

Integration of Topology Optimisation for Additive Manufacturing

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Abstract

Topology optimization has emerged as a distinct field of research in recent years, not only because it piques the intellectual community's interest but also because it delivers substantial solutions to real-world industrial challenges. Topology optimization is used to develop a lightweight product while satisfying functional requirements for a new product or a redesign of an existing product. The layer-by-layer fabrication of geometrically challenging components by additive manufacturing greatly reduces the complexity constraints placed on topology optimization by the previous subtractive approach. This viewpoint article enlists the compassion of these two strategies as they collaborate. The document compiles the approach as well as the benefits and drawbacks of the optimization process. A consideration of lightweight design and continuum optimization resulted in a weight reduction of 65% and the utilisation of grid-like ground structures. The purpose is to inspire both researchers and engineers to devise innovative answers to today's challenges in this sector.

Keywords: *Additive Manufacturing, Continuum Optimisation, Lightweight Design, Topological Optimisation.*

INTRODUCTION

Topology optimization is a comprehensive design approach for determining the best structural configuration by rationally

allocating materials while retaining specified load conditions, performance, and constraints. By addressing a material distribution issue, this approach provides

an optimum topology. It discards material that is not exposed to stress using specialised software, making the product more cost-effective to create. The initial advances in topology optimization were made using subtractive or formative manufacturing techniques.

These traditional manufacturing technologies are limited in their capacity to manufacture complex geometries due to their specific production restrictions. However, with manufacturing breakthroughs in the form of additive manufacturing, the intricacies in the geometries might be added, making it the best customer. Because additive manufacturing does not require any form of tool motion to build an object, layer-by-layer printing may constrain the complexity of geometry.

This process is based on layer-by-layer material deposition, which significantly lowers the geometric complexity barrier. From the standpoint of geometric complexity [18], both manufacturing performance and production costs are unaffected.

Topology optimization produces lightweight components while maintaining strength. Topology optimization combined

with additive manufacturing enables the production of light-weight and complicated systems. It relocates the material within the design space and eliminates the need for outside barriers, resulting in an organically formed component that bears little resemblance to its heritage counterpart and is significantly lighter in weight. STELIA Aerospace used fast prototyping and topology optimization to build sturdier fuselage panels for aero planes. More than just creating a physical product, additive manufacturing prioritizes design and innovation. One of the primary benefits of additive manufacturing is the freedom to be creative without regard to cost or time limits. By using less material and removing superfluous procedures, additive manufacturing may significantly reduce energy usage as compared to traditional production.

With the continued improvement over the previous three decades, topology optimization has yet to find its footing and has been chastised for its organic character owing to manufacturing constraints. It is difficult to verify that a topologically optimal design is also manufacturable and visually pleasing (contrasts from what a mechanical part would look like in the typical sense).

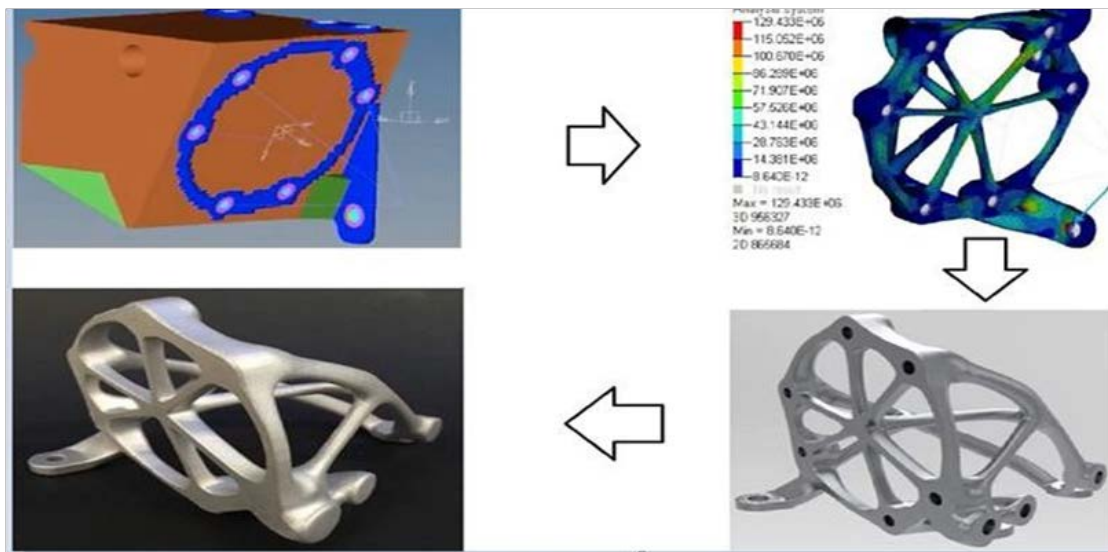


Figure 1 Stages in Topology Optimisation [16]

Approach of Topology Optimisation

Topology Optimisation Strategic Methodology

In topology optimization, CAD is used to create a rough or initial model of the item to be optimised, whilst Finite Element Analysis is used to determine how stresses and displacements are distributed across the product. The Solid Isotropic Material with Penalization (SIMP) approach, Evolutionary Structural Optimization (ESO)/Bidirectional Evolutionary Structural Optimization (BESO) method, and level set method have emerged as the three major achievements in topology optimization [21]. It is used to remove components that are not efficiently bearing the imposed loads, are not undergoing considerable deformation, and so do not contribute to the overall function [16]. The process of optimisation begins with

developing the model using CAD software and optimising it till the desired design is reached. The topology optimization tools construct a sophisticated natural form based on the objectives and constraints provided in the design challenge. The design is then finalised on CAD software to generate a smooth and manufacturable part based on the form acquired by the topology optimization technique. Finally, using Finite Element Analysis methods, the final optimised design is assessed to confirm that the product meets its overall performance objectives [16].

Initial Steps of Optimization-

1. **DESIGN:** The procedure begins when the design has been finalised on the CAD programme, which meets the basic performance criteria and acts as the foundation for the optimisation process.

2. **CONSTRAINTS:** The beginning circumstances of the optimization need the use of boundary conditions; the design space is the area in which the optimization process occurs. This region is the existing design's border. The algorithm exclusively removes content from this location. The Part capability allows the user to select the load conditions and fixed points, as well as the material of the item to be optimised. Part of the functionality process is repeated as the load and the points change.
3. **MESHING-**The optimised object is transformed into a mesh. It lets the user set many element attributes such as mesh quality (fine or coarse), element form and size, and so on. The coarser the grid, the less accurate the findings are, and the simulation is done quickly.
4. **OPTIMISATION VARIABLE-**
 - a) **Desired Weight-** When the required weight is reached, the optimization procedure ends. This desired weight is an input variable around which the optimisation process revolves, but it fails to operate when a maximum weight reduction is required.
 - b) **Number of Runs-** The number of runs that can be put up to finish the optimization process in a given amount of time. Unless the time required for optimization is uncertain.
 - c) **Convergence-** The convergence criteria allow the optimization to be stopped after two to three iterations if the sum of the two output weights is less than the preset value.
 - d) **Factor of Safety-** It describes the maximum or least amount of stress that the targeted product can withstand.
5. **FINAL PRODUCT-** Steps one through four are carried out in order to obtain the optimised components. Finite Element Analysis is performed on the optimised part to check that the stresses and deflections are within the prescribed limits.



Figure 2. Flow Chart of Product Manufacturing

CASE STUDY-

Continuum Optimisation-

In this work, a review of structural steel design employing topology optimisation for its approach up to form and size alone [12] was conducted. Topology optimisation is simple to express in terms of shape and size, but it is limited by changeable cross section, product geometry, and some pre-defined restraint variables. A major topic in structural optimization is reliability-based optimization, which takes into account inconsistencies in geometric dimensions, material characteristics, stresses, operating circumstances, and so on that arise in real engineering problems. Numerous dependable approaches, such as probability methods and interval methods, have been presented up to this point [19]. It does, however, strive to improve on the present design. It is worth noting that topology optimisation is not limited to physically homogenous volumes. It might be applied to a heterogeneous material like a composite or microstructurally produced material. Steel weight is lowered by 18% to 75%, which has a significant impact on steel construction. However, when it comes to structural steel interconnections, the reduction is usually 12% to 25%, which is the majority of the total weight of the steel structure, and its design concept

has a significant impact on its weight and effectiveness, making it particularly susceptible to topology optimisation. The continuum topology optimization approach has been successfully developed during the last few decades. It may also be used to create grid-like "ground structures" using one-dimensional pieces. Continuum structures are one-dimensional ground structures that are subjected to discrete optimization. The optimisation is limited to the form and size, with the goal of finding the ideal number, size, shape, coordinates of the nodes, and structural element connection. As a result, it is often referred to as truss topology optimisation or skeletal structure topology optimisation. One of the primary difficulties is the optimization of nodes [12]. These optimization strategies work for solids and shells with defined boundaries.

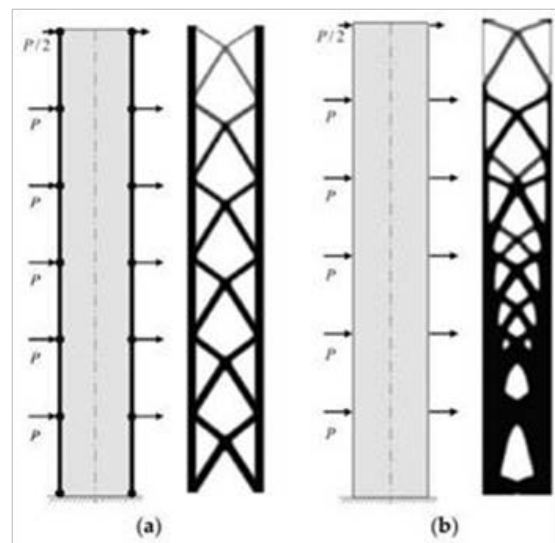


Figure 3. (a) Discrete optimisation (b) Continua Optimisation [12]

Lightweight Design-

In this work, an evaluation of a jet engine bracket was conducted to demonstrate its weight reduction benefits and the use of additive manufacturing techniques for production reasons [16, 25]. The stress distribution was investigated using finite element analysis, and the Von Mises distribution contour was displayed. The programme displays a blue region indicating that the material that has to be removed has a negligible influence on the performance of the parts. The bracket is exposed to four different load circumstances, with the goal of reducing its weight to a manageable level. The

bracket's material properties are as follows:

1. The material used is Ti-6Al-4V with a strength of 904MPa at a 23 degree C temperature.
2. The diameter of the pin is 1:19 mm.
3. The pin's stiffness is infinite.
4. The maximum diameter of the nut face is 10.287 mm (inner diameter) and 14.173 mm (minimum outer diameter).

The optimisation is subject to minimising the weight of the bracket.
Subject to

1. 30% mass fraction
2. Minimum feature size: > 1.13 mm.

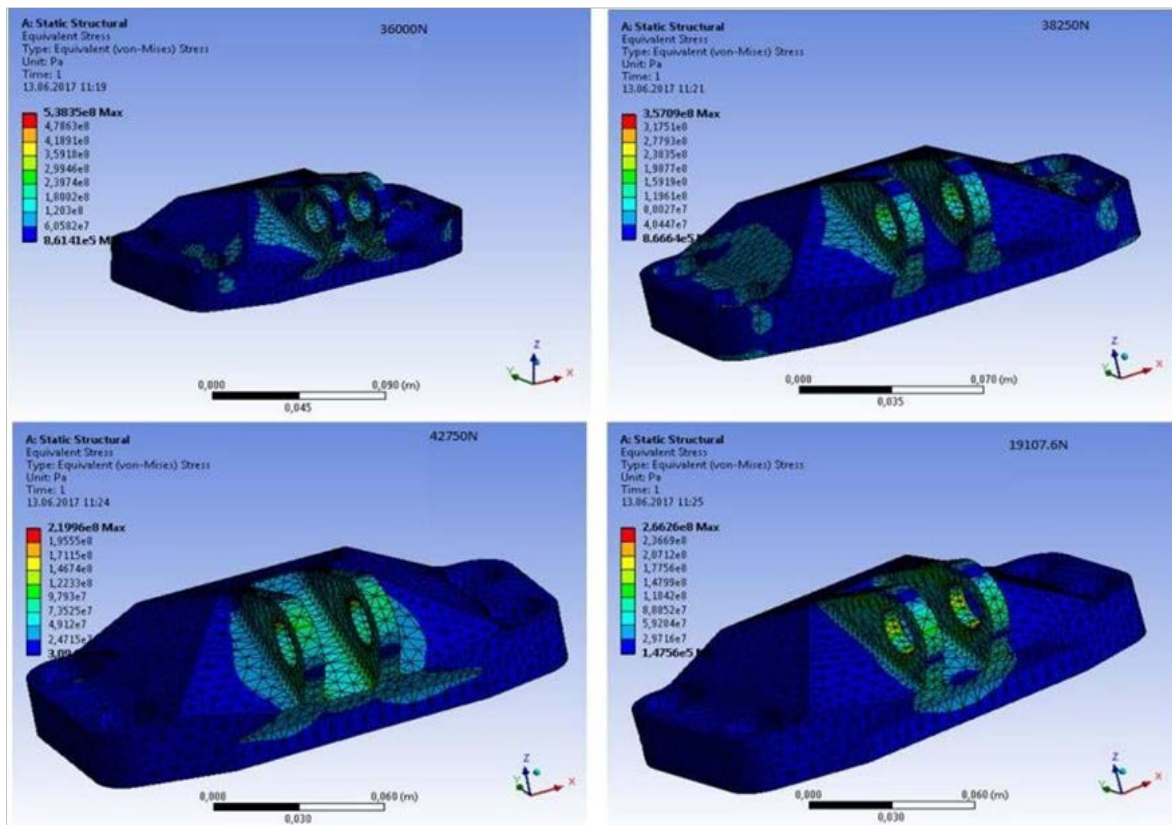


Figure 4. Von Mises distribution contour plot marked by blue [16]

The optimisation process begins by splitting the design into two parts: the design space and the non-design area, where the topology optimisation tools operate. These areas are then meshed using the commercial Altair Hypemesh 14 Optistruct software's meshing tool, with a fine mesh of 0.25 mm element size. The non-design areas are then exposed to loading circumstances and limitations, with two equal couple forces delivered in opposite directions instead of torque. The topology optimisation tool analyses the

distribution of applied stresses and displacement for all loads separately. The programme eliminates the locations with negligible loads based on the stress and displacement distribution. A crude geometry is generated, which is later redesigned to provide a pleasing and appealing appearance. Figure 10 [16] depicts the finalised design, which was built in Autodesk Inventor Professional. The mechanical load is supported by this final design in accordance with the precondition requirement.

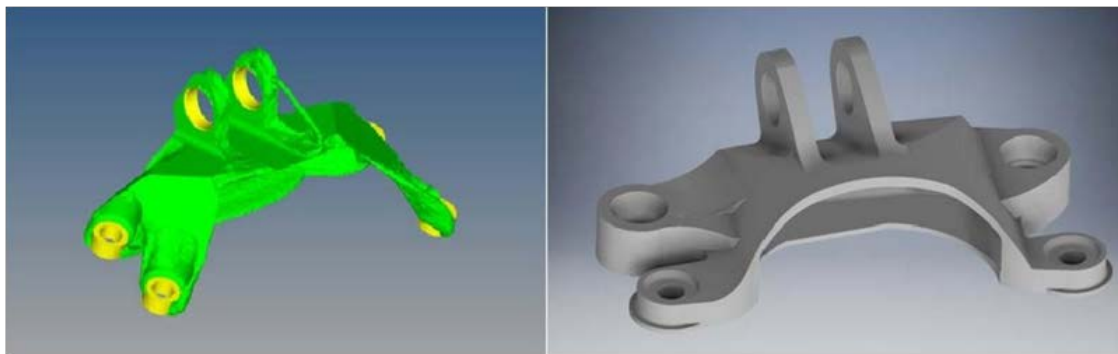


Figure 5. Optimal Geometry and Remodeled design [25]



***Figure 6. Engine Bracket after Fused Deposition Modelling
(Additive Manufacturing) [16]***

This structural verification is carried out using the ANSYS R17 Academia Educational Tool programme, and the von Mises stress value is examined and compared to the yield strength of the material utilised. After the design has been thoroughly stress-tested, it is built using a fast prototyping approach based on fused deposition modelling (FDM). Figure 12 [16] depicts the end product, and it can be observed that the jet engine bracket resulted in a 65% weight reduction. The weight has been lowered from 2.067 kg to 0.72 kg.

CONCLUSIONS

A full overview of the Topology Optimisation approach was investigated here, as well as its relationship with additive manufacturing. The strategic planning of the optimising approach has been thoroughly studied so that it may be easily understood. This study has looked at its advantages and disadvantages. According to the case study, continual optimization is limited to modifying cross section and size. Attempts have been made to improve the present product. It is now possible to apply it to both homogeneous and heterogeneous materials. The second case study demonstrates how the redundant stress-free component of the product may be removed and therefore the

weight reduced. The jet engine bracket's weight has been reduced by 65%, from 2.067 kg to 0.72 kg. Overall, topology optimization, in conjunction with additive manufacturing, is critical in the design and manufacture of lightweight objects for use in a range of sectors.

Future Scope

The expected use of Additive Manufacturing is the most powerful motivator for incorporating Topology Optimisation into design practise. For waste management, this strategy should be employed in the majority of production sectors. It can have a role in space science by producing satellites and rockets. Furthermore, with greater complexity, the software tools should be able to finish the optimization procedure in a reasonable amount of time.

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