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nTopology Optimization of an Additive Manufactured Support for Smart Glasses

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Abstract

This study delves into optimizing support for Vuzix smart glasses using innovative techniques. By customizing the design for comfort and ergonomics, emphasizing lightweight yet durable materials (Onyx), and employing Fused Filament Fabrication, the research aims to enhance user experience and product longevity, as well as focusing on optimizing the support structure to strike a balance between these essential characteristics. Utilizing cutting-edge software like Fusion 360 and nTopology ensures precision in CAD modeling and validation through simulation, aligning with market demands and driving innovation in wearable technology. A static analysis simulation was also performed to validate the different models made. In the course of this study, generative design and mass usage optimization techniques were applied, resulting in a 31% weight reduction in the hybrid model and 47% in the optimized model, through lattice structures and topological optimizations. While static simulations identified the higher value of stress and displacement in the optimized design, deformation remained consistently low across all models.

1. Introduction

The fast development of Additive Manufacturing (AM) technology over the past few decades has been remarkable, and it is expected that this development will continue. This technology has benefits over conventional production techniques, such as its flexibility, dependability, energy usage, and material efficiency. The first method of building three-dimensional structures layer by layer, rapid prototyping, was developed in the 1980s. This approach involved utilizing CAD (computer-aided design) software to create models and prototype components. However, due to the increase in the development rate and the number of studies being done to advance it, this technology began to be utilized to create finished components and prototypes. ISO describes AM as a “technology that, based on a geometrical representation, normally a 3D model data, creates physical objects by successive addition of material usually layer upon layer, as opposed to subtractive and formative manufacturing methodologies" (ISO/ASTM 2015; Wong and Hernandez 2012).

In recent years, this manufacturing technology has been incredibly competitive when producing small numbers of highly customized components. Compared to subtractive manufacturing, AM enables the fabrication of highly complex components with any shape, combined with the reduction of the product development time, reducing the product development cycle (Colombo Zefinetti et al. 2023; Wong and Hernandez 2012).

However, AM has significant limitations that must be improved in a larger market. These issues include the variety of materials and alloys that can be applied in this process, the production rate, the cost of the necessary equipment, and the fact that some techniques give inefficient surface finishing (Wong 2012).

A CAD file, which enables the user to describe the shape and size of the component that will be made, is required before producing a part using AM technology. The design of this file can be created from scratch in a computer drawing program, or it can be extracted from an item using 3D scanning methods like tomography, product scanning, or magnetic resonance imaging. AM requires numerous processes, from the CAD description to the real final part. Additionally, AM is used when the early stages of the product development process need rough components because of how quickly they can be created. Later in the process, parts could require rigorous cleaning and post-processing before they can be used (Gibson et al. 2021). Figure 1 represents a scheme of usual steps in developing an AM part, from the initial idea to the final product (Bian, Shamsaei and Usher 2017).

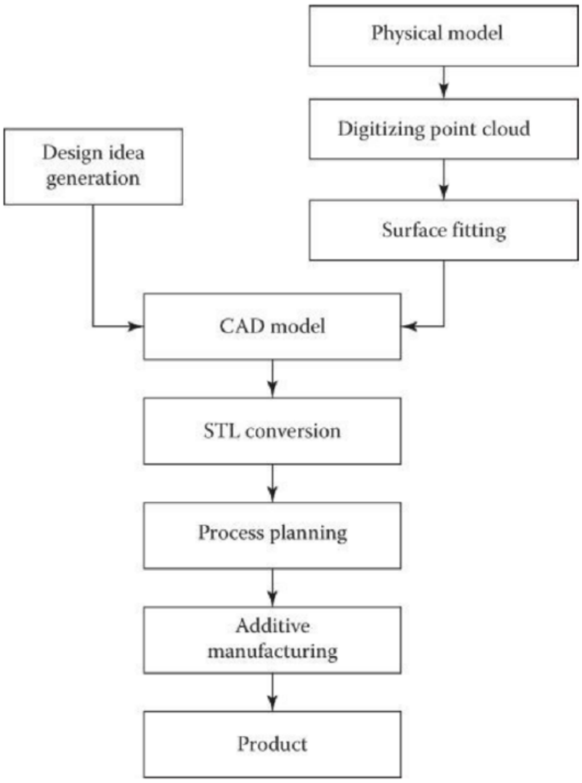


Figure 1: Steps of producing an AM part.

Among the additive manufacturing processes (Figure 2), there is a process that is known for "material being selectively dispensed through a nozzle or orifice," called Material Extrusion (MEX) (ISO/ASTM 2015; Costa et al. 2021). Fused Filament Fabrication (FFF) is a 3D printing method to produce parts using building materials in filament form, inserted in the material extrusion types, as seen in Figure 2.

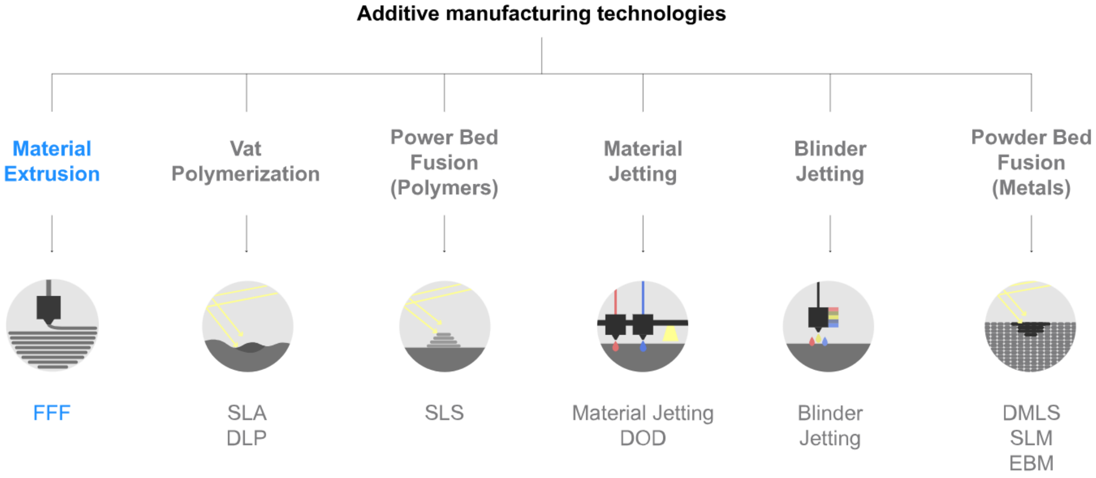


Figure 2: AM technologies.

A big filament coil is fed into an extruder, a moving heated print head, where it melts and is driven out of the nozzle. It is subsequently deposited on the growing workpiece, and the item is built up layer by layer using computer-controlled nozzle motions, as demonstrated in Figure 3 (Herderick 2011; Gonzalez-Gutierrez et al. 2018; Hia et al. 2023).

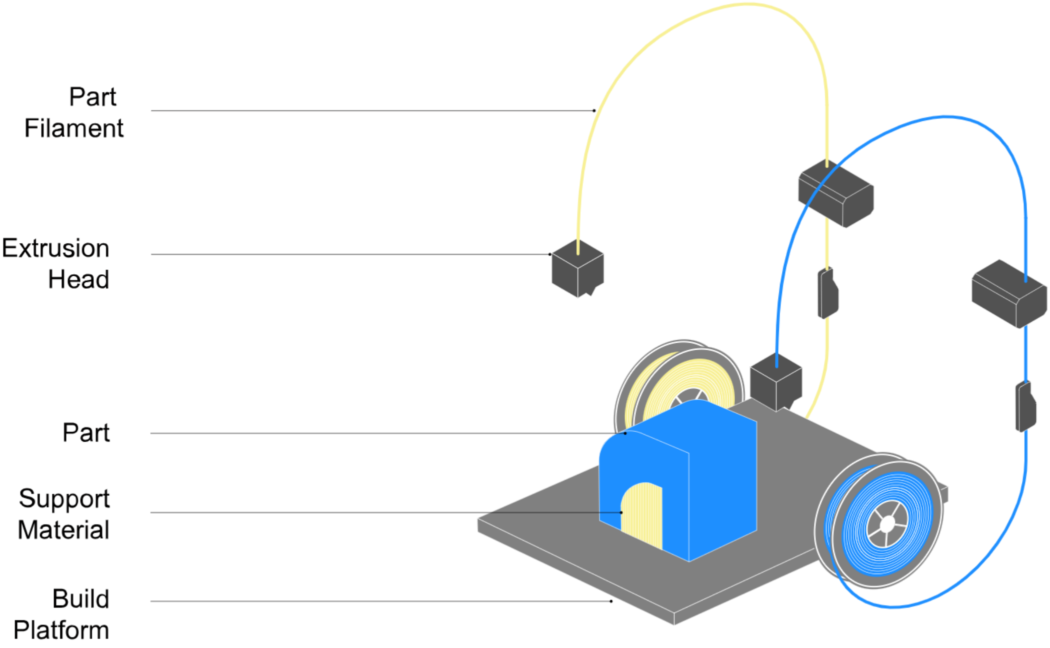


Figure 3: FFF AM process.

This technique allows the simultaneous use of two filaments to create composites from two different materials and form a single component. For this purpose, two separate extruders are used, one for each filament, producing a composite item a layer at a time, on the deposition plate, according to this process. Using as an example of manufacturing a part made of a composite of plastic with carbon fiber, according to the chosen arrangement, the first nozzle creates the plastic matrix. In contrast, the second wrap the fiber simultaneously but one at a time. Fiber composite parts can be produced using a variety of AM processes. However, MEX is the most preferred technique since it provides a more straightforward and affordable approach to creating these composites because the reinforcement can be precisely positioned, and each layer of the laminated structure may be adjusted (Shanmugam et al. 2021; Costa et al. 2021). Additionally, since it does not use the conventional flat layer architecture, it permits changing the fiber orientations in all dimensions to meet the component's requirements better while providing a new level of design freedom. Markforged is one of the leading businesses creating commercial 3D printers that can handle continuous fiber reinforced in composite materials (Blok et al. 2018). This process may manufacture parts with a complex geometry in one piece without needing further tool changes or pressures. Fused Filament Fabrication is appropriate for more expensive materials since there is virtually no production-based material waste (Costa et al. 2021; Gibson et al. 2018).

DfAM (Design for Additive Manufacturing) summarizes several techniques and instruments used to create additive manufacturing components, even though there is no agreed-upon definition. For DfAM, topology optimization, a sub-field of structural optimization, is one potential design technique. Topology optimizations are appropriate for AM due to possible savings in weight, cost, and build time (Kneissl et al. 2022; Mata, Pinto and Costa 2023; Meng et al. 2020; Naik, Shanmugam and Desai 2022).

Structural optimization, used in product design, effectively achieves stiffness, strength, and endurance-fulfilled designs at the component level. Even though it is a cutting-edge method for creating topologically optimum designs, additive manufacturing was destined to fail when printing some parts containing voids and overhang features since these areas have high-stress concentrations. The conceptual design seeks a better material distribution by forming, merging, and dividing internal voids throughout structural evolution. Structural performances and manufacturing-related restrictions are the two main factors influencing the design requirements (Meng et al. 2020; Oliveira, Maia and Costa 2023).

A hands-free platform for accessing digital information and teamwork tools is provided by the Vuzix M300 Smart Glasses (Figure 4), which was designed to help in current processes and create new ones in the supply chain, industrial, medical, and other areas. These smart glasses can be ergonomically designed and are constituted by a monocular display, integrated processing, internal storage, recording functions, and robust wireless connectivity. The HD camera may be used as a barcode scanner and record, store, and play images and video. Apps can access the current view's position, direction, and angle due to integrated head tracking and GPS technology, giving situational awareness. It incorporates the adaptability of improved battery packs for prolonged, high-intensity use and light batteries for intermittent and low-intensity use (Vuzix 2017).

Figure 4: Vuzix M300 smart glasses.

2. Materials and Methods

2.1. Onyx

Markforged Onyx composite is used in 3D printers. Onyx is made of resilient nylon combined with micro carbon fiber that may be used to 3D print stiff and sturdy objects. The Onyx micro-carbon reinforcement fibers provide 3D printed products with a high-quality surface finish and add stiffness to the pieces, making this material almost twice as strong as ABS. This material's engineering toughness and wear resistance are equivalent, and it has a heat deflection temperature of 145ºC. The 3D printed products' strength may reach astounding heights using Onyx and composite fibers. The mechanical and physical properties of this material can be seen in Table 1. In addition to the material characteristics, Onyx also has a nice feature called dimensional stability, which implies that the parts will match the CAD model more accurately (Markforged 2022b, 2022a; Fernandes et al. 2021; Blok et al. 2018).

Property	Tensile Modulus (GPa)	Tensile Stress at Yield (MPa)	Tensile Stress at Break (MPa)	Tensile Strain at Break (%)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Density (g/cm3)	Poisson ratio
Onyx	2.4	40	37	25	71	3.0	1.2	0.43

Table 1: Markforged Onyx Properties

Using this material in fused filament fabrication, the composite filament, made of microscale carbon fibers contained in a polymer matrix, becomes malleable when heated and is subsequently extruded. Once the material exits the extruder and begins to cool down, the micro-carbon reinforcement alters its behavior due to the lower thermal deformation and the faster heat dissipation inside the material. The stiffness of the part is increased by adding short fibers to the Onyx printing filament, but the strength gain is constrained since fiber pull may occur before fiber breaking. There is no need to post-process the components frequently because of the excellent surface polish and dimensional stability (Markforged 2022b, 2022a; Fernandes et al. 2021; Blok et al. 2018).

2.2. Process of Manufacturing smart glasses support

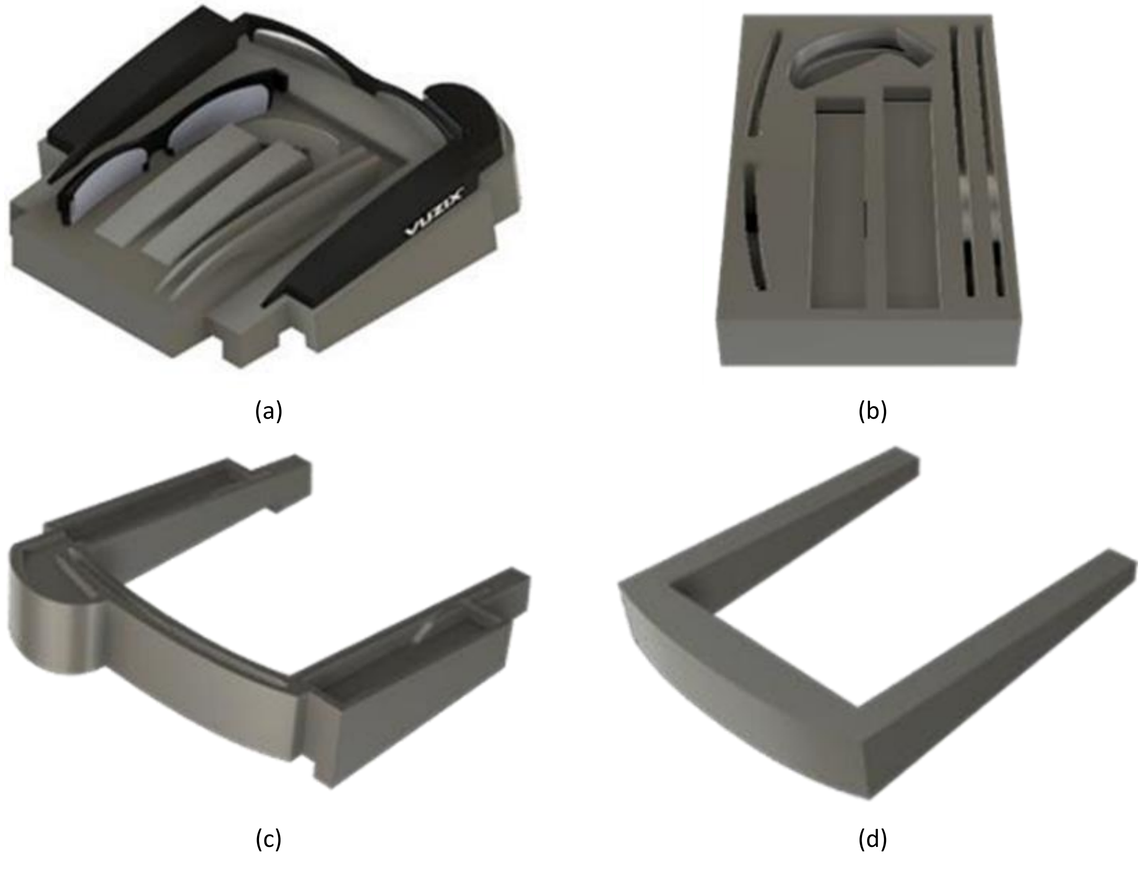
In the first approach, a CAD model, like the smart glasses design, was imported (Figure 5a), where some modifications were made using Fusion 360. Namely, a camera was adapted to the glasses, and the batteries were resized to dimensions closer to reality, among other minor adjustments needed. The result, presented in Figure 5b, represents a CAD model adapted to the Vuzix smart glasses model.

(a) (b)

Figure 5: Smart Glasses CAD model: a) Imported model. b) Redesigned model (Vuzix M300).

The design of the initial support was also accomplished using Fusion 360. It consisted of creating a piece to support, store, and simultaneously ensure the safety of the Vuzix glasses when they are not being used. Thus, all the components inherent to the glasses were separated and oversized to generate cavities in the mold for the correct fit of these. Figure 6a shows the model all assembled.

This model has three principal components: the inner support, which is divided into compartments, each with the appropriate measures for every part, to be able to store them when disassembled (Figure 6b); The external support, which is designed for storing the glasses all assembled (Figure 6c); and finally, the linking component, that makes the connection between the inner and the external support (Figure 6d).



(a) (b)

(c) (d)

Figure 6: Initial model: a) components all assembled. b) Inner support. c) External support. d) Linking component.

The hybrid model was created through optimizations in the internal support and linking component, maintaining the external structure with its initial shape, as shown in Figure 7. Regarding the inner support, the interior of the support was modified to a lattice structure. To preserve the compartments and ensure that the glasses, when stored, were not exposed to anything that could damage them, it was necessary to create over-thickness in the areas that had direct contact with the smart glasses' components.

Regarding the linking component, a topological optimization was performed, which aimed to decrease the volume of the component, and an infill gyroid was implemented, a structure combining stiffness with a higher printing speed.

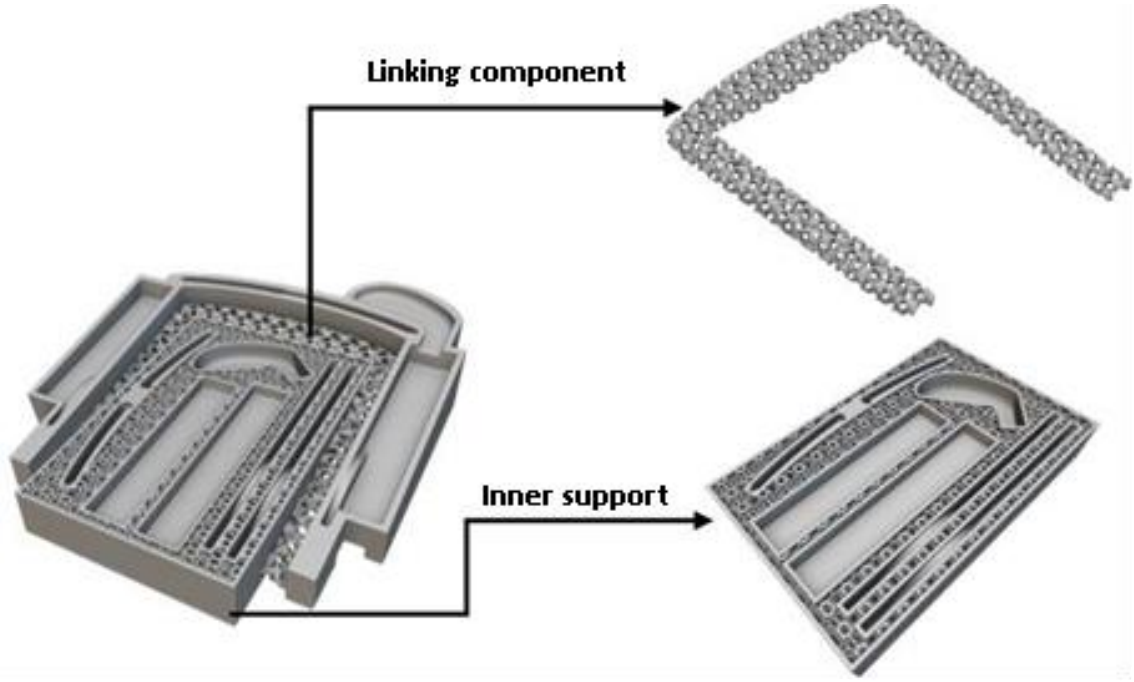


Figure 7: Optimized components in a hybrid model.

Regarding the exterior support of the glasses, a topological optimization was performed to reduce weight and eliminate unnecessary mass. This was done through the selective subtraction of the material, by the software, after the definition of boundary conditions, which were all the faces in contact with the surface where the support will be placed, and all the bottom faces of the compartments that are in direct contact with the glasses components. These constraints are set to maintain structural compliance. Figure 8 illustrates the optimized outer support (Figure 8a) and the same component assembled into the rest (Figure 8b) of the part.


(a) (b)

Figure 8: Optimized model: a) external support. b) all components assembled.

Concerning the validations for the models created some simulations were performed. However, these only portray static analysis since, in this case, the component will be mainly subjected to the forces associated with the weight the smart glasses exert. The process of developing optimizations is iterative, so each alteration in a design necessitates verification. In this instance, the goal of the aforementioned optimizations is to reduce the weight and volume of the support models while retaining the part's structural integrity when used. The initial model was examined to set a comparison with the optimized and hybrid models, where maximum displacement, maximum stress and maximum deformation were analyzed through static analysis simulation.

3. Results and Discussion

3.1. Light weighting of the initial model

The concept of lightweight consists in removing material from an assembly or a single part to make it lighter. In this way, the results were analyzed according to the topological optimizations in each component in the different models and, therefore, the amount of weight loss in the optimized models (hybrid and optimized). As the initial model did not present any topological optimization or changes in the design, it was used as a reference for comparing the models (Figure 9).

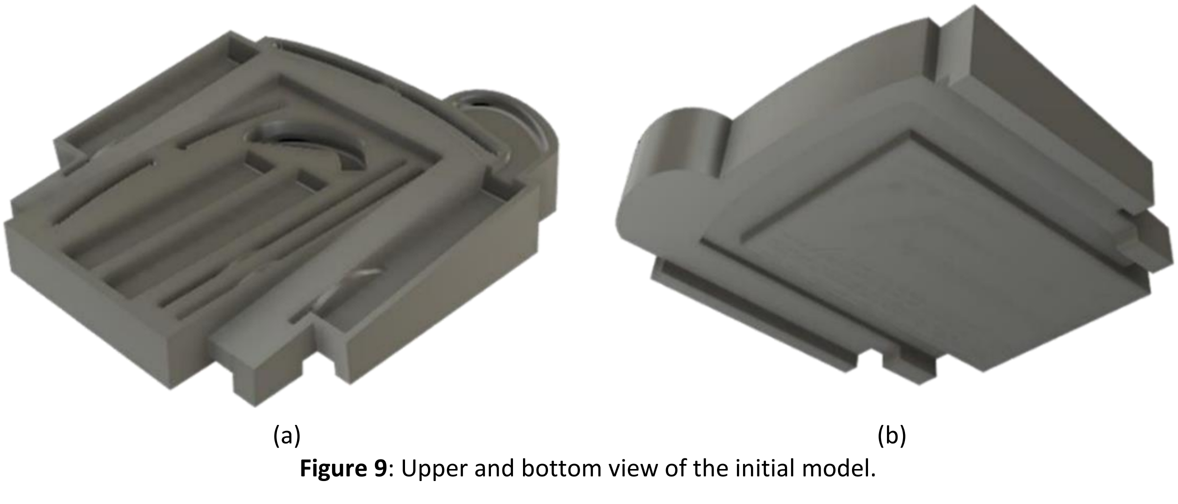

(a) (b)

Figure 9: Upper and bottom view of the initial model.

In the hybrid model (Figure 10), a lattice structure was applied inside the inner support, reducing the weight of the component, achieving a reduction of 32% when comparing the volumes of this component before and after the implementation of the lattice. Regarding the linking component, the application of the infill gyroid design, combined with topological optimization, revealed a weight loss of around 90%, allowing the creation of a lighter part with stiffness. By analyzing the hybrid model as a whole and comparing it with the initial model, it was demonstrated that optimizing the inner support and the linking component reduces the weight by about 31%.

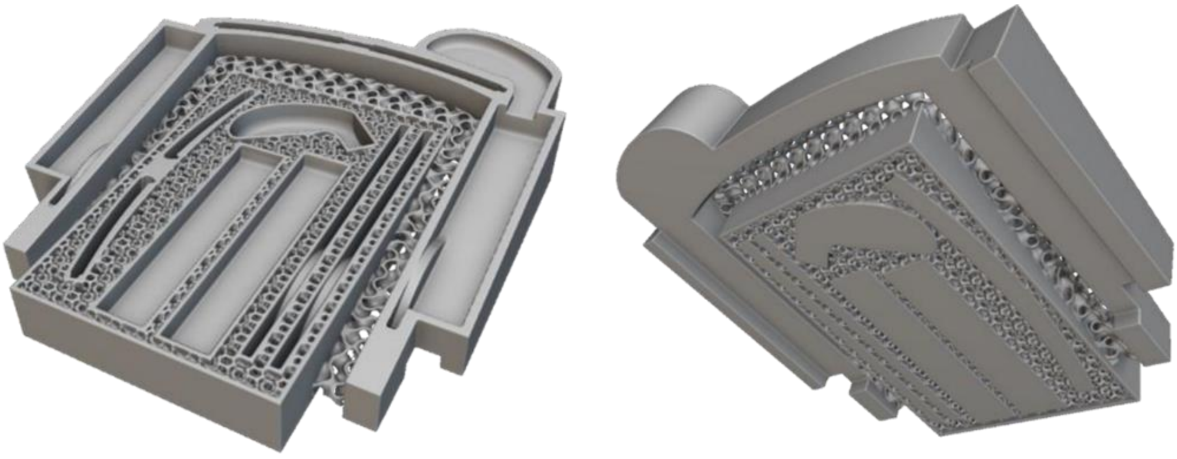

(a) (b)

Figure 10: Upper and bottom view of the hybrid model

The topological optimization of the external support performed in the optimized model showed a weight reduction of approximately 66% while maintaining a structure capable of supporting the glasses. Finally, combing all the optimizations achieved of both inner and external supports, and the linking part, the result of the complete support is presented in Figure 11, having a weight decrease of approximately 47% compared to the initial model. The material loss induced by the topological optimization was remarkable and more significant than the one performed in the hybrid model (31% reduction).

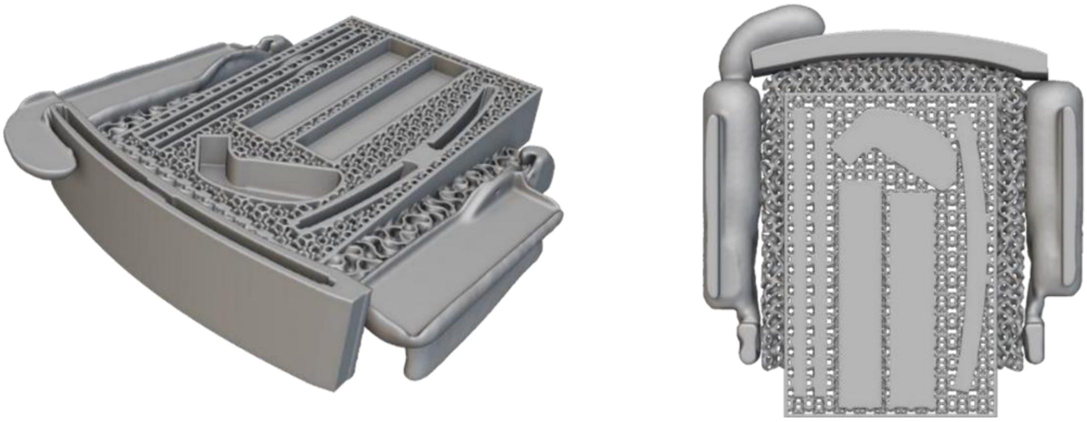
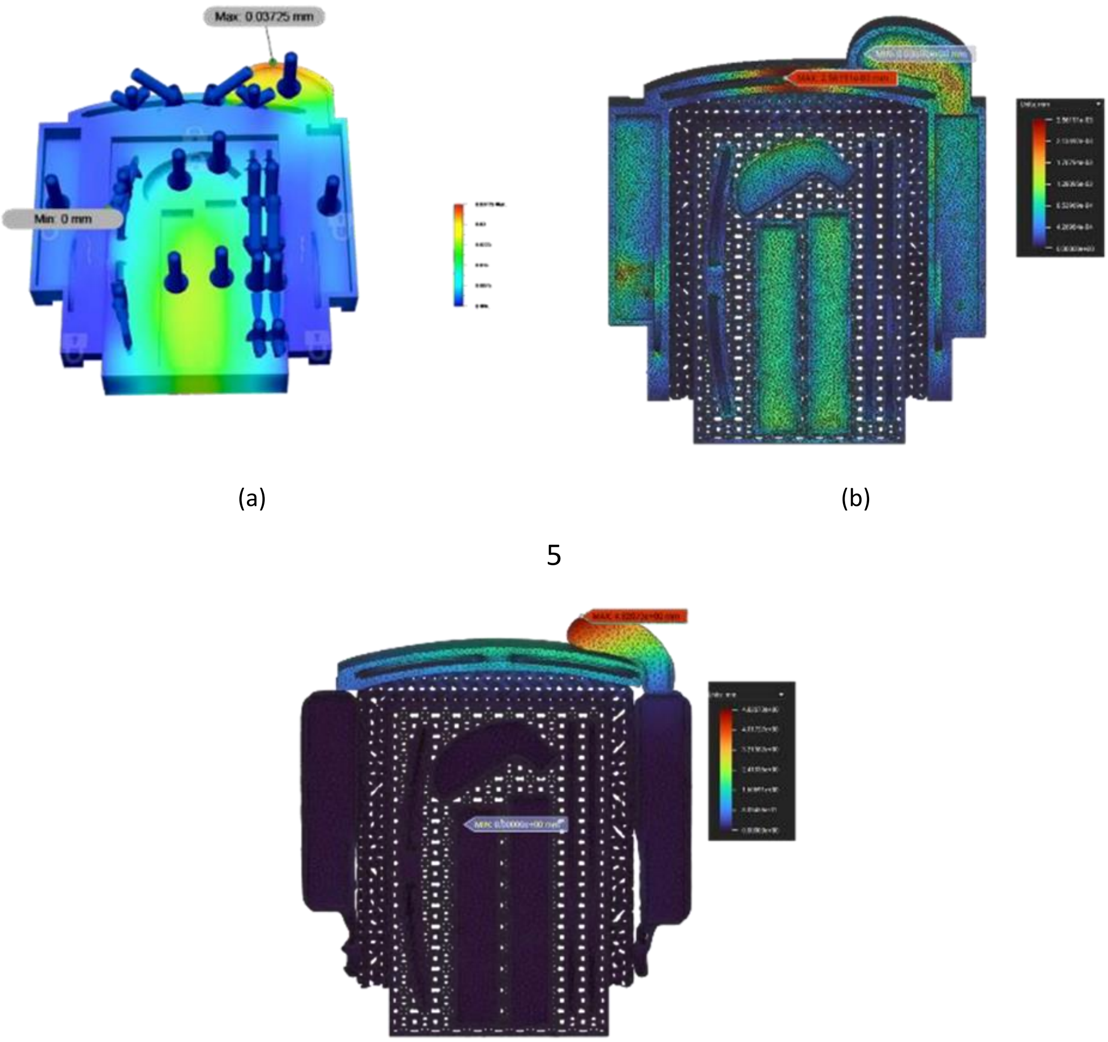

(a) (b)

Figure 11: Upper and bottom view of the optimized model

3.2. Static Analysis Simulation

After all the static analysis simulations were performed on the model, the maximum displacement (Figure 12) showed a more accentuated value in the external support, more specifically, the region of the camera compartment, since it is situated further away from the displacement constraint (surfaces in contact with the support platform). The highest value is registered in the optimized model, a consequence of the decrease in the material of this model relative to the others.



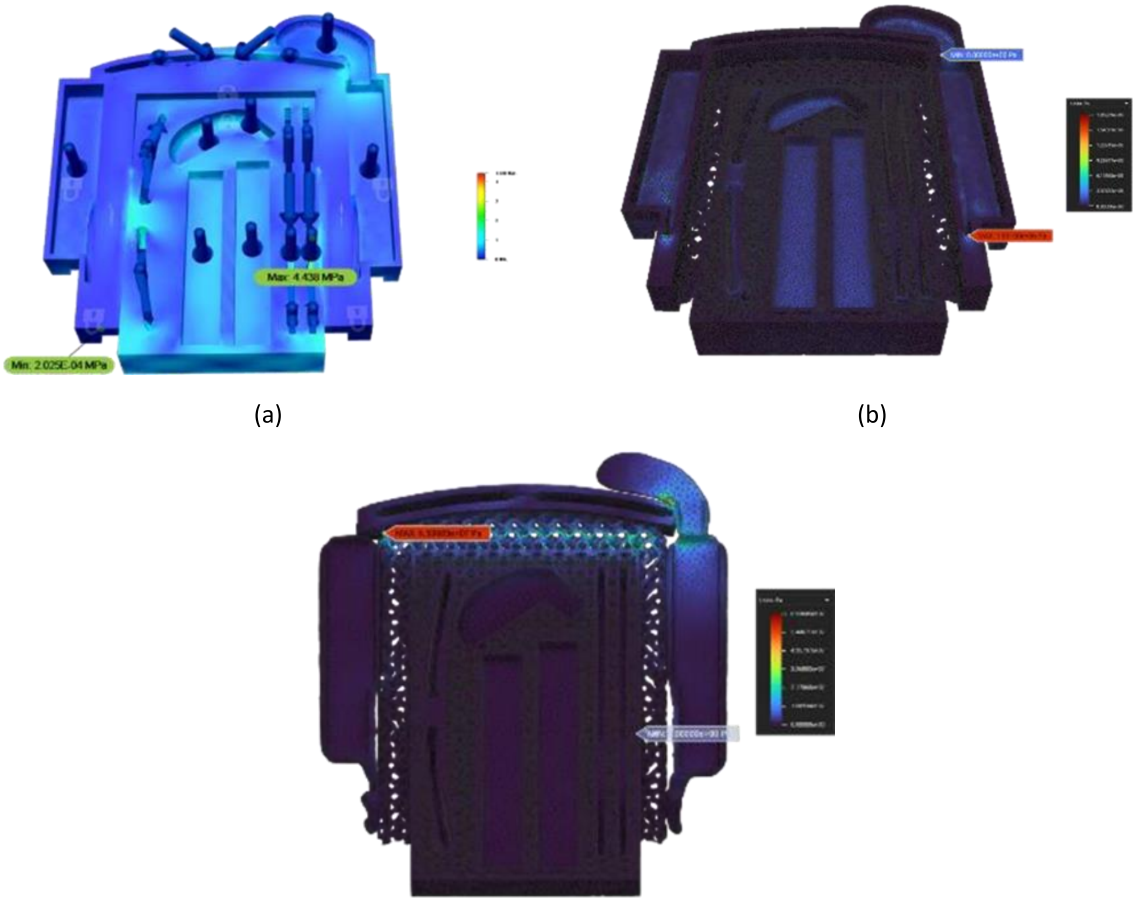
(a) (b)

5

(c)

Figure 12: Results for maximum displacement: a) Initial model. b) hybrid model. c) optimized model

Thus, by analyzing the maximum stress, a property that provides information about the performance of a material in service and analyzing Figure 13, it is possible to conclude that the maximum stress reached by each model is at a localized point. However, most of the piece presents very low stress values, close to 0 MPa, so the built structure presents enough resistance for the weight of the glasses. However, the optimized model presents, locally, a maximum stress value higher than the material's yield stress (40 MPa). Despite this stress being located only at a point of the structure and not in a region, it cannot be neglected once there is the risk of failure of the component in service.



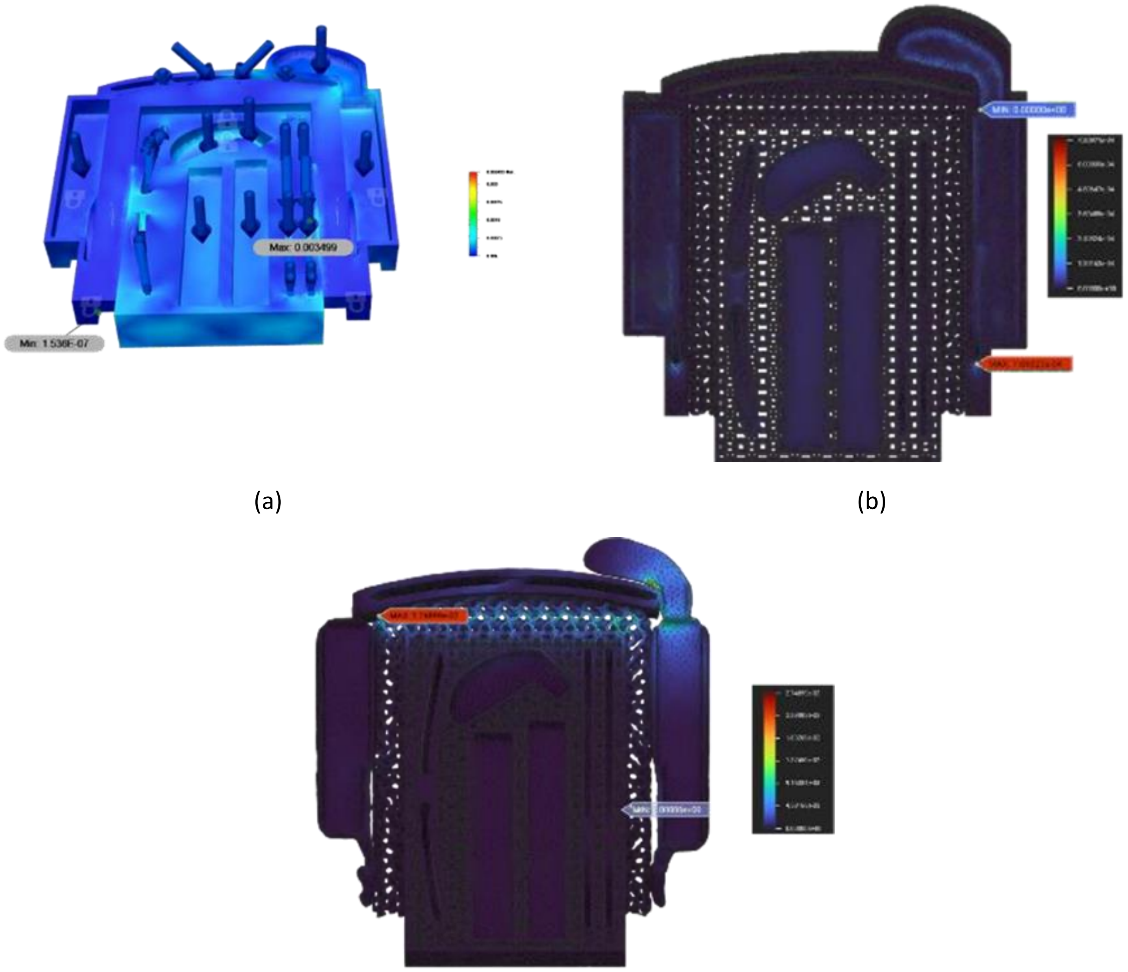
(a)

(b)

(c)

Figure 13: Results for maximum stress: a) Initial model. b) hybrid model. c) optimized model.

Finally, the deformation parameter presents relatively low values in all models (Figure 14), concluding that its structure will remain intact when the piece is put into service.



(a) (b)

(c)

Figure 14: Results for maximum deformation: a) Initial model. b) hybrid model. c) optimized model.

The optimized model was found to have the highest values for both maximum displacement and maximum applied stress. This could be explained by the fact that a body is more vulnerable to applying a force when its mass is smaller.

4. Conclusions

This investigation work permitted a practical approach, not only to additive manufacturing techniques applied to the manufacture of smart glasses support but also allowed the development of new skills using different software regarding generative design and optimization of mass usage. Concerning the optimization, the goal of minimizing mass and material unneeded for the part was fulfilled using lattice structures and topological optimizations. Thus, the topology optimization demonstrated a weight reduction of 31% in the hybrid model and a weight reduction of 47% in the optimized model.

As regards the static simulations performed to validate the optimized designs of the support, it was observed that the highest values for maximum applied stress and maximum displacement were noted in the optimized model. The deformation results were significantly low in all three models, leading to believe that this factor would not be an obstacle, regardless of which model was used. Although the optimized model is the one with the highest mass reduction and presents a more innovative design, it still needs some changes in the design to be released to the industry market.

References

Bian, Linkan, Nima Shamsaei, and John Usher, eds. 2018. Laser-Based Additive Manufacturing of Metal Parts: Modeling, Optimization, and Control of Mechanical Properties. Boca Raton: CRC Press, Taylor & Francis Group.

Blok, L.G., M.L. Longana, H. Yu, and B.K.S. Woods. 2018. “An Investigation into 3D Printing of Fibre Reinforced Thermoplastic Composites.” Additive Manufacturing 22 (August): 176–86. https://doi.org/10.1016/j.addma.2018.04.039.

Colombo Zefinetti, Filippo, Christian Spreafico, Daniele Regazzoni, and Daniele Landi. 2023. “Eco-Assessment of Design for Additive Manufacturing Solutions Defined at Different Levels of Detail.” In Advances on Mechanics, Design Engineering and Manufacturing IV, edited by Salvatore Gerbino, Antonio Lanzotti, Massimo Martorelli, Ramón Mirálbes Buil, Caterina Rizzi, and Lionel Roucoules, 1079–89. Lecture Notes in Mechanical Engineering. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-15928-2_94.

Costa, José, Elsa Sequeiros, Maria Teresa Vieira, and Manuel Vieira. 2021. “Additive Manufacturing: Material Extrusion of Metallic Parts.” U.Porto Journal of Engineering 7 (3): 53–69. https://doi.org/10.24840/2183-6493_007.003_0005.

Fernandes, Rossana R., Nekoda Van De Werken, Pratik Koirala, Timothy Yap, Ali Y. Tamijani, and Mehran Tehrani. 2021. “Experimental Investigation of Additively Manufactured Continuous Fiber Reinforced Composite Parts with Optimized Topology and Fiber Paths.” Additive Manufacturing 44 (August): 102056. https://doi.org/10.1016/j.addma.2021.102056.

Gibson, Michael A., Nicholas M. Mykulowycz, Joseph Shim, Richard Fontana, Peter Schmitt, Andrew Roberts, Jittisa Ketkaew, et al. 2018. “3D Printing Metals like Thermoplastics: Fused Filament Fabrication of Metallic Glasses.” Materials Today 21 (7): 697–702. https://doi.org/10.1016/j.mattod.2018.07.001.

Gonzalez-Gutierrez, Joamin, Santiago Cano, Stephan Schuschnigg, Christian Kukla, Janak Sapkota, and Clemens Holzer. 2018. “Additive Manufacturing of Metallic and Ceramic Components by the Material Extrusion of Highly-Filled Polymers: A Review and Future Perspectives.” Materials 11 (5): 840. https://doi.org/10.3390/ma11050840.

Herderick, E. 2011. “Additive Manufacturing of Metals: A Review.” In . https://www.semanticscholar.org/paper/Additive-Manufacturing-of-Metals%3A-A-Review-Herderick/156b0bcef5d03cdf0a35947030c1c0729ca923d3.

Hia, Iee Lee, Alexander D. Snyder, Jack S. Turicek, Fernanda Blanc, Jason F. Patrick, and Daniel Therriault. 2023. “Electrically Conductive and 3D-Printable Copolymer/MWCNT Nanocomposites for Strain Sensing.” Composites Science and Technology 232 (February): 109850. https://doi.org/10.1016/j.compscitech.2022.109850.

ISO/ASTM. 2015. “ISO/ASTM 52900:2015.” ISO. 2015. https://www.iso.org/standard/69669.html.

Kneissl, Barbara, Moritz Warnck, Matthias Schneck, Matthias Schmitt, and Georg Schlick. 2022. “Optimisation of a Hydraulic Housing for a Brake-by-Wire System for Electrical Drives by Additive Manufacturing.” Procedia CIRP 107: 641–46. https://doi.org/10.1016/j.procir.2022.05.039.

Markforged. 2022a. “Introducing Our New Markforged Material: Onyx.” 2022a. https://markforged.com/resources/blog/introducing-our-new-markforged-material-onyx.

———. 2022b. “Onyx - Composite 3D Printing Material.” 2022b. https://markforged.com/materials/plastics/onyx.

Mata, Margarida, Mateus Pinto, and José Costa. 2023. "Topological Optimization of a Metal Extruded Doorhandle Using nTopology." U.Porto Journal of Engineering 9 (1): 42–54. https://doi.org/10.24840/2183-6493_009-001_001620.

Meng, Liang, Weihong Zhang, Dongliang Quan, Guanghui Shi, Lei Tang, Yuliang Hou, Piotr Breitkopf, Jihong Zhu, and Tong Gao. 2020. "From Topology Optimization Design to Additive Manufacturing: Today's Success and Tomorrow's Roadmap." Archives of Computational Methods in Engineering 27 (3): 805–30. https://doi.org/10.1007/s11831-019-09331-1.

Naik, Abhijith, Saravanakumar Shanmugam, and Suraj Desai. 2022. "Light Weighting of a Body Jig Using Computational and Topology Optimization Methods." In , 2022-28–0062. https://doi.org/10.4271/2022-28-0062.

Oliveira, Carolina, Mariana Maia, and José Costa. 2023. "Production of an Office Stapler by Material Extrusion Process, Using DfAM as Optimization Strategy." U.Porto Journal of Engineering 9 (1): 28–41. https://doi.org/10.24840/2183-6493_009-001_001635.

Shanmugam, Vigneshwaran, Deepak Joel Johnson Rajendran, Karthik Babu, Sundarakannan Rajendran, Arumugaprabu Veerasimman, Uthayakumar Marimuthu, Sunpreet Singh, et al. 2021. "The Mechanical Testing and Performance Analysis of Polymer-Fibre Composites Prepared through the Additive Manufacturing." Polymer Testing 93 (January): 106925. https://doi.org/10.1016/j.polymertesting.2020.106925.

Vuzix. 2017. "VUZIX M300 Smart Glasses." 2017. https://cdn.cs.1worldsync.com/42/7a/427aec93-70a9-41e1-abba-022cc1b6edc3.pdf.

Wong, Kaufui V., and Aldo Hernandez. 2012. "A Review of Additive Manufacturing." ISRN Mechanical Engineering 2012 (August): 1–10. https://doi.org/10.5402/2012/208760.