PROJECT REPORT ON ADDITIVE MANUFACTURING

“Design and realization of an original armchair made with Wire arc Additive Manufacturing”

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1. Introduction:

1.1 Design for Additive Manufacturing (DFAM):

Design for Additive Manufacturing is the branch of Additive Manufacturing Engineering, which allows us to produce optimized designs for Additive Manufacturing. It is an evolution in design to support a breakthrough in manufacturing. This process removes many of the mainstream manufacturing limitations and allows the part or product design to be more complex, while also providing the opportunity to combine several parts into one. To take full advantage of unique capabilities from AM processes, DFAM methods or tools are needed. Typical DFAM tools includes topology optimization, design for multiscale structures, mass customization and other design methods which can make use of AM- enabled features

Reasons to consider DFAM over traditional machining:

- Minimal waste of material
- Can create complex parts not possible with traditional machining processes
- Part consolidation
- Minimum support structures
- Cost effective
- Significantly enlarge design freedom for designers

1.2 Tools for DFAM:

- Topology Optimization

Topology optimization is a structural optimization technique which can optimize material layout within a given design space. Compared to other typical structural optimization techniques, such as size optimization or shape optimization, topology optimization can update both shape and topology of a part.

- Multiscale structure design

Due to the unique capabilities of AM processes, parts with multiscale complexities can be realized. This provides a great design freedom for designers to use cellular structures or lattice structures on micro or meso-scales for the preferred properties. For example, in the aerospace field, lattice structures fabricated by AM process can be used for weight reduction.

- Multi – material design

Parts with multi - material or complex material distribution can be achieved by additive manufacturing processes. To help designers to take use of this advantage, several design and simulation methods have been proposed to support design a part with multiple materials or Functionally graded materials.

- Design for mass customization

Since additive manufacturing can directly fabricate from products' digital model, it significantly reduced the cost and leading time of producing customized products. Thus, several design methods have been proposed to help designers or users to obtain the customized product in an easy way.

- Parts consolidation

Due to the constraints of traditional manufacturing methods, some complex components are usually separated into several parts for the ease of manufacturing as well as assembly. This situation has been changed by using of additive manufacturing technologies.

- Lattice Structures

Lattice structures are cellular type of structures. Need very sophisticated, high end machines to manufacture. They have high strength and low mass mechanical properties and multifunctionality. It has been further reported that the yield strength and ductility of the struts can be increased drastically by taking advantage of the non-equilibrium solidification phenomenon in Additive Manufacturing, thus increasing the performance of the bulk structures.

2. Fused Deposition Modelling (FDM):

FDM is a method of additive manufacturing where layers of substrate material are fused together layer by layer in a pattern to create an object. It is used for fabrication, production applications, and mechanical system modelling. The technique produces a tissue scaffold by the melt extrusion method that is making use of layer – by – layer thermoplastic polymer. The material is usually melted just past its glass transition temperature, and then extruded in a pattern next to or on top of previous extrusions, creating an object layer by layer. It is one of the most widely used additive manufacturing technique due to its cost effectiveness and simplicity.

Advantages:

- Reduce costs and shorten development timelines
- Reduces time

2.1 Project Objective:

- To design an optimized scale CAD model of the armchair in Additive Manufacturing
- To realize a prototype of the component with FDM process
- The largest dimension of the prototype should not exceed 80mm

3. Design Proposals:

The chair is designed using PTC Creo. Below is the image showing the basic design of the chair, without any optimization.

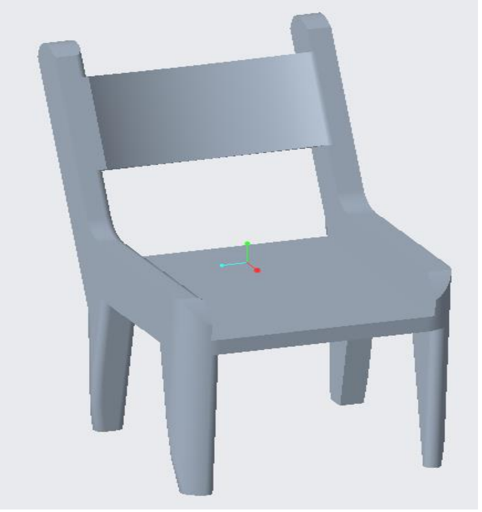


Figure 1: Initial model

After the simulation of the basic part, it was discovered that the excess material could be removed with affecting the strength of the material. In fact, removing material at particular points actually increased the strength of the chair. After running numerous simulations, I removed material from the leg and arms of the chair to make it light weight.

After obtaining the results from the analysis, we have removed more material.

As can be observed, we have removed the material elliptically, so that the deposition of the material in the additive manufacturing does not affect the change in angle from layer-to-layer deposition.

Below is the image of the final model. For the purpose of modelling and simulation the material chosen is Aluminium 6061.

Figure 2: Final CAD model

A comparison of the final model with the initial model reveals some intricate details in the part. The final model weighs less than the initial one. A few ellipse shaped extrusions are projected on the back rest of the chair. Material is also extruded out from the chair legs and arm rest. Observations suggest that such a model prepared by removing material increases the strength of the model.

Design Constraints:

- No details less than 1 mm as they do not appear on the prototype
- Walls should not be thinner than 4 mm
- Design should be compatible with the WAAM machine in the lab. Complex design such as lattice structures or small dimension polygon slits on the chair cannot be identified on the machine

2D Drawing of the chair:

The image shows the different views of the chair along with the dimensions (all dimensions are in mm).

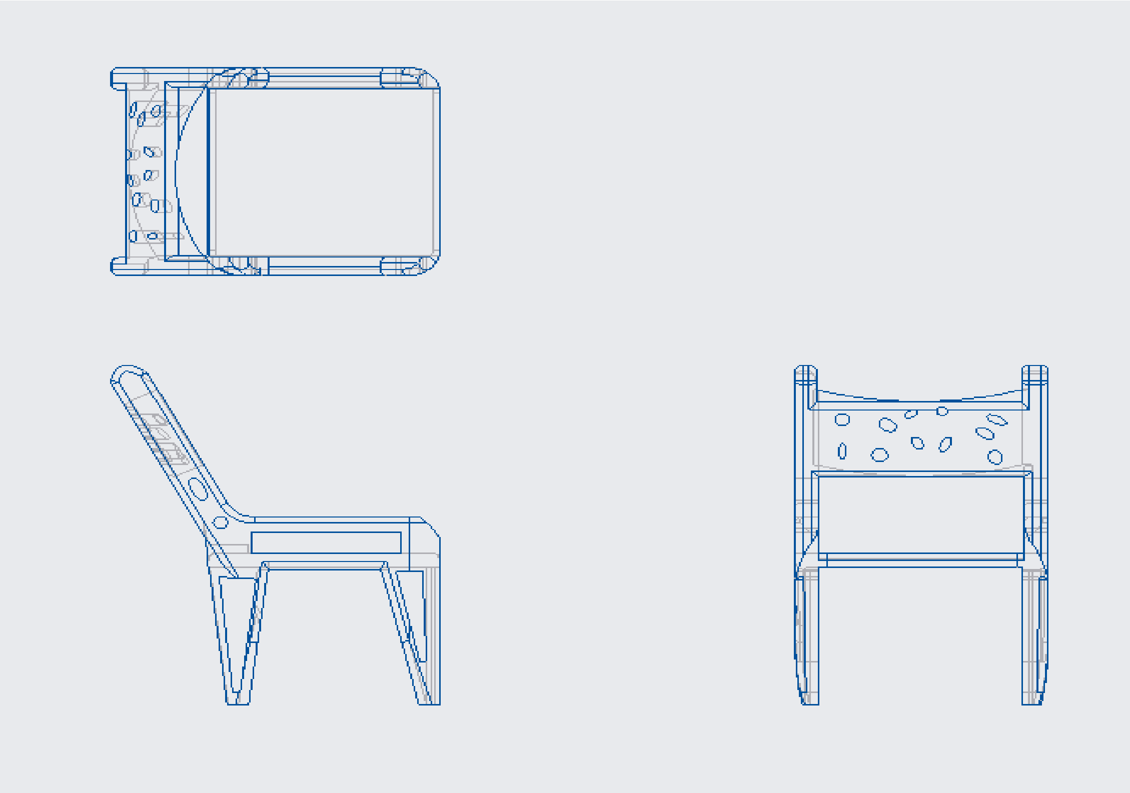


Figure 3: 2D Sketch of the model

4. Structural Analysis and Results:

As we don't have a flat surface for the application of force and loading, we have the command surface region and applied the load as shown in the below image. Meshing is refined for 50 mm. Both rotational and translational displacement are constrained at the bottom end of the chair legs. As seen in the figure below we apply the load vertically downwards on the seat of the chair.

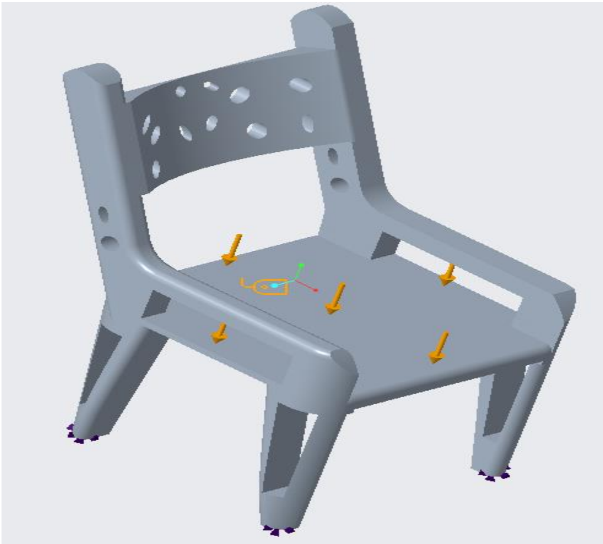
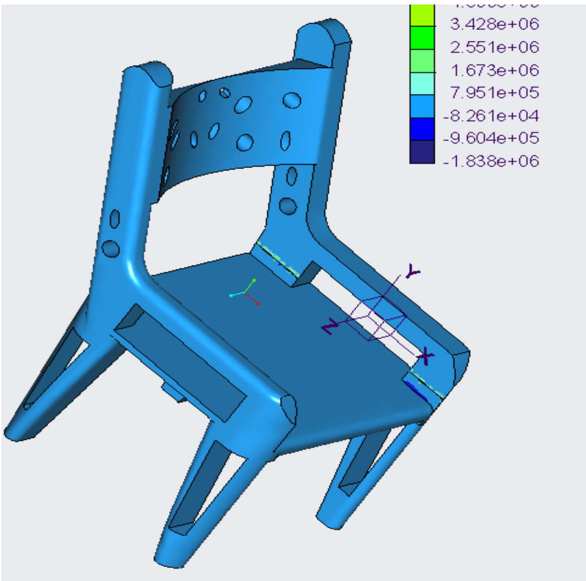


Figure 4: Application of constraints and forces

Simulations are run for the scaled model and graphs for maximum principal stress and Von Mises are obtained for the loading of 12 Kg-f in -Y direction as it is a scaled model, which is within the safe limits. The original dimension was scaled down to 10 times with the maximum end to end dimension being 77mm.



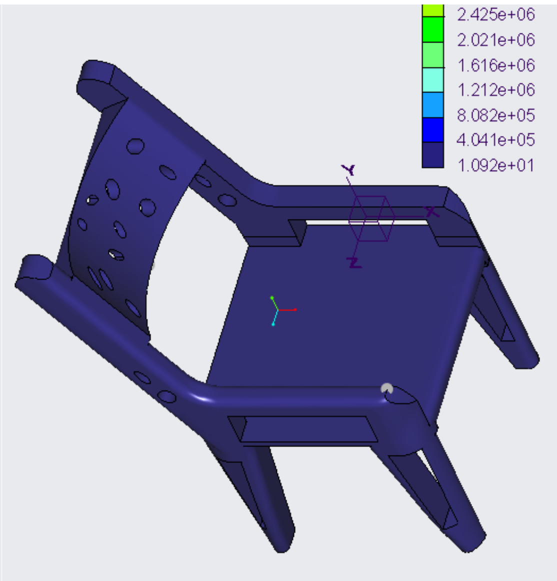


Figure 5: Maximum Principal Stress

Figure 6: Von Mises Stress Analyses

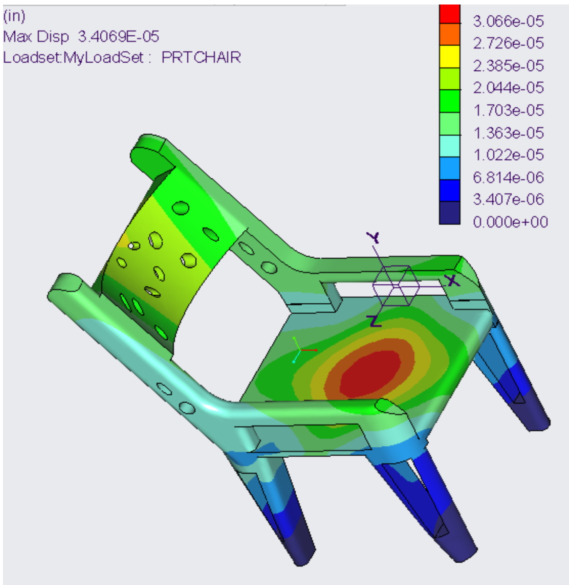


Figure 7 : Displacement of the model scale

<u>Mass properties of the material (Scaled model):</u>

Below is the image showing the mass properties of Aluminium 6061 metal for the scaled model.

VOLUME = 8.7501131e-01 INCH^3

SURFACE AREA = 1.9903221e+01 INCH^2

DENSITY = 1.0000000e+00 POUND / INCH^3

MASS = 8.7501131e-01 POUND

5. <u>Manufacturing Process:</u>

5.1 Design Process for Additive Manufacturing:

The design of the component can be best achieved by knowing the process and the material.

1) **Design for support**: Many of the Additive Manufacturing processes require some form of support structure. The major reasons for providing this are as follows:
   - to allow the printing of overhangs,
   - to anchor the part to the print bed to keep it static during build
   - to reduce the distortion of the model by anchoring the model material to the bed.

   With FDM, it is pretty straight forward. You have two options in terms of support material (soluble and breakaway).

2) **Design in multiples of layer heights to maintain accuracy**: To achieve an accurate part, the dimensions should be the multiple of the width (w) along the x and y directions and the height (h) along the z direction of the deposited layer.

3) **Strong, sturdy walls**: The walls need to be strong and thick enough so that they don't collapse or distort during the process. The ideal condition would be to have walls

designed in FDM to be at least two filaments thick and should be designed such that the thickness is in multiples of the filament track width to maintain the accuracy.

4) **Design and optimize topology**: Simulate where the loads will run through that part and remove the superfluous material, leaving only the load paths remaining. This removes weight retaining the outer shape of the design.

Detailed Manufacturing Process:

Our CAD 3D model (.prt) file is saved. Precautions are taken to check the file has no inbuilt errors. The file is then converted to a stereolithography (.stl) file. Below is the screenshot of the same.

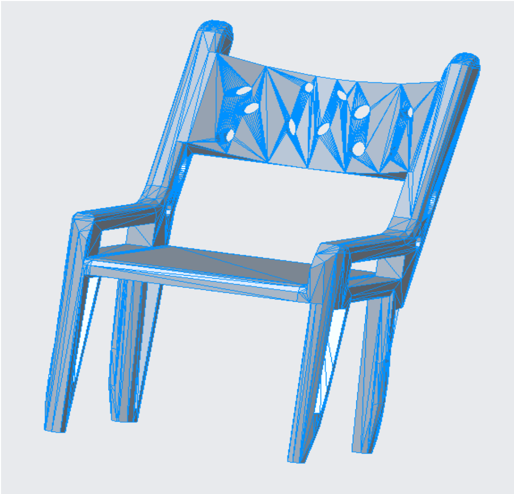


Figure 7: stereolithography model of the chair

The model is then input in the Ultimaker Cura software.

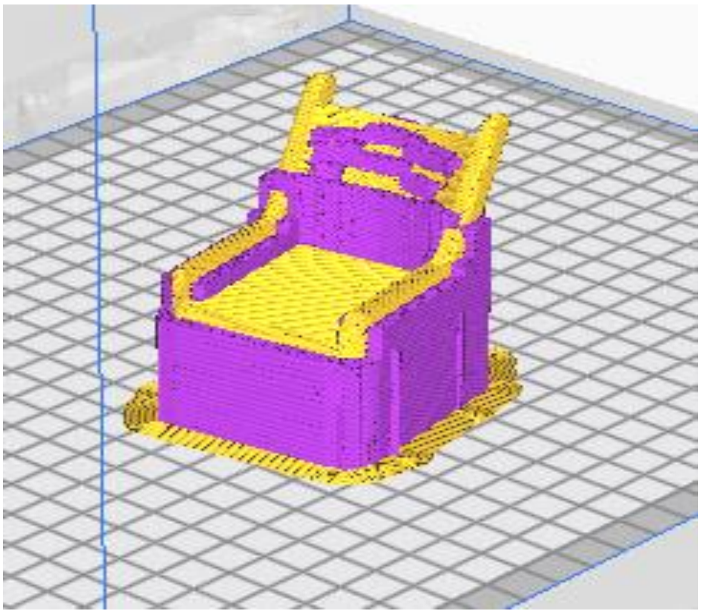


Figure 8: Simulation after slicing in Cura Software

STL is a file format native to the stereolithography CAD software created by 3D Systems. STL has several backronyms such as "Standard Triangle Language" and

"Standard Tessellation Language". This file format is supported by many other software packages; it is widely used for rapid prototyping, 3D printing and computer-aided manufacturing. STL files describe only the surface geometry of a three-dimensional object without any representation of colour, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact. Our model does not need any assemblies as it is a single solid model which can be singly produced on the Ultimaker machine. Taking into consideration the design constraints, may be the small extrusions on the back rest part of the seat in elliptical shape may be excluded. Hence this can be done use any other traditional milling machine or a CNC milling centre.

Critical review for the prototype to be manufactured:

- The dimensions are to be adjusted as per the process requirements
- Considering the prototype manufacturing in 3D printing, the product can be more optimized for the real robotic additive manufacturing.

6. Feedback of Scale Model Prototype:

Our model scale in the Cura software shows a mass of 38 grams and has a maximum dimension of 76.1 mm. We set the speed of modelling to “Fast” at 0.2mm. We use 2 types of materials for our model, one for the model which is PVA (Polyvinyl Alcohol) through the nozzle AA 0.4 and the support material as PLA through the nozzle BB 0.4 which is basically a water-soluble material which can be dissolved after the printing is complete. The base plate for the printing is selected depending on the material we use for a model; it can be a glass or a metal plate. The printing head compensates for the thickness of the base plate before the printing begins.

7. Conclusion:

The design requirements had to be met considering the design constraints and the capability of the Ultimaker machine. The wall thickness should not be less than 4mm or the dimension cannot be replicated on the prototype to be produced. After stress analysis simulation, the displacements are within the acceptable limit so are the maximum principal stresses and Von Mises. We definitely got hands on experience on how a product is engineered by Additive manufacturing process beginning from conception to its production.