AUTOMATIC ADDITIVE MANUFACTURING PRODUCT GENERATION THROUGH COMPUTER AIDED PROCESS PLANNING USING 3D/4D/5D PRINTING

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.
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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF ABBREVIATIONS

FYP	FINAL YEAR PROJECT
3D	3-DIMENSIONAL
4D	4-DIMENSIONAL
5D	5-DIMENSIONAL
6D	6-DIMENSIONAL
AM	ADDITIVE MANUFACTURING
3DP	3-DIMENSIONAL PRINTING
SLA	STEREOITHOGRAPHY
SLS	SELECTIVE LASER SINTERING
MJF	MULTI JET FUSION
FDM	FUSED DEPOSITION MODELLING
CAD	COMPUTER-AIDED DESIGN
CAD/CAM	COMPUTER-AIDED DESIGN AND MANUFACTURING
CAPP	COMPUTER-AIDED PROCESS PLANNING
API	APPLICATION PROGRAMMING INTERFACE
VBA	VISUAL BASIC APPLICATION

ABSTRAK

Pengilangan aditif (AM), sering dirujuk sebagai prototaip pantas atau percetakan 3D dalam kesusasteraan saintifik, telah berkembang sebagai teknologi pembuatan yang popular sejak 1980-an. Penggunaan teknologi AM atau Percetakan 3D telah terus berkembang sepanjang tahun kerana ia merupakan salah satu teknologi baru muncul terkemuka dalam Industri 4.0. Walau bagaimanapun, kebanyakan proses dilakukan secara manual di mana pengguna perlu menukar model 3D kepada bahasa mesin, iaitu kod G untuk mencetak model. Oleh itu, sistem CAD/CAM bersepadu digunakan untuk mengautomasikan proses pencetakan dengan mencipta algoritma yang dapat menentukan jenis proses pencetakan (pencetakan 3D, 4D atau 5D) yang sesuai dengan model dan menukarkannya kepada fail STL secara automatik. Kemudian, algoritma akan diuji sama ada ia boleh dilanjutkan sehingga cetakan 5D dengan menggunakan tiga jenis model yang berbeza dengan proses cetakan yang berbeza. Hasil projek ini tertumpu kepada penciptaan hasil makro, penjanaan hasil kod G dan fabrikasi produk. Projek ini telah berjaya mencipta algoritma yang boleh mengenal pasti jenis proses pencetakan dan menukar fail CAD kepada fail STL secara automatik. Algoritma ini juga telah diuji dan mampu menghasilkan produk pembuatan aditif yang lengkap dengan menggunakan sistem CAD/CAM bersepadu dengan pencetak 3D. Percubaan lanjut perlu dilakukan untuk menguji kefungsian algoritma dan mengenal pasti ketepatan algoritma.

ABSTRACT

Additive manufacturing (AM), often referred to as rapid prototyping or 3D printing in the scientific literature, has evolved as a popular manufacturing technology since the 1980s. The utilisation of AM technology or 3D Printing has continues to grow throughout the years as it is one of the leading emerging technologies of Industry 4.0. However, most of the process are done manually where the users need to convert the 3D model to machine language, which is G-code in order to print the model. Therefore, an integrated CAD/CAM system are used to automated the printing process by creating an algorithm that able to decide the type of printing process (3D, 4D or 5D printing) suitable with the model and convert it to STL file automatically. Then, the algorithm will be tested whether it can be extended up to 5D printing by using three different types of models with a different printing process. The results of this project are focused on the creation of macro result, generation of G-code result and fabrication of product. This project has successfully created an algorithm that can identify the type of printing process and convert CAD file to STL file automatically. The algorithm has also been tested and able to produce a complete additive manufacturing product by using an integrated CAD/CAM system with a 3D printer. A further experiment should be done to test functionality of the algorithm and identify the accuracy of the algorithm.

CHAPTER ONE: INTRODUCTION

1.1 Overview of Additive Manufacturing

Since the 1980s, additive manufacturing (AM), also known as rapid prototyping or 3D printing in the scientific literature, has grown in popularity as a manufacturing method. Chuck Hull suggested the creation of three-dimensional (3D) systems in 1986 using a process known as stereolithography (SLA), which piqued the interest of researchers and gave rise to AM technology, often known as 3D printing (or 3DP). Over the last 40 years, 3D printing has advanced, allowing researchers to build complex geometrical shapes using design software that were previously difficult to make using traditional fabrication processes. According to Wohlers et al. (2018), the worldwide additive manufacturing industry (i.e. all AM goods and services) expanded by 21% in 2017 and surpassed 7.3 billion US dollars, with a compound annual revenue growth rate of 25.4 percent over the previous 25 years. This demonstrates that the utilisation of AM technology is increasing significantly, and the public sector continues to push its use (Jiang et al., 2017).

Common 3D printing technologies are stereolithography (SLA), fused deposition modelling (FDM), Selective Laser Sintering (SLS) and Multi Jet Fusion (MJF). FDM and SLA are the most widely used among these techniques. FDM is a material extrusion technology that feeds material filaments into a heated nozzle before depositing the molten material layer by layer on a printing bed. Meanwhile, SLA is a vat photopolymerization technology that uses a laser to scan a liquid UV-curable material. This technology is more expensive than FDM, but it can attain higher resolutions and printing speeds. Table 1 shows a summary of different techniques used in AM according to Buswell et al. (2007).

Table 1 Summary of AM techniques (Buswell et al. 2007)

Process	Description
Stereolithography (SLA)	Liquid photopolymer resin is held in a tank. A flat bed is immersed to a depth equivalent to one layer. Lasers are used to activate the resin and cause it to solidify. The bed is lowered and the next layer is built.
Fused Deposition Modelling (FDM)	Extrudes a narrow bead of hot plastic, which is selectively deposited where it fuses to the existing structure and hardens as it cools.
Selective Laser Sintering (SLS)	Utilises a laser t partially melt successive layer of powder. One layer of powder is deposited over the bed area and the laser targets the areas that are required to be solid in the final component.
3D Printing (3DP)	Based on inkjet printer technology. The inkjet selectively deposits a liquid binder onto a bed of powder. The binder effectively "glues' the powder together.

3D printing is mostly utilised in the manufacturing industry to fabricate complicated 3D objects and components of new products in the early stages of development. Despite its many advantages, one of the challenges is the layer-by-layer printing speed. 3D printing takes a long time to manufacture the parts and is a slow process, which has a negative impact on the technology. As a result, 3D printing has not been able to totally or even partially replace traditional production methods. Due to the drawbacks of 3D printing, additive manufacturing has evolved through time, resulting in the invention of new technologies such as 4D printing and 5D printing. Skylar Tibbits first proposed the concept of 4D printing in February 2013. 4D printing is a type of additive manufacturing that allows objects to remodel or self-assemble over time. 4D printed materials react to environmental factors such as humidity, temperature, and other factors, changing their structure as a result.

4D printing, on the other hand, has a limitation in that it cannot create complex objects with curved surfaces. As a result, 5D printing has evolved to counteract these undesirable effects. William Yerazunis of Mitsubishi Electric Research Labs (MERL) developed the concept of 5D printing at American University. The principle behind 5D additive manufacturing is to print in 5 separate axes by rotating the extruder head and the print bed. Curved complex surfaces may be printed using 5D printing technology, and its applications are mostly in biomedical, automotive, and aerospace components.

1.2 Workflow of 3D printing

Workflow of the 3D printing process can be divided into three (3) phases as shown in Figure 1 below, namely the Design phase, Slicing phase and Print phase.

Figure 1 Workflow of 3D Printing

- Design - Design phase is the first and most important phase in the process workflow. Without this phase, a 3D printer will not be able to manufacture a prototype or product without a CAD file. In this phase, user will design their model by using CAD software, such as SolidWorks or CATIA.
- Compilation - Compilation or slicing can happen in two phases:
  - CAD to STL

    In this phase, a CAD model is will be converted or translated to an interpreted language, typically in STL format. In a 3D coordinate system, this depicts the surface mesh as polygons.
  - STL to G-code

    In this phase, STL is sliced to obtain G-code. This code will control the movement of the extrusion, movement and temperature. The movement of the path for the printing process will be based on the G-code.

- Print – The G-code that has been inserted inside printer will control control signals to motors, heating elements, and cooling fans. Then, the nozzle of printer will be melted to fed the melt filament onto the bed base of printer. It will produce the part by building it layer by layer.

1.3 Overview of Computer Aided Process Planning

Four decades ago, the use of computer technology for process planning was introduced. Since then, a significant amount of research has been conducted in the field of computer-aided process planning (CAPP). One of the reasons for this is CAPP's involvement in decreasing costs and increasing quality over time. CAPP is a computer programme that assists process planners in their planning duties. It entails determining the techniques and conditions needed to turn a block into a final part/product [19].

Computer aided process planning (CAPP) keeps an important role between the design and manufacturing engineering processes. A CAPP system serves as a digital link between a CAD model and manufacturing instructions. Interpreting design data, choosing and sequencing the operations to create the component or product, choosing the machine and cutting tools, deciding on the cutting parameters, selecting jigs and fixtures, and calculating machining times and costs are all included in the process planning processes. Since CAPP's inception 20 years ago, the direction and implementation have undergone significant changes due to the quick growth of computer-aided techniques. In the past 20 years, more than 200 publications have been published in the subject. The majority of studies introduce particular CAPP systems [20].

1.4 Objectives

The specific objectives of this research are:

- To generate a complete additive manufacturing product towards Industry 5.0.
- To create an algorithm that can identify the type of printing process and convert CAD file to STL file automatically.
- To test if the algorithm can produce a complete additive manufacturing product using an integrated CAD/CAM system with 3D printers.

1. 5 Problem Statement

There is a lot of current literature in the field of process planning for 3D printing. Additive manufacturing, or also known as 3D Printing has continues to grow throughout the years as it is one of the leading emerging technologies of Industry 4.0. However, most of the process are done manually where the users need to convert the 3D model to machine language, which is G-code in order to print the model. Therefore, an integrated CAD/CAM system are used to automated the printing process by creating an algorithm that able to decide the type of printing process (3D, 4D or 5D printing) suitable with the model and convert it to STL file automatically. Then, the algorithm will be tested whether it can be extended up to 5D printing by using three different types of models with a different printing process.

1. 6 Scope of the Project

In this project, a model will be designed by using a computer-aided design (CAD) software, which is SolidWorks. Then, SolidWorks Application Programming Interface (API) will be used to automated the process started from the designing stage to the printing stage. An algorithm will be created by using Macro Visual Basic Application (VBA), which is one of the functions of API. The algorithm will be created to helps the user decide the types of printing process that is suitable with their model and convert the CAD file to STL file automatically. After that, the algorithm will be tested by printing the model after the slicing process to see whether a complete additive manufacturing product can be generated. However, the printer that are used to test the algorithm is a 3D printer. Therefore, a model with a characteristic of 4D and 5D printing product cannot be printed because it is not suitable with the printer used.

CHAPTER TWO: LITERATURE REVIEW

2.1 Additive Manufacturing in Industry 4.0

Additive manufacturing is a critical component of contributing to Industry 4.0 in a significant way. It minimizes material waste to have a large environmental effect. As a disruptive technology, additive manufacturing is now accessible to perform the essential task in Industry 4.0. It is the process of combining design software with 3D printing equipment to complete the manufacturing of the product. Manufacturing is done automatically in this process by sending commands through software and eliminating human labour.

Additive Manufacturing (AM), as an emerging manufacturing technology, has brought phenomenal changes to industries and markets, and accordingly attracted academics and practitioners' attention in the recent years. Industries have been attracted since they could benefit from the implementation of AM by accelerating and making cost-effective the new product development processes (Chen et al., 2015), producing customized products (Bogers et al., 2016) and presenting innovative and complex parts to their customers (Despeisse and Ford, 2015). For instance, GE Aviation could efficiently produce more than 100,000 jet engine fuel nozzles using AM technologies (GE, 2015). GE could print this part with 25 percent lighter weight and as much as five times greater durability than what was produced using conventional manufacturing (Khorram Niaki and Nonino, 2018). AM allowed the nozzle that previously was assembled from 20 separate cast parts, to be fabricated in one piece. GE declared that this would cut the cost of manufacturing by 75% (D'Aveni, 2015), yielding significant savings of up to $3 million per aircraft per year (Rao, 2016). Moreover, various customized medical parts are being mass-produced using AM technologies. More than 10 million hearing aid shells, around 50 million dental bridges, copings and crowns have already been made using AM technologies (Oettmeier and Hofmann, 2017). Aforementioned cases imply the reasons that attracted companies to adopt AM technologies.

Beside these opportunities, researchers argue that AM offers several benefits from the sustainability view (e.g. Chen et al., 2015; Ford and Despeisse, 2016) and it would be a key manufacturing technology in the sustainable society of the future (Huang et al., 2013; Ma et al., 2018). Regarding the economic characteristics, AM uses less resources (Ullah et al., 2013), resulting in less operational costs in a manufacturing firm (Weller et al., 2015). As regards environmental sustainability, AM conserves energy (Tang et al., 2016), resources and emissions (Yang and Li, 2018). AM also promises such social impacts, particularly, on the way people consume and companies satisfy the demand (Huang et al., 2013).

2.2 Automatic segmentation of a large-scale object for 3D printing

Additive manufacturing of large-scale prototypes is needed in various areas, such as 3D-printed houses for fast construction (Bos et al. 2016), dummies for car-safety testing (Boström et al. 2000), human organs for biomedical applications (Tielen & Delbressine, 2016), and manikins for the apparel industry (Nayak & Padhye, 2017). Because most conventional 3D printers do not support large-scale printing features, the user should decompose raw mesh data into smaller parts using 3D CAD or modeling tools. Several researchers already tackled this printer control issue; MIT's "Chopper" algorithm was the pioneer in slicing large objects (Luo et al. 2012). It decomposes a big model into 3D-printable sizes considering printing volume, connector feasibility and finite element method-based structural soundness (Luo et al. 2012) as objective functions.

2.3 Design for 3D Printing

Design for 3D printing is an essential study issue that needs a thorough understanding of 3D printing techniques' capabilities and limits. It is the first and most important phase in the workflow. A well-designed computer-aided design (CAD) model not only ensures print quality but also reduces the quantity of support material required when it is needed.

The design feature database, according to Bin Maidin et al. (2012), provided ideas and design features for less-experienced designers. The application of machine learning in 3D printing allows feature suggestions to be made to existing CAD models, allowing designers to make faster decisions throughout the design stage. It assisted inexperienced designers who were new to 3D printing in determining appropriate AM design elements for remote-controlled automotive components without having to go through physical trials and mistakes.

2.5 Slicing

The slicing process is very important in 3D printing. It greatly influences the surface roughness form, error preparation time and actual machine build time. Slicing is the process of transferring an STL file to a series of layers. This procedure, for FDM machines using AM technology, involves vector generation by intersecting an XY plane at a particular height t create the model layers (slices). The result of slicing process is the toolpath, also known as machine path.

The toolpath creation procedure requires information from the slicing method to generate the information required for the G-code file. Normally this procedure reading entire facets into the computer’s memory, then the facets are sliced and generated vectors are sorted. This method demands a considerable amount of computer memory, and encounters difficulties in processing very large and complex STL files, thus affecting the final physical models’ quality and build time. Hayasi & Asiabanpour et al. (2009) proposed a new toolpath generation algorithm that solves the computer bottleneck in toolpath generation for very large STL files. Tata et al. demonstrated that the productivity of the AM processes can be very significantly improved by upgrading the slicing software.

Besides, Brown et al. (2013) also described an efficient STL slicing and G-Code generating approach in their paper. This algorithm is customised for entry-level AM 3-D printers. The algorithm's performance was evaluated by executing the generated G-Code file through an entry-level 3-D printer (the BFB 3000 3-D printer). Using G-Code generated by the programme, many STL models were successfully opened and manufactured.

2.5 Smart Material for Printing

The material used in additive manufacturing, should be compatible with the printing process. Nowadays, advancements in printing process have cause the material that will be used to print product to be diverse. There are three categories of these materials, which are electrical, biological, and smart materials. Metal, polymer, nanowires, and nanotubes are common materials employed. Figure 2 shows the classification of printed materials depending on their uses.

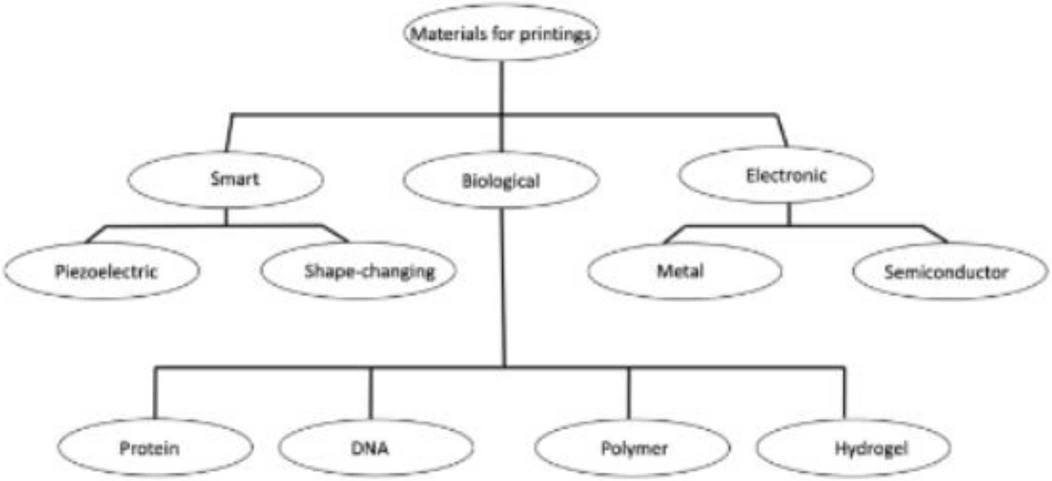


Figure 2 Classification of the printable materials [35]

Stimulus-responsive materials that alter their shape, size or functional properties under certain stimuli such as solvent, pH, temperature, electricity, light, etc. are known as smart materials. In other words, smart materials are materials that respond to changes in their environment and then undergo a material property change. High-resolution smart assemblies fabricated by advanced printing out of shape-changing materials can shift their shapes/sizes or properties with time. For instance, Kim et al. have demonstrated 3D printing of shape changing materials of ferromagnetic domains. The composite ink for 3D printing contains a magnetizable microparticles of neodymium–iron–boron (NdFeB) alloy and fumed silica nano particles impregnated in a silicone polymeric network containing a silicone catalyst and a crosslinker. Furthermore, they developed a model to envisage the revolution of complex 3D-printed structures with programmed ferromagnetic domains experiencing magnetic fields.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Process Flow Chart

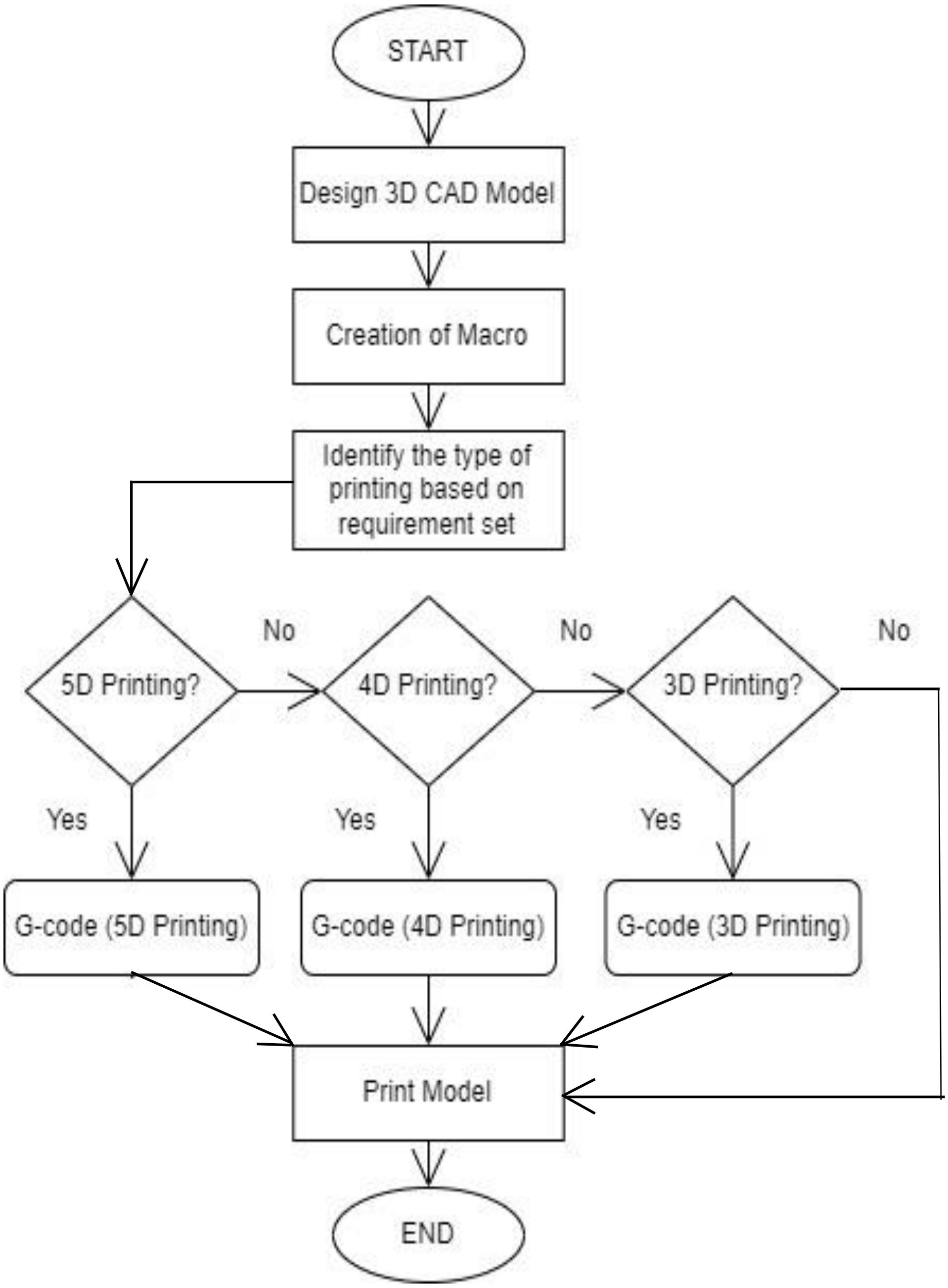


Figure 3 Flowchart for the Process Planning of Automatic Additive Manufacturing Product Generation

3.2 Design product for 3D, 4D and 5D printing

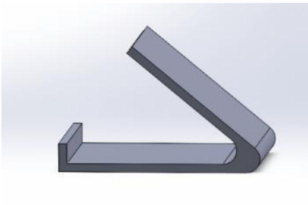
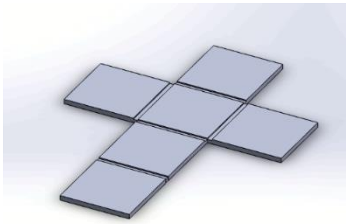
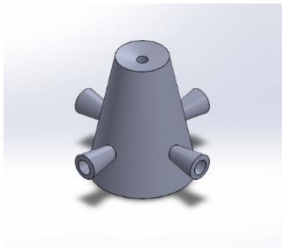
All of the parts were modelled using SOLIDWORKS 2021 each part are designs to have the featured for each type of printing product. Table 2 below shows the characteristic difference between 3D, 4D and 5D printing. Table 3 shows the design chosen for each of the printing types.

Table 2 Characteristics difference between 3D, 4D and 5D printing

Compared Characteristics	**3D Printing**	**4D Printing**	**5D Printing**
Manufacturing approach	Structure formed using layer by layer deposition of 2D ink material.	One more step of advancement of 3D printing with shape-changing programming property.	One more step of advancement of 4D printing with the ability to produce curved complex surfaces (layer).
Raw material	PLA, ABS, Polycarbonate, Nylon and Carbon	Hydrogel, Shape Memory Polymer (SMP), Shape memory alloy (SMA)	PLA, ABS, Polycarbonate, Nylon, Carbon, Metal, On-metal
Degree of freedom	3	4	5
Printing Head & Base	Movable & Stationary	Movable & Stationary	Both are movable
Printed Object	Static	Dynamic	Static

Area of applications	Engineering, electronics, medicine, dentistry, automotive, robotics, fashion, aerospace, defense, and nuclear.	Adds dynamic elements to all 3D printing applications, mostly employed in biomedical industries.	Biomedical, automobile and aerospace components.

Table 3 Design chosen for each type of printing process.

	3D Printing	4D Printing	5D Printing
Design	 37]	 3838]	 39]
Characteristics	Part maintained a fixed or static shape. Able to print this object with a printer that only have 3 degrees of freedom.	Part uses smart material, which is shape memory polymer that can transforms itself into another structure over the influence of external energy input such as temperature, light or heat.	Part contained complex curved surface which is hard to print by using 3D printer. Need to use 5D printer that have 5 degrees of freedom.

3.3 Creation of Algorithm for Macro

The first step in creating the algorithm for the automatic program is to open the SOLIDWORKS software and select new macro in the toolbox. Macro will be used to create algorithm because it is a type of scripts that let the user to run operations in the SOLIDWORKS automatically.

3.3.1 Opening Part File

The first step is to write an algorithm that that will open the CAD file for the part that is chosen. In this section, there are two ways of opening the part file. Table 1 shows the comparison between the two files to open 3D part file.

Table 4 Algorithm for opening file

Type of program	Algorithm for program (Opening File)	Explanation
Required user to interact	'Creating variables for SolidWorks application' Dim swApp As SldWorks.SldWorks 'Creating variable for SolidWorks document' Dim swModel As SldWorks.ModelDoc2 'Creating variable for SoliWorks drawing' Dim swDraw As SldWorks.DrawingDoc Dim time1, time2	Variable used for the macro
	'Main function of VBA program' Sub main() 'Setting SolidWorks variable to SolidWorks application' Set swApp = Application.SldWorks	
	MsgBox "Please open SolidWorks part file."	Command to ask user open the file
	time1 = Now time2 = Now + TimeValue("0:00:30") Do Until time1 >= time2 DoEvents time1 = Now() Loop answer = MsgBox("File are open?", vbYesNo + vbQuestion)	Add time to wait for user to open the file. User will have to answer the question. If yes continue to next part, if no, end program.

	If answer = vbYes Then
	MsgBox "Please open drawing for the part."
	
	time1 = Now
	time2 = Now + TimeValue("0:00:30")
	Do Until time1 >= time2
	DoEvents
	time1 = Now()
	Loop
	
	Else
	'do something
	
	End If
	
	answer = MsgBox("Drawing are open?", vbYesNo + vbQuestion)
	If answer = vbYes Then
	MsgBox "Proceed to next part."
	
	Else
	'do something
	
	End If
	
	End Sub
		If yes, the user the program will proceed to ask user open the drawing. A set of time is given to the user to open. If the user has not opened the CAD file, the program will stop.

Fully automated	‘Creating variables for SolidWorks application’ Dim swap As SldWorks.SldWorks ‘Creating variable for SolidWorks document’ Dim swModel As SldWorks.ModelDoc2 'Creating variable for SoliWorks drawing' Dim swDraw As SldWorks.DrawingDoc	Variable used for the macro
	‘Main function of VBA program’ Sub main() 'Setting SolidWorks variable to SolidWorks application' Set swApp = Application.SldWorks 'Open a part file' Set swDoc = swApp.OpenDoc("C:\Users\EMG261\Desktop\Macro\Phone Holder\Auto Phone Holder\Macro (wo fillet)\Phone Holder	

	wo fillet.sldprt", swDocumentTypes_e.swDocPART) 'Open a drawing file' Set swDraw = swApp.OpenDoc("C:\Users\EMG261\Desktop\Macro\Phone Holder\Auto Phone Holder\Macro (wo fillet) drawing\Phone Holder wo fillet drawing.slddrw", swDocumentTypes_e.swDocDRAWING) End Sub	The CAD file will open automatically by inserting the file location of CAD file in algorithm.

Based on the comparison, a fully automated algorithm is chosen because it is fully automated and it does not take a lot of time to open the file.

3.3.2 Algorithm for decision making

Create a user form where the user will have to fill in the details for the macro. In the user form as shown in Figure 2, the decision for the type of printing will be made based on the answer given by the user. The user will have to insert number for material as the instruction shown in the command and number of datums that is available in the drawing. In the algorithm as shown in Figure 3, the type of printing will be decided based on the following requirement:

- If the number of materials used for printing is 1 and the number of datums is more than or equal to 3, the type of printing is a 5D printing.
- If the number of materials used for printing is more than or equal to 2 and the number of datums is more than or equal to 1, it is a 4D printing.
- Else, it is a 3D printing.

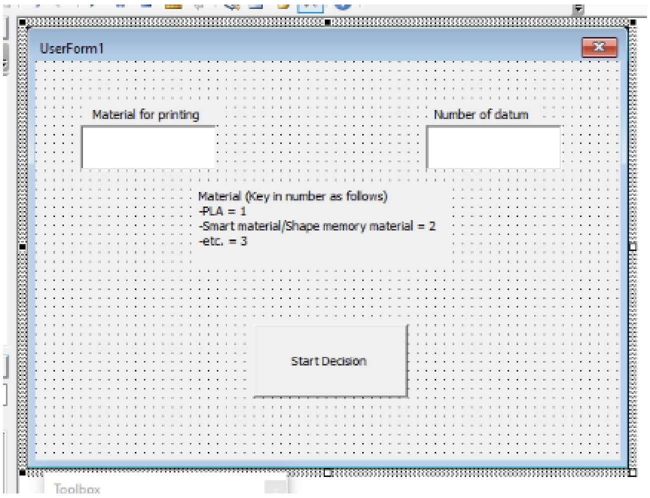


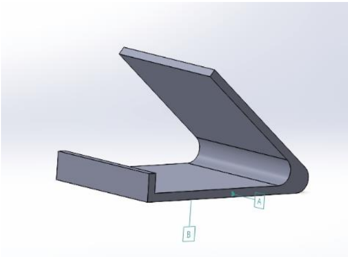
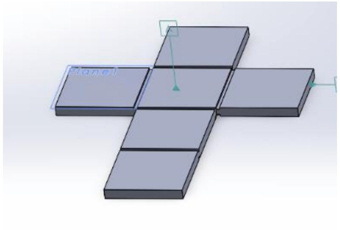
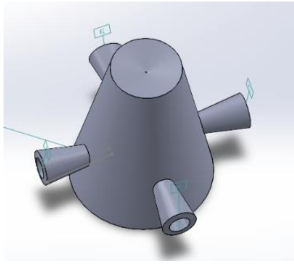
Figure 4 User Command for decision making

```
Private Sub CommandButton1_Click()

Dim material As Double
Dim datum As Double

'set material equal to the text in materialTextBox
material = materialTextBox.Text
'set datum equal to text in datumTextBox
datum = datumTextBox.Text

    If material > 1 And datum >= 3 Then
    MsgBox "It is a 5D Printing"

    ElseIf material = 1 And datum >= 1 Then
    MsgBox "It is a 4D Printing"

    Else:
    MsgBox "It is a 3D Printing"

    End If
```

Figure 5 Algorithm for user command to decide printing types

Table 5 shows the number of datum and material for printing. These 3 types of part that represent each printing types, which are 3D, 4D and 5D printing are used to test the algorithm to see whether it can identify the type of printing for each part correctly.

Table 5 Number of datum and material for each part that is chosen as representative for each printing types.

Types of Printing	3D Printing	4D Printing	5D Printing
Number of datums for each part	 Number of datum=2	 Number of datum=2	 Number of datum=5
Material for printing • Smart material/Shape memory material = 1 • PLA = 2 • etc. = 3	2	1	2

3.3.3 Generation of G-code and Printing Process

In order to generate a G-code for the part file, the CAD file should be saved as STL file. The process of saving CAD file as STL can be done automatically using macro. Table 6 shows the algorithm to save 3D CAD file as STL file automatically.

Table 6 Algorithm to save 3D CAD file as STL file automatically.

Type of Printing	Algorithm	Explanation
3D Printing	Dim swApp As Object Dim swap As SldWorks.SldWorks Dim swModel As SldWorks.ModelDoc2 Dim Part As Object Dim boolstatus As Boolean Dim longstatus As Long, longwarnings As Long Sub main()	Variable for this macro
	Set swApp = Application.SldWorks 'Setting SolidWorks variable to SolidWorks application' Set swApp = Application.SldWorks 'Open a part file' Set swDoc = swApp.OpenDoc("C:\Users\EMG261\Desktop\Macro\3d\3d.sldprt", swDocumentTypes_e.swDocPART)	Algorithm for opening part file. The part with yellow highlights is the file location for the part file.
	Set Part = swApp.ActiveDoc Dim COSMOSWORKSObj As Object Dim CWAddinCallBackObj As Object Set CWAddinCallBackObj = swApp.GetAddInObject("CosmosWorks.CosmosWorks") Set COSMOSWORKSObj = CWAddinCallBackObj.COSMOSWORKS ' Save As longstatus = Part.SaveAs3("C:\Users\EMG261\Desktop\Macro\3d\3d.STL", 0, 2) Set StudyManagerObj = Nothing Set ActiveDocObj = Nothing Set CWAddinCallBackObj = Nothing Set COSMOSWORKSObj = Nothing End Sub	Algorithm to save as STL file automatically. To save as STL, the end part for the file location as has been highlight beside should be changed to '.STL",0,2'.

After converting the CAD file to STL file automatically, slicing process need to be done. Slicing process, is the act of converting a 3D model into a set of instructions that can be recognized by the 3D printers. The set of instructions is known as a G-code file. In order to generate a G-code file, the STL file will be import into a slicer software, Ultimaker Cura and FDM machine method is used to fabricate the part. During the printing process, PLA filaments are used as a material. These filaments will be fed into the extrusion nozzle. The nozzle of 3D printer will then deposit or extrudes the molten filament onto the base of 3D printer and move in 3 different coordinates or axis, which are X coordinates (left and right directions), Y coordinates (forward and backward directions) and Z coordinates (up and down directions) as shown in Figure 4. Figure 5 shows the 3D printer machine that are used.

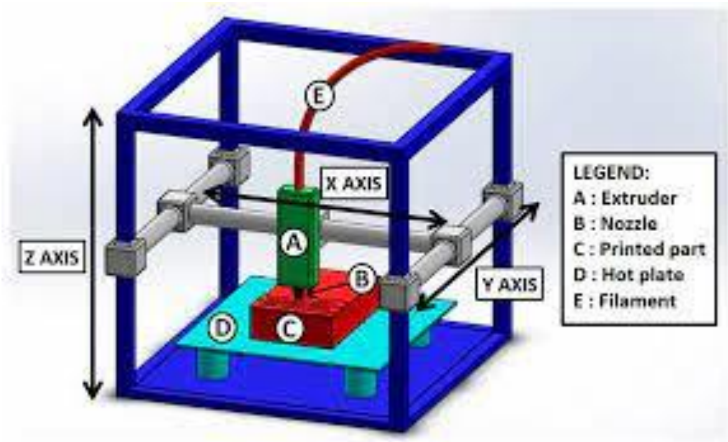


Figure 6 Coordinates or axis for 3D printer []

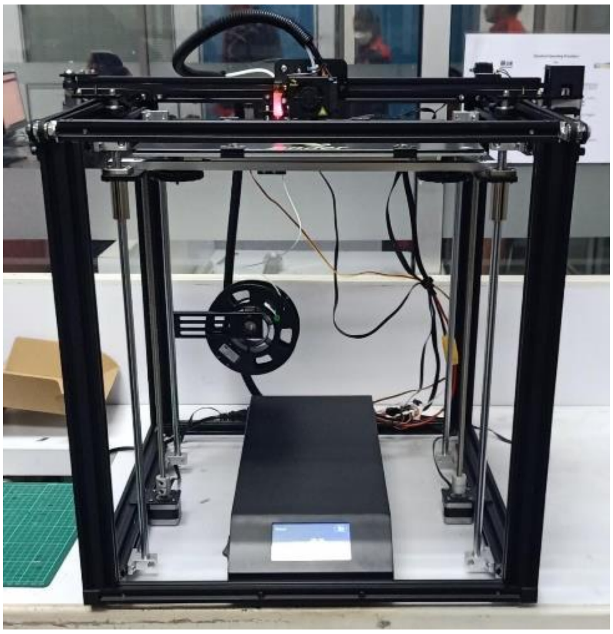


Figure 7 3D printer machine

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results

For the result of this project regarding the creation of algorithm for macro, there are three things that are focused. The results are focused on the creation of macro result, generation of G-code result and fabrication of product.

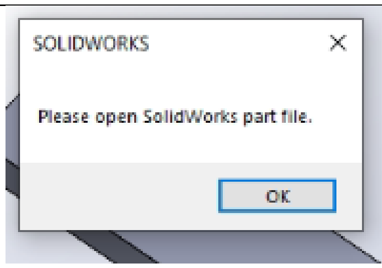
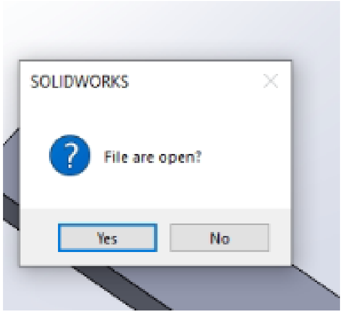
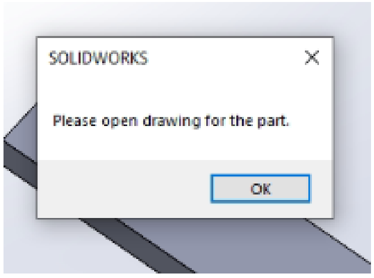
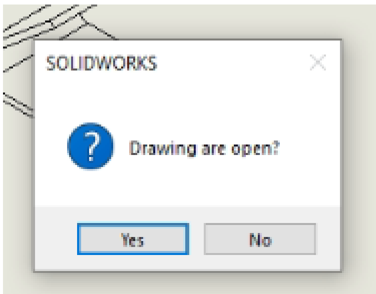
4.1.1 Creation of macro result

4.1.1.1 Opening Part File

Table 7 below shows the result for algorithm that has been created for opening part and drawing file.

Table 7 Result for the algorithm of opening part file

Type of program	Algorithm for program (Opening File)	Result
Required user to interact	'Creating variables for SolidWorks application' Dim swApp As SldWorks.SldWorks 'Creating variable for SolidWorks document' Dim swModel As SldWorks.ModelDoc2 'Creating variable for SoliWorks drawing' Dim swDraw As SldWorks.DrawingDoc Dim time1, time2 'Main function of VBA program' Sub main() 'Setting SolidWorks variable to SolidWorks application' Set swApp = Application.SldWorks MsgBox "Please open SolidWorks part file." time1 = Now	After run this program, a command window will pop up asking the user to open part file manually. The user is given some times to open the file. Then, a yes or no command window will pop up and ask question if the file has been open or not. If the answer is yes, the program will ask the user to open drawing file for the part. However, the program will end when the user clicks the no button.

	time2 = Now + TimeValue("0:00:30")
	Do Until time1 >= time2
	DoEvents
	time1 = Now()
	Loop
	
	answer = MsgBox("File are open?", vbYesNo + vbQuestion)
	
	If answer = vbYes Then
	MsgBox "Please open drawing for the part."
	
	time1 = Now
	time2 = Now + TimeValue("0:00:30")
	Do Until time1 >= time2
	DoEvents
	time1 = Now()
	Loop
	
	Else
	'do something
	
	End If
	
	answer = MsgBox("Drawing are open?", vbYesNo + vbQuestion)
	If answer = vbYes Then
	MsgBox "Proceed to next part."
	
	Else
	'do something
	
	End If
	
	End Sub
		
		
		
		

Fully automated	Dim swApp As Object Dim swap As SldWorks.SldWorks Dim swModel As SldWorks.ModelDoc2 Dim Part As Object Dim boolstatus As Boolean Dim longstatus As Long, longwarnings As Long ______________________________ Sub main() Set swApp = Application.SldWorks	After run the program, the macro will automatically open the part file and drawing as shown below. Therefore, the user will save a lot of time by using this program. However, the user should place part and drawing file in a specific folder because this program needs the file location of the files to open it automatically.