SUSTAINABLE COMPONENT DESIGN USING GENERATIVE TOOLS FOR ADDITIVE MANUFACTURING

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The present study proposes an innovative design approach and comparison between two different design methods for small vehicles structural components, aimed to optimize the use of material and methods of fabrication. It has been developed a case study for an industrial product of which assembly uses standardized structural materials alongside custom, software generated, components made with additive manufacturing. The predicted safety and cost effectiveness of a product in the early stage of design is an essential part of the design process that will influence the entire workflow of the product design life cycle. It consists in detailed structure analysis of a structural component, manufacturing process and assembly methods from a safety and cost point of view.

Keywords: generative design, shape optimization, FEA, chassis

1. Introduction

Automotive is a never ending and ever evolving sector. A vehicle success consists mainly in its key factor, design. When designing a vehicle, the major priority goes to the structure and capacity of its chassis. In motorsport the chassis of the vehicle is the main point of interest mainly of its influence on the vehicle handling characteristics and impact protection. Thus, the chassis is rigorously tested in various impact situations, track handling, and emergency exist capabilities for the drivers. This study is based on an electric go-cart frame component which has been redesigned to allow people with inferior locomotor disabilities to use it in safe conditions [1]. The chassis of the go-cart has been adapted to allow an easy side entry-exit for people who can’t move the lower part of their body [2]. In a conventional go-cart chassis design, the central components like gas tank, steering column are situated in the center of the frame between the driver’s legs, creating a major obstacle in the entry-exit procedure for people with such disabilities with major negative effects in case of an accident. In order to

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achieve a good design, the steering column had to be moved on one side of the vehicle, the gas tank was removed as is not required in this vehicle, being electric [3].

Due to the different positioning of the steering column, the steering mounting post for it had to be redesigned, as seen ion figure 1, and tested in order to withstand the forces resulted in an impact and for it being used as a support handle for entry-exit maneuvers from the driver as well for the normal forces resulted from the steering forces.

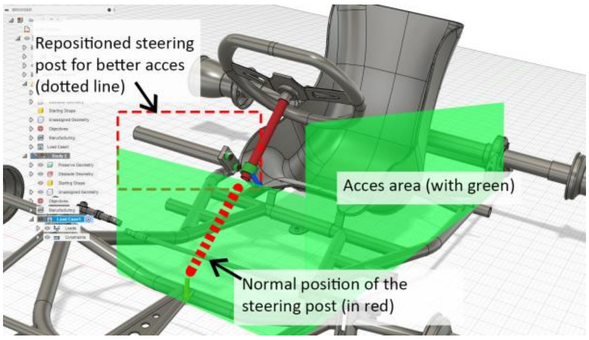

Fig. 1 Steering post repositioning for better access

2. Methodology description

The go-cart chassis was designed, using CAD software and split in two types of components. The first one, the main structure, is based on standard tubular profiles typically used for such applications. The tubular profiles used for the chassis are accessible in various thicknesses, ranging from 1mm to 1.5 mm. Typically used materials are, AISI 1018, AISI 1026, AISI4130, AISI 1020 and ASTM A106 GRADE-B etc. The second type of components are linkages and supports, designed for specific applications, that are custom made, where special geometries are required due to the atypical design of the vehicle [4]. The materials used for these components are AISI 446 (for additive and 3 axis milling manufacturing), Aluminum 6061 (for 3 axis milling manufacturing) and AlSi10Mg (for additive manufacturing). Due to the nature of these components, a different design method was chosen allowing the design to focus on specific tasks. The target is to establish a good base design and optimize it in order to perform the required tasks but keeping manufacturing costs low at the same time. At this point two design methods were chosen, first, a base component design followed by a topological optimization process and the second, the use of a generative design tool in order to obtain an optimal part.

Generative design mimics nature’s evolutionary approach to design. Unlike topology optimization, the software explores all the possible permutations of a solution, quickly generating design alternatives. It tests and learns from each iteration what works and what doesn't.

3. Study case in component design

The study is set in Fusion 360 from Autodesk using its simulation tools "Shape Optimization" and "Generative Design" based on NASTRAN solver and aPriori's Design for Manufacturing & Cost. The input data was set at mass of the kart m=250kgs =2452.5N (including driver, m=250kgs =2452.5N), maximum velocity, v= 76kmph, T=0.1s time taken from top speed to stop.
The design process of the steering mounting post is iterative and is based on various engineering and reverse engineering processes depending upon the availability, cost and other such factors [5]. The design objectives for each component of the chassis are: durable, light-weight, and high performance, to optimizing the design by avoiding over designing, which would also help in reducing the cost. The geometry of the steering column post was determined by the position of the steering wheel, the steering wheel column diameter, optimal supporting points, the position and dimensions of the structure on which it will be attached on the chassis and the forces it will need to withstand during usage (normal use and impact situations). The base design of the steering column post is presented in figure 2.

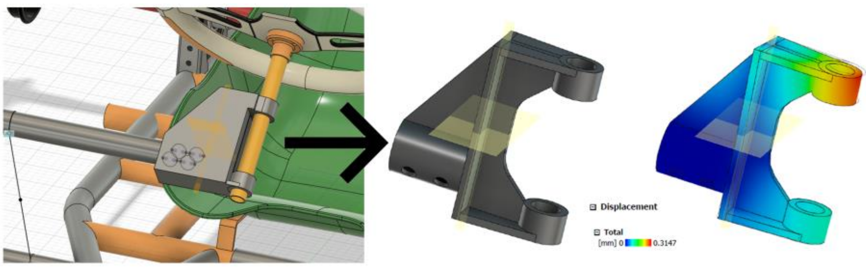

Fig. 2 Steering mounting post design and study results

This design is bulky and overbuild in order for it to handle the stress during its use, overall, it's not a high-performance part and it needs a topological optimization. Thus, it will use less material and create new geometries, increasing the strength of the component. The input data for the topological optimization study is based on the information presented earlier. A topology optimization shows the geometry required from the component in order to withstand the stress during use, as well the material that can be removed and the areas which will not affect the integrity of the part [6]. For the study to behave realistically a convergence test is required in order to establish the discretization element size.

Otherwise the results may not be realistic. The topological result indicates that the part should pe manufacture on a CNC milling machine as the part is to complex to be made using normal fabrication methods. The topological optimization generated an optimized distribution of various reinforcements based on the shape of the part, such as stamped reinforcements in the structure of the part, as seen in figure 4. It is an advanced form of shape optimization in which a region designed for a particular part has been defined and which has generated a reinforced model based on the variables within that region. The projected region was divided into a large number of separate variables, whose influence on the structure was calculated and optimized in a series of iterations. In order to perform this study, a convergence analysis of the size of the discretization element, the relative number of nodes required and the deformation of the material on the structure model, as seen in figure 3, was performed. It used the parabolic mesh element.

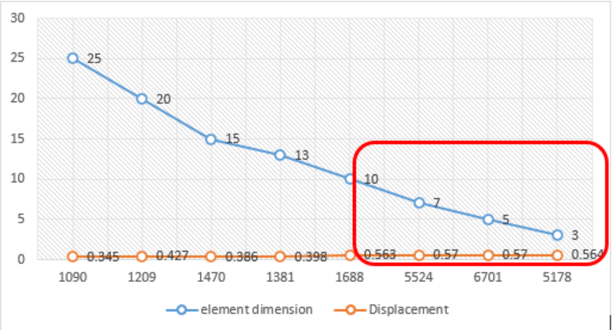

Fig. 3 The results of the convergence study [7]

It is concluded that, for an analysis of the efficient stress states of the structure, the required number of nodes can be limited around 2000. Around this value, the size of the discretization element can vary between 10 mm and 3 mm for convergent results.

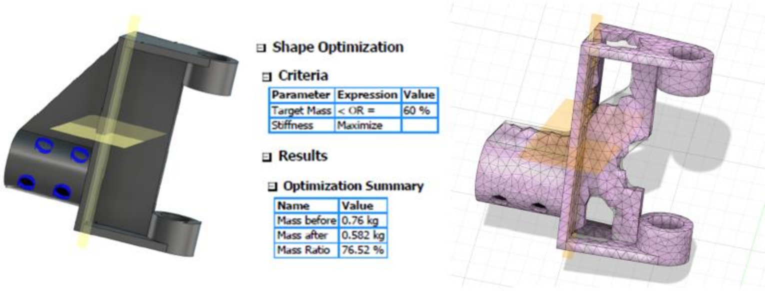

Fig. 4 Shape optimization results

Cost calculation wise, for this study would consider several recommendations which consists in a product development process, respectively four stages namely, analyzing, concepting, designing and finalizing. All phases have many steps, and the core activity is designing and concepting. Hence, the analyze is very important in the design process [8].

In order to provide a comprehensive cost estimation for this part, the following relation can be used with different types of material and fabrication methods. The material data library would be based on the mechanical properties, dimensions, shapes and relative costs.

$$M = V_b \cdot k_v^* \cdot k_{v0} \cdot (1 + g_{w/z}) \quad (1)$$

Where: V_b- gross materials volume, k_v^* - relative costs, k_v0 - relative material costs based on volume, (1+g_(w/z)) – overall maintenance/ subcontracting costs - w≅z.

The gross material volume would be provided by the CAD files of the component. Taking all of the information into account this design approach is more time, energy and material consuming. And even though the strength of the topological part is higher than the normal designed one, the production costs for this part would still be substantially higher than for the one manufactured using standard methods. This situation can be improved using a generative design tool, that could theoretically offer a higher quality part at a similar topological optimized part costs, using less time and energy.

4. Generative design, a sustainable approach

The core mechanism of generative design is a level-set approach to topology synthesis. Level-set methods, by their nature, use surface area as their main acting stage. The solver is able to explore a much larger design space than a traditional topology optimization system. The main goals of generative design are to conceptualize a sustainability framework to identify and define key design elements plus manufacturing constraints of the workflow and areas for resource optimization as well to reduce material and resource usage and to make more conscious and informed decisions when designing a sustainable component. Combining generative design with additive manufacturing reduces lead times through rapid part prototyping using near shape printing designs, thus meeting sustainability goals. A generative design tool will increase productivity through thousands of iteration AI-generated with lower costs using a minimum of material and energy required during production with a lower carbon footprint [9].

The goal in this design is to generate a stiff bridge (mounting post) between the steering column and the chassis using as little material as possible. For this application the input data was the same as for the previous studies. The material preferred for this study is AlSi10Mg, for its great additive manufacturing capabilities. For the first generative study a single support point was established for the steering column, as seen in figure 5.

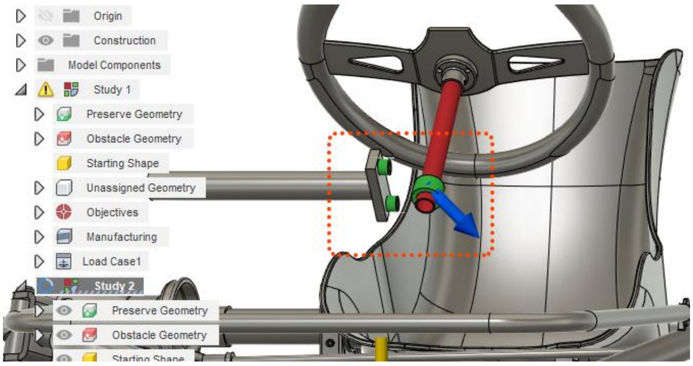

Fig. 5 Generative design study set-up

After setting the objectives for the study, establishing the components that needed to be connected as well the general path for the bridge and the assembly features that needed to be avoided, the material and fabrication methods for the generated part were chosen. For this part the fabrication methods are on a 3- axis milling machine and additive manufacturing (SLS). As seen in figure 6 and 7, the software generated 27 iterations of which 5 of them responded best to the usage scenario.

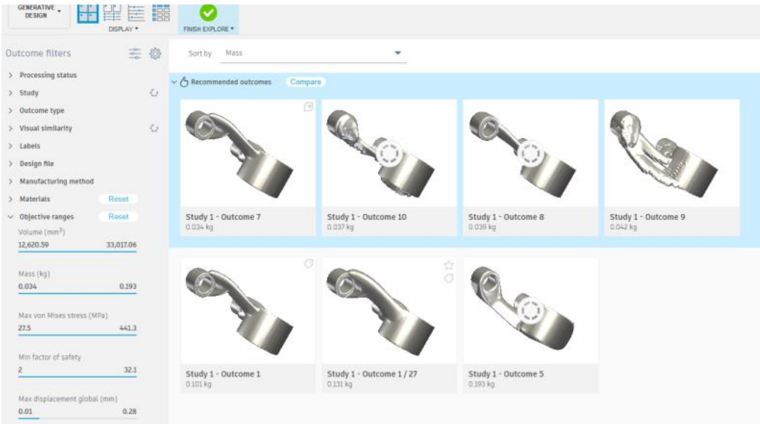

Fig. 6 Generated design solutions

Though the generated solutions by the computer theoretically offer the best design, further studies have to be done in order to establish if the part will withstand the mechanical loads during use. After further testing the best iteration offered by the generative tool, subjecting it to both a static stress test and buckling, due to the single support point on the steering column design, the part fails the safety factor due to a high contact pressure point as shown in figure 8.

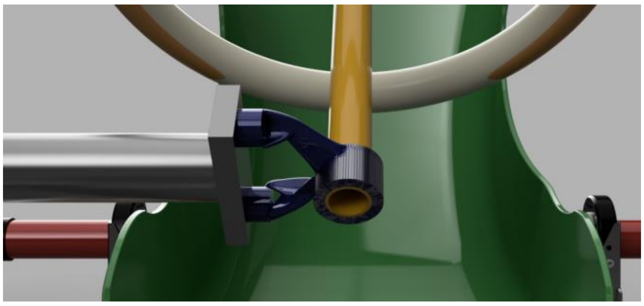

Fig. 7 Steering mount support

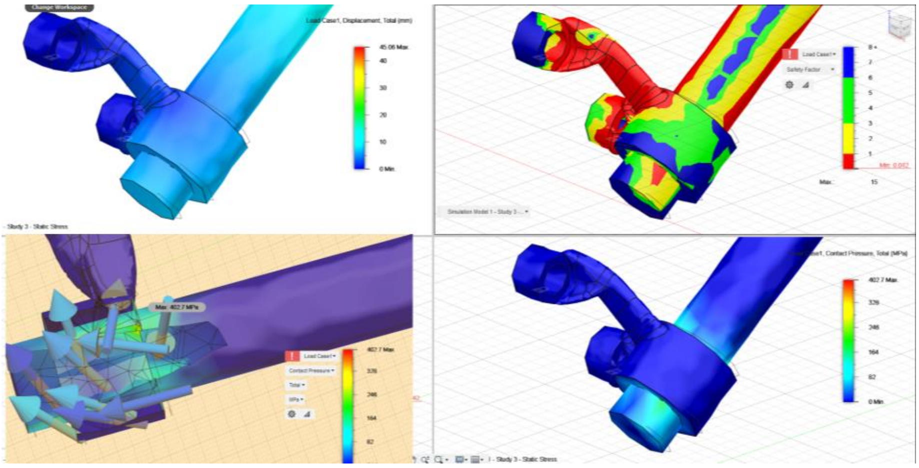

Fig. 8 Mechanical stress study results

The study shows that a new design approach should be made using two supporting points on the steering column thus avoiding areas with high contact pressure points.

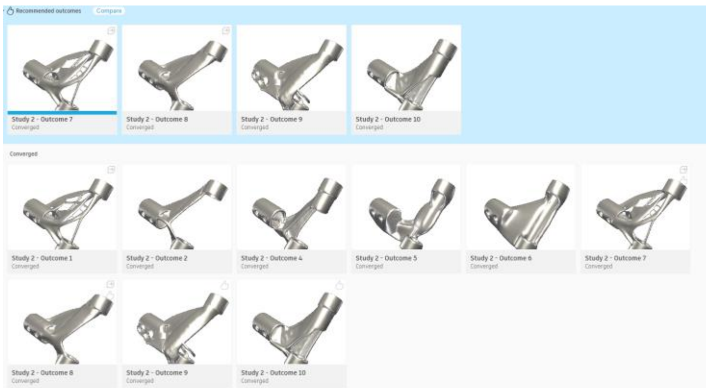

Fig. 9 Improved generated design with two supporting points

From the various outcomes generated by the program, as seen in figure 9, the following shape was selected to further study, meeting the stress reference-based requirement for the part, figure 10 and respectively 11.

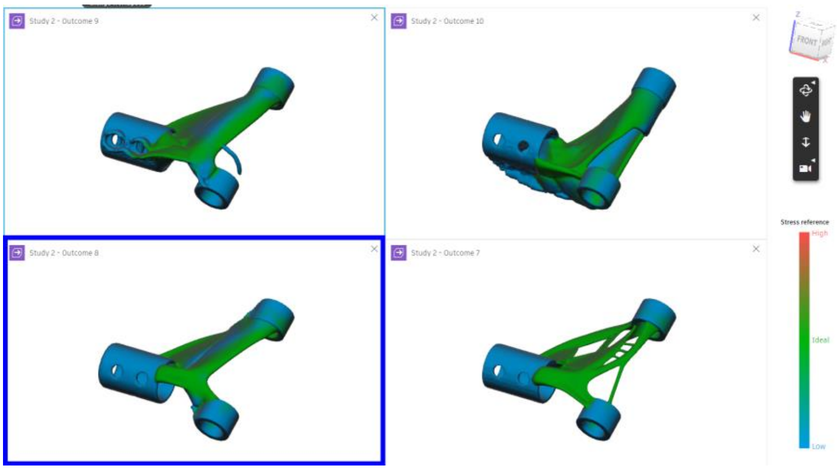

Fig. 10 Stress reference-based selection for the part

Fig. 11 Best technical specification shape

For this second approach study, the load applied on the steering column was split into two equal structural loads totaling the first iteration loads. The structural loads were applied on the steering column on the two support points areas. The results can be observed in figure 12.

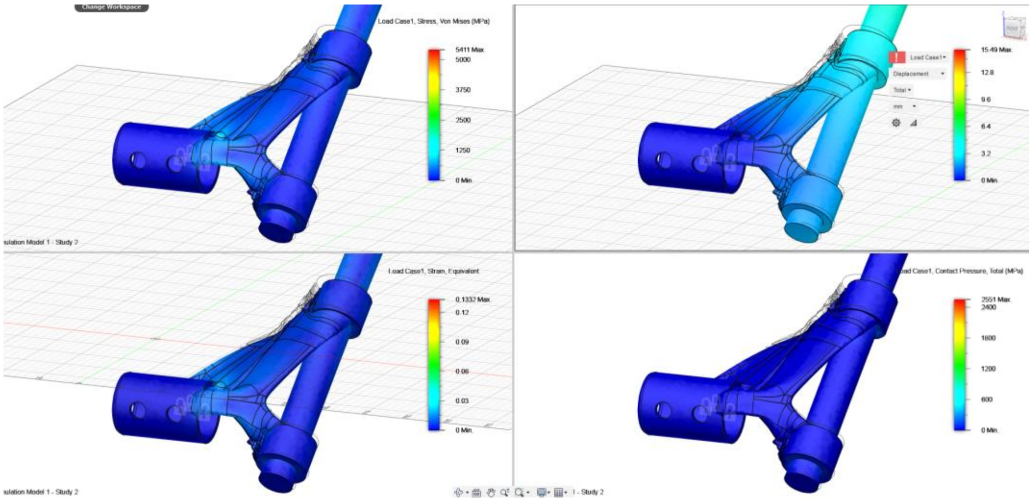

Fig. 12 Mechanical stress study result for second iteration

At this point it should be reminded that the loads applied on the part are calculated for a crash scenario, thus the results are in the tolerable limits.

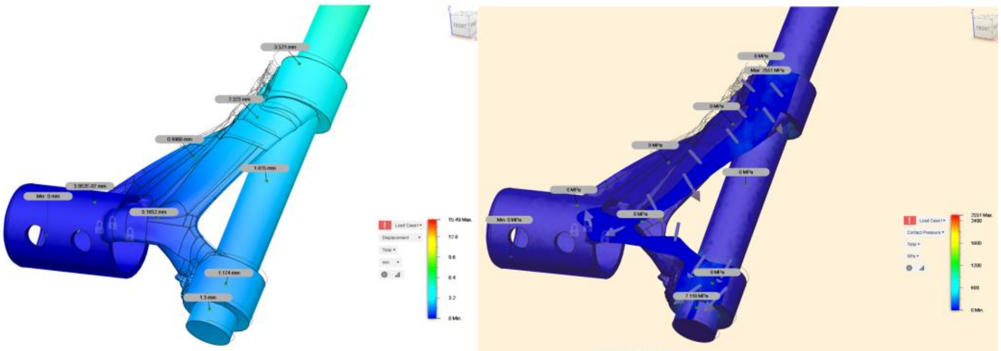

Fig. 13 Total displacement and contact pressure point of the part

The results of the study, as seen in figure 13, show that the second iteration part with two support points will withstand the stress forces resulted from a crash of the go-cart. The part can be manufactured with better precision and better tolerances using additive manufacturing. It also shows the final costs for it to be manufactured, can be observed in figure 14. This feature allows us to rapidly make adjustments to the part in order to optimize the ratio between cost and performance.

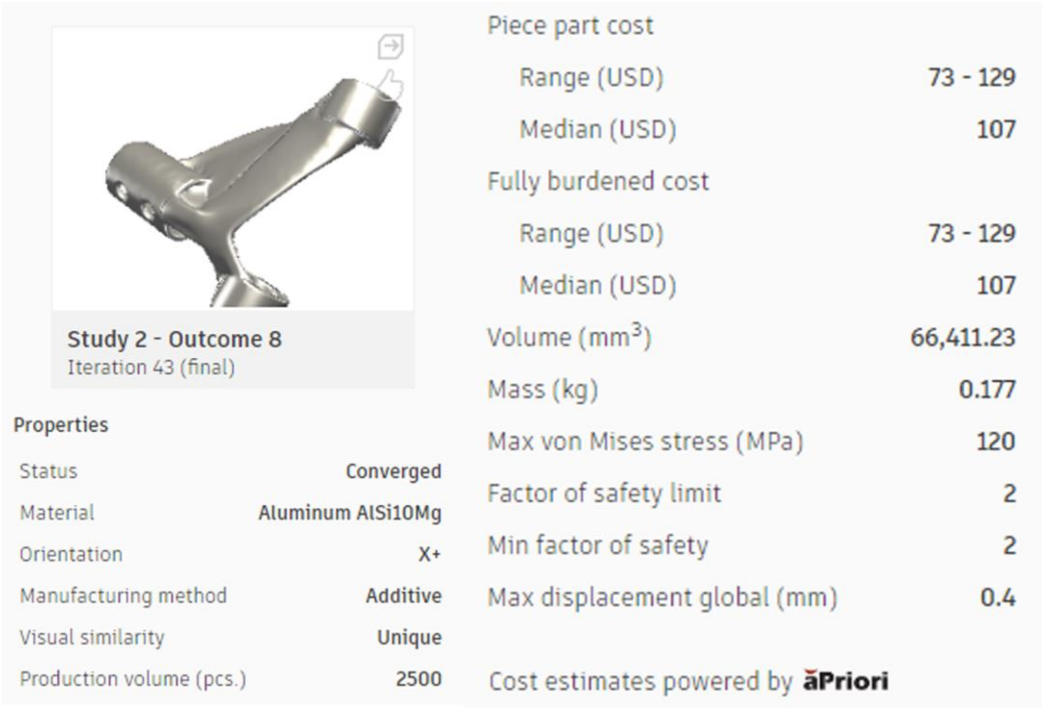

Fig. 14 Additive manufacturing cost per part for 2500 pieces

5. Conclusions

Product design breaks down into four categories: function of the part, materials used, manufacturing process, and how it needs to perform. Using a generative design tool increases the overall productivity of the designer allowing him to explore a multitude of options for a single part taking into consideration all the possible variable that could appear during production or in use of that product. Generative design allowed for rapid calculations for the part studied in this paper regarding the number of valid solutions that we have at our disposal in order to design the steering mounting support, the material needed for its fabrication and as well the fabrication method, and final cost for the finished part. This technology promotes a sustainable environment for product design and production methods, reducing time, energy and material waste, needed for a multitude of tests for different prototypes needed in order to test the part in various usage scenarios. In the first part of this paper the design approach was iterative, based on various engineering and reverse engineering processes depending upon different aspects that the designer cannot control or take fully into account in the early design stage.

Thus, the first method requires an intense feedback loop that can alter the initial design or prototype indefinitely, meaning greater costs and longer research time in the end, a wasteful method. Using a generative tool allows the designer to obtain the feedback instantly if the input data is correct, to make real time adjustments before the product goes into production and adding additive manufacturing to this process eliminates waste completely, thus making not only the product sustainable but the entire workflow required to design that product.

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