

Optimization of Design thinking process for 3D printed products

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ABSTRACT: 3D printing, or Additive manufacturing, is an important technological advancement in the field of manufacturing. It provides us with the ease of creating complex geometry and creating more economical and efficient products. 3D printing is not just a method of rapid prototyping anymore, with the advent of technologies such as DMLS (Direct metal laser sintering), 5 axis and 6 axis robot 3D printers; it has become an important manufacturing tool which allows us to make products of wide range of materials, size and strengths. Therefore, it is our responsibility as designer, as well as engineers to use this technology to its maximum potential with the help of various tools. An attempt is made in the paper to optimize the products made with the help of this technology by creating a workflow which adheres to the manufacturing aspects of design. This paper deals with implementing the design thinking process along with design tools such as DFAM (Design for Additive Manufacturing), DFMA (Design for Manufacturing and Assembly) and Generative Design to develop and manufacture the most efficient design for a drone using 3D printing. The final result achieved in the end is a more efficient as well as sustainable (less wastage and carbon footprint) product.

KEYWORDS: 3D Printing, DFAM, DFMA, Generative Design

I. INTRODUCTION

Ever since the beginning of human kind, we have been experimenting to find new materials to produce better tools to improve the quality of living. The different ages of human kind from Stone Age to Bronze Age to Iron Age are classified based on the type of tools used in the time period. As we preserved over the ages to produce tools with more strength and durability with help of newer materials, the methods used to produce or manufacture them remained more less the same. These traditional methods of manufacturing which have remained the same for centuries are generally very rigid in their workflow and capabilities, and are not sustainable. As we are beginning to understand the environmental impacts of manufacturing processes and other production related activities have through fields such as Industrial Ecology, it becomes the responsibility of designers and engineers to reduce these adverse effects. 3D printing or additive manufacturing is a step towards manufacturing and producing more flexible and sustainable products. 3D printing, or additive manufacturing, is the construction of a three-dimensional object from a CAD model or a digital 3D model [1]. The CAD model is sent to slicing software which slices the model to multiple layers and sends the specific g codes to the 3D printing machine. Once ready, the machine prints the model layer by layer at micron level thickness with the help of the g codes. The additive nature of the process gives it the ability to produce complex geometry with very little wastage in the form of support structures.

In the 1990s, 3D printing techniques were considered suitable only for the production of functional or aesthetic prototypes, and a more appropriate term for it at the time was rapid prototyping. However, as the precision, repeatability, and material range of 3D printing has increased to the point that some 3D printing processes are considered viable as an industrial-production technology [1]. The dawn of Industry 4.0 and the digital transformation and automation of manufacturing/production and value creation process, has given rise to another concept called Digital manufacturing. Digital manufacturing is an integrated approach to manufacturing of products which revolves around computer systems, comprising tools for simulation, 3D modelling, analytics and collaboration. It consists of a cloud-based system wherein the engineers, designers and machinists can all work together with the help of CAD, CAE and CAM tools, seamlessly providing feedback and ideas at every step of the process to produce more efficient products with minimum wastage of time and resources. Software such as Autodesk fusion 360 and Dassault 3DExperience are some elementary software in the field. At the core of Digital manufacturing is Additive manufacturing, due to its ability to produce complex geometry with minimum wastage in short periods of time.

As the Additive manufacturing becomes an integral part of our manufacturing process, we need to make our design keeping in mind the capabilities and limitations of manufacturing as well as utilizing this technology in the most efficient way, to produce products which in a sustainable and efficient method.

II. METHODOLOGY

2.1 Design Thinking Process

The designing and manufacturing of products is a very complex procedure, but this procedure is simplified with the help of Stanford D-school design thinking process. The design thinking process is generalized and step-by-step procedures which can be followed to streamline the workflow and better develop products [2]. The steps of the process are shown in Figure 1. However, since the growth of ideas such as digital manufacturing and additive manufacturing it becomes the responsibility of the designer to keep in my mind the manufacturing aspects to create the most efficient design. Therefore, we need to update this process in order to account for the manufacturing; this is where tools like DFAM, DFMA and Generative design come into play.

Design thinking process consists of primarily 6 steps-Empathize, Define, Ideate, Prototype, Test. Empathize, it is a process of finding out user preferences and discovering their need, both overt and latent. Define, this phase builds on the need of peoples ‘needs and preferences, towards developing insights into what their core problem is that seeks a solution [2]. Ideate, this includes sharing of ideas, diverging into many different ideas and converging to select the best one. Prototype, this involves narrowing the ideation results towards a rough early solution to an early problem. Test, this part forms the iterative process of learning what works and what does not [2]. The whole design process is circular and iterative; with each iteration we learn and improve the product. In this paper we have attempted 3 iterations in order to make the design more efficient.

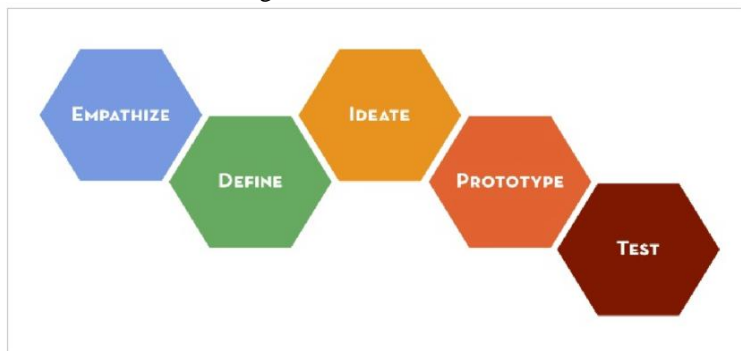


Fig.1. Design Thinking Process

2.2 House of Quality

House of Quality, it is a tool that helps us in the first stage of the Design process. It is a process or product development that is inspired by customer desires for product or process development and anchored by the capabilities and resources of the organization seeking to meet those desires. It is a process of listening to customers, translating their desires into a written plan, prioritizing steps of execution based on what is most important to the customer, and putting a realistic plan on paper [3]. Figure 2 shows the outline of a house of quality.

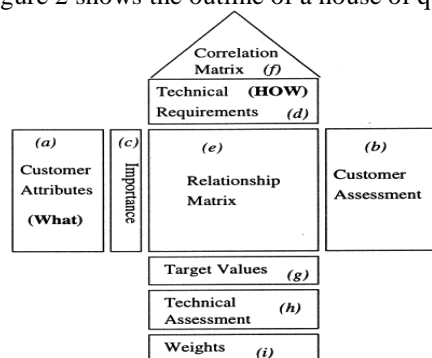


Fig.2. Outline for House of Quality [4]



2.3 DFAM

DFAM (Design for Additive Manufacturing) is a general design methods or tool whereby functional performance and/or other key product life-cycle considerations such as manufacturability, reliability, and cost can be optimized subjected to the capabilities of additive manufacturing technologies [6]. There are principles for design for additive manufacturing which need to be followed in order to fully and efficiently utilize the additive manufacturing technology. Table 1 consists of some of the principles, these principles can sometimes counter act one another therefore it is our responsibility as designers to realize which ones to use and to what extent.

Table 1.DFAM Principles

Principle	Description
Reduction of part count	If the AM part is intended as a final product, the number of parts in an assembly may be reduced.
Avoid sharp edges	Removing sharp results in better accuracy; rounding radii correlate with outer radii of simple-curved elements.
Round inner edges	Rounding the edges simplifies the removal of disperse support structures.
Short overhang	This ensures robust manufacturability and prevents falling off of layers.
Removal of supports	Removing support structures significantly reduces surface finish and increases the need for post processing.
Topology optimization	Topology optimization is a type of structural optimization technique which can optimize material layout within a given design space.

In this paper we made use of worksheet developed in the paper [5] to successfully produce products that comply with design for additive manufacturing. Figure 3 is the worksheet according to which DFAM is carried out and to get feedback and improve the design. The goals of the worksheet are to (1) reduce print failures, (2) improve understanding of AM limitations for novice users, and (3) recommend a course of action.

Design for Additive Manufacturing
 A quick method for reducing the number of printing and prototyping failures, by Jason Booth
 Instructions: Mark one for each category for the part you plan to print. Check daggers and stars first, then scores

Mark One	Complexity	Functionality	Material Removal	Unsupported Features	Sum Across Rows	Totals
<input checked="" type="checkbox"/>	The part is the same shape as common stock materials, or is completely 2D	<input checked="" type="checkbox"/> Mating surfaces are bearing surfaces, or are expected to endure for 1000+ of cycles	<input checked="" type="checkbox"/> The part is smaller than or the same size as the required support structure	<input checked="" type="checkbox"/> There are long, unsupported features	x5 =	
<input checked="" type="checkbox"/>	The part is mostly 2D and can be made in a mill or lathe without repositioning it in the clamp	<input checked="" type="checkbox"/> Mating surfaces move significantly, experience large forces, or must endure 100-1000 cycles	<input checked="" type="checkbox"/> There are small gaps that will require support structures	<input checked="" type="checkbox"/> There are short, unsupported features	x4 =	
<input type="checkbox"/>	The part can be made in a mill or lathe, but only after repositioning it in the clamp at least once	<input type="checkbox"/> Mating surfaces move somewhat, experience moderate forces, or are expected to last 10-100 cycles	<input type="checkbox"/> Internal cavities, channels, or holes do not have openings for removing materials	<input type="checkbox"/> Overhanging features have a stopped support	x3 =	
<input type="checkbox"/>	The part curvature is complex (spines or arcs) for a machining operation such as a mill or lathe	<input type="checkbox"/> Mating surfaces will move minimally, experience low forces, or are intended to endure 2-10 cycles	<input type="checkbox"/> Material can be easily removed from internal cavities, channels, or holes	<input type="checkbox"/> Overhanging features have a minimum of 45deg support	x2 =	
<input type="checkbox"/>	There are interior features or surface curvature is too complex to be machined	<input type="checkbox"/> Surfaces are purely non-functional or experience virtually no cycles	<input type="checkbox"/> There are no internal cavities, channels, or holes	<input type="checkbox"/> Part is oriented so there are no overhanging features	x1 =	
<input type="checkbox"/>	Thin Features Thin features will almost always break Some walls are less than 1/16" (1.5mm) thick	<input type="checkbox"/> Stress Concentration Interior corners have no chamfers, fillets, or ribs	<input type="checkbox"/> Tolerances Hole or length dimensions are nominal	<input type="checkbox"/> Geometric Exactness Large, flat areas tend to warp	x5 =	
<input type="checkbox"/>	Walls are between 1/16" (1.5mm) and 1/8" (3mm) thick	<input type="checkbox"/> Interior corners have chamfers, fillets, and/or ribs	<input type="checkbox"/> Hole or length tolerances are adjusted for shrinkage or fit	<input type="checkbox"/> The part has medium-sized, flat surfaces, or forms that are should be close to exact	x3 =	
<input type="checkbox"/>	Walls are more than 1/8" (3mm) thick	<input type="checkbox"/> Interior corners have generous chamfers, fillets, and/or ribs	<input type="checkbox"/> Hole and length tolerances are considered or are not important	<input type="checkbox"/> The part has small or no flat surfaces, or forms that need to be exact	x1 =	

Starred Ratings
 4- Consider a different manufacturing process
 3- Strongly consider a different manufacturing process

Total Score
 25-40 Needs redesign
 20-25 Consider redesign
 15-20 Moderate likelihood of success
 8-15 Higher likelihood of success

Overall Total []

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Fig.3. DFAM worksheet

2.4 DFMA

DFMA stands for Design for Manufacturing and Assembly. In today’s world, the rapid development of the companies aiming to produce their products at lower cost and better quality. Most of the companies use DFMA which includes the consideration of the requirements from the manufacture and assembly of the product. This results in the design product



to have good manufacturability and efficient assembly. This avoids the problem of building the final prototype of the product. Its basic idea is reducing the total assembly time of the product resulting in the reduction in the number of parts, manufacture time, manufacture cost and also the weight. This can be implemented on the products which are designed before, that is the product can be redesigned by implementing DFMA resulting in the shortening the cycle time of product development, reducing the cost and improving the quality of the product.

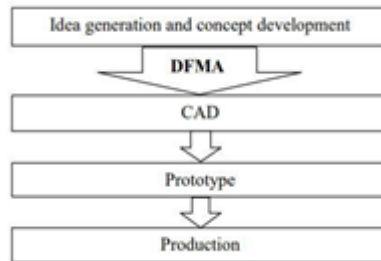


Fig.4. Design stages of DFMA

2.5 Generative Design

Generative design uses artificial intelligence (AI) built into a software application, ‘generative design’ enables engineers explore all the possible combinations design options by simply defining basic parameters such as height, weight it must support, strength, and material options with or without considering the manufacturing method to be used. Generative design leverages machine learning to mimic nature’s evolutionary approach to design [7, 8].

Generative design solutions come into existence in the form of digital representations, allowing early evaluations and the option to select the right model necessary for a particular application, before manufacturing an actual physical model, production or application. It rules out the necessity to create multiple designs and the testing necessary for slowly obtaining a model that is well optimized to sustain the static and dynamic loads being applied. The Generative design approach allows the designer to think through design solutions in a deeper and more dynamic way than possible with traditional methods [7, 8].

III. RESULTS AND DISCUSSIONS

3.1 1st Iteration

The first iteration is a multi-part design made out of PLA (Polylactic acid) through FDM technique. Figure 5 is the CAD drawing of the base and exploded view of the design.

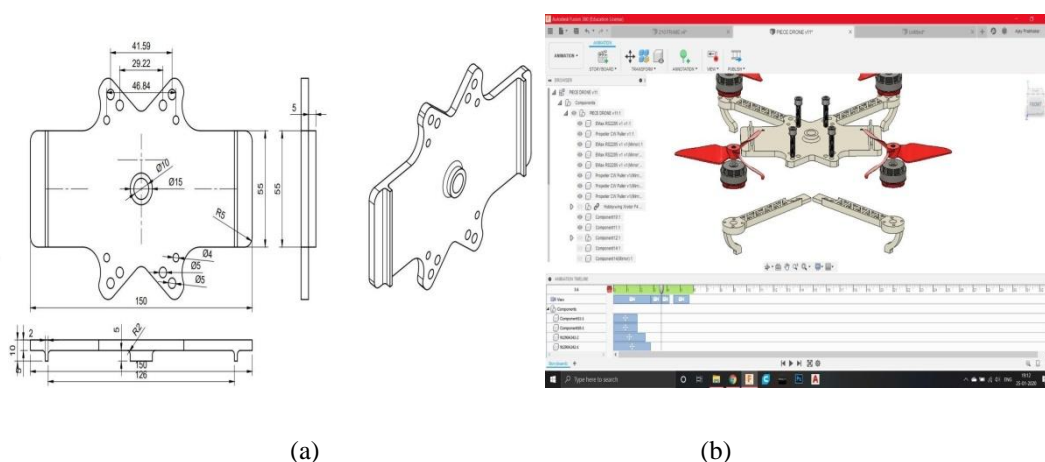


Fig.5. a) CAD Model and b) Exploded view

3.2. 2nd Iteration

The second Iteration is a single part design made out of PLA (Polylactic Acid) through FDM technique. Figure 6 is the CAD drawing of the base and rendered drawing of the mode. It is made a single part on the recommendations of the DFMA and DFAM as single part bodies have lesser parts meaning assembly will be easier and wastage of material is less.

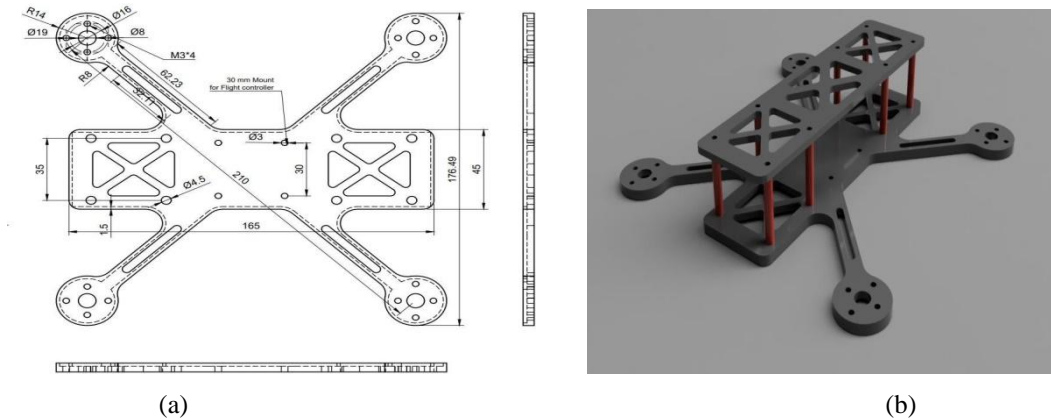


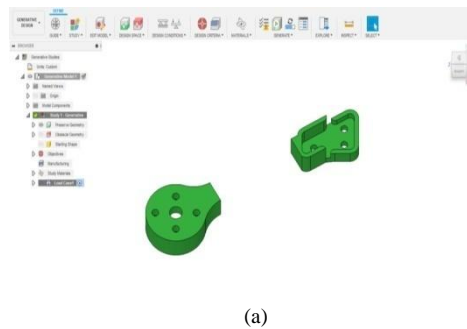
Fig.6. a) CAD Model and b) Rendered Model

3.3. Generative Model

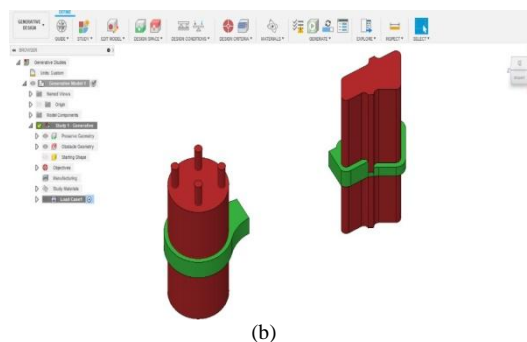
Step-By-Step Solve Process:

For the software to start the design process, there are a few inputs the designer has to specify so that it can start to solve and generate the design outcomes.

Preserve Geometry (In Green colour): The shapes that are to be preserved or the shapes that have to be the same as designed and can't change while the solver generates the shape are specified as preserve geometries. This includes surfaces, holes, slots, movement paths etc. As the generative output is an organic shape, it is important to specific certain geometries to obtain a good fit to make it mechanically viable.



Obstacle Geometry (in Red colour): These indicate obstacles that specify the physical obstruction in the functioning of the object and no material can be added. This includes obstructing holes, motion of relative objects, mounting points. This is done so as to preserve the regions that are required to have certain geometric designs for various purposes.



Constraints and Loading: After the initial geometry is specified, we specify the constraints and loads on the preserved components or at certain places that we give the starting information to the solver to generate the shape and optimize the design. Here, the motor mounts are given a load of 5N and the mount piece away from the motor mount is constrained.

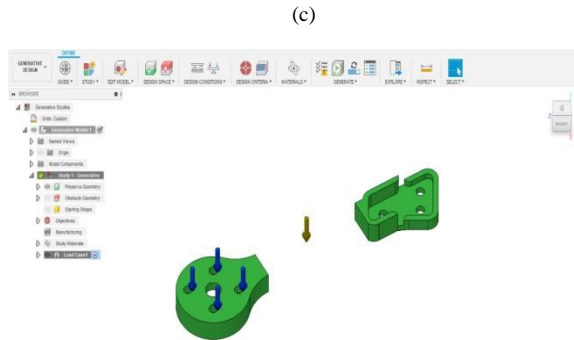


Fig.7. a) Preserve Geometry, b) Obstacle Geometry and c) Constraints and Loading

3.4. Final Design

The final design is a generative design, single part model made of nylon 6,6 through SLS technique. Figure 8 is the CAD model of the design and the rendered model of the design. The model is topologically optimized to be lighter at the same time be structurally sound. The generative design removes any material that is not required for the design's structural integrity, this makes the design more efficient and utilizes the potential of 3D printing to its extent.

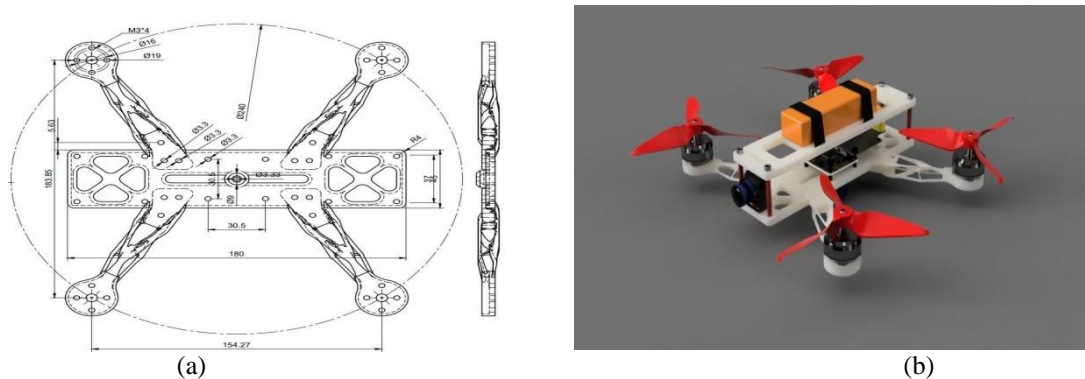


Fig.6. a) CAD drawing and b) Rendered Model

3.5. DFAM Analysis

The first iteration scores 16 in the worksheet created which suggests that the design has a moderate likelihood of success. In order to get a better design, we should be in the bracket of 8-15 points. In the second and third iteration we will try to include other principles of DFAM like reducing the total number of parts required as well as topological optimization of the part through lattice structures as well as generative design technique.

The second iteration scores 9 on the worksheet which gives it a high likelihood of success as compared to the first iteration which scores 16 on the worksheet. In the second iteration we incorporate another principle of DFAM by decreasing the total no. of parts by creating a uni-body design for the base of the drone.

Our 3rd and final iteration score a perfect 8 on the worksheet while incorporating important principles of DFAM like topological optimization and reducing the total parts in the design. The topological optimization is achieved through the process of generative design.

3.6. DFMA

The parts of the drone are analyzed any identification of any improvements are determined that can result in an improved product design. After the analysis, in order to obtain the best possible outcome few decisions had been made like the component should not move in relation to the preceding component. Here there was an analysis made for the material to be incorporated in the parts and it had concluded that all the parts need to be manufactured with same material. According to DFMA, alteration in the design result in improving the design efficiency and the key alteration in the design is to make all the parts intact as a uni-body design. Eliminating the fasteners which prevent the vibrations on the frame maximises the efficiency of the flight time. If we had to compare the initial and the final design, it has a drastic effect in terms of part count, assembly time and cost.

IV. CONCLUSION

The driving force behind the optimization of any 3D printed products is to circumvent the unnecessary iterative processes. Topological optimization of a specific product (i.e. drone frame) resulted in multiple changes, such as the reduction of the total number of parts in the design. The DFMA analysis eases the stress on the production line as part assembly completes in a shorter span. The Generative design provides a creative thinking process as well as an inclination to opt for the decisive result.

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