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Review Article

Innovative and Unique Generative design Solution for the leg Part of a Robot Using Autodesk Fusion 360 CAD Software

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ABSTRACT

Generative design is the innovative and novel feature of Fusion 360. As AI has become a common and compulsory tool in every search engine, the concept of generative design has also been for the designing software, to generate optimum models of designs. To showcase the concept above, in this paper four best outcomes of the generative design of the leg-2 have been discussed with tabular, pictorial, and graphical analysis. Leg-2 is the name given to the component of one of the glass cleaning robots. This paper will also show how a design is being optimized through multiple iterations, about the structural load and other constraints. For all four case studies/outcomes mass, stress and displacement analysis is presented graphically with respect to different types of materials. The results of these case studies are found within the critical yield strength values of respective material along with mass optimization through generative design analysis.

Keywords: Parametric Modeling, Generative Design Analysis, Autodesk Fusion 360, novel, CAD/CAM – Computer Aided Design and Computer-Aided Manufacturing.

Introduction

This Using Fusion 360, versatile CAD/CAM software that offers parametric modeling, integrated CAM and Generative design like features synchronously. With collaborative workflows, cost efficiency and rapid design iteration speed, the author preferred fusion 360.[1]

Generative design, a data driven AI technology that explores a wide range of design possibilities, offering solutions that may not be apparent through manual design processes. In today's fast paced world, this significantly speeds up the design iteration process. Generative AI provides a competitive edge by enabling companies to produce innovative, cost effective and high-performance products. Generative AI has optimized designs not only for performance but also for manufacturability.[2] Autodesk has developed this generative design feature in their software tool called fusion 360. In this, generation of design can be started either by sketching conceptual design or by providing existing design of the product. In this software, three design regions of the product need to be specified. One is an obstacle region; it refers to a specific area or volume within the design where the user wants to restrict the generation of geometry. These obstacle regions are used to prevent the generative design algorithm from creating geometry within those areas. It is displayed in red color. The second one is the preserved region. Region which the user does not want to alter, it is essentially the opposite of an "obstacle region," which restricts the generation of geometry in a particular area. Third is the Starting region where the designer wants to generate new optimized designs through generative design.[3] Another important specification which is required to give are study materials (i.e., different material selected for manufacturing product, generative design is altered according to the type and properties of material), desired manufacturing criteria, structural constraints, structural loads, cost estimation and minimum factor of safety. All the other specifications are explained below as in Fig. 1. This software tool includes various objectives such as mass reduction and improved stiffness in the generated outcomes. In the objective of mass reduction, fusion tries to reduce mass as much as possible and wants to maintain maximum desired strength and stiffness.[4]

The main contribution of this paper includes:

- Understanding the uniqueness and effectiveness of generative design approach for optimizing designs and use of generative design in fusion 360.[1]
- Understanding the process of generative design, process by process which includes 2D drawing, 3D designs, generative design (all constraints and specifications), rendering, simulation, and manufacturing cost estimation methods in Autodesk Fusion 360.
- The procedure carried out by generative design features to generate outcomes from this generative tool.
- Analysis and study of generated outcomes by pictorial, graphical and tabular data representation. Finally, the results and conclusion from this study.[5]

Methodology

Procedure of Generative design and analysis

The design process for a product starts from a problem statement or a loophole to idea generalization, conceptualization, visualization, and imagining how a product will look like. How will it work, Once the design is visualized and conceptually verified by the designer/ developer. The design needs to be sketched out in software, Then the prototype of the developed design goes through simulation, in simulation real environmental conditions are created in which it will be working in the future.

After obtaining various outcomes in terms of stress retention, generated volume, mass, max displacement global, piece part cost, strength of product, reliability of the product. Based on these results an optimized design is selected, produced, and launched in the market. Here the process is categorized and divided into 3 stages: early, medieval and end stage.

In the Early stage, imagination, idea generation and conceptualization were included. In medieval stage, work on design. Starts with drawing a sketch of prototype, 3D modeling and generating designs with respect to real life environmental conditions.

In the End stage, the best outcome out of multiple designs is selected based on optimization and analysis.[6]

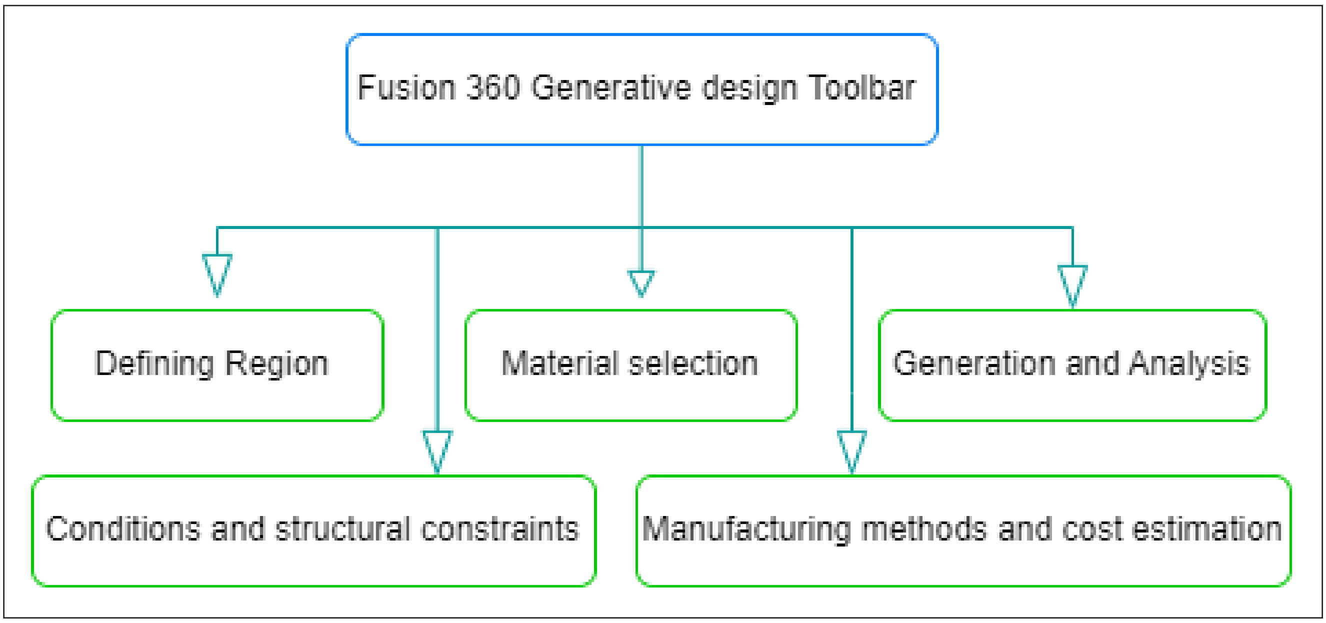

Figure 1.Procedure in toolbar of generative design

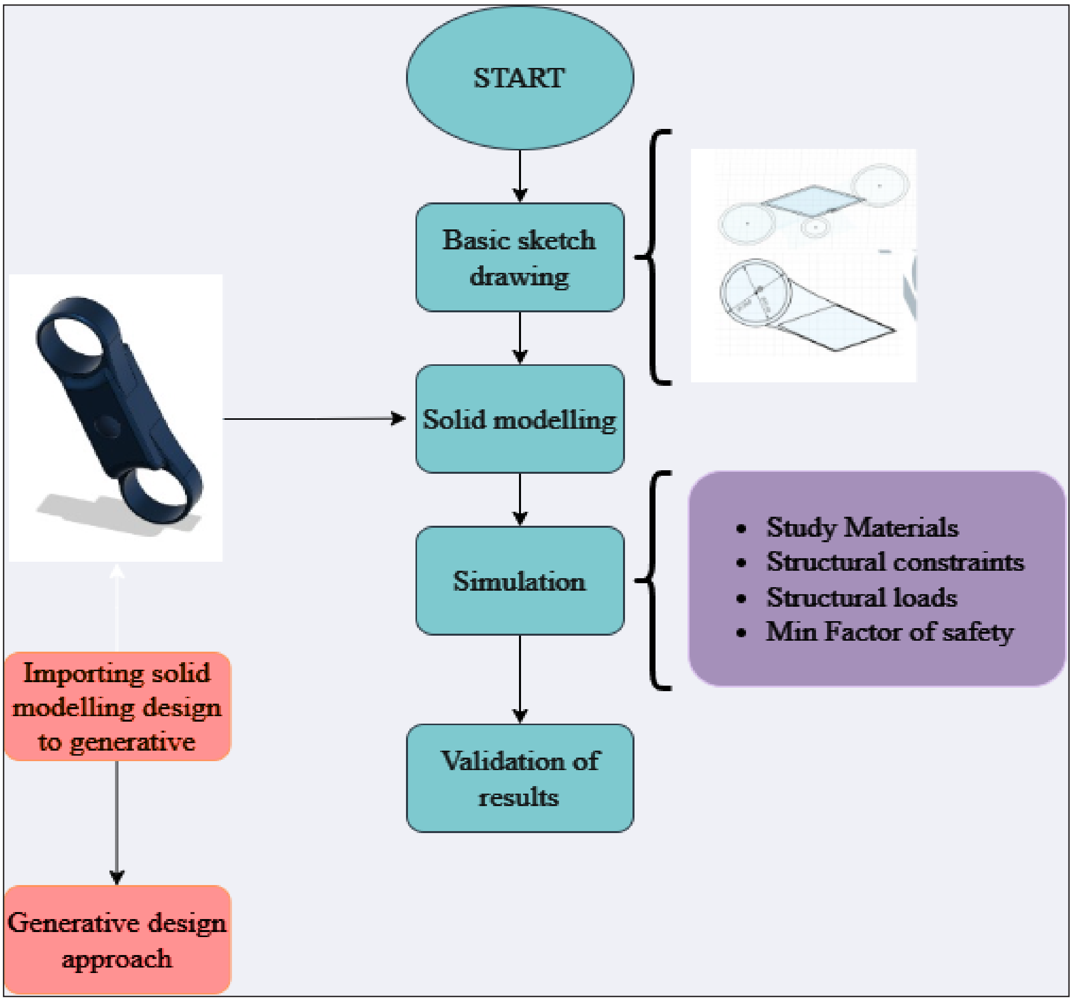

Figure 2.Traditional design Approach

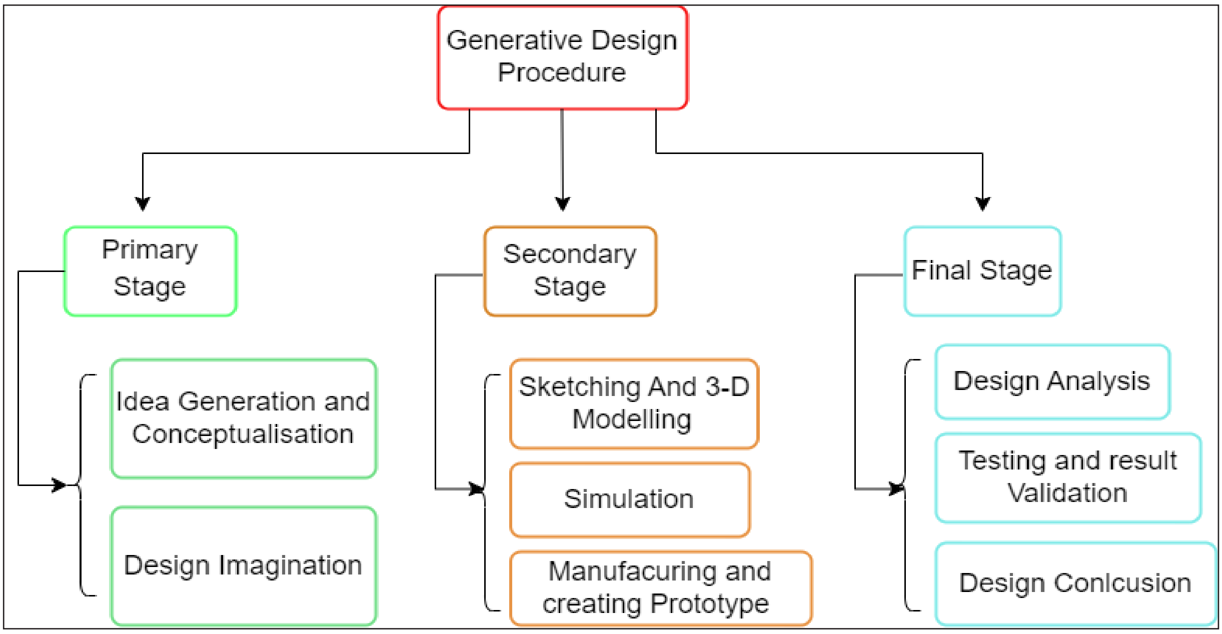

Figure 3.Process for Generative Design

Applying the generative design in leg_2 part

The image shown in Figure 3 is the initial design of the component which will be used for generative design process and analysis in this paper. This component in the design is part of the main design of the glass cleaning robot for high-rise buildings as in Figure 5.

Figure 4.Design of the component

In Figure 5, represented a picture of glass cleaning robot designed by the 2nd author of this paper which can be used to clean the outer glasses of high-rise glass buildings of height till 500 meters, it also acquires the capability of overcoming the obstacles of height till 15-25 cm and can carry 10 liters of cleaning liquid.

Figure 5.Part of the design of glass cleaning robots for high-rise buildings

Generative Design Defining Procedure

Generative design's process includes importing the design in the fusion software, then performing generative design function from the design button display. User must provide multiple conditions and constraints before generating design's function, During the process of generative design, First the preserved geometry of the design is selected, which on selecting for the preserved geometry turns the particular portion of the component into green color as shown in Figure 6.

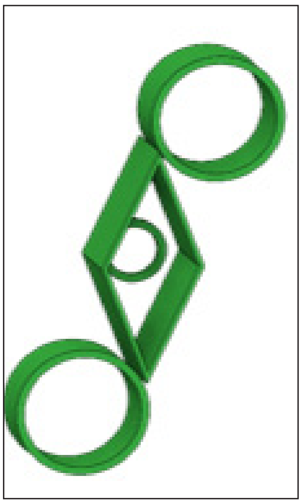

Figure 6.Preserve geometry

The preserved geometry parts are not modified in the generative design process, they remain as it is. Next, starting shape is selected, starting shape is the portion of design which needs to be optimized in terms of both mass and volume, such that it can hold the given pressure while maintaining its structure, after selecting the starting shape for some particular portion of design it turns into yellow color as shown in Figure 7.

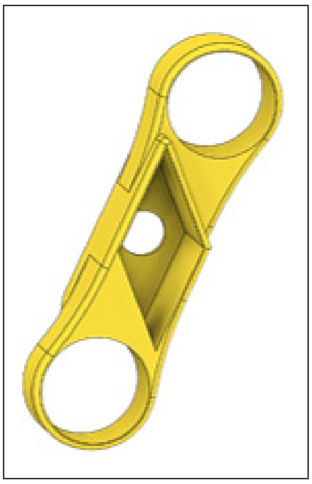

Figure 7.Starting Shape

Next, structural load is selected, it is the load which the component needs to sustain, for this component the top cylinder ring is connected to the main design and bottom one to the remaining part (leg) of the component thus the load will be exerted on them, in downwards direction as shown in Figure 8 in blue array in upward direction. A load of 800 newton (80 kgs) is applied here on the component. Structural loads can be provided only in selected preserve geometry. Gravity of 9.8 m/s^2 is also applied on the design in downwards direction, so as to develop the generative designs according to the real time situations/gravity. Next the structural constraints are selected, to prevent movement in selected directions. By default, all three global directions are constrained. For static simulations, you need to prevent all rigid body motion, such as free translational and rotational movement to make the model statically stable. The rhombus and middle cylinder are selected as structural constraints, as shown in Figure 9, ensuring stability and permanence in design. A lock sign can be seen on structural constraints. Next the objectives for the generative design are required to be selected, here one objective is to minimize mass and second is to provide limit.[7]

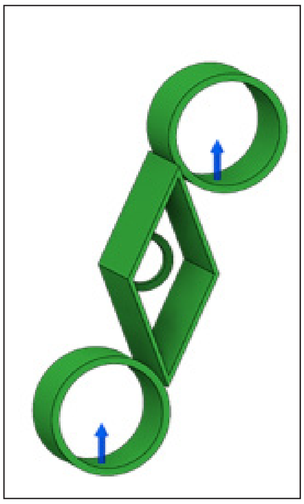

Figure 8.Structural load

In limit target Safety factor (n) is selected equals to 2 (by selecting, it generates the designs that can sustain/ resist the magnitude/pressure of n (2) times applied on the part, i.e. - 800 n x 2 = 1600 N, two times the given magnitude.). N is selected for the worst-case scenario, so as the product can work in the worst conditions. To get the manufacturing cost of the product, users are provided to select the manufacturing criteria for its product along with volume of production of parts per year. In this component unrestricted Addictive (Orientation in Z+ with overhang angle of 45 degrees and minimum thickness of 3 mm) and milling (tool direction in Z- with minimum tool diameter of 10 mm, total shoulder length of 40 mm and head diameter of 60 mm) manufacturing methods are considered and to get the cost estimation, production volume is selected equals to 4.[2]

Next, Materials are selected for the generative design This will provide us with the generative designs with respect to the provided materials as input, as different materials

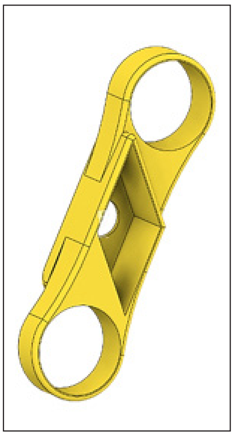

Figure 9.Structural constraints

possess different physical properties. Steel, Stainless steel, Titanium, Aluminum, and CFRP (carbon fiber) are the materials that are selected for our component. After providing all constraints, conditions, objectives, manufacturing and material information, the author goes to generate in the toolbar. 18 designs are available as the outcome of generative design. The generative design feature of fusion 360 provides the user with the best 4 recommended outcomes by comparing all 18 outcomes in terms of cost, mass volume, material, manufacturing method, stress and maximum displacement.

Generative Design Outcome

The Autodesk fusion 360 software generates 18 outcomes, but it recommends 4 outcomes which are best in terms of mass, strength, cost, displacement, and material. Fusion provides the outcomes by comparing it in terms of volume mm^3 , mass (in kg), max von mises Stress (MPa), factor of safety limit and minimum safety, max displacement global (mm) , material type and its cost in terms of minimum piece cost, maximum piece cost, piece cost median, minimum full cost, maximum full cost, full cost median. Also, it provides a recommendation percentage based on the comparisons of the outcomes on the basis of above discussed factors.[8]

This is the representation of the information of the best four recommended outcomes as in Figure 8 in the tabular form.

Through the four recommended outcomes as in Table 1, outcome 7 was of minimum recommendation 82.279 of material type steel and outcome 13 with maximum recommendation percentage of 88.258 of material type CFRP. Manufacturing methods suggested for outcomes are Unrestricted and 3-axis milling. Here CFRP is carbon fiber reinforced plastic, it provides high strength-to-weight ratio and corrosion resistance, making it ideal for lightweight structures and aerospace applications. Figure 11 and 12 gives a brief description of the four recommended outcomes.

Table 1.Recommended outcomes among all generative designs

Properties	Outcome - 13	Outcome - 15	Outcome - 10	Outcome - 7
Recommendation - %	88.258	84.204	83.399	82.279
Material	CFRP	CFRP	Titanium	Steel
Manufacturing method	Unrestricted	3 axis milling	Unrestricted	Unrestricted
Volume (mm^3)	158,593.942	966,456.726	159,016.123	158,451.836
Mass (Kg)	0.227	1.382	0.717	1.244
Stress (MPa)	11.054	0.908	10.802	11.17
Max Displacement (mm)	0.032	0.001	0.041	0.021

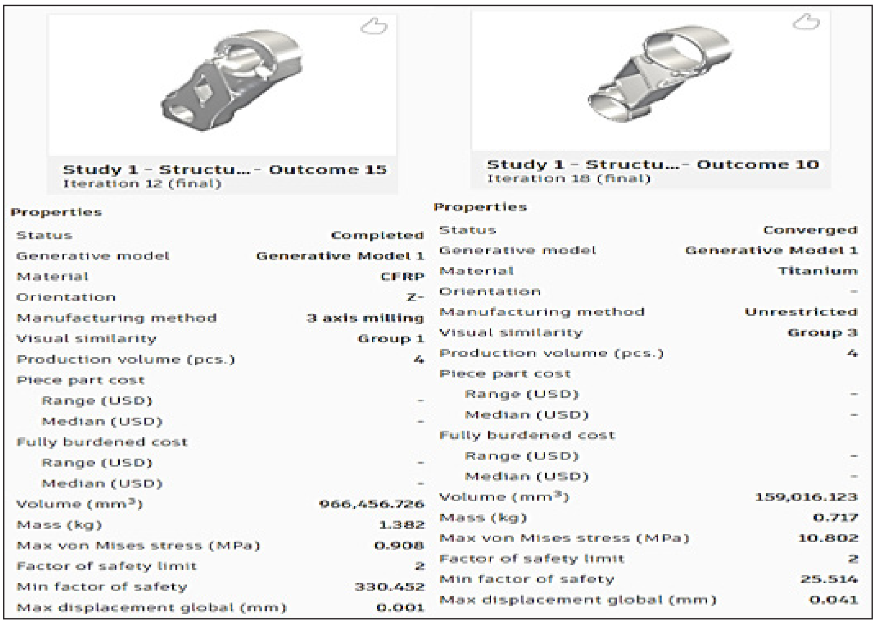

Figure 11(a)(b).Brief description of outcome 15 and 10

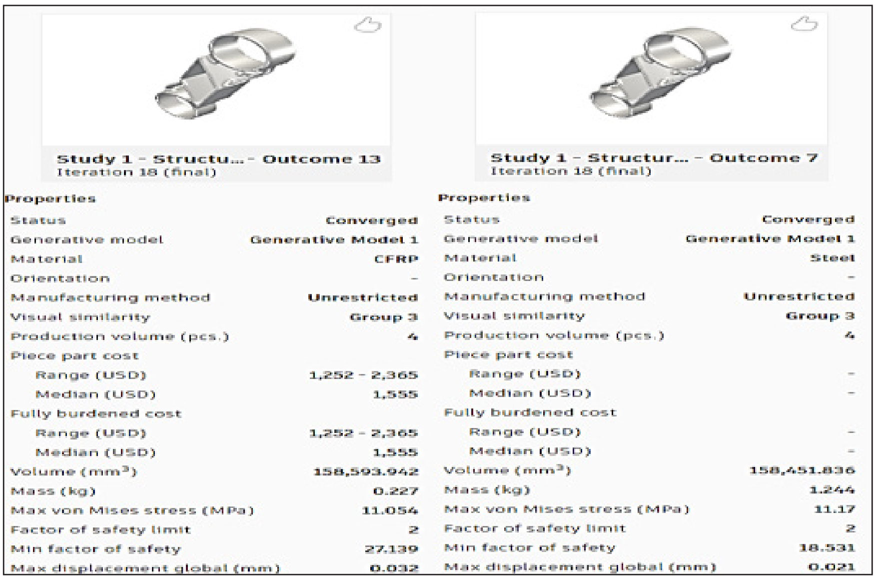

Figure 12(a)(b).Brief description of outcome 13 and 7

The generative design process is described below as in Figure 13 with multiple iterations which are processed during the process of Generative design feature of fusion 360.

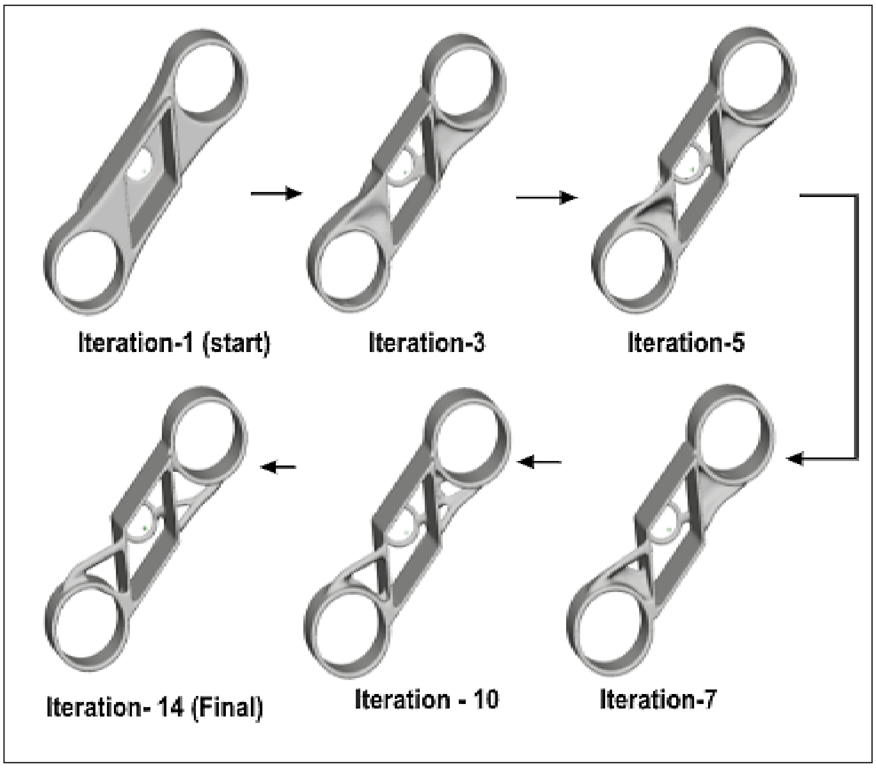

Figure 13.Shows how a design is reduced with respect to mass without affecting its strength

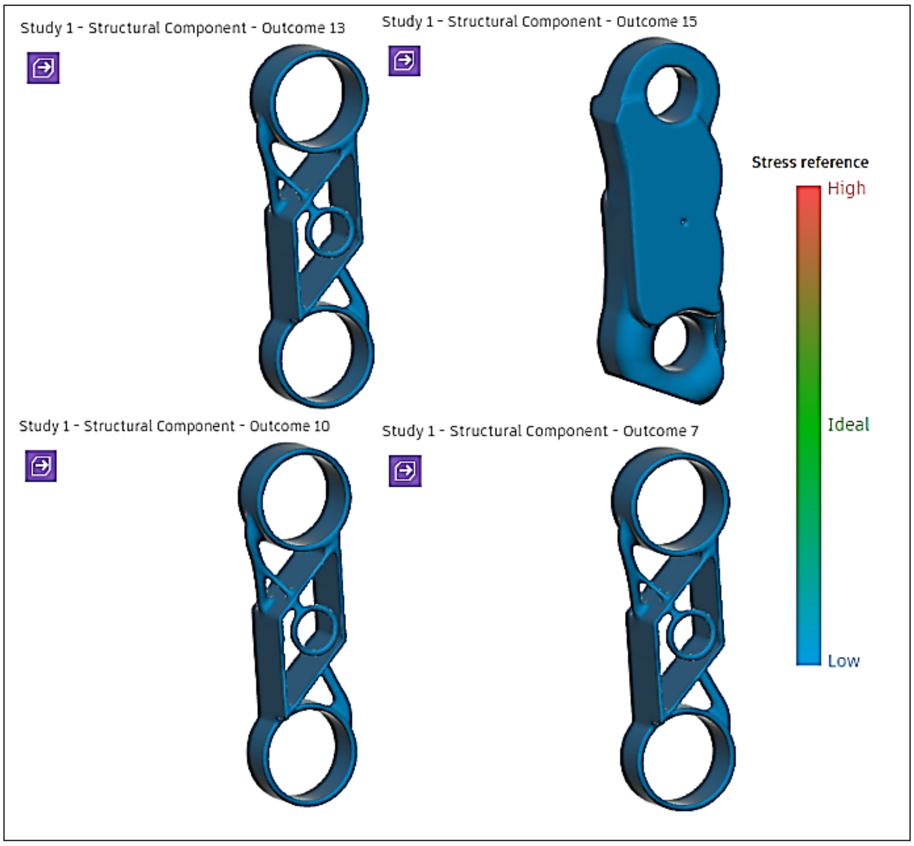

Figure 14.Stress analysis of the four recommended outcomes

In Figure 13, multiple iterations are shown, Iteration 1 shows the given design and iteration 14 shows the final design which is the most optimized one with respect to mass and having least problems among the others. The Changes can be observed in the rest of the generated iterations.

Result and Discussion

Stress Analysis

Fusion generates a stress analysis graph of the best four outcomes. There is a strip at the right side which shows the color representation of red as high stress, green as ideal stress, and blue as low stress.[9] From Figure 14, it can be concluded that out of all outcomes are best in terms of retaining stress as all are shown in blue which denotes low stress level.

Graphical Analysis

- The color coding shown in Fig. 15 shows the following:
- Blue circle denotes aluminum.
- Parrot Green hollow circle denotes aluminum 6061.
- Orange square denotes aluminum ALSi10Mg.
- Hollow Pink square denotes CFRP- i.e., Carbon Fiber
- Triangle in green denotes stainless steel.
- Brown triangle denotes steel.
- The purple circle denotes Titanium.

Figure 16, 17, and 18, shows a graphical representation of the comparison of stress, volume, displacement versus mass for the differences that have been used. Figure 16, shows the volume versus mass analysis which shows that CFRP is the best among them, linearity among the mass and volume of CRPF, titanium and steel can easily be seen here. CFRP exhibits a significantly lower volume-to-mass ratio compared to titanium and steel, indicating its superior density and compactness. Figure 17 shows the stress holding capacity of each of the materials with respect to mass in which CFRP is the best. CFRP demonstrates a remarkable ability to withstand substantial stress while maintaining its structural integrity, outperforming both titanium and steel in terms of maximum von Mises stress per unit mass. This exceptional strength-to-weight ratio enables the fabrication of lightweight components capable of enduring demanding mechanical loads.[10] Figure 18, which shows displacement versus mass graphs, gives CFRP as the best among all other materials, CFRP offers superior stiffness-to-weight ratio compared to titanium and steel, as evidenced by its lower maximum displacement per unit mass. This property ensures that CFRP components can resist deformation under significant loads, maintaining their shape and ensuring optimal performance.[11] Thus, CFRP surpasses titanium and steel in specific strength, stiffness-to-weight ratio, fatigue resistance, and design adaptability, enabling optimized performance and reduced weight.

Graphs for different materials based on the best 4 recommended outcomes.

Figure 15.Chart shows the colored symbol representing different material

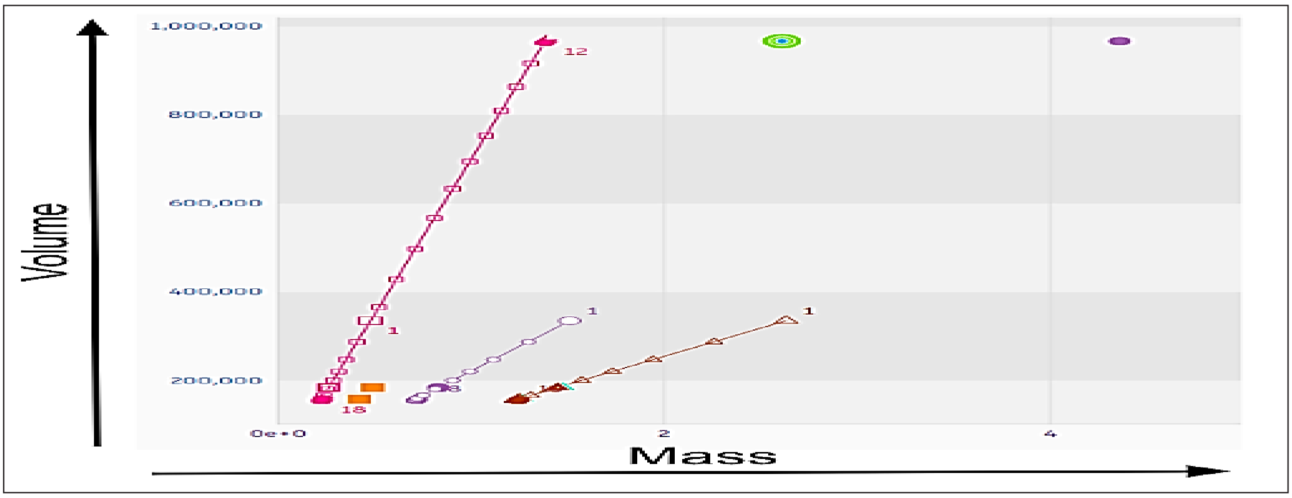

Figure 16.Volume versus mass graph

Final Result

A conclusion table in table 2 describes the initial design of the leg_2 part, then the selected design generated by the generative design function of fusion 360 by reducing the design in terms of mass and volume and the last row representing the stress analysis on the design by applying the stress of 80 newton with gravity. Concluding the stress analysis, design with low stress in all portions is achieved with corresponding mass reduction.

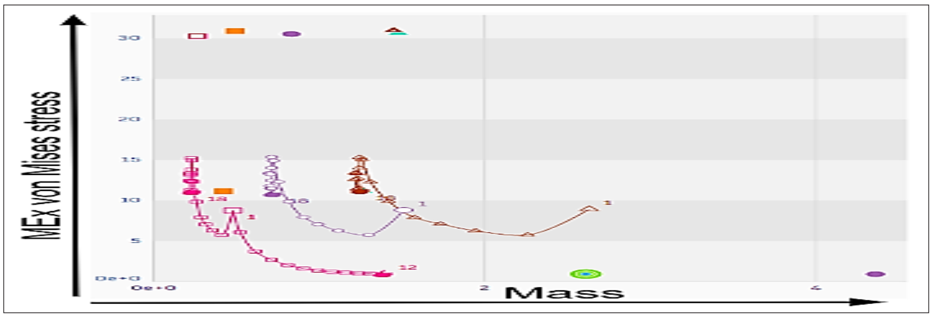

Figure 17.Mex von Mises stress versus mass graph

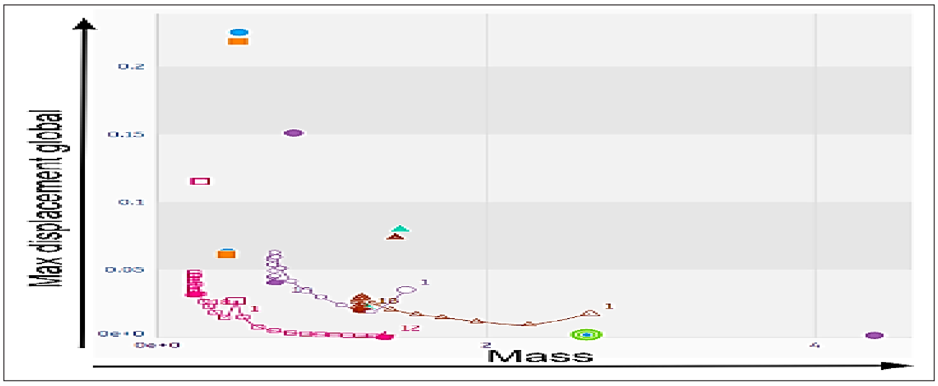

Figure 18.Max displacement global versus mass graph

Table 2.Conclusion table

	Outcome-13
Initial design	
Selected Generative Design	
Stress Analysis Design	

Conclusion

- Out of 18 generative designs for the leg part of the robot, 4 are recommended ones. Out of those four, outcome 13 was analyzed to be the design with best performance.
- It is the design of CFRP material, its recommended percentage is 88.258 %. As the design needs the minimum mass of 0.30 kg which is the minimum mass among the other outcomes.
- It also has a high stress sustaining capacity of 30.25 MPa with respect to other outcomes, it is the 2nd best outcome in terms of stress. It has Displacement of 0.032 mm.
- Outcome 13 will be the best in terms of performance and longevity and thus is the final selected outcome for our design.

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- **Conflicts of interest:** The authors declare that they have no involvement in any organization or entity with any financial interest.

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