Nicolae Razvan MITITELU, Marius Ionut RÎPANU, Oussama ABDA

INTEGRATING GENERATIVE DESIGN AND FEM IN THE DEVELOPMENT OF OPTIMIZED STRUCTURES FOR AM

Abstract: *This paper investigates the application of Generative Design for the development of a lightweight load-bearing structural arm manufactured from AlSi10Mg alloy and intended for additive manufacturing. The study is based on the definition of functional interfaces, design space, loading conditions, and manufacturing constraints, allowing the algorithm to generate an optimized geometry. The structural performance of the selected configuration is validated through linear static finite element analysis. The results highlight a coherent material distribution along the load paths, a maximum von Mises stress below the yield strength, a safety factor close to the imposed target, and moderate displacement values. The approach demonstrates the capability of Generative Design to produce structurally efficient components with reduced mass.*

Key words: *Generative Design, Fusion 360, structural optimization, additive manufacturing, design space exploration.*

1. INTRODUCTION

The design of structural components subjected to complex mechanical stresses involves striking a balance between often conflicting requirements such as strength, stiffness, mass, and manufacturability. In fields such as the automotive industry, aerospace, and the construction of high-performance mechanical equipment, reducing mass without compromising structural safety has become a priority for development. At the same time, increasing demands for energy efficiency and dynamic behavior of mechanical systems have necessitated the use of advanced computer-aided design methods capable of exploring a much larger number of variants than conventional approaches [1], [2].

Classical structural design methods usually start from predefined standard geometries, beams, plates or profiles, which are then checked for strength. This approach involves a time-consuming iterative process, in which the shape is gradually modified to meet the required conditions [3]. In practice, various methods have been tried for the automatic generation of 3D models, including using artificial intelligence algorithms in various forms, but currently without very great applicable results [4], [5], [6].

This paper analyzes the application of the Generative Design method for the development of a structural component subjected to vertical static stress, characterized by the transmission of forces between two upper loading zones and a fixed lower zone. The component is made of AlSi10Mg alloy, a material widely used in additive manufacturing due to its favorable strength-to-weight ratio and stable mechanical properties in the elastic range.

The objective of the study is not limited to obtaining a functional geometry, but aims to evaluate the structural coherence of the algorithmically generated shape. In this regard, the distribution of material along the stress transmission paths is analyzed, as well as how the resulting solution utilizes the mechanical capacity of the material, avoiding the occurrence of local overloads or excessive deformations [7], [8], [9].

The generated configuration is validated through a finite element numerical analysis in a linear static regime. The purpose of this stage is not to redesign the component, but to confirm its elastic behavior and determine the stress and displacement levels associated with the geometry obtained through Generative Design.

2. METHODOLOGY

The study was carried out in Autodesk Fusion 360, using the Generative Design module to obtain the geometric configuration and the Static Stress module for subsequent numerical validation. The workflow was structured in two distinct stages: shape generation based on geometric and functional constraints, followed by verification of the structural behavior of the selected solution.

The starting point of the study was the creation of the boundary elements as seen in figure 1, to which several constraints and forces were applied.

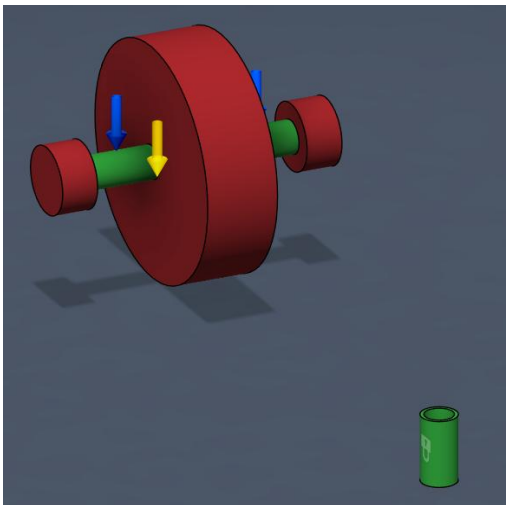


Figure 1. Defining boundary elements and applying constraints.

The assigned material was Aluminum AlSi10Mg alloy, with a yield strength of 240 MPa and a modulus of elasticity of 71,000 MPa, according to the analysis report.

The loading and support conditions used later in the validation were:

• complete fixation on the vertical cylinder interface;

• application of a force of 1000 N in the negative direction of the Z axis;

• inclusion of the gravitational effect.

The design space was modeled as a three-dimensional volume connecting the two parallel bushings with the vertical cylinder. No predetermined intermediate structural shape was imposed and the initial volume had the exclusive role of delimiting the region in which the algorithm can generate material.

In addition, the presence of the wheel and axle as a whole was taken into account, so that the resulting shape did not interfere with these elements. This restriction limited the volume development in certain areas of the design space.

5 3D models were thus generated using the same parameters (Figure 2).

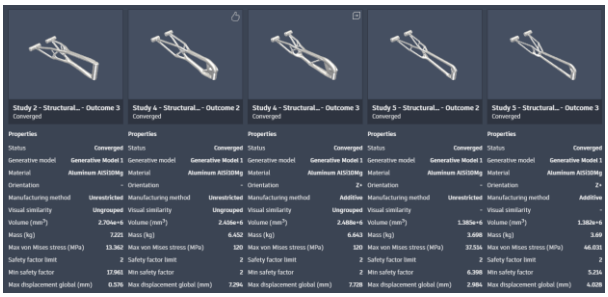


Figure 2 Models automatically generated by Fusion 360.

One of the generated 3D models was then selected for detailed analysis. Thus, as can be seen in Figure 3, for this landmark, the generative process produced several intermediate iterations, observable in the screenshots presented (Iteration 1, 10, 20, 34). The morphological evolution indicates the progressive elimination of material from non-essential areas and the development of two main branches between interfaces.

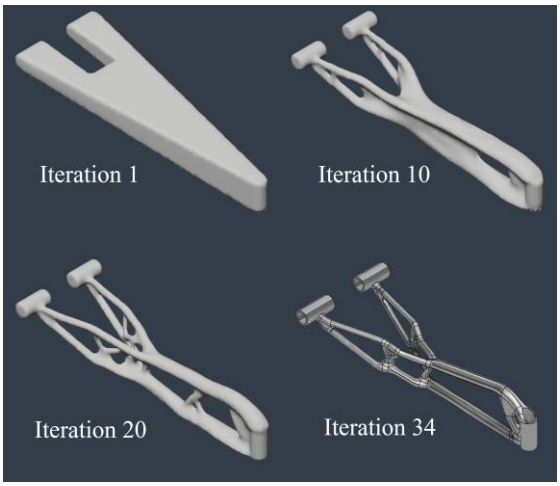


Figure 3 The 3D model at different iterations of the process.

The solution selected for analysis was the one that simultaneously met the following criteria:

• full connectivity between the three interfaces;

• compliance with the required safety factor;

• no interference with the wheel volume;

• compatibility with the selected manufacturing method (Additive).

The generated geometry was converted into a B-Rep solid model to allow structural analysis. The cylindrical surfaces of the interfaces were kept as distinct geometric entities for the correct application of support and load conditions.

The mesh used in the static analysis was generated with parabolic elements, the model containing 24,441 nodes and 13,007 elements. This discretization was considered adequate for evaluating the overall behavior of the part.

3. RESULTS AND ANALYSIS

The generative process led to a progressive evolution of the geometry, observable in the intermediate iterations presented. The initial configuration was characterized by a compact connecting volume between the two parallel bushings and the vertical cylinder. As the algorithm optimized the distribution of material, the central volume was reduced, and the shape evolved into a branched structure.

In the advanced iterations (Iteration 20–34), the material is concentrated in two main branches that start from the area of the two bushings and converge towards the vertical cylinder. The median area between the branches is progressively emptied, leading to a reduction in mass without compromising structural connectivity.

The final shape features an "A-arm" configuration, with two distinct arms joined at a single attachment point (Figure 4).

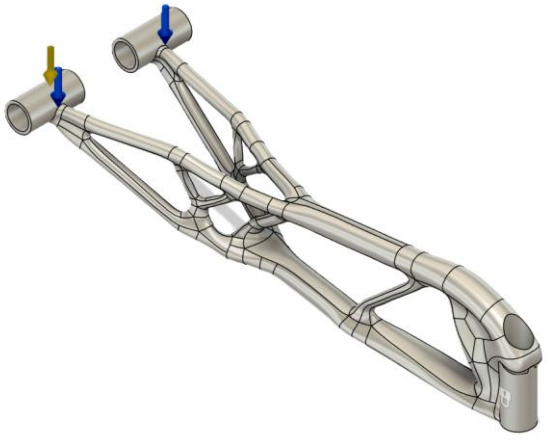


Figure 4 The final 3D model, chosen for study.

The cross-section of the branches varies along the length, with a noticeable increase in thickness near the vertical cylinder.

3.1 Stress distribution

To evaluate the structural behavior of the

configuration obtained through Generative Design, the distributions of the Von Mises equivalent stress and the principal stresses were analyzed, corresponding to the static loading case defined in the study. The vertical force applied to the two parallel bushings and the complete fixation of the vertical cylinder generate a predominantly bending stress regime, with the transmission of stresses from the double end to the singular support point.

The distribution of the Von Mises equivalent stress (Figure 5) indicates a maximum value of 126,868 MPa, located in the convergence zone of the two branches towards the vertical cylinder. This region corresponds to the accumulation point of the load flow coming from the two parallel interfaces. As the stresses are transferred to the support, the two structural paths unify, determining the local increase in the stress. In the rest of the part, the equivalent stress values are distributed uniformly, without critical concentrations or pronounced discontinuities. The values obtained are below the yield strength of the AlSi10Mg material, which confirms the operation in the elastic range for the analyzed regime.

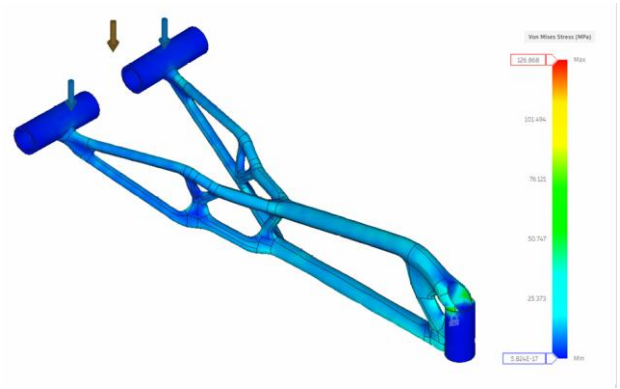


Figure 5 Von Mises equivalent stress distribution.

The distribution of the first principal stress shows a maximum value of 158.62 MPa, associated with the areas in tension (figure 6). These regions are located on the outer side of the upper branch, near the fixing area, suggesting the existence of a significant bending moment.

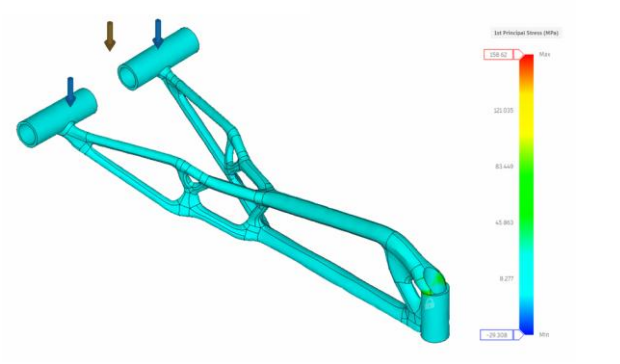


Figure 6 Distribution of the first principal stress.

The resulting structural configuration thus functions as an element subjected to bending, in which one of the extreme fibers is stressed in tension and the opposite fiber in compression. The progressive distribution of the values along the length of the arms confirms the geometric continuity of the part and the absence of discontinuities that could generate excessive local concentrations.

The third principal stress, with a minimum value of -121.71 MPa and a maximum value of 22.147 MPa, indicates the areas in compression (figure 7). The regions with maximum compression are located complementary to the areas in tension, especially near the vertical cylinder and on the lower part of the main branch.

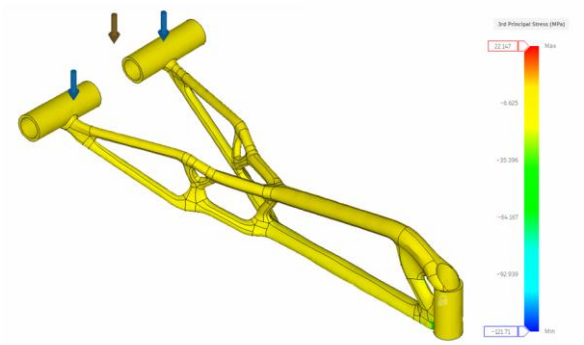


Figure 7 Third principal Stress.

This distribution confirms the combined stress character specific to bending, where tension and compression coexist in the same cross-section.

Overall, the analysis of the principal and equivalent stresses confirms that the shape resulting from the generative process is structurally coherent, distributing the stresses along two main paths without the appearance of isolated critical zones.

3.2 Safety Factor

The minimum safety factor reported is 1.892. This value is close to the threshold imposed in the generative study (FS = 2), which indicates an efficient use of the material (Figure 8).

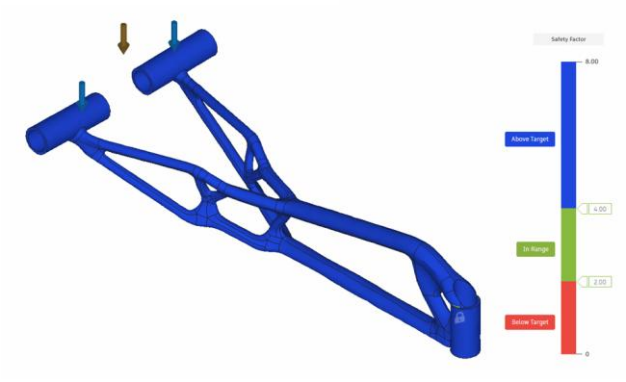


Figure 8 Safety factor simulation.

The safety factor distribution shows higher values in the median areas of the branches and minimum values in the area of convergence towards the vertical cylinder. The absence of regions with sub-unit safety factor confirms that the selected solution complies with the established strength criterion.

3.3 Total displacement

The maximum total displacement obtained in the analysis is 1,733 mm. The maximum value is located in the area opposite the support, in the vicinity of the parallel bushings, where the cross-section is smaller (Figure 9).

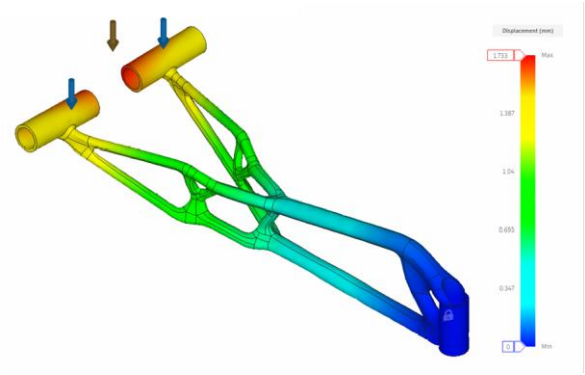


Figure 9 Displacement simulation.

4. CONCLUSIONS

The objective of the work was to apply the Generative Design method to develop a structural arm-type component, defined by three functional cylindrical interfaces and integrated into an assembly with geometric restrictions imposed by the wheel gauge.

The generative result highlights a branched "A" type configuration, in which the material is distributed in two main arms that connect the parallel bushings with the vertical clamping cylinder. The morphological evolution observed in the intermediate iterations confirms the progressive elimination of non-essential volume and the concentration of material in the areas necessary to ensure connectivity and rigidity.

The correlation between the geometric morphology and the stress distribution highlights the fact that the thickening of the section in the area of the vertical cylinder corresponds to the region with higher stress, and the progressive thinning of the branches towards the bushings is compatible with the reduced level of stresses in that area. The resulting shape is not arbitrary, but directly determined by the relative position of the interfaces and the conditions imposed in the study.

The results obtained demonstrate that, in the analyzed case, the Generative Design method allows obtaining an efficient geometry in terms of material use, while simultaneously respecting the functional and geometric constraints of the assembly. The subsequent integration of the FEM analysis as a validation step confirms the adequacy of the solution for the considered loading regime.

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Author(s):

PhD. student, Nicolae-Razvan MITITELU, "Gheorghe Asachi" Technical University of Iasi, Department of Machine Manufacturing Technology, Romania nicolae-razvan.mititelu@student.tuiasi.ro

Asst. Prof. PhD. Eng, Marius-Ionut RIPANU, "Gheorghe Asachi" Technical University of Iași, Romania, Department of Machine Manufacturing Technology,Romania, marius-ionut.ripanu@academic.tuiasi.ro

PhD. student Oussama ABDA, Laboratoire de Modélisation Simulation et Optimisation des Systèmes Complexes Réels, Faculty of Sciences and Technology, University of Djelfa, PO Box 3117, 17000, Djelfa, Algeria, oussama.abda@univ-djelfa.dz