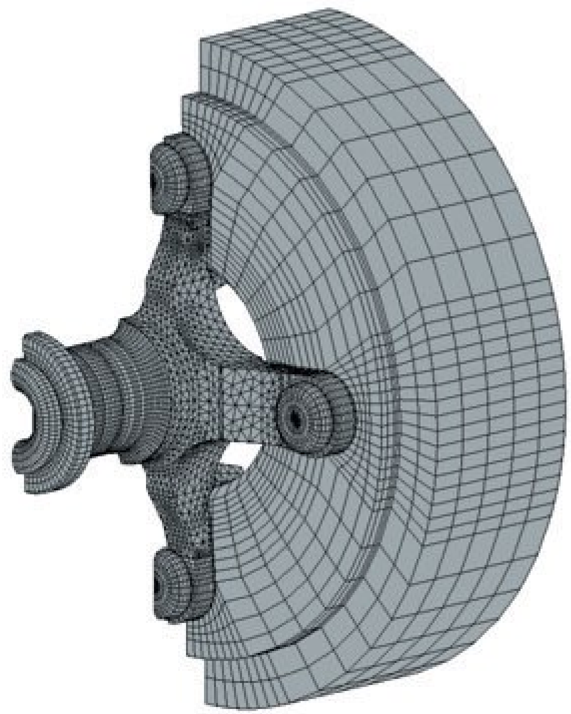


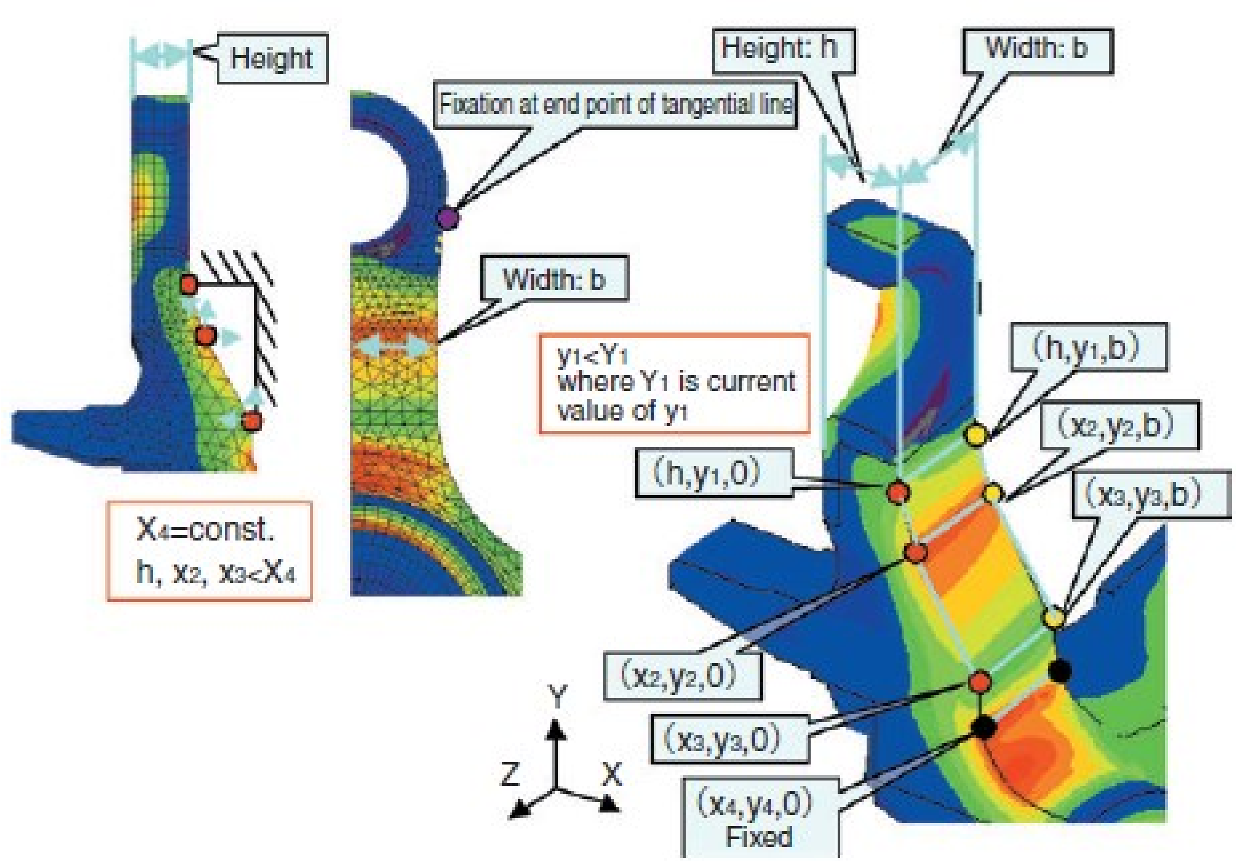
# Result of Topology Optimization



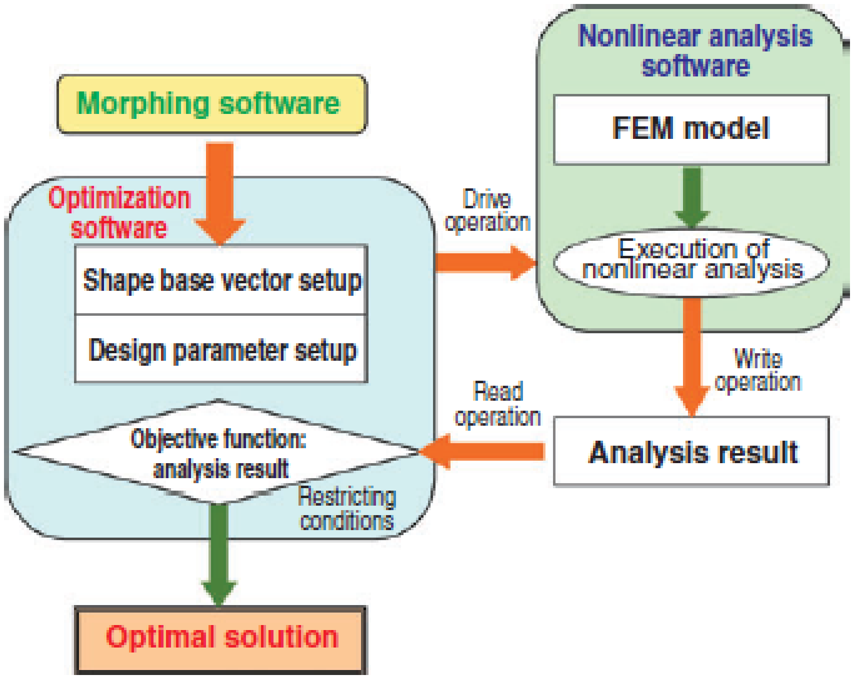
# Shape Optimization

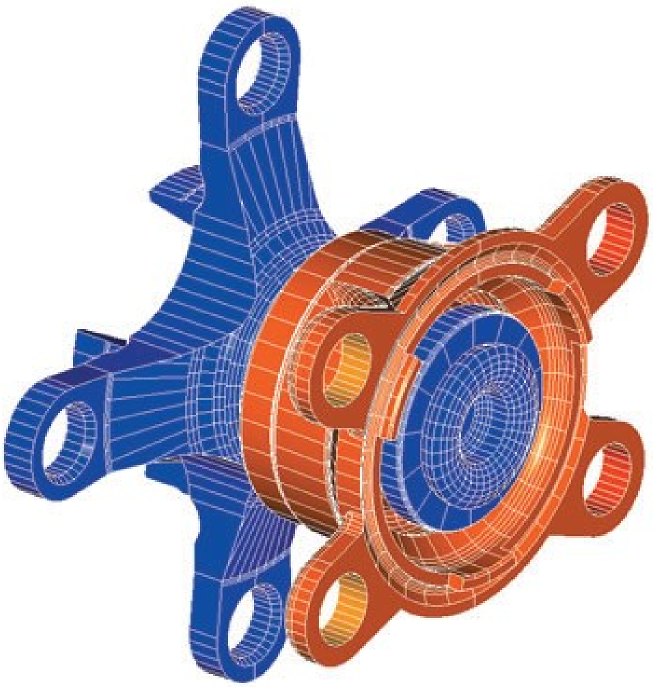


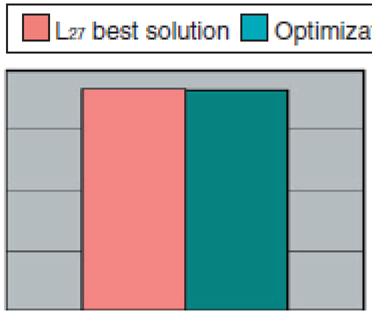



(h, b, y1, x2, y2, x3, y3)

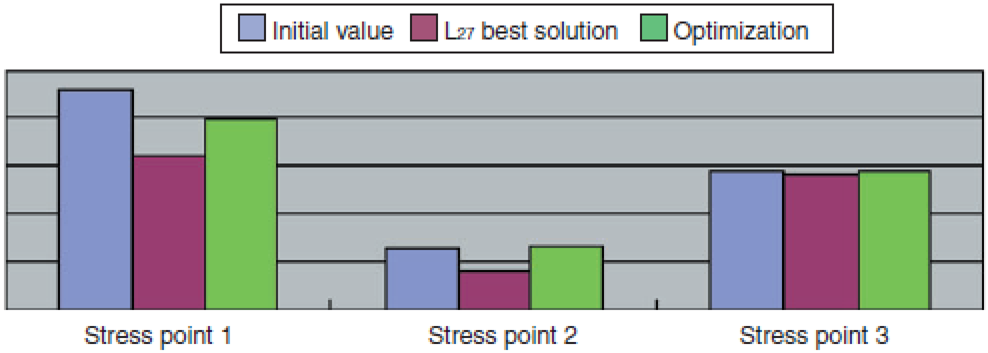
# Result of Shape Optimization






(a) Volume




(b) Stress value

# Final Design