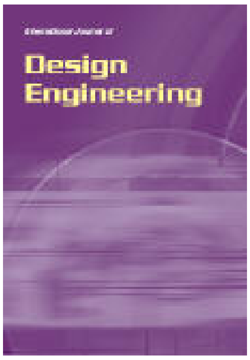

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Multiple novel generative design solutions for various mechanical engineering related products using Autodesk Fusion 360 software

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Multiple novel generative design solutions for various mechanical engineering related products using Autodesk Fusion 360 software

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Abstract: Generative design concept for product design is now evolving in design industries day by day. Many design software developers are now trying to develop software which can generate design solutions using this concept. Companies like Autodesk, Creo, Altair and Siemens have already started providing this functionality in their software products. To showcase the above concept, in this paper we generated multiple novel generative design solutions for mechanical related products on Autodesk Fusion 360 software by performing three design case studies, viz., wall bracket, connecting rod and knuckle joint fork end. The methodology adopted by these software tools to develop multiple novel solutions is presented using flowchart. From these multiple solutions, one optimal design is selected. The static FEA simulation results can be visualised using the simulation user interface provided in the software. For all the three case studies, it is observed that, the stress and global displacement results are found within the critical yield strength values of respective material along with mass customisation.

Keywords: generative design; novel design solutions; wall bracket; connecting rod; knuckle joint fork end; Autodesk Fusion 360.

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Biographical notes: Prasad Umakant Bhad completed his Batchelor degree in Mechanical Engineering from D.Y. Patil College of Engineering and Technology, Kolhapur. Further, he has joined Sardar Patel College of Engineering for Masters degree in Machine Design. He has done his masters project in "Generative design: An Artificial Intelligence-based Product Design". His areas of interest in technology are artificial intelligence, augmented reality, digital twin, big data etc. integrated with mechanical engineering.

Rajesh B. Buktar is working in Sardar Patel College Engineering, Mumbai, India as a Professor and Dean Academics. He has completed his Masters in CAD/CAM from SRTM University, Nanded and Bachelors in Mechanical Engineering from Dr. Babasaheb Ambedkar Marathwada University, Aurangabad. He completed his PhD from Mumbai University in the area of ICT integration in Indian Automotive and Auto Component Industry.

Currently, his area of interest is INDUSTRY 4.0. He is working on leveraging INDUSTRY 4.0 tools and technologies such as Augmented Reality, VR, BIG DATA, machine learning and deep learning to solve problems in Mechanical Engineering Domain.

1 Introduction

Generative design is an artificial intelligence technology that replicates natural evolutionary approach of living things with the help of cloud computing to provide thousands of solutions to one engineering problem without human intervention (Back, 1996). This definition tells us very general working approach based on which many companies have started developing generative design software tool (Generative Design for Architecture, Engineering and Construction, https://www.autodesk.com/solutions/generative-design/architecture-engineering-construction; Generative Design and Topology Optimization Place in Product Development Process, https://www.improvians.com/blogs/generative-design.html). Autodesk Company also developed such generative design software tool called Fusion 360. In this you can start your generation of design either by sketching conceptual design first or by providing existing design of product (Generative Design for Architecture, Engineering and Construction, https://www.autodesk.com/solutions/generative-design/architecture-engineering-construction; Generative Design by PTC Creo, https://www.ptc.com/en/technologies/cad/generative-design). In this software tool, we need to specify three design regions of product. One is obstacle region; it is a region where we do not want to generated extra design in existing design or region used for connection purpose like bolting holes, etc. Second one is preserved region; it is a region where we do not want to alter existing design just keep it as it is. Third one is design region or starting region where we want to generate new design or change or modify the design. This software tool includes various objectives such as mass reduction and stiffness improvement. In objective of mass reduction, we try to reduce mass as maximum as possible and also want to keep desired strength and stiffness.

1.1 The main contribution of this paper include

1 The understanding of an effectiveness of generative design approach and use of generative design software tools available has been done in this paper.

2 Understanding the use of drawing, design, generative design, rendering, simulation and manufacturing workspace available in Fusion 360 software.

3 Study of procedures to be carried out in generative design workspace to generate solutions from this tool.

4 Design of wall bracket, connecting rod and knuckle joint fork end with the help of generative design workspace.

5 Analysis of generated outcomes with the help of simulation workspace and discussion over results generated.

The research paper study is categorised in various sections given below. In Section 1 we have seen generative design concepts and available software tools. The design procedure followed is also been discussed. In Section 2, study of generative design work space in Fusion 360 software and available options and procedure to be carried out has been discussed. Section 3 is related to case study of wall bracket where we can see design outcomes from generative workspace and their analysis results. Section 4 is of case study of connecting rod where we can see design outcomes from generative design workspace and their analysis results. And Section 5 is of case study of knuckle joint fork end where we can see design outcomes from generative design and their analysis results. Finally, we have discussed results and conclusion from research study.

1.2 Design process

Any design process of a product starts from idea generation, conceptualisation and starting imagining how product will look alike. After design engineers design a product from his imagination power. Once the design is finalised, we simulate that design by generating a prototype to real life environmental conditions in which it will get installed. In those conditions we see for various result outcomes like stress generation, deformation, strength of product, reliability of product. Based on these results we select optimised design and launch that product in the market. This all-design procedure of product we can categorise in three categories like pre-processing, processing and post-processing of product as shown in Figure 1. In pre-processing we can include idea generation, conceptualisation and imagination. In processing where actual work of design starts, here we can include sketch drawing, 3D modelling and simulation of product design to real life environmental conditions (Blecker et al., 2014) While, in case of post-processing stage we can include result analysis and try to obtain the best optimised design.

Figure 1 Product design process (see online version for colours)

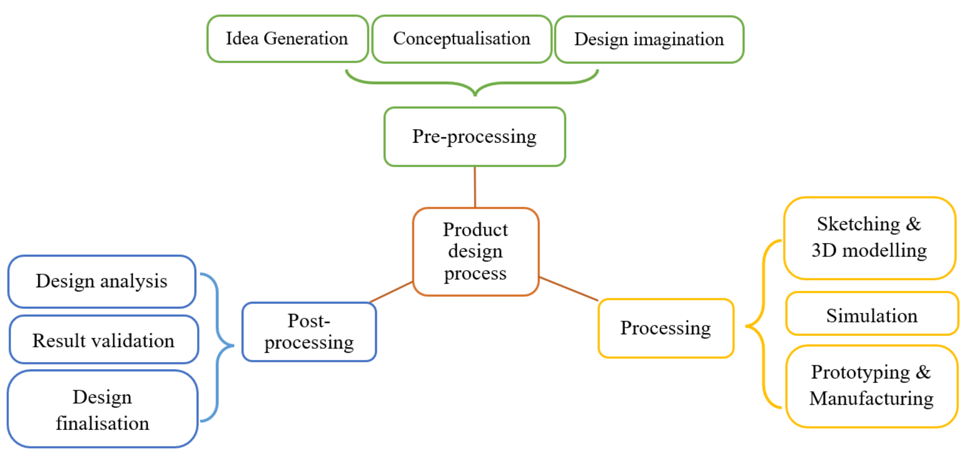


Figure 2 is of traditional approach of product design procedure, has now been replaced by generative design in which we can categorise the design procedure as generate, evaluate and evolve/explore as shown in Figure 3 (Nordin, 2015). In design generation stage, we try to generate new multiple novel designs from existing designs with the help of generative design software tool. Once the multiple designs are been generated, we evaluate those designs in simulations by considering different manufacturing conditions and environmental conditions. Thereafter, we try to modify or evolve new designs and select the best optimised, reliable and high-performance design.

Figure 2 Traditional design approach (see online version for colours)

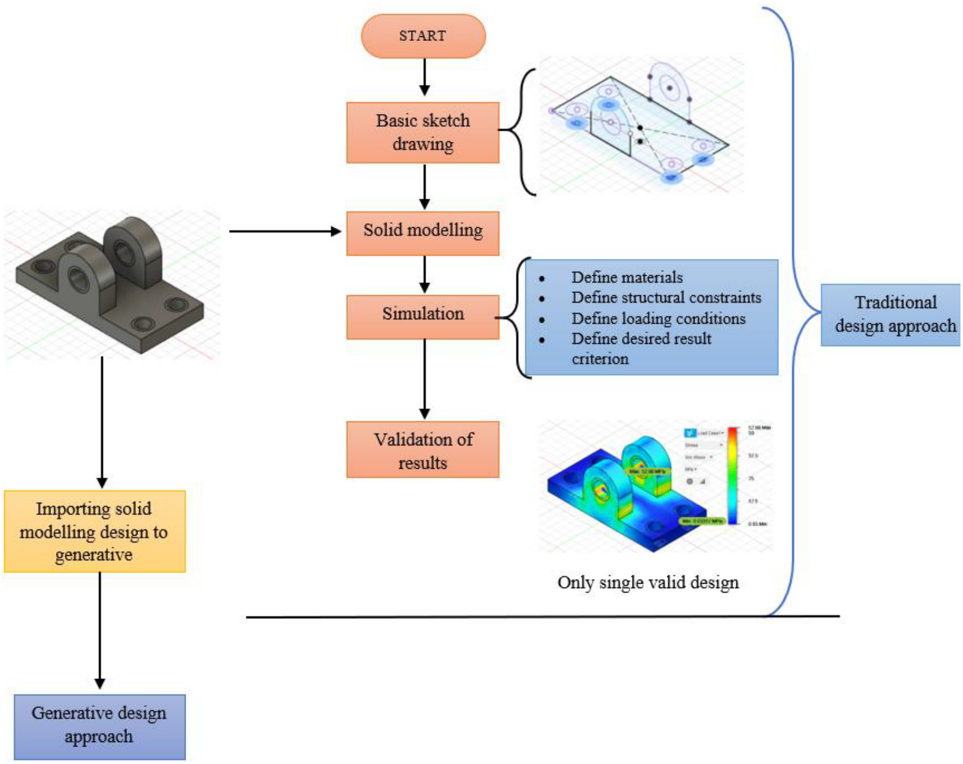
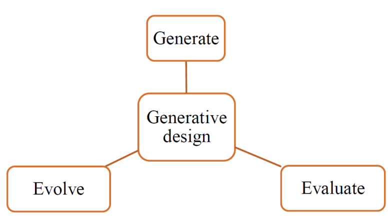


Figure 3 Generative design approach for product design (see online version for colours)



This paper deals with the three case studies of mechanical product like wall bracket, connecting rod and knuckle joint fork end. Wall bracket is a part in machine to joint one component to another in different plane or to hang any component to vertical plane. Wall bracket is containing four bush and holes to mount it on vertical plane/wall and another two holes to hang or joining purpose. One of the previous wall bracket designs is shown Figure 4.

Figure 4 Wall bracket (see online version for colours)

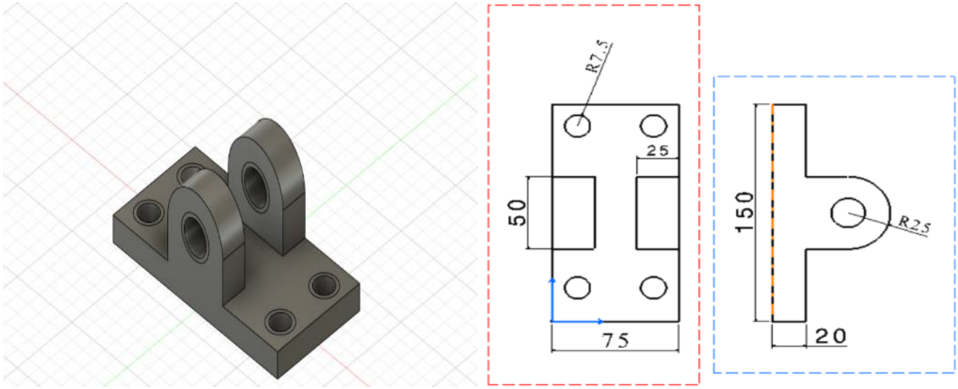


Figure 5 Connecting rod (see online version for colours)

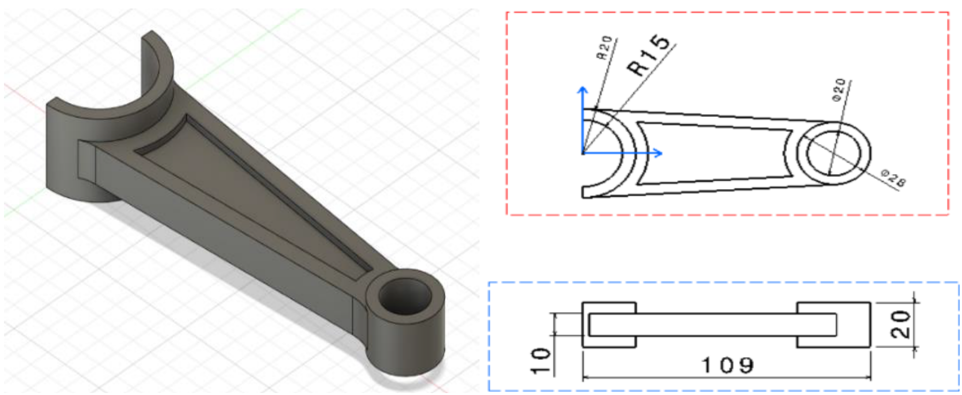
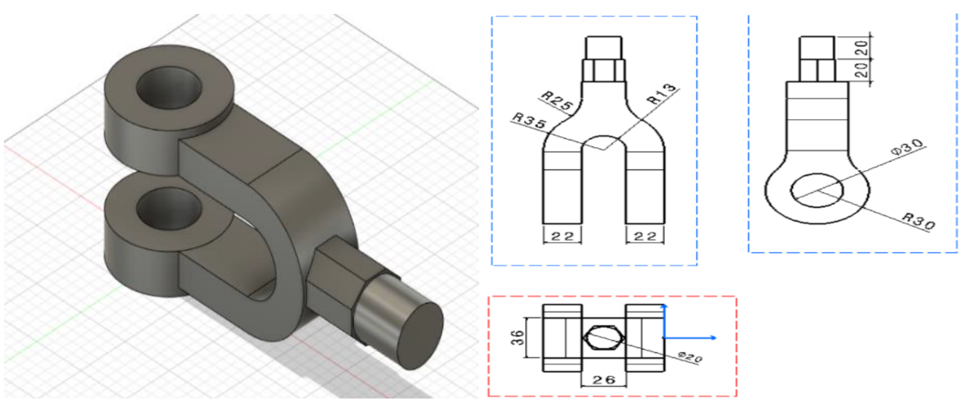


Figure 6 Knuckle joint fork end (see online version for colours)



Connecting rod is used in IC engines, its bigger end is connected to the crank and smaller end is connected to piston head. It is designed for compressive loading conditions and analysed for buckling and fatigue conditions. Its existing design is as shown in Figure 5.

Our third case study is related with design of knuckle joint fork end. It is mostly used for connecting two ends of shaft. It is one of the applications is joining trolley to tractor. It is subjected to tensile loads. The existing design of knuckle fork end is shown in Figure 6.

Figures 4, 5 and 6 shows all three design case studies that are designed, based on desired objectives like mass reduction, stiffness improvement. All dimensions provided are in mm. The inputs provided are factor of safety, constraints and loading conditions and design is validated through finite element analysis with the help of simulations. Industries require product with high performance, sophisticated design and reliable, with the help of this tool with try to get this entire outcome in our case study products.

2 Related work

2.1 Literature review

The work done by Blecker et al. (2014) proposes application of Artificial Intelligence with the help of product configurator which helps design engineers in right decision making in design of product. The work done by Singh (2012) proposes the integration of different generative design methods and generative multiple novel design outcomes from them. The work done by Johan et al. (2019) includes research study on selection of best material for product design based on different algorithms. The work done by Umetani (2017) proposed the exploration of 3D shapes using autoencoder networks. In this the new algorithm is proposed for converting unstructured triangular meshes into consistent topology optimisation for machine learning applications. The work done by Nordin (2015) is about the challenges that were encountered during the development of two generative design systems intended for industrial applications. One case study was oriented towards adding new measurements, changing the objectives of the optimisation and including more phenomena in the simulation. While second case study was entirely focused on the shape generation. The work done by Salta et al. (2019) is about mass customisation in building construction. Digital design offers the possibility to incorporate optimisation strategies. Value of introducing additive manufacturing technique instead of conventional approach, relies in the ability to move from mass standardisation to mass customisation. The work done by Nishimura et al. (2020) is of the formulation of behaviour system and proposed a deep generative model based on generative adversarial nets, where design is based on the three concepts ‘interaction intensity’, ‘time evolution’ and ‘time resolution’. The work done by Harshvardhan et al. (2020), they provide high level overview and analysis of all the generative models used in modern day applications by studying their ideology of operations, properties, advantages and disadvantages. All the methods described in this paper are fields of active research in the literature. This paper also points out the flaws in the evaluation of generated samples and provides future directions to the field of generative models. The work done by Monizza et al. (2018), they have studied two techniques as effective enablers of Industry 4.0 approaches in the building industry. For implementing such techniques investment plans and payback evaluations have to be carried out.

The work done by Chokwitthaya et al. (2020), suggests that the GAN-based framework is in general better in performance than the previous ANN-based greedy algorithm. Causes of the instability in performance of the framework require further research. The work done by Khan and Awan (2018) proposes the generative design techniques for automatic search and generation of design variations for given CAD model-based design specification, aesthetic preference. It has the ability to generate design in constrained and unconstrained design spaces. It uses Jaya algorithm for search approach in multiple generated solutions. The work done by Caetano et al. (2019) discusses various computational tools for computational design process. This paper empowers tools like parametric, generative and algorithmic design tools to explore and evaluate complex solutions, create and deploy advanced fabrication techniques. The work done by Lin et al. (2019), provides biomimetic generative design approach used to solve the classic 'volume-to-point' heat conduction problem. The cooling performance obtained by this novel method is better than that obtained by other methods. The work done by Kallioras and Lagaros (2020) provides ability to produce a population of prototype designs with the only necessary inputs being the domain dimensions, the support and loading conditions and desired final volume. Also pointing out that apart from 2D problems.

However, the above all research studies talks about use of generative design or use of Artificial Intelligence in product design and development process. None of the paper has discussed about availability of any software tool that neither works on generative design nor discussed about their working interface. Most of the software companies like CREO, Autodesk has recently started developing such tools of generative design (Generative Design for Manufacturing, https://www.autodesk.com/solutions/generative-design/manufacturing; Generative Design for Architecture, Engineering and Construction, https://www.autodesk.com/solutions/generative-design/architecture-engineering-construction; Generative Design by PTC Creo, https://www.ptc.com/en/technologies/cad/generative-design; Generative Design and Topology Optimization Place in Product Development Process, https://www.improvians.com/blogs/generative-design.html). The idea behind this research study is all about letting everyone know about working of such generative design software tools and discussing how such tools are beneficial in generating multiple novel design solutions easily and quickly.

3 Generative design and study generation in software

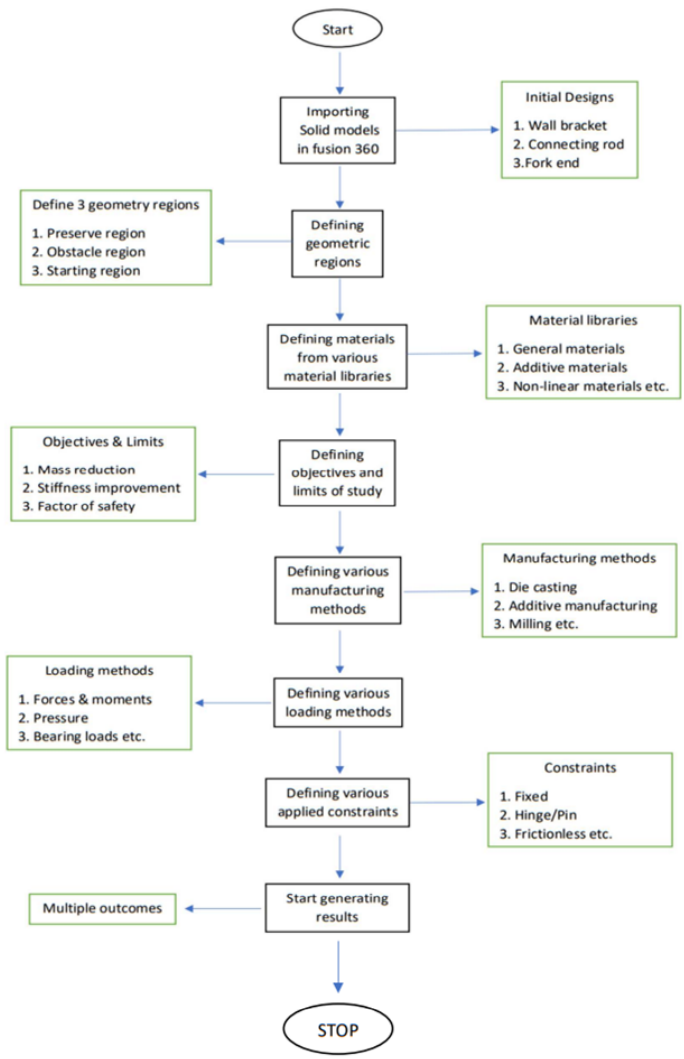
As already been discussed, we all know that traditional product design process includes sketching, modelling, simulation and manufacturing. However, in generative design process methodology of designing a product is relatively different.

Figure 7 shows the generalised working methodology flowchart of generative design software. At start we import initial designs to Fusion 360 software where, we define three geometric regions, i.e., preserve region, obstacle region and starting region. After that we assign different materials to product available in various material libraries. Then, we provide objectives and limits of design study. In next step, we provide loading conditions and constraints in which product is going to be used. Once, all these inputs are provided software start generating multiple design outcomes. Considering all this as requirements of product design process Autodesk company have included all these workspaces in their Fusion 360 software along with generative design and animation workspace (Generative Design for Architecture, Engineering and Construction, https://www.autodesk.com/solutions/generative-design/architecture-engineering-construction; Generative Design by

PTC Creo, https://www.ptc.com/en/technologies/cad/generative-design). The workspaces included are:

- design
- generative design
- render
- animation
- simulation
- manufacture
- drawing.

Figure 7 Working methodology of generative software (see online version for colours)



Starting with drawing workspace here we can sketch the design of product, after that in design workspace we can start modelling the design of product in 3D form. Simulation workspace includes material assigning, constraints and loading condition assigning and analysing the results. In manufacturing workspace one can see which manufacturing method we can adopt for our product design. In generative design, we can provide the existing design and in workspace it can start generating the novel designs. All Workspaces of this software perform operations over cloud to reduce computation time.

Figure 8 Fusion 360 generative design workspace toolbar (see online version for colours)

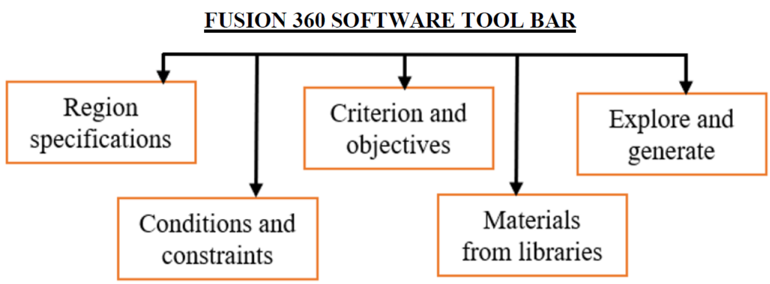
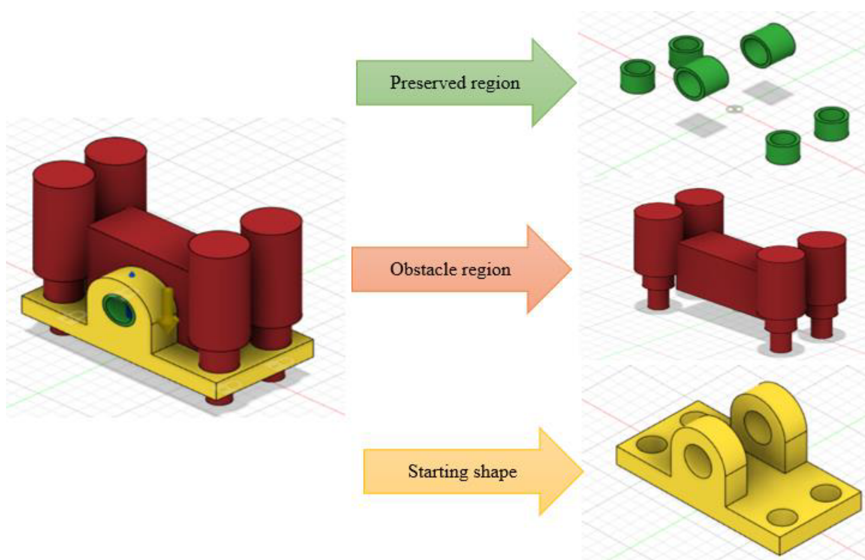


Figure 9 Specification of regions in wall bracket (see online version for colours)



3.1 *Generative design study initialisation*

Figure 8 shows the tool bar options available in software. Initialisation of product design in generative design workspace requires mentioning of three design regions. One is preserved region indicated in green colour in workspace shows that which component of product need to be kept as it is while processing as shown in Figure 9. Here, there will be no change in design during processing in workspace. Second is obstacle region indicted in red colour in workspace shows that our processing or modification of design should not go to that region as shown in Figure 10. This region also includes spacing for tool mounting and connectors. Third region is starting shape region indicted in yellow colour where actual processing or modification of design is being takes place as shown in Figure 11.

All these three regions for our case study have shown below:

1 wall bracket
2 connecting rod
3 knuckle joint fork end.

Figure 10 Specification of regions in connecting rod (see online version for colours)

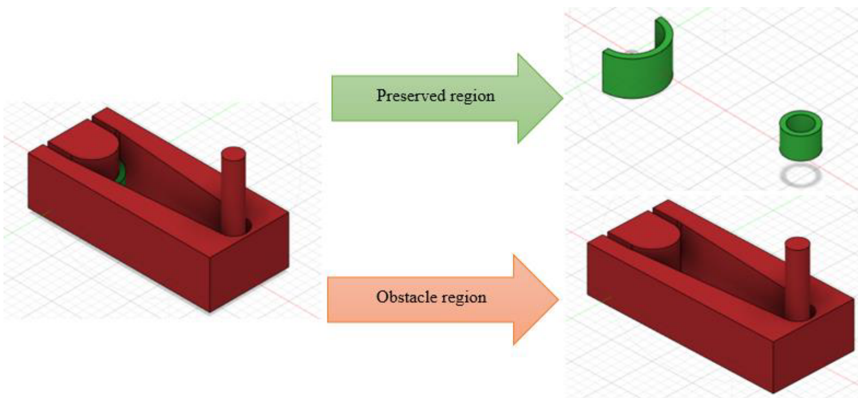
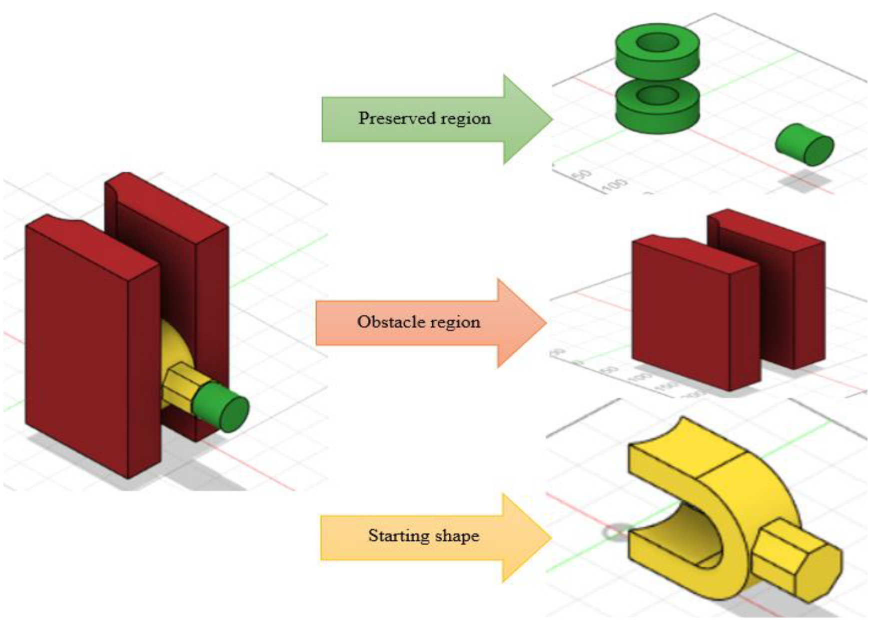


Figure 11 Specification of regions in knuckle joint fork end (see online version for colours)



3.2 Generative design study setup

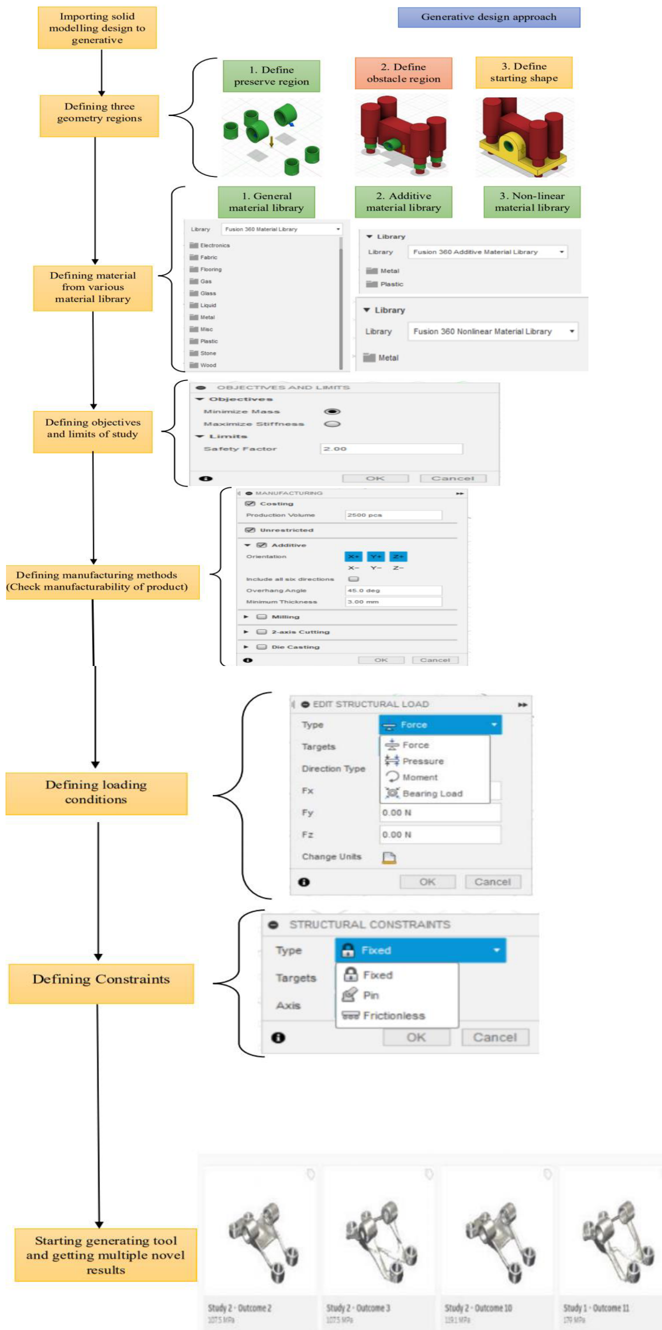
As discussed earlier any design process includes modelling, simulations and manufacturing. Generative design workspace in software includes all these in one. Study starts with setting up of synthesis resolution which is nothing but meshing during simulation. In involves two option that is fine meshing and coarse meshing. Fine meshing gives more accurate results and requires more computation time as it contains a greater number of elements. While in case of coarse meshing less computation time is required as it contains a smaller number of elements. Further we need to mention structural constraints, structural loads and design conditions. Gravity is already included load in all type of analysis by the software itself. Different loading conditions for all three case studies are as given below:

- 1,000 N force in +Z direction on mounting holes in study of wall bracket design.
- 1,000 N force in +X direction on mounting holes in study of wall bracket design.
- 5,000 N force in –X direction on small end of connecting rod in study of connecting rod design.
- 600 N force in +X direction on small end of connecting rod in study of connecting rod design.
- 1,050 N force in +Y direction on small end of connecting rod in study of connecting rod design.
- 75,000 N force in –X direction on mounting holes of knuckle fork end in study of knuckle joint fork end design.

The above all applied loads are taken from some of applications. The results are generated for these conditions with different environmental conditions. One can also vary loading magnitudes, directions and loading points depending on their application and generate results. In case of connecting rod, with the application of compressive force and torsional force and buckling of connecting rod is also considered in simulation.

Design criterion is further need to be specified in the software for study generation. Design criterion includes specification of objectives and manufacturing method to be adopted in study setup. Objective of study in generative design includes mass reduction and stiffness improvement. Most of the industries require light weight but high performing products. This software exactly focuses this aspect of product design and generates and explore such multiple designs. Study also includes limit as factor of safety. In our all three-case studies mass reduction is main objective and limit of factor of safety is 2. The key feature of this generative design workspace is consideration of manufacturing methods in design stage itself. In Fusion 360 software the manufacturing methods provided are unrestricted, additive manufacturing, three-axis and five-axis milling, two-axis cutting and die casting. Unrestricted method has high performance and low weight than designs constrained by a manufacturing process, but harder to manufacture. Additive manufacturing is one of the advanced manufacturing methods which includes complex design manufacturing and light weight prototyping. For Additive manufacturing we need to mention orientation (+X, +Y, +Z, –X, –Y, and –Z directions), overhang angle (set as 45 degree as default) and minimum thickness. The milling method includes two configurations of tool axis, three-axis milling and five-axis milling. Further methods are two-axis cutting and die casting methods.

Figure 12 Generative design procedure flowchart of Autodesk Fusion 360 (see online version for colours)



Materials are important aspect of any product. In the generative design work space further, we have to specify the best suitable materials for our products depending on environmental conditions in which we want to install the product, desired physical and chemical properties of product and depending upon manufacturing method adopted for our product design (Generative Design by PTC Creo, https://www.ptc.com/en/technologies/cad/generative-design). For our case studies material included are:

- aluminium AlSi10Mg
- cobalt chrome
- stainless steel AISI 304
- stainless steel 17-4 PH
- aluminium
- Aluminium 6061.

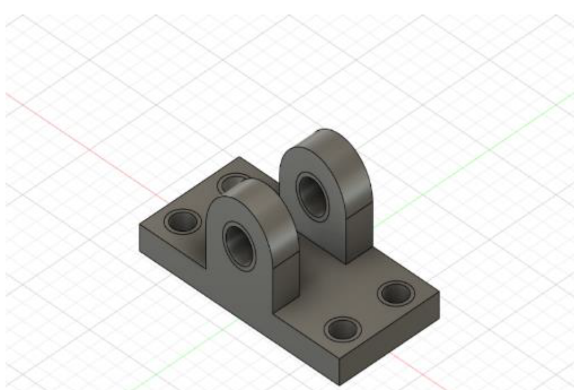
These materials are selected to get all desired design objectives like less mass, less cost, more strength, more efficient, easily available. Thereafter, we have option pre-check of study setup before generating designs. In pre-check we have seen for all conditions, values, methods specified in study are correct. Once the pre-check is done our design is ready to generate in workspace. Each study requires 25 cloud points which will be bought online. This is the generation process where software does cloud computation and generate multiple novel designs.

3.3 Outcome generation and exploration

We first see wall bracket design generation step by step with flowchart as we discussed in above discussion. Figure 12 shows steps followed in generative design of wall bracket.

4 Case study 1

Figure 13 Design of wall bracket (see online version for colours)



4.1 Multiple design solutions

In design case study of wall bracket we provided one previously available design from human perspective is provided in generative design workspace. After mentioning all design regions in existing design and applying all loading conditions and constraints, and stating objectives and manufacturing methods various design outcomes has been generated as shown in Figure 14. We got results for additive manufacturing, unrestricted manufacturing methods and materials like stainless steel, aluminium alloy and cobalt chrome. These design outcomes are further analysed in simulation workspace.

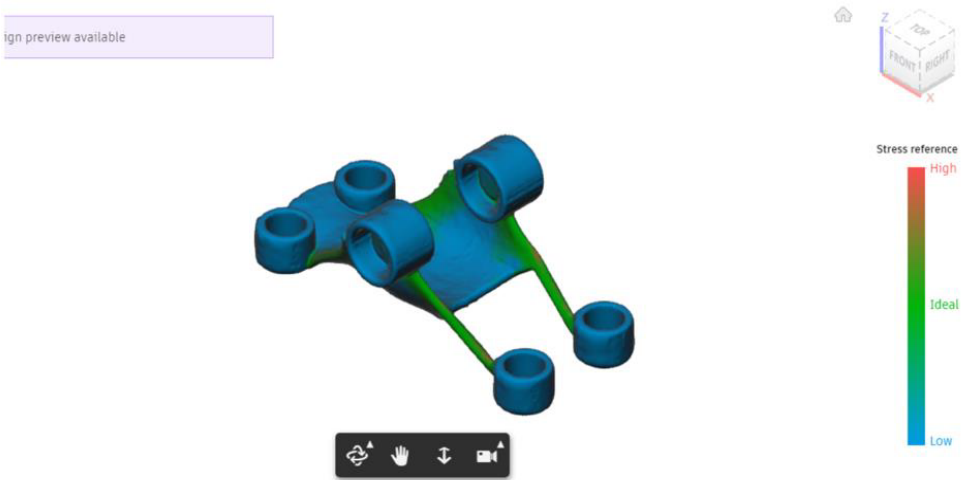
Figure 14 Design outcomes generated for wall bracket (see online version for colours)

Name	Tech-Preview	Processing status	Material	Manufacturing method
Study 1 - Outcome 1		Completed	Stainless Steel AISI 304	Unrestricted
Study 1 - Outcome 2		Completed	Stainless Steel AISI 304	Additive
Study 1 - Outcome 3		Completed	Stainless Steel AISI 304	Additive
Study 1 - Outcome 5		Completed	Cobalt Chrome	Unrestricted
Study 1 - Outcome 11		Completed	Aluminum AlSi10Mg	Additive
Study 2 - Outcome 2		Completed	Stainless Steel AISI 304	Additive
Study 2 - Outcome 3		Converged	Stainless Steel AISI 304	Additive
Study 2 - Outcome 6		Completed	Cobalt Chrome	Additive
Study 2 - Outcome 10		Converged	Aluminum AlSi10Mg	Additive

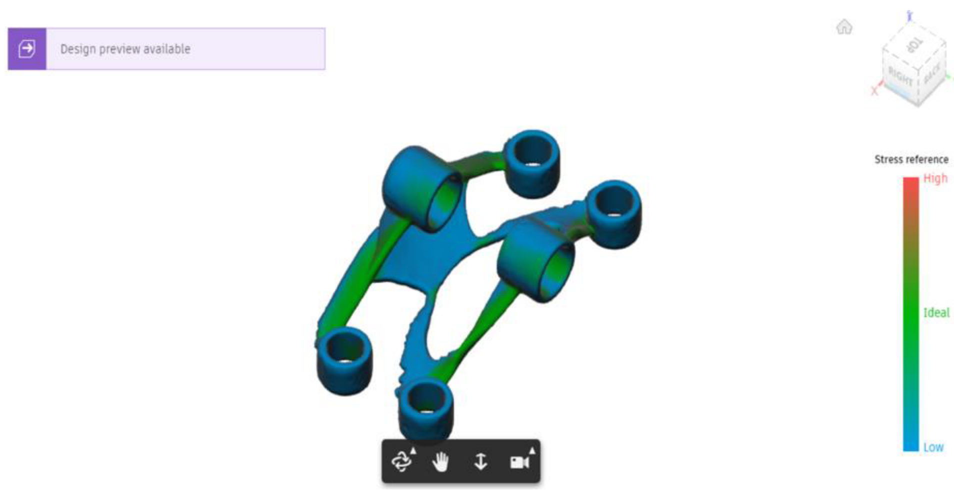
Figure 15 (a) Design outcome 1 (b) Design outcome 2 (c) Design outcome 3 (d) Design outcome 4 (see online version for colours)

(a)

Figure 15 (a) Design outcome 1 (b) Design outcome 2 (c) Design outcome 3 (d) Design outcome 4 (continued) (see online version for colours)



(b)

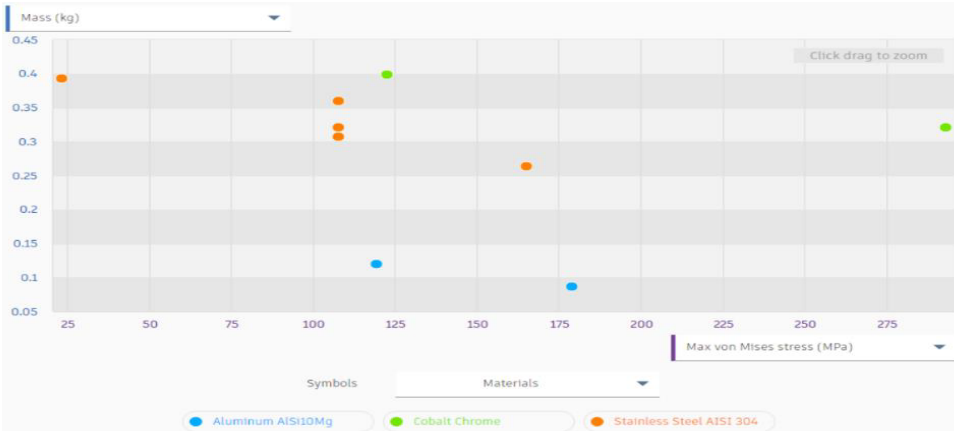


(c)

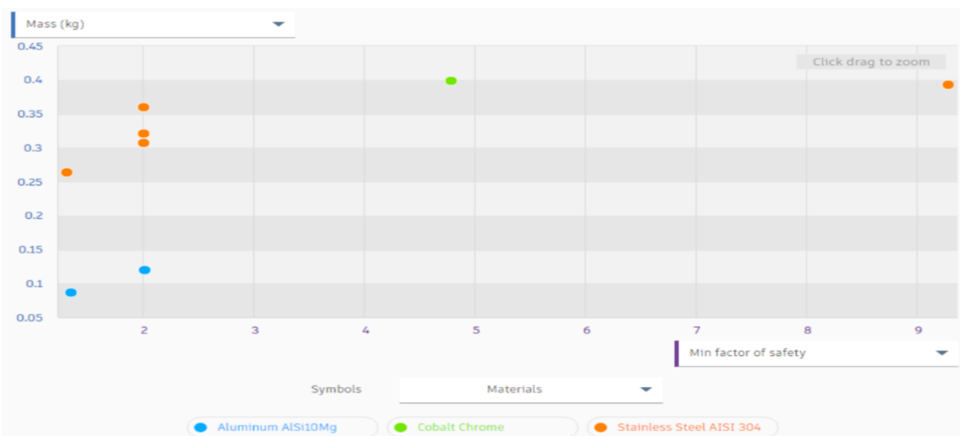
4.2 Result comparison

From Figure 15 we can see various design outcomes generated and from Figure 16 we can check their analysis result comparison between mass, stress generated, deformation and factor of safety. We can check, to generate optimum design which manufacturing method and material would be effective. We can see aluminium material is providing less weight while stainless steel is providing less stress-strain value for applied loading conditions.

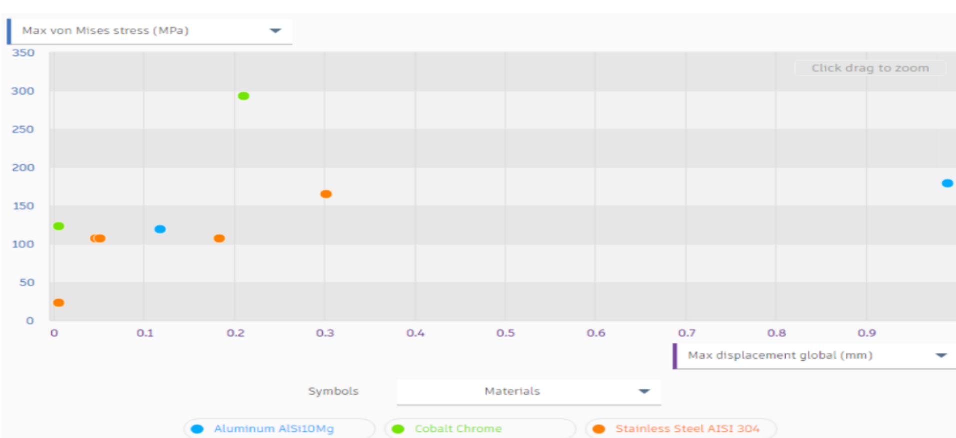
Figure 16 (a) Mass vs. stress result (b) Mass vs. factor of safety result (c) Stress vs. global displacement result (see online version for colours)



(a)



(b)



(c)

5 Case study 2

Figure 17 Design of connecting rod (see online version for colours)

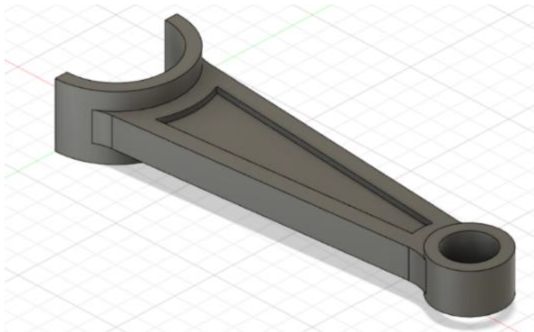


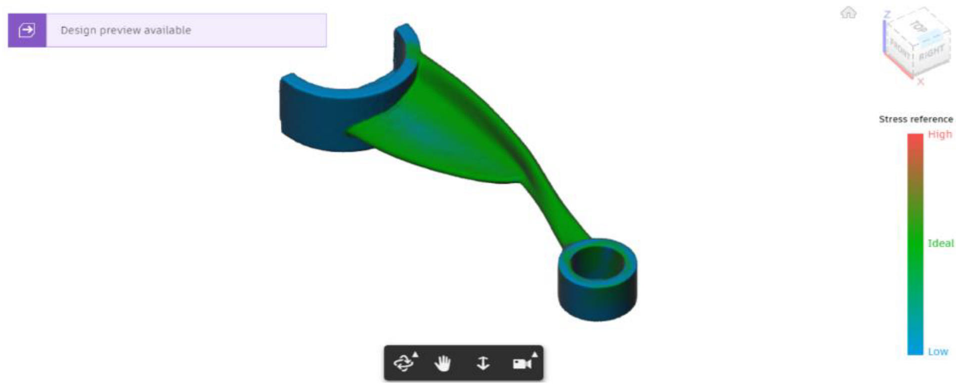
Figure 18 Design outcomes generated for connecting rod (see online version for colours)

Name	Tech-Preview	Processing status	Material	Manufacturing method
Study 1 - Outcome 1		Converged	Aluminum	Unrestricted
Study 1 - Outcome 2		Completed	Aluminum	Additive
Study 1 - Outcome 3		Converged	Aluminum	Additive
Study 1 - Outcome 5		Completed	Aluminum	3 axis milling
Study 1 - Outcome 6		Converged	Stainless Steel AISI 304	Unrestricted
Study 1 - Outcome 7		Converged	Stainless Steel AISI 304	Additive

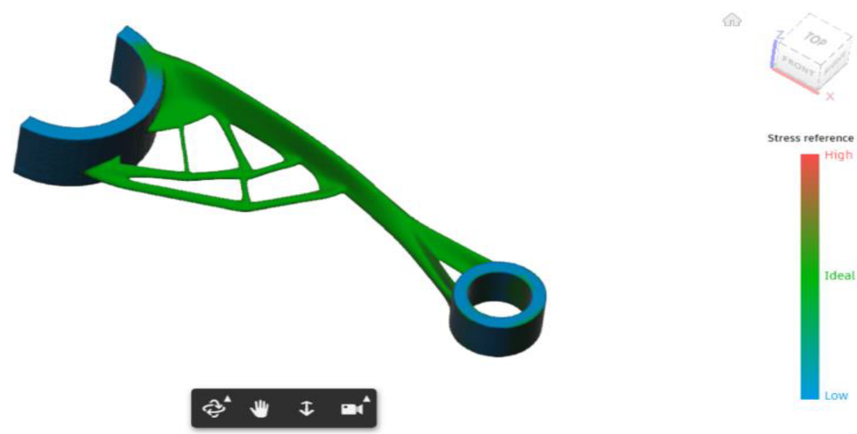
Figure 19 (a) Design outcome 1 (b) Design outcome 2 (c) Design outcome 3 (see online version for colours)

(a)

Figure 19 (a) Design outcome 1 (b) Design outcome 2 (c) Design outcome 3 (continued) (see online version for colours)



(b)



(c)

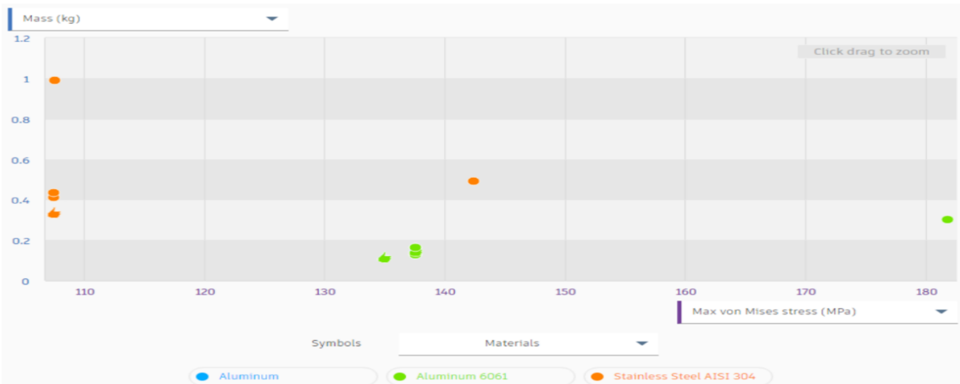
5.1 Multiple design solutions

In design case study of connecting rod, we provide previously existing design to generative workspace where we can specify design regions, loading conditions and constraints applied, material and manufacturing methods and objectives of design. Additive manufacturing, three axes milling and unrestricted method are the methods adopted. Aluminium and stainless steel are the best suitable material. Figure 18 shows the design outcomes generated.

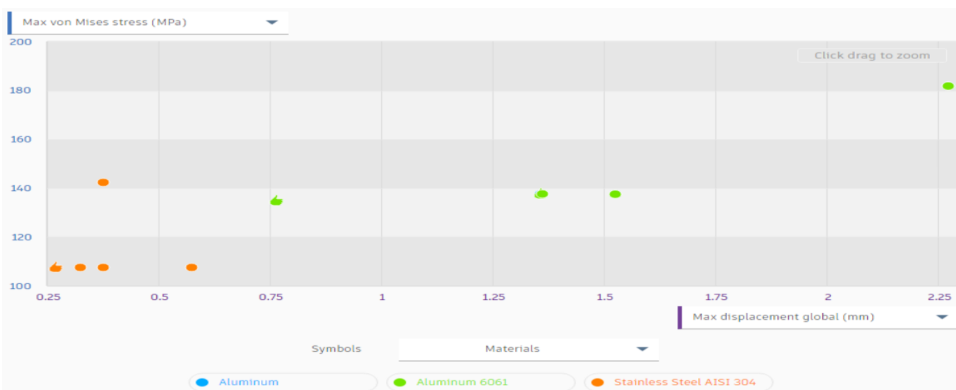
5.2 Result comparison

From Figure 19 we can see various design outcomes generated and from Figure 20 we can see their analysis result comparison between mass, stress generated, deformation and factor of safety. We can check, to generate optimum design which manufacturing method and material would be effective. We can see aluminium material is providing less weight while stainless steel is providing less stress-strain value for applied loading conditions.

Figure 20 (a) Mass vs. stress result (b) Stress vs. global displacement result (c) Mass vs. factor of safety result (see online version for colours)



(a)

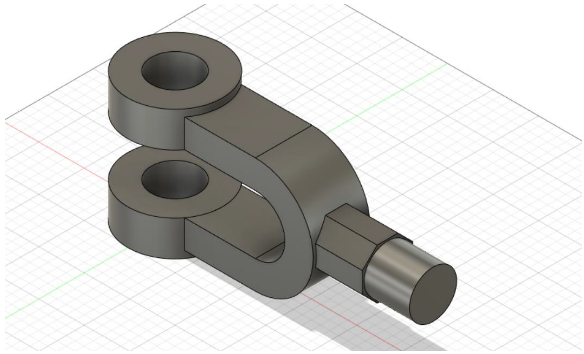


(b)

(c)

6 Case study 3

Figure 21 Design of knuckle joint fork end (see online version for colours)



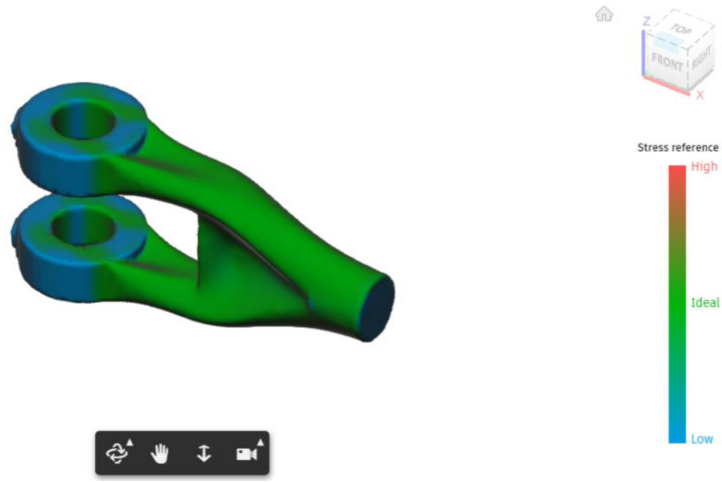
6.1 Multiple design Solutions

In design case study of knuckle joint fork end, we provide previously existing design to generative workspace where we can specify design regions, loading conditions and constraints applied, material and manufacturing methods and objectives of design. Additive manufacturing, three axes milling and unrestricted method are the methods adopted. Aluminium alloy and stainless steel are the suitable materials. Figure 22 shows the multiple design outcomes generated.

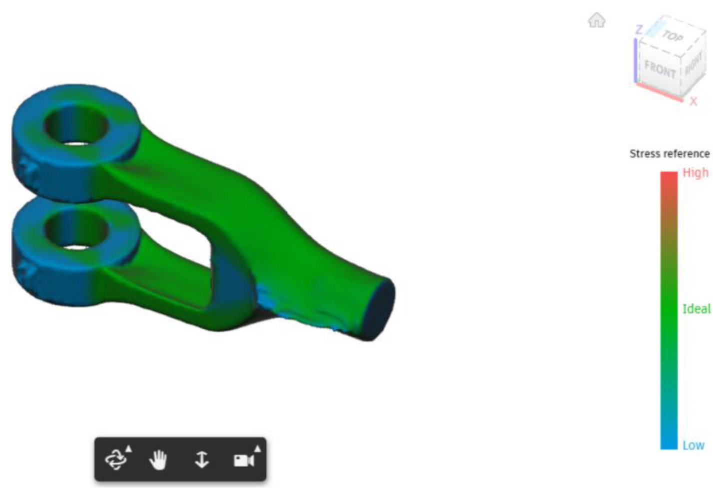
Figure 22 Multiple design outcomes for knuckle joint fork end (see online version for colours)

Name ↓	Tech-Preview	Processing status	Material	Manufacturing method
Study 3 - Outcome 1		Converged	Stainless Steel AISI 304	Unrestricted
Study 3 - Outcome 2		Converged	Stainless Steel AISI 304	Additive
Study 3 - Outcome 3		Converged	Stainless Steel AISI 304	Additive
Study 3 - Outcome 4		Converged	Stainless Steel AISI 304	Additive
Study 3 - Outcome 5		Completed	Stainless Steel AISI 304	3 axis milling
Study 3 - Outcome 6		Converged	Aluminum 6061	3 axis milling
Study 3 - Outcome 7		Converged	Aluminum AlSi10Mg	Unrestricted
Study 3 - Outcome 8		Converged	Aluminum AlSi10Mg	Additive
Study 3 - Outcome 9		Converged	Aluminum AlSi10Mg	Additive
Study 3 - Outcome 10		Converged	Aluminum AlSi10Mg	Additive

Figure 23 (a) Design outcome 1 (b) Design outcome 2 (see online version for colours)



(a)

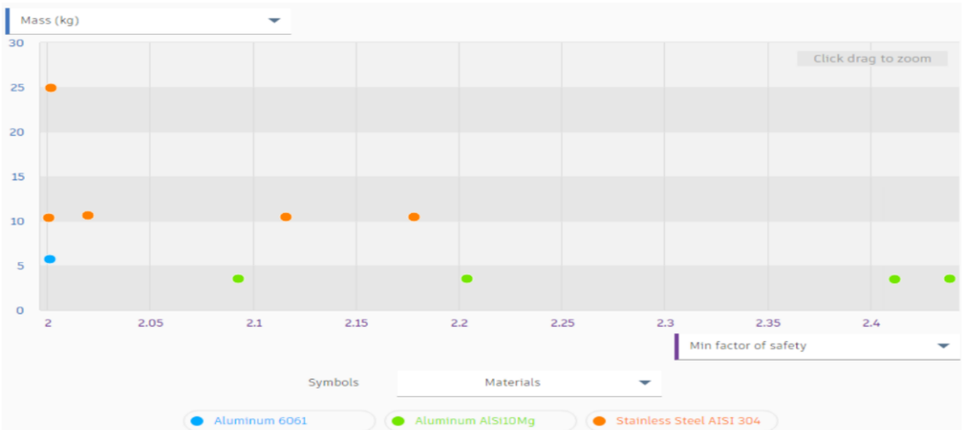


(b)

6.2 Result comparison

From Figure 23 we can see various design outcomes generated and from Figure 24 we can check their analysis results generated. We can see that aluminium alloy material is providing less weight as well as less stress-strain values to given applied conditions. While stainless steel also provides similar stress-strain results but having more weight compared to aluminium alloy.

Figure 24 (a) Mass vs. factor of safety result (b) Mass vs. global displacement result (c) Stress vs. displacement results (see online version for colours)



(a)

(b)

(c)

7 Result validation

From the above results from Tables 1, 2, 3 and 4 we can check for stresses generated in respective material design outcomes and comparing the results with yield values of material. The stresses generated in material are well below yield values. The factor of safety considered in each design outcome is 2.

Table 1 Material properties

Stainless steel AISI 304	
Density	7,900 kg/m^3
Elastic modulus	193 GPa
Yield strength	205 MPa
Tensile strength	515 MPa
Thermal conductivity	18.9 W/m.k
Specific heat	500 J/Kg.k
Cobalt chrome	
Density	10 g/cm^3
Elastic modulus	210 GPa
Yield strength	470 MPa
Tensile strength	1130 MPa
Thermal conductivity	9.4 W/m.k
Specific heat	390 J/Kg.k
Aluminium AlSi10Mg	
Density	2.67 g/cm^3
Elastic modulus	75 GPa
Yield strength	260 MPa
Tensile strength	460 MPa
Thermal conductivity	110 W/m°C
Specific heat	910 J/kg°C
Aluminium	
Density	2.7 g/cm^3
Elastic modulus	70 GPa
Yield strength	125 MPa
Tensile strength	275 MPa
Thermal conductivity	237 W/m.k

8 Result and discussion

From the given research case study, we can see how generative design software tools generates effective multiple design outcomes for applied constraints and loading conditions as discussed in respective case studies. From the results we can see which manufacturing methods, materials are best suitable for design of those products. Also, the analysis results can show the stress-strain value generated, deformation happened and obtained mass reduction and factor of safety at applied constraints and loading conditions. The respective stress-strain results generated in product designs are compared with their respective material properties.

Table 2 Results of wall bracket

Design outcome 1	
Von-Mises stress	22.8 MPa–23.8 MPa
Global displacement	0 mm–0.01 mm
Factor of safety	2
Design outcome 2	
Von-Mises stress	107.5 MPa–119.1 MPa
Global displacement	0.05 mm–0.12 mm
Factor of safety	2
Design outcome 3	
Von-Mises stress	107.5 MPa–120 MPa
Global displacement	0.05 mm–0.15 mm
Factor of safety	2
Design outcome 4	
Von-Mises stress	164.9 MPa–179 MPa
Global displacement	0.3 mm–0.99 mm
Factor of safety	2

Table 3 Results of connecting rod

Design outcome 1	
Von-Mises stress	107.5 MPa–181.8 MPa
Global displacement	0 mm–0.57 mm
Factor of safety	2
Design outcome 2	
Von-Mises stress	107.5 MPa–137.5 MPa
Global displacement	0.32 mm–1.52 mm
Factor of safety	2
Design outcome 3	
Von-Mises stress	107.5 MPa–135 MPa
Global displacement	0.27 mm–0.76 mm
Factor of safety	2

From the research study we come to know that, how generative design tools will be effective in product development process. The consideration of manufacturability and cloud computation has again provided some advantages like complex designing, time reduction in design process, etc. Following advantages are added on values to the generative design.

1 Multiple design outcomes: From all three case studies we can see the generative design tool provides multiple solutions. From that we can choose one optimised solution by analysing it for various results.

2 Manufacturability consideration: Due to this, in design phase itself we come to know which manufacturing method can be adopted for available product design. Also, we can check for advanced and effective manufacturing methods to generate best results.

Table 4 Results of knuckle joint fork end

Design outcome 1	
Von-Mises stress	101.6 MPa–107.5 MPa
Global displacement	0.12 mm–0.42 mm
Factor of safety	2
Design outcome 2	
Von-Mises stress	106.4 MPa–114.7 MPa
Global displacement	0.16 mm–0.57 mm
Factor of safety	2

9 Conclusions

The proposed paper is aimed at generation of optimum multiple design solutions based on desired objectives, applied conditions and constraint using generative design workspace in Autodesk Fusion 360 software. At first stage the paper is focuses on study of such available generative design software tools and working of tools in generating multiple novel designs. The paper also focuses on design generation of three case studies as per requirement of industrial application. This tool gives all desired aspects of product design like less weight, less cost, high performance, ease of manufacturability, durability of product in workspace of generative design. Thus, generative design software tools are very essential in each industry for design consideration. One can understand how we can use this tool for design creation and problem solving. Along with Autodesk other companies like PTC Creo, Siemens, Altair, etc. are developing similar software. Most of their graphic-user interface is quite similar. But most of them are in developing stage so competition is there for user friendly software development. The generative design approach will provide different opportunities to design engineers and companies to add on values in product designs. This will create optimised design and improves product development process.

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