The 22nd International Conference on
Technical and Physical Problems of Engineering
ICTPE-2026
31 October 2026
International Organization of IOTPE

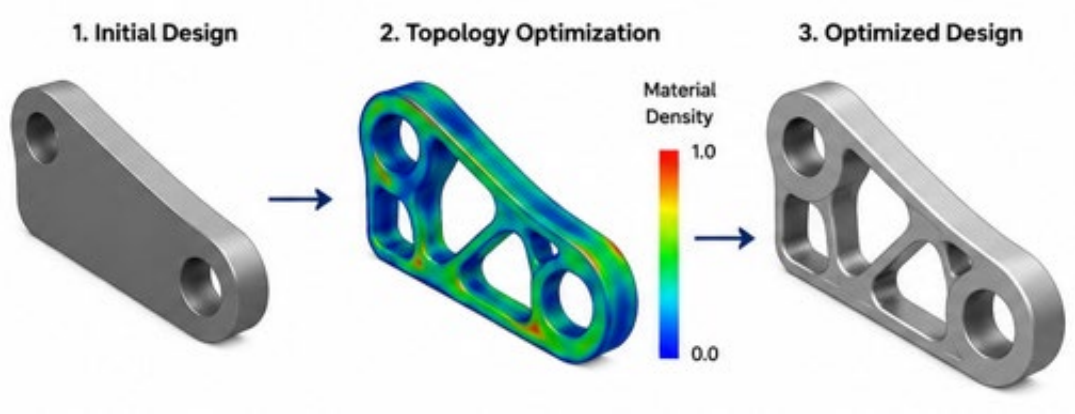
OPTIMIZED DESIGN THROUGH STATIC AND TOPOLOGY OPTIMIZATION OF A ROBOTIC ARM LINK

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Introduction





Apply topology optimization in SOLIDWORKS to obtain a lightweight and structurally efficient design for the links of a robotic arm, while maintaining the required stiffness and strength.

WHAT IS TOPOLOGY OPTIMIZATION?

It is a computational methodology that optimally distributes material within a given design domain, removing unnecessary material and preserving only the efficient load paths.

APPLICATION IN ROBOTIC ARMS

- Weight reduction
- Maintenance of stiffness and strength
- Improved strength-to-weight ratio
- Higher energy efficiency and dynamic performance

TOOL USED

SOLIDWORKS | Simulation Module
Topology Study

Methodology

Finite element preprocessing → static structural analysis → topology optimization → CAD redesign → validation

1. MODEL PREPARATION

3D robotic-arm link modeled in SOLIDWORKS. PETG assigned as the structural material.

2. FINITE ELEMENT MODEL

Blended curvature-based solid mesh: 118,574 nodes and 80,205 elements.

3. STATIC FEA

343.35 N applied load; stress, deformation and safety factor evaluated.

4. TOPOLOGY

SIMP-based optimization used to remove low-contribution material.

BOUNDARY CONDITIONS

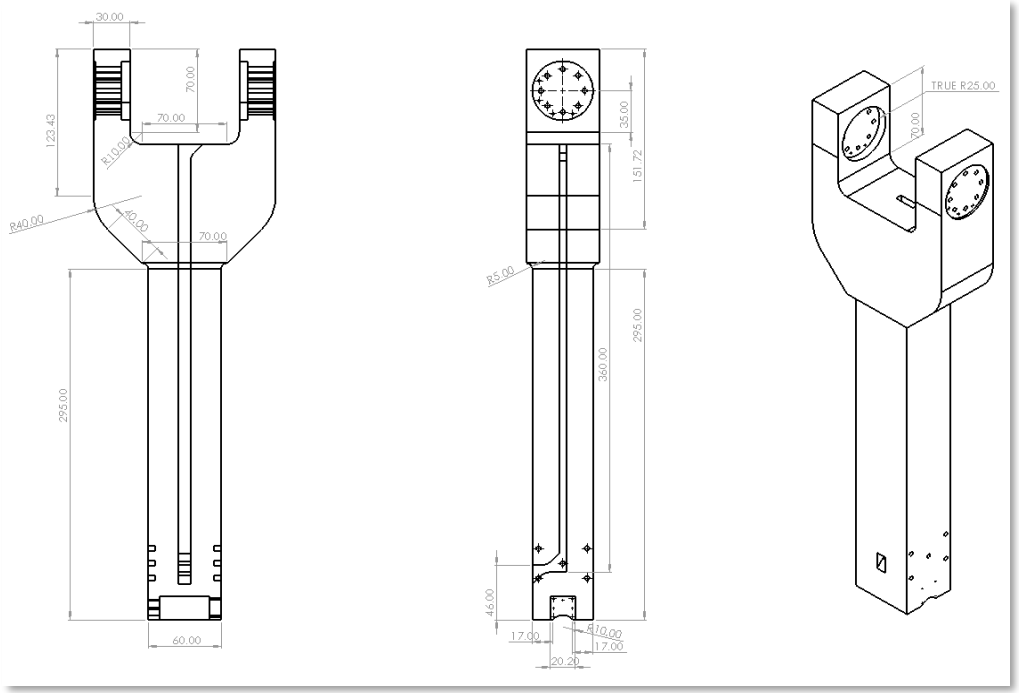
- Fixed constraint at the lower servo-motor mounting region.
- 343.35 N force applied to the upper connection region.
- Minimum adopted safety factor criterion: SF ≥ 2.
- Preserved zones included supports, assembly surfaces, symmetry and servo wiring paths.

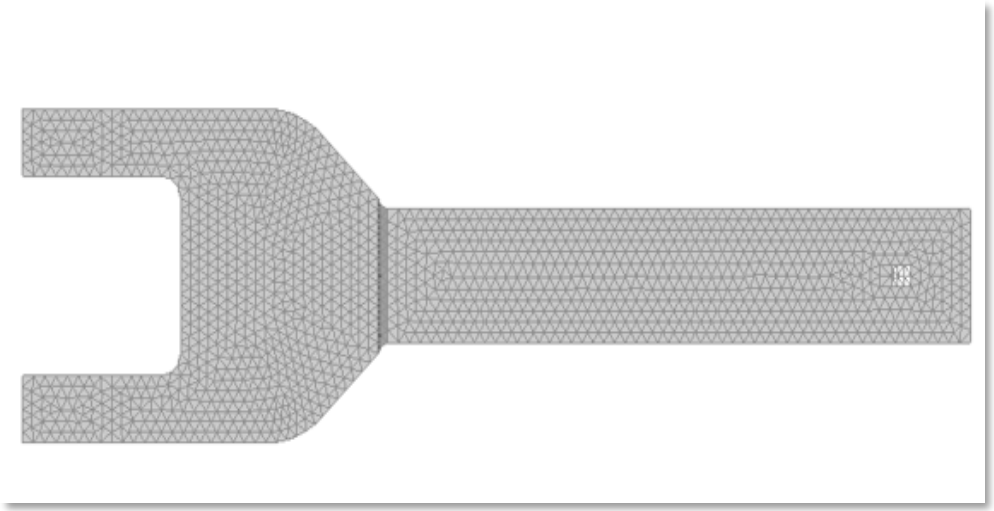
OPTIMIZATION STRATEGY

- Initial target: 30% material reduction.
- Second iteration: 50% material reduction.
- Topology results manually reconstructed into manufacturable CAD geometry.
- Each redesigned configuration was re-analyzed under the same loading conditions.

PETG properties: E = 2.96 GPa · ν = 0.37 · density = 1420 kg/m³ · yield strength = 73 MPa

Methodology





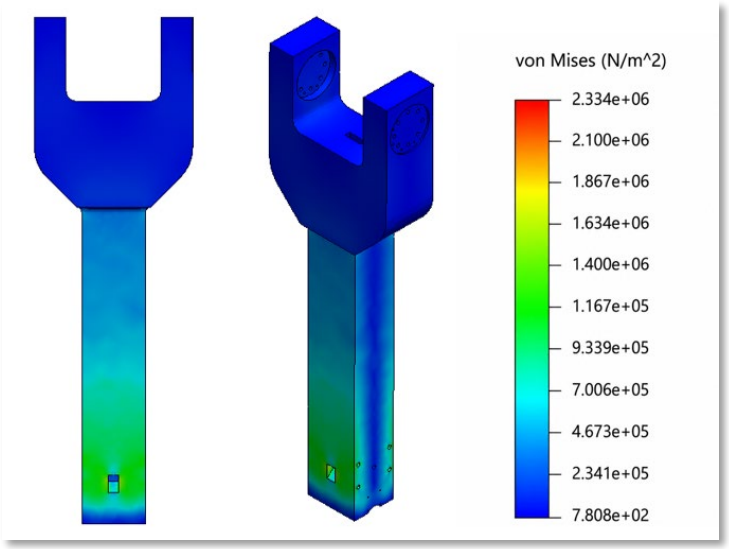
GEOMETRY

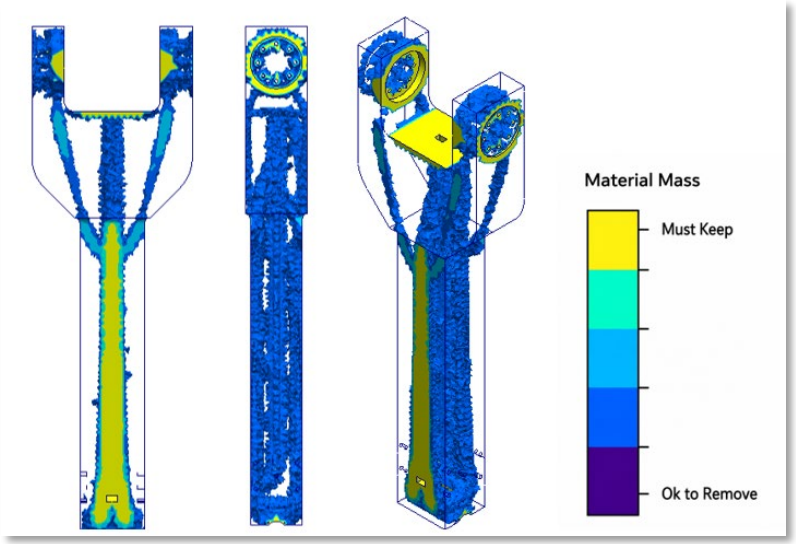
- Geometry designed from real working-area measurements.
- Center of gravity positioned near the central region.
- Solid tetrahedral elements used for structural evaluation.

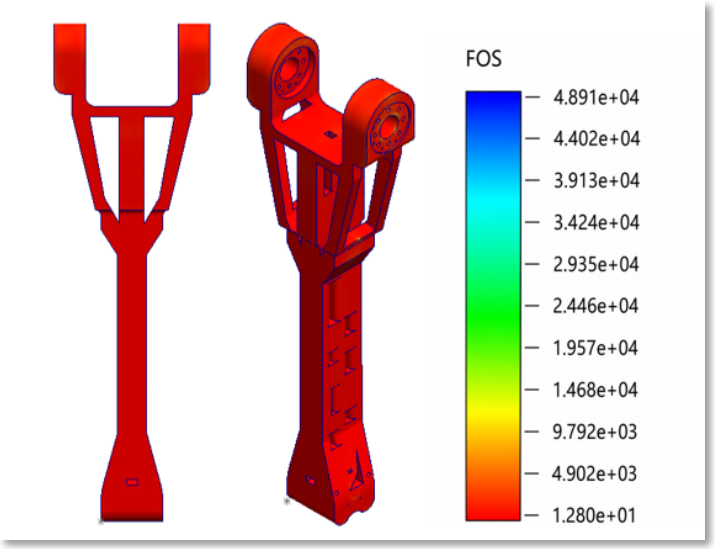
MESH QUALITY

- High-quality blended curvature-based mesh.
- Maximum element size: 5.99758 mm.
- 99.1% of elements have aspect ratio < 3.
- No distorted elements were reported.

Static analysis & topology setup







STATIC FEA

- Original geometry evaluated under 343.35 N.
- Von Mises stress and safety factor used for structural assessment.
- Original configuration: SF = 21.

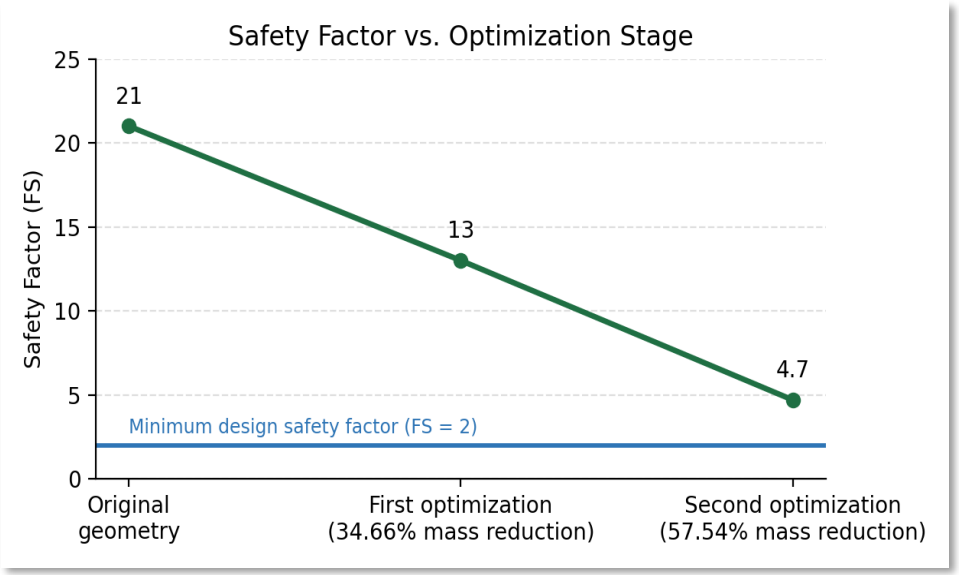
TOPOLOGY OPTIMIZATION

- SolidWorks Simulation topology module.
- SIMP material interpolation.
- Objective: maximize stiffness while reducing material.
- Preserved functional and assembly regions.

VALIDATION LOOP

- Topology map interpreted and reconstructed as CAD.
- Redesigned geometry re-simulated.
- Acceptance criterion: SF ≥ 2.

Results



1908.69 g → 1247.14 g

MASS REDUCTION = 34.66%

MAXIMUM STRESS

2.281 MPa

SAFETY FACTOR

13

DESIGN CRITERION

SF ≥ 2

The stress increase is consistent with material removal, while the redesigned geometry remains well above the adopted structural criterion.

Results

ORIGINAL 1908.69 g → FIRST OPTIMIZATION 1247.14 g → FINAL 810.36 g

Configuration	Mass (g)	Mass reduction	Safety factor
Original geometry	1908.69	0.00%	21
First optimization	1247.14	34.66%	13
Second optimization	810.36	57.54%	4.7

Final configuration: maximum stress = 3.083 MPa · safety factor = 4.7 · criterion satisfied (SF > 2)

Conclusions

1. SIGNIFICANT LIGHTWEIGHTING

The final redesigned link reduced mass by 57.54%, from 1908.69 g to 810.36 g.

2. STRUCTURAL PERFORMANCE

Despite increased stresses, the final configuration maintained a safety factor of 4.7, above the adopted SF ≥ 2 criterion.

3. PROGRESSIVE TRADE-OFF

Safety factor decreased from 21 → 13 → 4.7 as material removal increased, demonstrating the expected stiffness/weight trade-off.

4. MANUFACTURABLE REDESIGN

Topology results were manually reconstructed into CAD while preserving supports, assembly interfaces and functional regions.

ENGINEERING TAKEAWAY

Topology optimization combined with finite element analysis provides an effective route to lighter robotic-arm components while maintaining the adopted structural safety criterion under the analyzed loading condition.

Future work: evaluate multiple load cases and time-varying loading conditions; perform a formal mesh-independence study.