# TOPOLOGICAL OPTIMIZATION IN 3D PRINTING DESIGN

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**2017**

**DECLARATION**

I declare that this project report entitled "Investigation On Structural Vibration Problem At MARS Building UTeM" is the result of my own work except as cited in the references

Signature : ..........................................

Name : ..........................................

Date : ..........................................

**SUPERVISOR'S DECLARATION**

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to supervisor and to the second examiner.

Signature : ...................................

Name of Supervisor : ...................................

Date : ...................................

## DEDICATION

I would like to dedicated this dissertation to my loving parent. They have been my rock throughout this research. They have been nothing but patient and willing to give me some space. Always keeping in mind that their son is a capable person. They have been working their whole life to just finance my journey to getting my degree, never saying 'give up' or 'try something else'. They would always say to finish what I started always keep an eye on my goals.

I would like to give thanks to my friends. Their negative support for always saying that it was a waste of time and keeping my will of fire burning hot and strong. Their negative encouragement also have finish my research paper to the point of always focus on my goals.

My course mate, they have given me enough information for all of us to finish and able to reduce the stress us student are commonly known to have. Their assistance have cut to work load in half so to speak.

I am grateful too for the support and advice from my faculty colleagues and the seniors. Thanks to the university to have given me this opportunities to do research and able to successfully finish it.

## ABSTRACT

In the industry sector, the demand for material even more so raw material has risen quite a lot in this coming years. The purpose of this thesis was to conduct the process of topology optimization on an object, then test it whether or it is viable to be printed using 3D printer. Afterward evaluate the data from the experimental and the theoretical data. The topological optimization process is a revolutionary process in which it reduce the use of material but still able to maintain the product mechanical characteristic and its feature. In this thesis, the part chosen was a brake pedal, it is believe that there is still room for improvement to be done. The brake pedal was then constructed into a 3D model using CAD then it was imported into the Optimization software. After the topology optimization process was completed, the final design and a number of sets of data was obtain. From the final design, it was reconstructed back using CAD software to look similar to the final optimization design. Afterward the 3D model of the final design was then printed using CubePro 3D printer. The finish product of the 3D printer was then compare with 3D model. The max value of data obtained from the analysis for the deflection value drop 86.84%, the von mises value increased about 40.06%, the pressure drastically about 90% and for the max shear stress increase 33.3%. For its exterior data obtained from using CATIA CAD is was determined that the weight was reduce up to 33.33%, the volume also reduce 15% but the area stayed the same. The data comparison between the 3D model CAD and the actual printed part is undesirable the overall aesthetic appeal was only satisfactory. The data obtained was as expected even with the CubePro because the ABS 3D printer are well known for their weakness. The aim to determine the viability of printing the topology optimize part was achieve and the result it just on the level satisfactory.

# ABSTRAK

Dalam sektor industri, keperluan bahan-bahan mentah semakin meningkat berikutan era sekarang. Tujuan tesis ini adalah untuk menjalankan proses pengoptimuman topologi terhadap sesuatu bahan, kemudian menguji sama ada bahan habis optimasi tu boleh dihasilkan menggunakan pencetak 3D. Selepas itu, data yang telah diperolehi melalui analisis akan di bandingkan dengan data eksperimen. Proses pengoptimuman topologi adalah satu proses revolusi di mana ia mengurangkan bahan mentah yg digunakan untuk menghasilkan bahan tersebut tetapi masih mengekalkan ciri-ciri mekanikal nya. Dalam tesis ini, bahagian yang dipilih adalah pedal brek, masih dipercayai ada lagi ruang untuk diperbaiki. Brek padel ini telah pon dihasilkan nya wakil 3D modal menggunkan CAD perisian dan kemudian diimportkan ke dalam perisian Optimization. Selepas proses pengoptimuman topologi telah disiapkan, reka bentuk akhir dan beberapa set data telah diperolehi. Dari reka bentuk akhir, dari situ ia telah direka bentuk semula menggunakan perisian CAD untuk kelihatan serupa dengan pengoptimuman reka bentuk akhir. Selepas itu modal 3D reka bentuk itu telah kemudian dicetak menggunakan pencetak CubePro 3D. Produk yang dihasilkan dari pencetak 3D itu kemudiannya dibandingkan dengan model 3D. Nilai max data yang diperolehi daripada analisis untuk nilai “deflection” 86,84%, nilai “von mises” meningkat kira-kira 40.06%, nilai “pressure” turun drastik kira-kira 90% dan bagi “max shear stress” meningkat 33.3%. Untuk data luaran yang diperolehi daripada menggunakan CATIA CAD telah didapati bahawa berat badan itu telah dikurangkan sebanyak 33.33%, jumlah isipadu juga mengurang 15% tetapi nilai kawasan tidak berubah. Perbandingan data antara model CAD 3D dan bahan dicetak adalah tidak diingini tarikan estetik keseluruhan hanya memuaskan. Data yang diperolehi adalah seperti yang diharapkan walaupun dengan CubePro kerana pencetak 3D ABS terkenal dengan kelemahan mereka. Antara tujuan tesis adalah untuk menentukan sama ada bahagian topologi mengoptimumkan dapat dicetak atau tidak telah pon tercapai dan hasilnya ia hanya pada tahap yang memuaskan.

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# LIST OF ABBEREVATIONS

| | |
|---|---|
| SLA | Stereo lithography apparatus |
| SLS | Selective laser sintering |
| FDM | Fuse deposition modelling |
| 3D | Three-dimension |
| CAD | Computer aided design |
| ESO | Evolutionary structural optimization |
| BESO | Bi-directional evolutionary structural optimization |
| SIMP | Solid isotropic material and penalization |
| MMA | Method of moving asymptotes |
| NA | Naturally aspiration |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Topological optimization is a method of effectively using material (optimize) layout for a certain design using a calculated mathematical approach. The design should have gone through rigorist analysis from load bearing analysis to stress analysis thus providing multiple parameter, within that parameter is the topological optimization will be conducted without changing any parameter. Engineer can conduct experiment or studies to find out which design is the most cost effective and optimum design structure without losing any vital function of the design.

In Topological optimization they are different field of optimization, with which of them address a different problem. Sizing, shape and topological all confront different problem. Through sizing optimization it mainly discuss around the idea that there is an optimum thickness for all design. By configuring the maximum or minimum thickness for each region of the design it can provide an effective design structure that can support the truss structure that holds the design in place. By doing so it can also preserve or not altering the physical quality of the design. For shape optimization, as the name suggest it focus on developing or finding the best design structure that can accompany the functionality of the original design. By implementing the shape optimization, engineer can innately create an optimum shape that as it was mention before can accompany the original propose without any problem. In topological optimization mainly focus on the determination of the feature of the design. These feature mainly concern the location, hole and the connectivity of all the domain that make up the design.

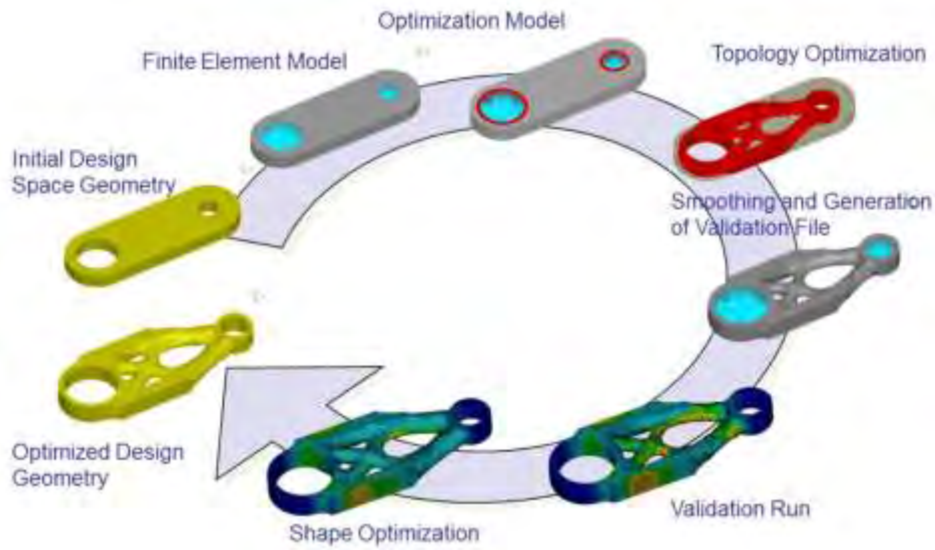


Figure 1.1: Proses of topological optimization

3D printer as an amazing one of a kind machine. The 3D printing machine's purpose is to convert CAD drawing into a 3d sculptor. The 3D printer was first develop in 1980 by an amazing Japanese innovator. At that time it was called rapid prototyping technology or in short RP tech. Its main purpose was too effectively and shorted the time of manufacturing prototype for product development for Industry Company. By 1986 the first patent 3D printer was develop. The stereo lithography apparatus (SLA) was the first patent 3D printing machine belongs to Charles Hull just exactly like figure 2. The stereo lithography apparatus or in other name optical-fabrication, photo-solidification or resin printing create or print the product by laying material on top of the previous material using photo polymerization as its bonding method. The photo polymerization process works by using light that cause a chain of molecules to link or combine together then produce polymer. After countless testing and quality control the final 3D printer was sold 1988. Not counting Charles Hull they are many other countless entrepreneurs that are within his time are doing or developing the same technology. Thus producing many other method of 3D printing for example Carl Deckard help develop the selective laser sintering (SLS) and Scott Crump ensure the future of fuse deposition modelling (FDM) which now very famous among open source 3D printer.

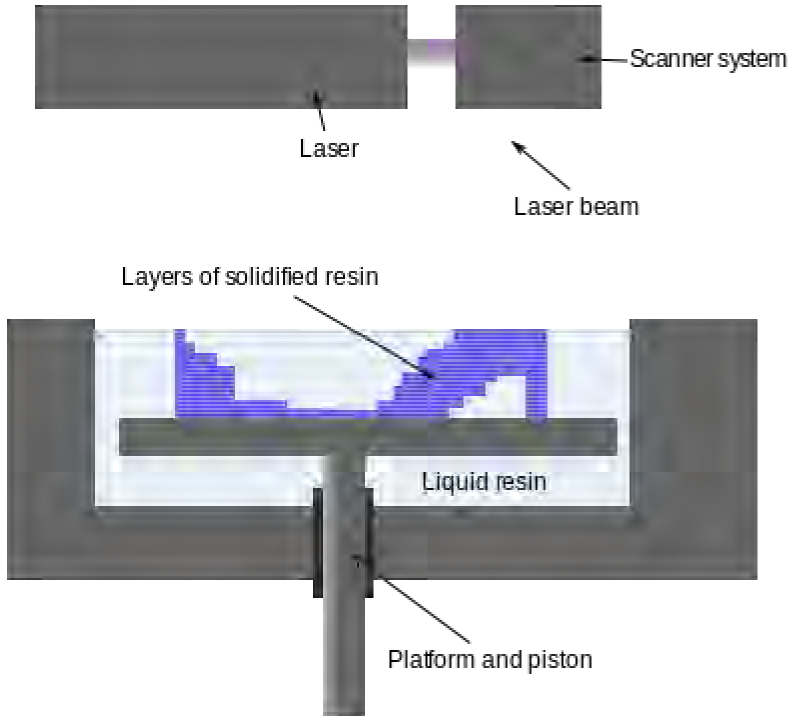


Figure 1.2: Stereo Lithography Apparatus (SLA)

By combining this two idea topological optimization 3D printing create an enormous amount of opportunity and advantage for both designer and manufacturer. 3D printing is the technology of rapid prototyping and combine with topological optimization where by optimizing its sizing, shape and topological structure without discarding its vital part and function will benefit the manufacturer in cost effectiveness greatly and also help the designer develop a master piece design and reduce the time of rapid prototype process.

## 1.2 PROBLEM STATEMENT

The problem that is responsible for this project to arise is as follows:-

i. The cost required to manufacturer the product is expansive.
ii. Material use to mass manufacturer product is too high.
iii. Waste material and capital on excessive use of it.

## 1.3 OBJECTIVE

The objective of this experiment is as follows:-

i. To perform topological optimization on product to reduce its weight or mass by using software Hyperworks.
ii. To determine whether or not is it viable to fabricate product of topological optimization using 3D printer
iii. To evaluate the theoretical data and experimental data.

## 1.4 SCOPE OF PROJECT

This thesis aim is the implement the Topological Optimization process on the Additive manufacturing technology. Using the following process:-

i. Software modelling using CAD CATIA.
   - Using CAD CATIA for 3D modelling and representation of the before and after topological optimization.
ii. Software analysis using Hyperworks.
   - After done creating the 3D model using CAD, the model is then transfer to this analysis software to be conducted different analysis such as stress analysis or static analysis.
iii. Actual fabricating the CAD model using 3D printer model Kossel.
   - The Kossel is one of the open source 3D printer provided for this project. After the analysis is done, its model is then transfer into the 3D printer database.
iv. Compared theoretical data with experimental data.
   - The theoretical data was provided by the analysis software Hyper works and the experimental data will be provided from the finish printed 3d part.

v. Report writing.
   - After all discussion were made and all argument is settle towards the data, a full report will be provided explaining all the work was done for this research.

## 1.5 GENERAL METHODOLOGY

These are the activities that are needed to be carried out in order to accomplish or achieve the objective of this project:-

i. Literature Review
   - Journal, articles or even any reading material that are occupy the field of studies of this project are reviewed.

ii. 3D Representation
   - Draw the full 3D design using computer aided design Catia to inspect any flaws before start to print and are able to modify to implement the topological optimization concept on it.

iii. Analysis and Propose Solution
   - Analysis will be conducted before moving on to the 3D printing, the analysis will be done using the software hyper works. Hyper works is a software specifically design to be an analysis software. The analysis will continue until the modification on the product is stable and no change in appearance or its micro structure.

iv. Producing product through 3D printing
   - After analysis process is successful, the 3D representation of the product will be transfer into another software called slicer where it will be reconstructed into a format that the 3D printer can read then print.

v. Conduct a string of experiment to determine the mechanical properties

- The product produce by the 3D printer will be then submitted to countless experiment to test its mechanical properties and gather experimental data at the same time.

vi. Comparison between the experimental data and the theoretical data

- The experimental data gather through the experiment and the data gather by the analysis software will be compare to create a viable hypothesis of the properties of the 3D model.

vii. Report writing

- Report writing on this project will be done at the end of this project.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 3D MODELLING

In the late 1980's, the need of engineer to hand drawn design, schematic or plan for a project had been greatly reduced (Hazrat Ali, Katsuki, Kurokawa and Sajima 2013). This is because virtual 3D modelling was introduce into the world. At the time of exposure, small and medium size company have already incorporated this revolutionary idea into their ranks. They are easy to access and even more compatible with personal computer making it easier for engineer to perform 3D modelling outside of work. This also means that company are able to cut cost by reducing obsolete department.

This does not only effect the industrial world. On this present time, almost all university or higher learning institute have completely abolish the need to expose student to manual drafting or hand drawing (technical drawing by hand). Student are no longer have the need to use any drawing tool such as protractor, compasses and etc. Student are to focus using computer aided design CAD. Computer aided design or CAD are a complex intricate design software that have greatly benefit not just for students to learn but also for engineer, designer and even scientist. As can be observe in Figure 2.1 an example of intricate 3D model.

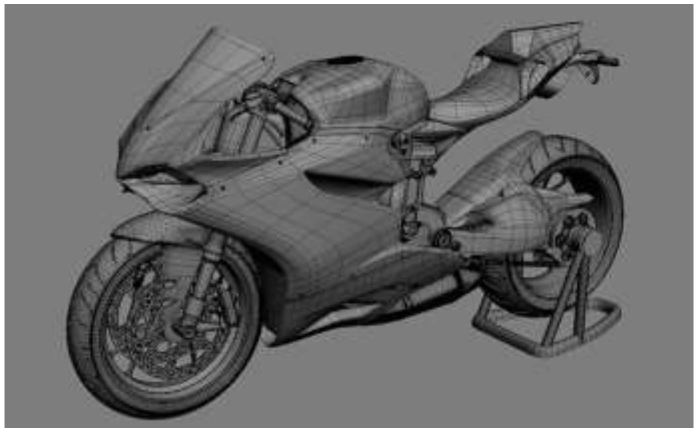

Figure 2.1: Example of 3d model using CAD

3D modelling is define as producing three-dimensional object or surface into a mathematical representation using specialize software either its automatic or manual. These CAD produce such amazing 3D model by first using the available or already drawn 2D design and put it through a process call 3D rendering and use computer simulation. 3D model can also be seen as combine line, shapes and curve surface, than are also form because of combination of point present in 3D space.

## 2.2 METHOD OF ANALYSIS

Topological optimization is a study of optimizing a certain structure design of its geometrical layout while still under the prescribe targeted performance level (X.F.SUN, J.YANG, Y.M.XIE, X.HUANG, Z.H.ZUO 2011). Various optimizing method were discovered throughout the years. Solid isotropic material with penalization SIMP (Bendsoe 1989) and the evolutionary structural optimization ESO. The evolutionary structural optimization ESO method focus by obtaining the best shape and topology of continuum structure whiles slowly material that are not in use will be remove from the structural domain. BESO is bi-directional evolutionary structural optimization and is an extension of the early evolutionary structural optimization ESO.

The optimization employed by BESO is similar to ESO, but at the same time it can also add material that it think it can be beneficial or effective to the structure. It is a more robust method compared to evolutionary structural optimization ESO. Level set method is an applied method of changing the whereabouts of boundary in other word moving boundaries. In some condition, these moving boundaries will come in contact and are join together and a new hole is created (S.Shgaee, M.Mohammadian 2012).

In the early year, structural optimization had to only rely on integer values to use as design variable. Bendsoe (1989) was able to come up with brilliant idea, Bendsoe propose a method that will result in a non-discrete solution by varying the design variables in a loop. In pursuing to achieve a non-discrete solution that can come close to a discrete solution method of analysis (mathematical model) used was change to provide a less influence to the intermediate value of the variable. This method was later name as solid isotropic material with penalization (SIMP) (Philip Anthony Browne 2013, D.Brackett, I.Ashcroff and R.Hague 2011).

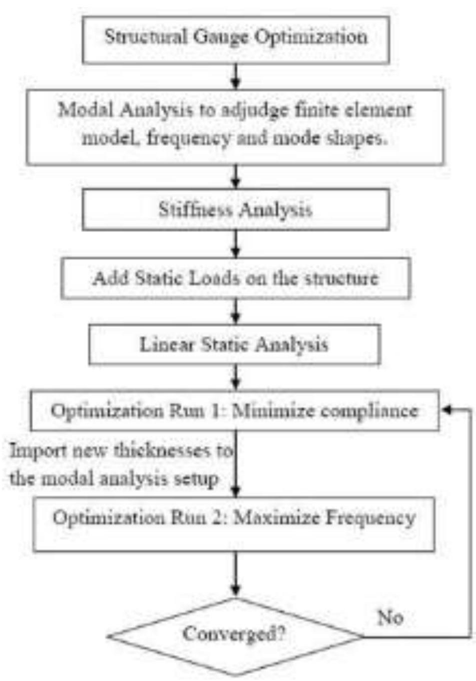


Figure 2.2: Flow chart for solid isotropic material with penalization