TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Corso di Laurea
Triennale in
Ingegneria Meccanica

# Structural optimization of an automotive wheel rim using the BGM method

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# INTRODUCTION

In the *Automotive* sector, wheel rims play both a structural and stylistic role.

They significantly contribute to the vehicle’s aesthetics, brand perception, and market positioning.

In discussions with Nissan, it emerged that the Automotive industry is driven by the ***Design First*** paradigm.

This approach imposes strict constraints on the design engineer.

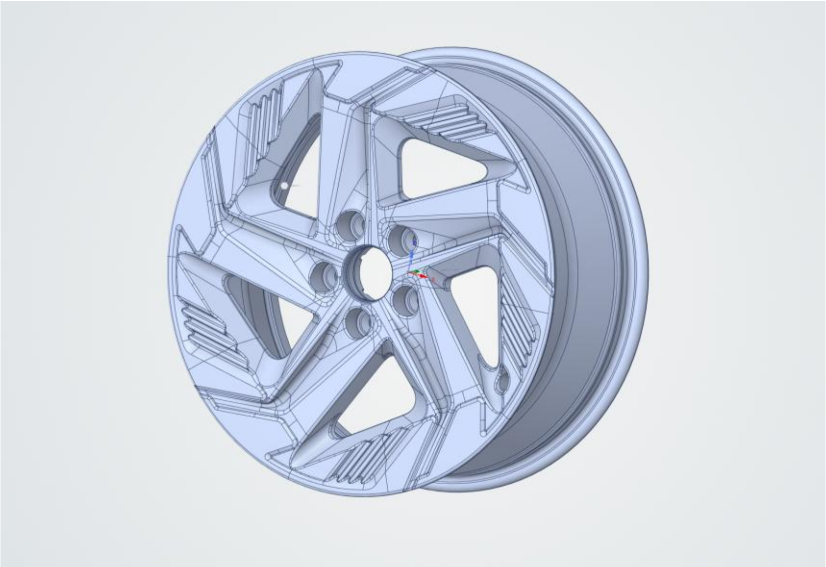
# INTRODUCTION

- Real-world geometry provided by Nissan, subject to design constraints.
- Preliminary structural analysis performed using the FEM method
- Two-phase optimization:
  - Mesh morphing for mass reduction.
  - BGM to improve stress distribution.
- Activity carried out in Ansys Workbench, using Ansys Mechanical and RBF Morph.

# OBJECTIVES

- To optimize a real wheel rim provided by Nissan, while preserving its original design.
- Mass reduction through mesh morphing with stress control.
- Optimization of stress distribution using the Biological Growth Method (BGM).

# CASE STUDY



| Parameters | Value |
|---|---|
| Mass | 14,1 kg |
| Diameter | 0,50 m |
| Density | 2700 $kg/m^3$ |
| Young's Modulus | 71 $GPa$ |
| Yield Strength | 190 $MPa$ |

- Five-spoke design
- *Material*: Aluminum Alloy AlSi7Mg0.3

# LOAD TESTS

Nissan provided three load tests, internally developed by the company:

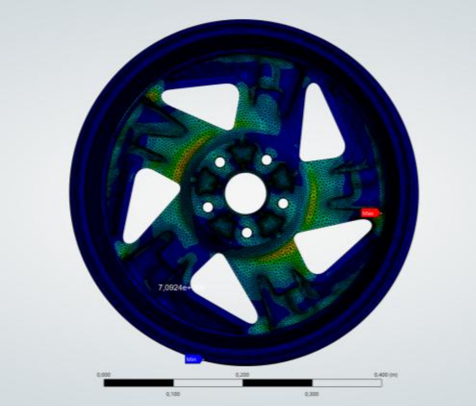
- **Rotary bending test**: simulates the lateral forces acting on the wheel during cornering;
- **Impact test**: simulates forces generated by road surface irregularities;
- **Drum durability test**: simulates the stresses experienced by the wheel during ground contact.

# STRUCTURAL ANALYSIS

CAD

MESH

RESULTS



FEM

# STRUCTURAL ANALYSIS

| Load Test | Maximun Stress |
|---|---|
| Drum durability test | 81,24 MPa |
| Rotay bending test | 69,9 MPa |
| Impact Test | 53,3 MPa |

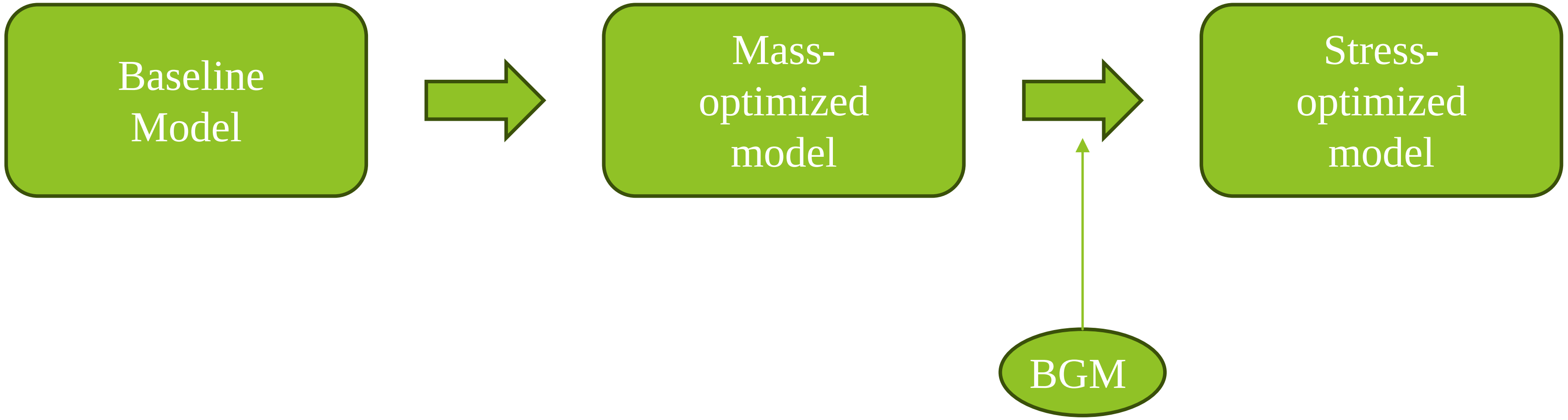
The drum durability test proves to be the most demanding.

$$k = \frac{\sigma_{max}}{\sigma_{allowable}} < 1$$

$$k = 0{,}43 < 1$$

Optimization is possible!

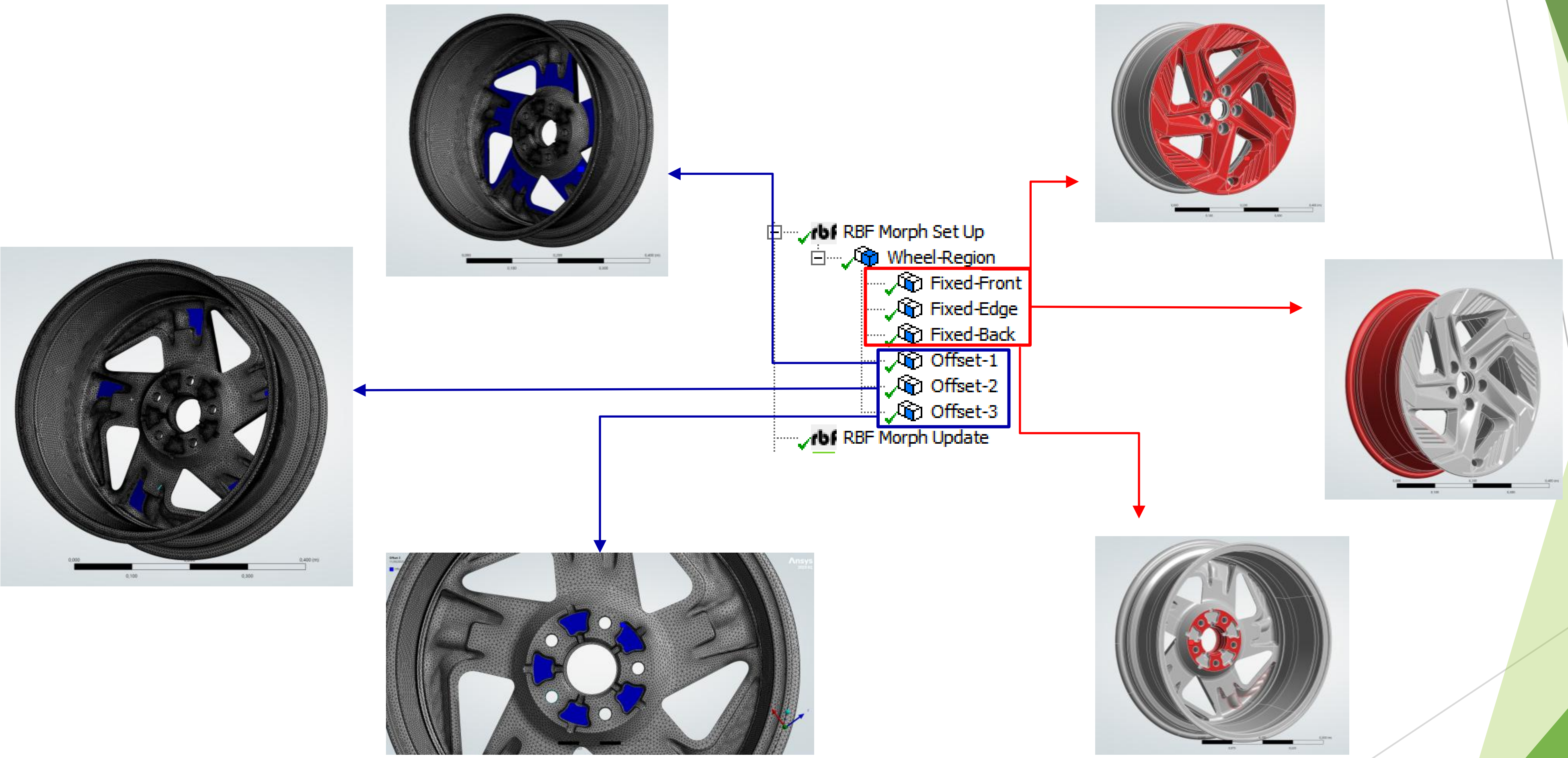
# OPTIMIZATION WORKFLOW



# SHAPE OPTIMIZATION

- Improve structural performance by modifying the external geometry.
- The mesh topology remains unchanged.
- Mesh morphing was used: no mesh regeneration required.
- Managed with RBF Morph, which applies continuous and controlled deformations to the mesh using Radial Basis Functions (RBF).

# RBF MORPH SET-UP



# MASS OPTIMIZATION RESULTS

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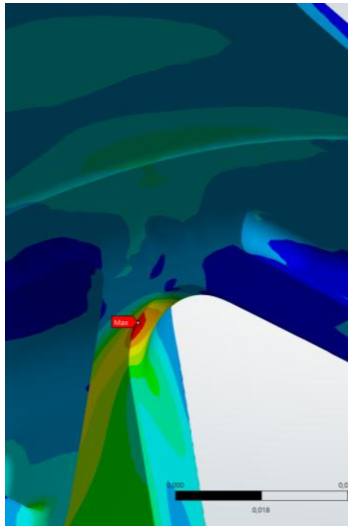
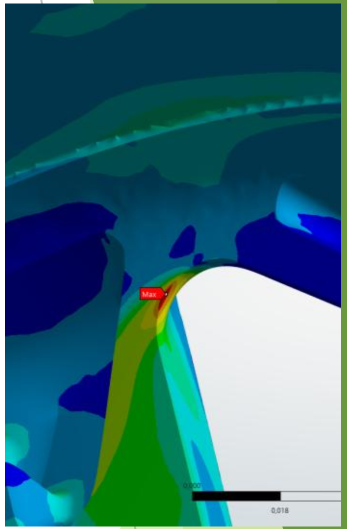
*Trial and Error*

| Parameters | Values |
|---|---|
| Offset-1 | -1,6 *mm* |
| Offset-2 | -4,5 *mm* |
| Offset-3 | -4 *mm* |



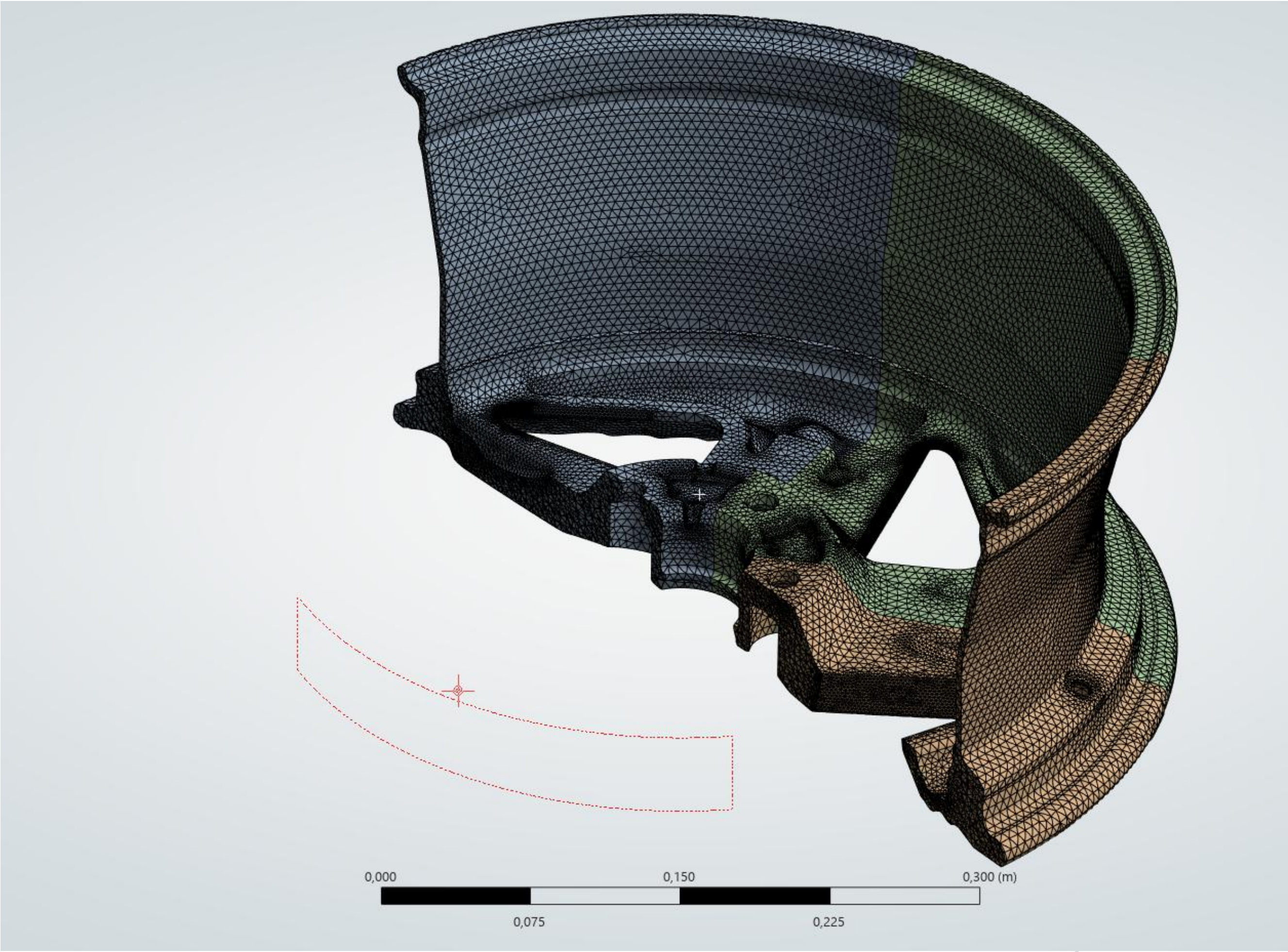


-3,55%

| Parameters | Baseline model values | Optimized model values |
|---|---|---|
| Mass (*kg*) | 14,1 | 13,72 |
| Volume ($m^3$) | $5{,}22 \cdot 10^{-3}$ | $5{,}08 \cdot 10^{-3}$ |
| Maximum Stress (*MPa*) | 81,24 | 93,10 |

# MASS OPTIMIZATION RESULTS

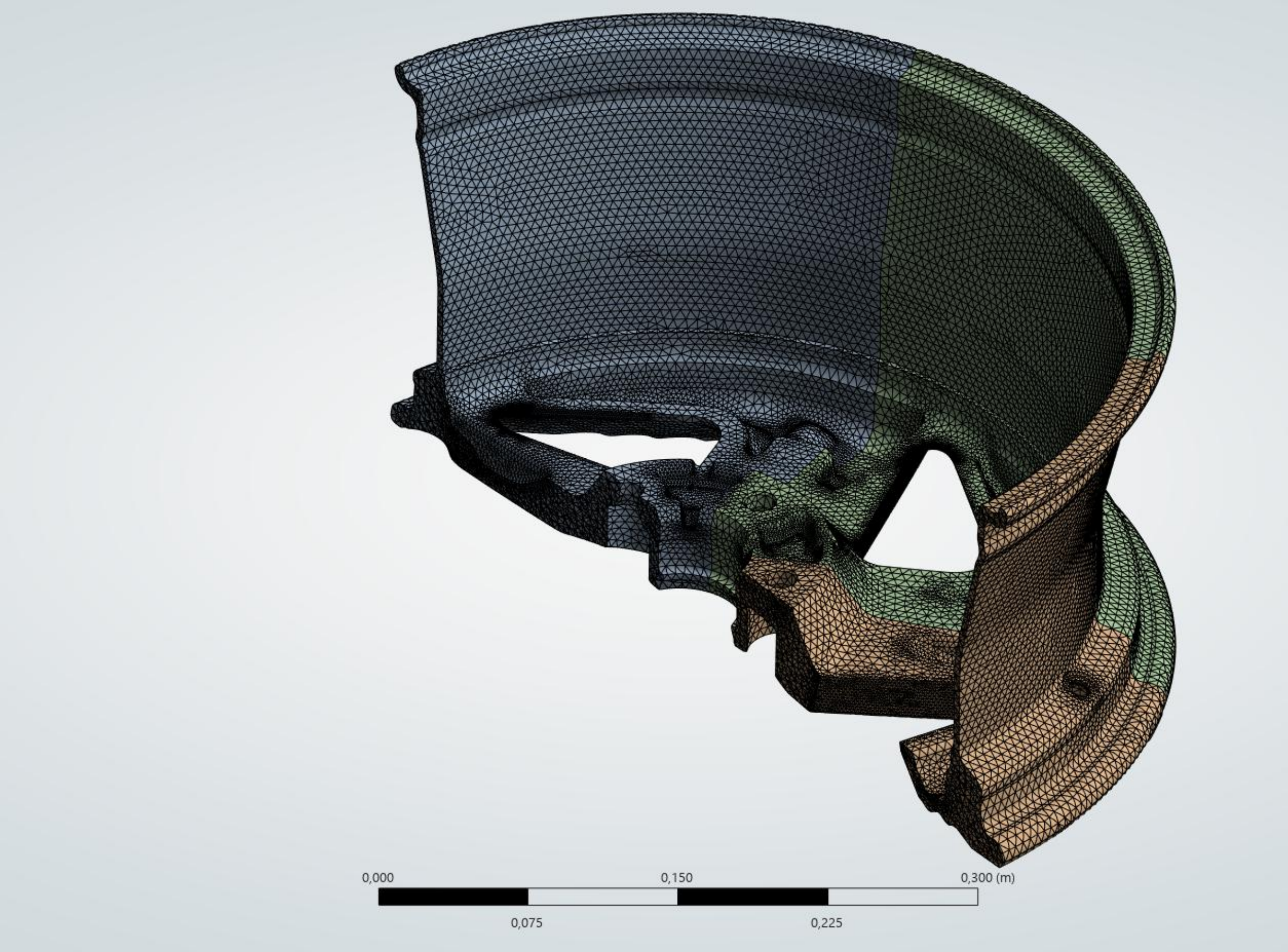
Baseline View



# MASS OPTIMIZATION RESULTS

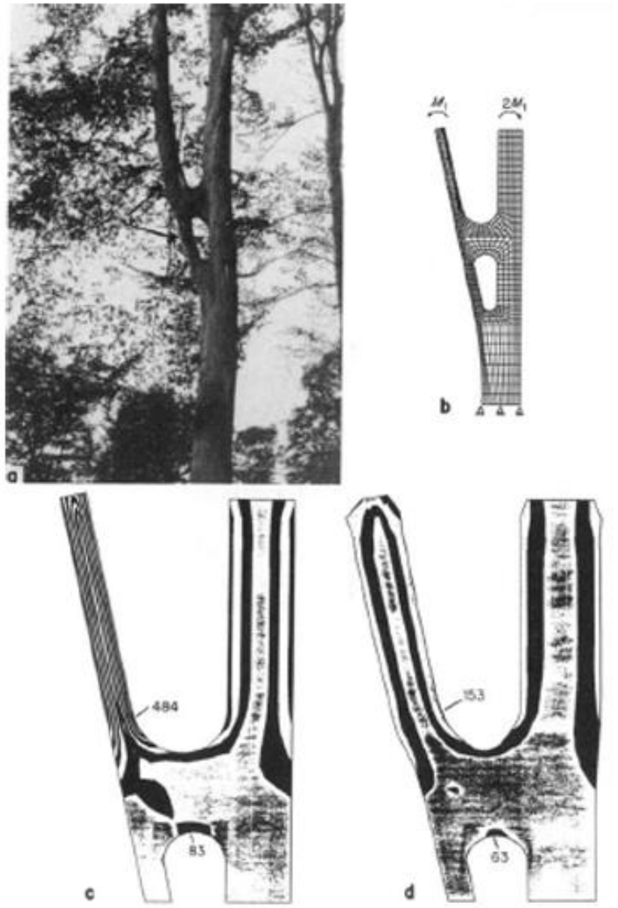


Morphed View



# BIOLOGICAL GROWTH METHOD (BGM)

- BGM is an optimization method inspired by biological growth mechanisms (bones, trees).
- It aims to achieve a target stress by adding material where needed and removing it where excessive.
- The geometry is modified locally.
- Implemented through RBF Morph, it operates iteratively based on FEM results.




$$\dot{\varepsilon}_{def} = \beta\left(\sigma(x,y,z) - \sigma_{ref}\right) \quad \forall x,y,z \in D$$

→

$$\varepsilon_{def} = \beta\left(\sigma(x,y,z) - \sigma_{ref}\right)\Delta t$$

# BGM IN RBF MORPH

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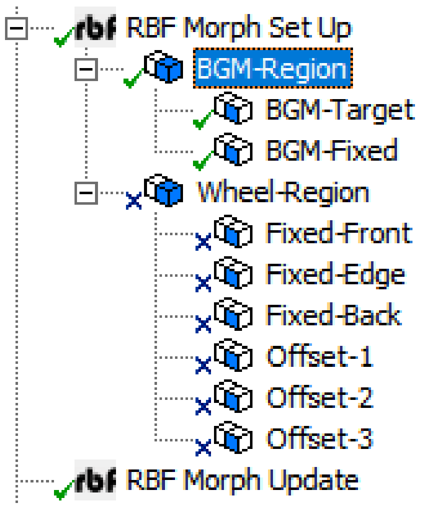


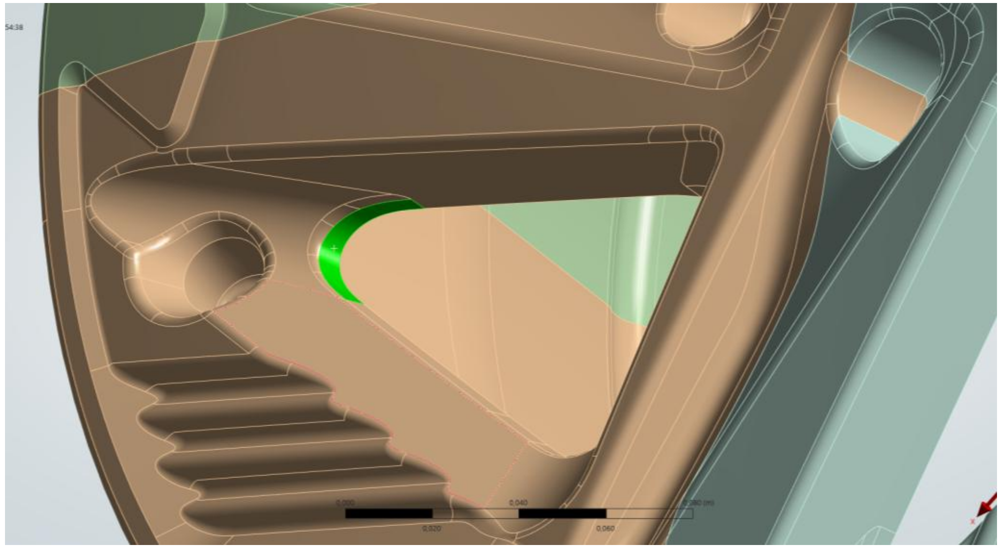

## Legge spostamento in RBF Morph

$$S_{node} = \frac{\sigma_{node} - \sigma_{th}}{\sigma_{max} - \sigma_{min}} \cdot d$$

$\sigma_{th}$ → $80\ MPa$

- The coordinates of the displaced or fixed nodes are passed to the RBF function.
- The RBF function interpolates a known function at discrete points and updates the new mesh.

# BGM OPTIMIZATION RESULTS

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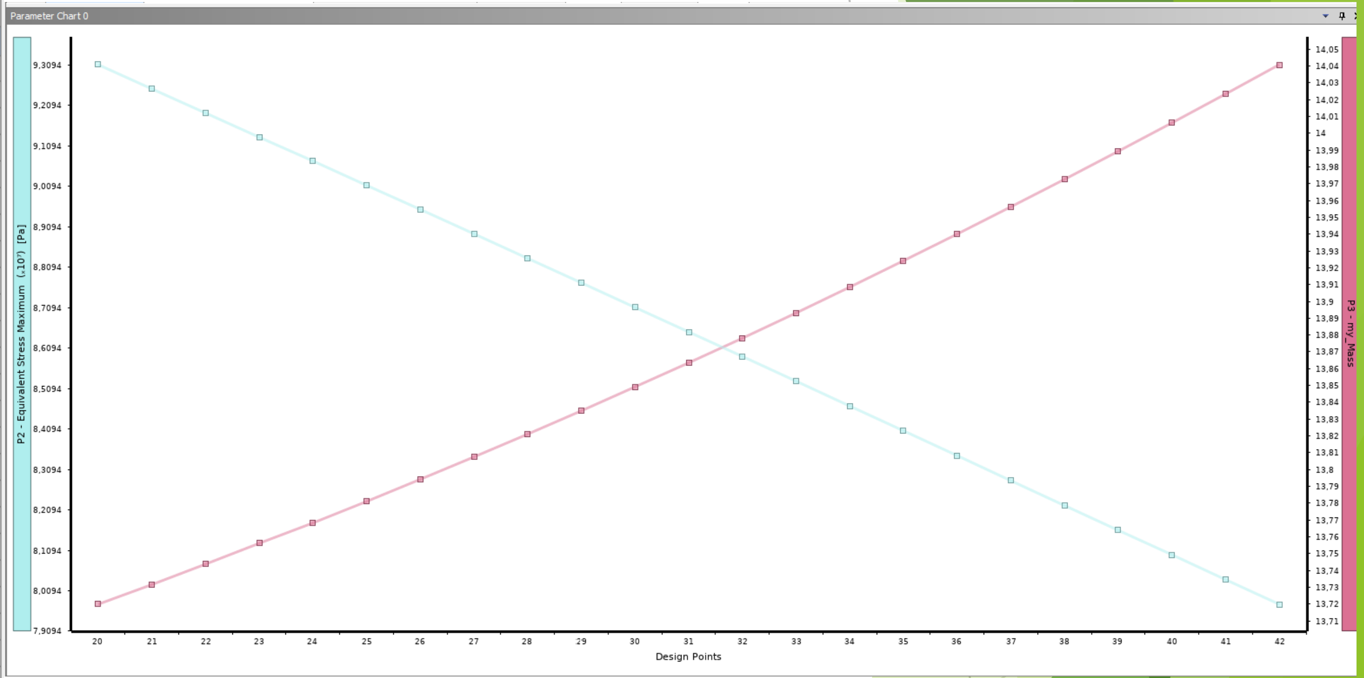
Table of Design Points

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Name | P1 - RBF Morph Set Up Shape ID | P2 - Equivalent Stress Maximum | P3 - my_Mass | ☑ Retain | Retained Data | Note |
| 2 | Units | | Pa | | | | |
| 3 | DP 20 | 0 | 9,3098E+07 | 13,72 | ☑ | ✓ | |
| 4 | DP 21 | 1 | 9,2499E+07 | 13,732 | ☑ | ✓ | |
| 5 | DP 22 | 2 | 9,1903E+07 | 13,744 | ☑ | ✓ | |
| 6 | DP 23 | 3 | 9,1304E+07 | 13,756 | ☑ | ✓ | |
| 7 | DP 24 | 4 | 9,0718E+07 | 13,768 | ☑ | ✓ | |
| 8 | DP 25 | 5 | 9,0115E+07 | 13,781 | ☑ | ✓ | |
| 9 | DP 26 | 6 | 8,952E+07 | 13,794 | ☑ | ✓ | |
| 10 | DP 27 | 7 | 8,8917E+07 | 13,807 | ☑ | ✓ | |
| 11 | DP 28 | 8 | 8,831E+07 | 13,821 | ☑ | ✓ | |
| 12 | DP 29 | 9 | 8,7707E+07 | 13,835 | ☑ | ✓ | |
| 13 | DP 30 | 10 | 8,7097E+07 | 13,849 | ☑ | ✓ | |
| 14 | DP 31 | 11 | 8,6492E+07 | 13,863 | ☑ | ✓ | |
| 15 | DP 32 | 12 | 8,5886E+07 | 13,878 | ☑ | ✓ | |
| 16 | DP 33 | 13 | 8,5275E+07 | 13,893 | ☑ | ✓ | |
| 17 | DP 34 (Current) | 14 | 8,466E+07 | 13,909 | ☑ | ✓ | |
| 18 | DP 35 | 15 | 8,4049E+07 | 13,924 | ☑ | ✓ | |
| 19 | DP 36 | 16 | 8,3436E+07 | 13,94 | ☑ | ✓ | |
| 20 | DP 37 | 17 | 8,2815E+07 | 13,956 | ☑ | ✓ | |
| 21 | DP 38 | 18 | 8,2201E+07 | 13,973 | ☑ | ✓ | |
| 22 | DP 39 | 19 | 8,159E+07 | 13,989 | ☑ | ✓ | |
| 23 | DP 40 | 20 | 8,0986E+07 | 14,006 | ☑ | ✓ | |
| 24 | DP 41 | 21 | 8,037E+07 | 14,023 | ☑ | ✓ | |
| 25 | DP 42 | 22 | 7,9761E+07 | 14,041 | ☑ | ✓ | |
| * | | | | | ☐ | | |

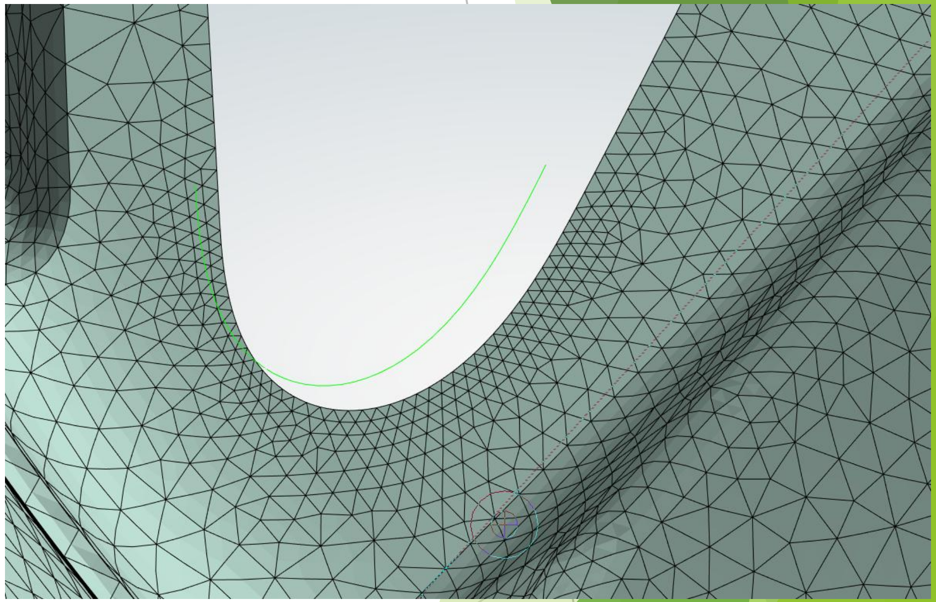



The algorithm will converge to the set target stress, providing a solution at each completed iteration step.

A choice must be made!

# BGM OPTIMIZATION RESULTS

| Configuration | Maximum Stress (*MPa*) | Mass (Kg) |
|---|---|---|
| Baseline | 81,24 | 14,1 |
| Mass-optimized model | 93,10 | 13,72 |
| Selected Configuration (BGM) | 84,66 | 13,91 |
| Last BGM Configuration | 79,8 | 14,04 |



The selected configuration:

- ✓ reduces the overall mass by 1.35% compared to the initial model.
- ✓ keeps the increase in maximum stress within 4% compared to the initial model.

# CONCLUSIONS

- Mass reduction of 1.5 kg;
- Stress redistribution;
- Multiple solutions, all implementable depending on the specific requirements and the relevant industrial context;
- Preservation of the design style.

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