DESIGN AND FABRICATION OF UDOSEN'S SOCCER BOARD GAME PLAYER FIGURINE WITH 3D PRINTER

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CERTIFICATION

This is to certify that this project work was carried out by JAMES ASSURANCE BLESSBE with matriculation number ENG1403920 of the Department of Production Engineering, University of Benin, Benin City, Edo State, under the supervision of Prof U. J. Udosen.

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External Examiner	Date

DEDICATION

This project work is dedicated to ALMIGHTY GOD, my source of life, encouragement and inspiration.

ACKNOWLEDGEMENT

I wish to express my profound gratitude to God Almighty. I am also grateful to my parents Mr. and Mrs. James Ugwudike who have been very encouraging, supportive and prayerful ensuring this work comes to a reality.

With utmost respect, joy and appreciation, words won't be enough to express how grateful I am to my ever supportive, wonderful and motivating project supervisor and lecturer Prof. U. J. Udosen for his unwavering support, motivation and patience with which he supervised this research work.

I want to express my deepest appreciation to my family members and friends, for their unwavering support at all times. My appreciation also goes to all the lecturers especially Dr. Francis in the Department of Production Engineering for all their contributions and tutelage during the course of this project.

I wish to also appreciate Success for assisting during the course of this research work. I would love to appreciate my siblings, James Victory, James Marvelous, James Faith, Chinagorom Precious and Chinagorom Judith once again for their financial support towards my studies since I gained admission into the University of Benin.

Finally, I would like to thank everyone who has in one way or the other contributed to the success of this research project and my course of study in the Department of Production Engineering.

ABSTRACT

Digital fabrication technology, also referred to as 3D printing or additive manufacturing, creates physical objects from a geometrical representation by successive addition of materials. 3D printing technology is a fast-emerging technology. Nowadays, 3D Printing is widely used in the world. 3D printing technology increasingly used for the mass customization, production of any types of open source designs in the field of agriculture, in healthcare, automotive industry, locomotive industry and aviation industries. 3D printing technology can print an object layer by layer deposition of material directly. This study is on 3D printing, it is different from traditional manufacturing processes that shape products through milling, grinding etc. Instead, with additive manufacturing, layers are added to a product. This allows for three dimensional manufacturing and limited scrap. Additive manufacturing has been viewed by many as a disr uptive innovation for society because it allows consumers to manufacture their own products. The current status of 3D printers will be provided together with an analysis of the main producers such as Makerbot a nd Ultimaker (consumer markets) and Stratasys and 3D Systems (industrial markets), their models and the ir current capabilities and overall adoption. It is concluded that additive manufacturing is experiencing high growth but that, in particular for industrial applications, it is not yet competitive with traditional manufacturing systems.

This project explores the use of 3D printing technology to create a figurine of a football player for games like Udosen's soccer game. A 3D modeling software was used to design the figurine, which was then 3D printed using a 3D printer. The finished figurine was detailed and accurately represented the chosen football player. The project demonstrated the capabilities of 3D printing in the realm of sports and athletics and highlighted the potential for creating personalized and unique collectibles and displays using this technology. To create a 3D printed player figurine for Udosen's soccer board game, one can start by designing the model using 3D modeling software such a Blender. The design can then be exported as a 3D printable file, such as an STL file, which is then loaded into our Creality 3D printer. Once the 3D model was complete, it was then necessary to prepare the model for printing and to set up the 3D printer in order to begin the printing process. This involved selecting the appropriate filament material and setting the printing parameters in order to achieve the desired results. The printing process itself took several hours depending on the size and complexity of the model. Overall, the project required a combination of technical skills, attention to detail, and problem-solving in order to achieve a successful outcome. The printer then prints the model layer by layer, using a variety of materials, including plastic, resin. In addition to the technical aspects of 3D printing, the project also involved a significant amount of research and planning. It was necessary to gather reference images and information about the chosen football player in order to create an accurate and detailed 3D model. The design process involved making decisions about the features and details to include in the figurine and required careful attention to proportion and detail. One of the main advantages of 3D printing is its ability to produce highly detailed

and accurate models, which makes it perfect for creating custom figurines for board games like Udosen's soccer board game. In addition, 3D printing allows for easy customization, enabling players to create unique player profiles that reflect their individual playing style. Using a 3D printer and 5g of filament, we were able to print a set of player figurines in 35 minutes that are lightweight, durable, and accurately represent the players on the field. The total cost of printing these figurines was 108.89 Nigerian Naira, making it an affordable and costeffective way to enhance the overall gaming experience. In conclusion, the use of 3D printing technology in the Udosen’s Soccer Board Game is a game-changer. It adds a new level of excitement and immersion to the game and is an affordable way to enhance the gaming experience. At a cost of 108.89 Nigerian Naira and using only 5g of filament, it is a cost-effective way to produce high-quality player figurines that are both durable and visually appealing

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NOTATIONS

A = Area in mm^2

C = Center distance between rods in mm

D = Diameter in mm

Dm = Mean Diameter in mm

Dstd = Standard Diameter in mm

E = Young's modulus in N/mm^2

F = Load in N

H = Height in mm

I = Inertia in mm4

Mt = Moment in Nmm

N = Speed in RPM

P = Pitch in mm

R = Radius in mm

Σ = Stress in N/mm^2

T = Torque in Nmm

μ = Co-efficient of friction

V = Velocity in ms^{-1}

W = Width in mm

Y = Deflection in mm

Ω = Angular Velocity in

CHAPTER ONE

INTRODUCTION

3D printing, also known as additive manufacturing (AM), refers to processes used to synthesize a three dimensional object, in which successive layers of material are formed under computer control to create an object. Objects can be of almost any shape or geometry and are produced using digital model data from a 3D model or another electronic data source such as an Additive Manufacturing File (AMF) file. The term 3D printing's origin sense is in reference to a process that deposits a binder material onto a powder bed with inkjet printer heads layer by layer. More recently, the term is being used in popular vernacular to encompass a wider variety of additive manufacturing techniques. 3D printing allows students to create prototypes of items without the use of expensive tooling required in subtractive methods. Students design and produce actual models they can hold. The classroom environment allows students to learn and employ new applications for 3D printing. Engineering and design principles are explored as well as architectural planning. Students recreate duplicates of museum items such as fossils and historical artifacts for study in the classroom without possibly damaging sensitive collections. Other students interested in graphic designing can construct models with complex working parts easily. 3D printing gives students a new perspective with topographic maps. Science students can study cross-sections of internal organs of the human body and other biological specimens. And chemistry students can explore 3D models of molecules and the relationship within chemical compounds. The future applications using the 3D printing which may create an open-source for the scientific equipment. To ensure a high quality 3D print it is essential to keep the design rules for 3D Printing in mind. When designing your model, you need to take into account the fact that your model is build up with closed surfaces and printable wall thicknesses. The great thing of 3D Printing is that you are able to print complex shapes and highly detailed designs that will be too time consuming if they were built by hand. A 3D Printer can be used to print detailed designs, e.g.: complex facades, interiors, environmental elements (cars, trees, people), roofs etc. A large flat floor surface can also be printed, however using a laser cutter for these kind of parts might suit this purpose better. The purpose of this research paper is to propose an ultimate solution for architecture students and employees around the kingdom of Saudi Arabia in regard to building 3D models by applying the new 3D printing technology to universities and companies. By doing so, this paper also aims to open up new opportunities in complex architectural design and construction techniques, improving the quality of both by using the technology of 3D printing. Using the 3D printing process is helpful for the undergraduates in the discipline of architecture and design specially in research and design courses, due to the ability of making professional 3D architectural models.

1.1 Background to the Study

While 3D printing has received attention from the wider public over only the last few years, its technological roots date back several decades (for 19th century examples of photosculpture and topography, see Bechthold, Fischer et al. 2015). In the late 1970s, Wyn Swainson from Denmark received a patent on a technology using two laser beams to create 3D objects. Other inventors explored the use of layered molding processes to create such objects.

In the 1980s, R&D activities concerning 3D printing technologies intensified considerably. In 1981, Hideo Kadama of the Japanese Nagoya Municipal Industrial Research Institute presented a method to create 3D plastic models by exposing liquid photo-hardening polymer to ultraviolet rays (Kodama 1981). In 1984, Chuck Hull applied for a patent on a prototype system based on stereolithography, which was described above. In 1986, Chuck Hull cofounded 3D Systems, which would later become one of the leading companies in the industry. 3D Systems commercialized stereolithography into the first commercial 3D printer in 1988. The company did not only develop the 3D printer itself. It also developed a new file format (STL, Stereolithography) which describes the surface geometry of 3D objects and which has evolved into an industry standard for many decades. Also in the late 1980s, Scott and Lisa Crump developed the fused deposition modeling technology described above. They received various patents on it and cofounded Stratasys, another important industry player.

In 1986, Carl Deckard filed a patent on selective sintering processes which enabled the use of materials other than polymers (e.g. metals and thermoplastics) for 3D printing purposes. The company he founded (Nova Automation, later renamed DTM Corporation) was acquired by 3D Systems in 2001. And in 1987, Michael Feygin filed a patent on sheet lamination in which a laser cuts thin sheets of paper or other material into a desired shape, and then layers of such shapes are added on top of each other. The company he founded (Hydronetics) was later renamed to Helisys and Cubic Technologies.

In the 1990s, companies started to use 3D printing technologies for prototyping purposes. In addition, researchers at Stanford and Carnegie Mellon proposed new techniques of additive manufacturing, involving microcasting (Amon, Beuth et al. 1998) and spraying of materials (Beck, Prinz et al. 1992). Starting in 1993, MIT received patents on 3D printing technologies in the narrow sense: this was inspired by inkjet technology used in normal inkjet printers. MIT later licensed its patents to Z Corporation and a few other companies for the development of 3D printers.

While 3D printing technologies gained wider acceptance in the commercial manufacturing industry in the early 2000s, it became apparent that these technologies could also be used to produce end consumer products. In 2005, Adrian Bowyer started the RepRap project at the University of Bath. Initiated as an open source project to create a 3D printer which can reproduce itself, it has had a considerable impact on the development of low-cost consumer market 3D printers and a flourishing ecosystem of hardware manufacturers, software programmers and service providers, all focusing on the 3D printing consumer market.

1.2 Statement of the Problem

The limitations of 3D printing in general include expensive hardware and expensive materials. This leads to expensive parts, thus making it hard if you were to compete with mass production. It also requires a CAD designer to create what the customer has in mind, and can be expensive if the part is very intricate.

1.3 Aim of the Study

The aim of this study is to produce a game piece for Udosen's Soccer Board Game using a 3D printer.

1.4 Objective of the Study

The main objective of the project is to create a unique model to enhance the gaming experience without any compromise at the product quality.

1.5 Scope of the Study

The 3D printing is the future of the rapid prototyping. It plays a major role in small and medium scale like house hold, laboratories, educational and hobby oriented applications.

1.6 Significance of the Study

3D printing has great potential to positively impact manufacturing processes in the industrial sector.

CHAPTER TWO

LITERATURE REVIEW

During recent years, 3D printing (3DP) (also known as additive manufacturing [AM]) technologies have become mainstream. The expiration of essential technology patents, as well as the development of new materials along with innovative additive processes, has attracted the renovated interest of industry, academia and public media. The claim is that additive manufacturing can replace conventional manufacturing solutions (Campbell, Bourell & Gibson, 2012) and reinvent the way products are designed, manufactured and distributed globally (Khajavi, Partanen & Holmström, 2014). Today the technology has a strategic position in the definition of innovation policies on a global scale. Additive manufacturing is considered an enabler for companies to gain competitive advantage. Thus, giving them a new range of opportunities in terms of quick product and production line reconfiguration, distributed manufacturing, customization and personalized product development. In the future, additive manufacturing systems will produce the key components of a product, driving the digitalization of design and manufacturing environments to the next industrial revolution (Horizon 2020 FP7, 2014). On the negative side, the hype is much more visible than the reality. Industry and academia have identified intrinsic drawbacks to additive manufacturing technology. The first issue is linked to the limited characterization of the additive machines and materials. Standardization of the technology, processes and material is at early stages. Tackling this issue is fundamental in order to make additive manufacturing technology accepted by regulated industries (such as the aeronautic, aerospace, automotive, medical and manufacturing industries). With this in mind, there is a lack of research that would help understand the societal, economic and technical implications of the technology for modern organizations (Flores Ituarte et al., 2015).

The second drawback is related to the reliability and repeatability of additive manufacturing processes. Improvements in quality, performance validation and expanding materials options as well as the size capabilities of new-generation machines are likely to impact positively as development in this area is in the early stages (Guo & Leu, 2013). Finally, there is a lack of understanding of the technology from the practical application perspective. This is still vague among the industry professionals, partly because the relevant standards only define additive manufacturing technology as machine process, not depending on the application areas in which the technology is being used. In addition, recent studies show that the additive manufacturing industry is still optimizing costs structures (i.e. those of machine costs, material costs and labour costs), this being a significant factor affecting whether companies adopt additive manufacturing technologies or not (Thomas, 2013). Reducing these costs may boost the additive manufacturing industry and truly drive the use of additive manufacturing technologies as a production method in the forthcoming digitalized era. However, currently the shift towards additive manufacturing as a production method is still not fully clear in traditional design and engineering industries as the positioning of additive manufacturing technology as something that creates value in company operations is still vague.

In this regard, this work will present ongoing industrial, medical and design case study research of early adopters in Finland. Based on this, we will shed light on future policy strategies for Nordic countries. This work intends to synthetize key enablers for the successful technology adoption in industry to connect with policy strategies which need to be articulated in order to benefit from 3D printing technology.

2.1 Soccer Game

Soccer is a game played by two teams with 11 players each on a field with a goal for each team. It is the most popular team sport on the planet, a fast-paced game with few breaks and one simple aim of scoring a goal. A soccer field is at least 100 yards long, 50 yards wide and has a goal centered at both ends. Within the field are markings including those for the penalty area and spot, the center spot for kick-offs, and, of course the corners- without which corner kicks would just be kicks.

2.2 Udosen's Soccer Board Game

It is a game of skill between two players. It is played on a board of 108 squares (9 x 12) marked with goal positions and the features of a football field. The squares on the board may be appropriately colored alternately dark and light. Each player has at his command a team of eleven pieces distinguished from his opponent's team as in a football contest.

A board distinguished from the pieces is also used in the game together with a number generator capable of generating whole numbers from one to six. The ball is passed or dribbled from one square to another on the board by counting squares according to a number generated in the sequence of playing the game.

The object of the game is to play the ball into the opponent's goal. A player who scores the greater number of goals within a specified period is the winner of the game.

At the start of a game from the initial position (often called the opening), the attacker moves his pieces to good squares on the board to play the ball to his opponent's side and create chances for scoring a goal. In reply, the defender moves his pieces to good positions on the board to keep the ball away from his half as well as tackling to gain control of the ball.

After the opening game comes the middle game. At this stage, each player has moved all or most of his pieces to strategic positions on the board and the player may be applying a system to boost his play. Also, in the middle game, the player may be employing tactical manoeuvres - laying traps or avoiding them, applying offensive tactics such as the pin and multiple attacks or defending his goal with offside tactics and so on.

The middle game is followed by the end game just before a goal is scored. At this stage of the game, choose skill or experience or even sheer luck, the tactics or strategy employed by the attacker pays off and he is then rewarded with a goal. (Udosen U. J., 2005).

Plate 2.1 Udosen’s Soccer Game Board (Udosen U. J., 2005).

2.3 Duration of Play

The duration of a game is the time set to play the game to determine a winner. The game may be repeated each time a goal is scored as long as the players agree to play. In a contest, however, it is necessary to play within a specified time limit. A game in which no sides scores a goal within the set time is regarded as a draw and a winner may then be decided in playing 'penalty'. A time limit of 90 minutes may be specified for a game. After a half time of 45 minutes, the players change ends and the opponent of the player who won the choice of ends restarts as the attacker.

2.4 Timing the Game

In a contest, a time limit is set for each move a player has to make so that no player sits and thinks for too long. A player who exceeds the time limit is regarded as having committed a foul in the game and penalties associated with fouls may then be invoked.

It is necessary to summarize what each player must do in his duration to play to make timing the game quite clear. If a player loses control of the ball and leaves the ball on a square, his opponent continues the game as the attacker in the following sequence during his duration to play.

2.5 The Attacker

- Places his dribbler with the ball if the ball is alone on a square
- Generates a number
- Passes or dribbles the ball to another square, (or leaves the ball alone on a square)
- Makes a move only if he has dribbled or passed the ball to a square occupied by his piece

2.6 The Defender

- The defender waits for the attacker to make a move before allowed to make any.
- Makes a move only if the attacker has made a move
- Becomes the attacker if his opponent has lost control of the ball as a result of wrong moves

Notice that there is a greater pressure on the attacker to perform with speed in the game.

A typical duration may be set at 1 minute for each player to perform either as a defender or an attacker given that no foul-play disrupts the game.

There are various timing devices capable of indicating or signaling the beginning and the end of a set duration, the choice of a timer is left to the player.

Apart from timing the game, in competitive play, silence during play and 'touch and move' may be enforced. It is also likely that you may be expected to keep a record of the game if score sheets are provided. In this case, you use a notation of your choice to record the game as it is played.

2.7 Definition of 3D Printing

3D printing is a hard term to define. Officially it is just one of the many new and upcoming manufacturing techniques and is used as a synonym for rapid manufacturing, digital manufacturing, direct digital manufacturing, rapid prototyping, desktop manufacturing, freeform fabrication or 'fabbing'. Each one of these terms has a distinct meaning but they are all competing for our attention to become the official term to describe any process whereby the information in a digital file describing an object virtually is used to rapidly make a real object, usually by one single machine and usually in limited production runs.

Plate 2.2 D Printer (Shenzhen, 2018)

2.8 Components of A 3d Printer

The main components of a 3D printer are:

2.8.1 Hot end

The part where the filament is melted into a malleable material that can be used to form layers of the object being printed.

2.8.2 Nozzle

The part where the molten filament comes out to the print bed. The smaller the nozzle size, the finer the print would be.

2.8.3 Extruder

The part from which the filament is fed into the nozzle.

2.8.4 Print bed

The surface on which the filament is extruded out of the nozzle.

2.8 5 Cooling fan

The part that cools down the extruded filament to solidify it.

2.8.6 Build area

The dimensions of the area where the object is built on. The dimensions of the object cannot exceed the build area.

2.8 7 LCD display

The part that displays the printer settings related to various aspects of the printer such as heat and bed level.

2.9 Working Principle of 3D Printing

The first process involved in 3D printing is the production of the 3D model with the help of computer aided design (CAD) software or via 3D scanner. The manual modelling process of preparing geometric data for 3D computer graphics is similar to method sculpting. It is the process of analyzing and collecting data on shape and appearance of an object. Based on this data, 3D models of scanned objects can be produced. Both manual and automatic creation of 3D printed models is very difficult for average consumers. As a result, several markets placed most popular are shapeways; thingverse, my mini factory and threading have been emerged over the last few years among world. There is several 3D modelling software's such as Google Sketch up, 3D crafter, Blender, etc.

The next step is to convert it into STL file. But before conversion it must be processed by piece of software called as 'Slicer'. This convert 3D model into a series of thin layer and produces G-code file from STL file containing instruction to printer. There are many slicer program including Slicer, KISSIicer and Clura. The 3D printer follows the G-code to add down a layer of liquid, powder of sheet material to build a model. These layers which correspond to virtual cross-section from CAD model are focussed or joined to build a final shape of model. Its main advantage is that it can create any geometric shape model construction by existing method require several hours to days depending on the method used. But due to advanced system, it reduces time to very few hours. It depends on machine used, size and quantity of models being produced.

Although the printer-produced resolution is sufficient for many applications, printing a slightly oversized version of the object in standard resolution and then removing material as a higher resolution process can achieve greater precision. As with the Accucraft iD-20 and other machines press release. International

Manufacturing Technology shows some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts.

2.10 Different Types of 3d Printing Technologies

There are several ways of 3D printing, differing various ways the layers are built to create the final object. Few basic and common methods are illustrated as follows.

Fused Filament Fabrication/ Fused Deposition Modelling (FFF/FDM)

Stereolithography

Selective laser sintering

Digital Light Processing (DLP)

2.10.1 Fused Filament Fabrication/ Fused Deposition Modelling:

This is the most common and very low cost method of 3D printing. This method usually consists of an extruder which extrudes the raw material on to a surface whilst the extruder or the surface moving in 3 axis linear motions which are driven by the stepper or servo motors. The raw materials most commonly used in prototyping are Thermoplasts like PLA (Poly Lactic Acid), ABS (Acrylonitrile butadiene styrene) and Wood material, fluorescence filaments, T-Glass, etc. Depending upon the raw material the temperature of the extruder and the surface are defined. For the complex structures where additional supports are required, the filaments like Hips which are water soluble can be utilized. This requires post processing of removing the support material manually. Depending upon the application one can also choose the no. of extruders required so that two or more filaments can be printed in the same cycle.

2.10.2 Stereolithography (SLA):

It is also known as Photo-solidification or solid free-form fabrication. The process works by solidifying a Liquid photo-polymer resin by projecting Ultra-violet light rays into the resin while the resin container moving slowly downwards making new layers of solidified resin above each other until, the object is completely built. In comparison with Fused Filament Fabrication method, this method of 3D printing is very fast, high resolution and very expensive. This method also requires lot of Post processing like cleaning the liquid resin over the solidified one, detaching the support structures, etc.

2.10.3 Selective Laser Sintering (SLS):

Selective Laser Sintering involves the use of a high power laser to fuse small particles of plastic, metal, ceramic, or glass powders into a mass that has a desired three-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one-layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed. Unlike Fused Deposition Modelling and Stereolithography, Selective Laser Sintering doesn't require the support structures due to the fact the part is constructed surrounding with the un-sintered powder all the time.

2.10.4 Digital Light Projection (DLP):

These printers make use of liquid photopolymer resins to build objects. For each cross-sectional slice of the object, the projector projects patterned light through a reflective mirror that selectively exposes and hardens the resin. Because an entire layer is exposed with a single pattern, fast build speeds are achieved independent of layer complexity. Projection optics can also be used to control the resolution on the image plane and adjust the layer thickness, leading to smooth and accurate finished parts. In this project, the major focus is upon making a consumer based 3D printer which gives a good quality output at a very low cost. The Fused Deposition Modelling technology comprises of less expensive hardware and many open source resources which are very helpful for support and cutting the research costs. The raw materials required for Fused Filament Fabrication process are very abundant and environment friendly and recyclable. There won't be any time consuming post processing required after the object is printed unless all the user needs any customized aesthetical appearances. The power consumption in this method is very less comparably to other process. The build volume of the object can be extended easily just be adjusting improvising on the linear motions. The prints can be done at high speeds but at the compromised qualities. For a greater quality output the print has to be done at minimal speed. The software packages are readily available for the users. Most of the softwares are Open-source and are free of cost. This lessens the price of buying a license software package which could be half the price of the machine. There are also many free designs platforms which host the designs readily available for 3D printing in Fused Deposition

Modelling machines. Overall, by choosing Fused Filament Fabrication/Fused Deposition Modelling method of 3D printing will fulfil the complete essential and crucial aspects of the project.

2.11 Types of 3D Printing

Varieties of 3D printing technologies have been developed with the different function. According to ASTM Standard F2792, ASTM catalogued 3D printing technologies into seven groups, including the binding jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photopolymerization. There are no debates about which machine or technology function better because each of them has its targeted applications. Nowadays, 3D printing technologies are no longer limited to prototyping usage but are increasingly also being used for making variety of products.

2.11.1 Binder jetting

Binder jetting is a rapid prototyping and 3D printing process in which a liquid binding agent is selectively deposited to join powder particles. The binder jetting technology uses jet chemical binder onto the spread powder to form the layer. The application of the binder jetting is would be producing the casting patterns, raw sintered products or similar large-volume products from sand. Binder jetting can print a variety of materials including metals, sands, polymers, hybrid and ceramics. Some materials like sand not required additional processing. Moreover, the process of binder jetting is simple, fast and cheap as powder particles are glued together. Lastly, binder jetting also has the ability to print very large products.

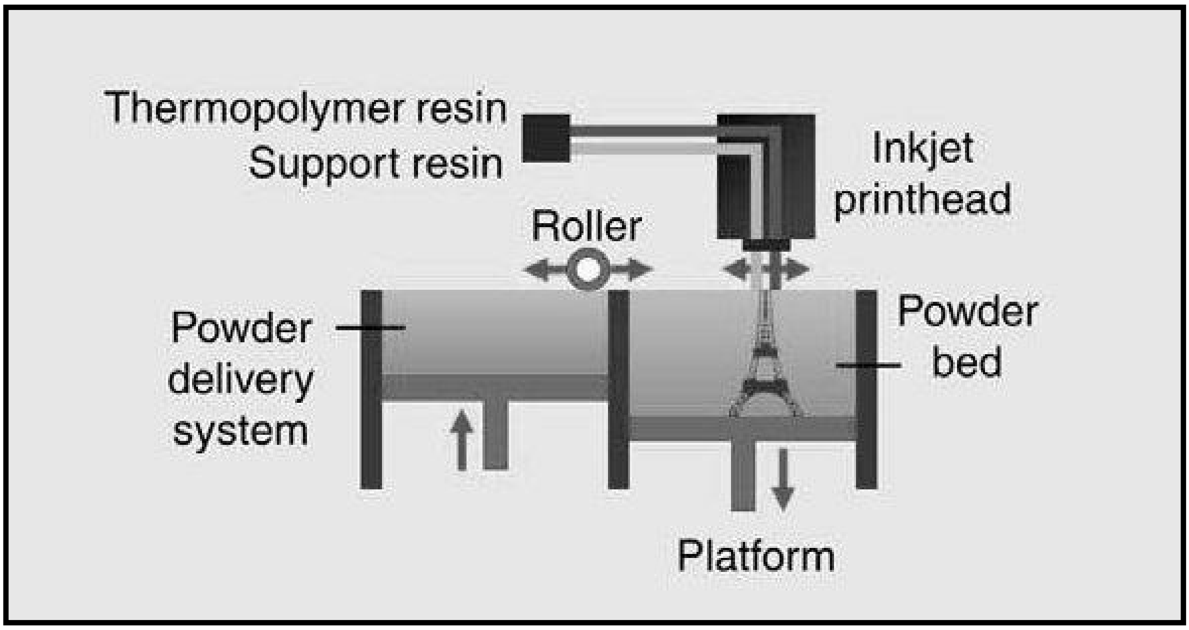

Plate 2.3 Binder Jetting (C.W. Hull, 1986)

2.11.2 Directed energy deposition

Directed energy deposition is a more complex printing process commonly used to repair or add additional material to existing components. Directed energy deposition has the high degree control of grain structure and can produce the good quality of the object. The process of directed energy deposition is similar in principle to material extrusion, but the nozzle not fixed to a specific axis and can move in multiple directions. Furthermore, the process can be used with ceramics, polymers but is typically used with metals and metal-based hybrids, in the form of either wire or powder. The example of this technology is laser deposition and laser engineered net shaping (LENS). Laser deposition is the emerging technology and can be used to produce or repair parts measured in millimeter to meters. Laser deposition technology is gaining attraction in the tooling, transportation, aerospace, and oil and gas sectors because it can provide scalability and the diverse capabilities in the single system. Meanwhile, laser engineered net shaping can exploit thermal energy for melting during the casting and parts are accomplished subsequently.

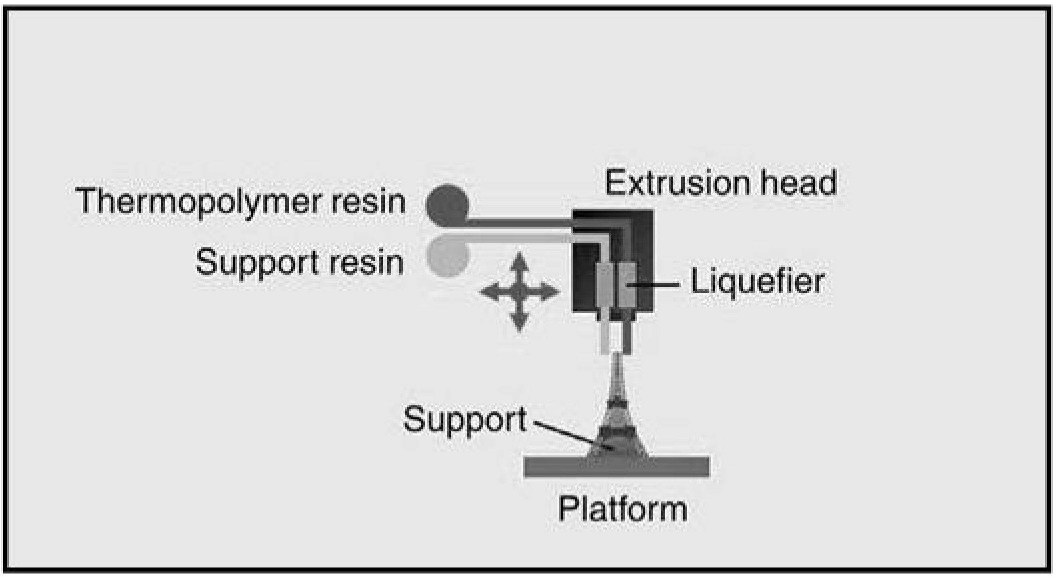

Plate 2.4 Fused Deposition Modelling (C.W. Hull, 1986)

2.11.3 Materials extrusion

Material extrusion-based 3D printing technology can be used to print multi-materials and multi-colour printing of plastics, food or living cells. This process has been widely used and the costs are very low. Moreover, this process can build fully functional parts of product. Fused deposition modelling (FDM) is the first example of a material extrusion system. Fused Deposition Modelling was developed in early 1990 and this method uses polymer as the main material. Fused Deposition Modelling builds parts layer-by-layer from the bottom to the top by heating and extruding thermoplastic filament. The operations of Fused Deposition Modelling are as follows:

I. Thermoplastic heated to a semi-liquid state and deposits it in ultra-fine beads along the extrusion path.
II. Where support or buffering needed, the 3D printer deposits a removable material that acts as

scaffolding. For example, Fused Deposition Modelling uses hard plastic material during the process to produce 3D bone model.

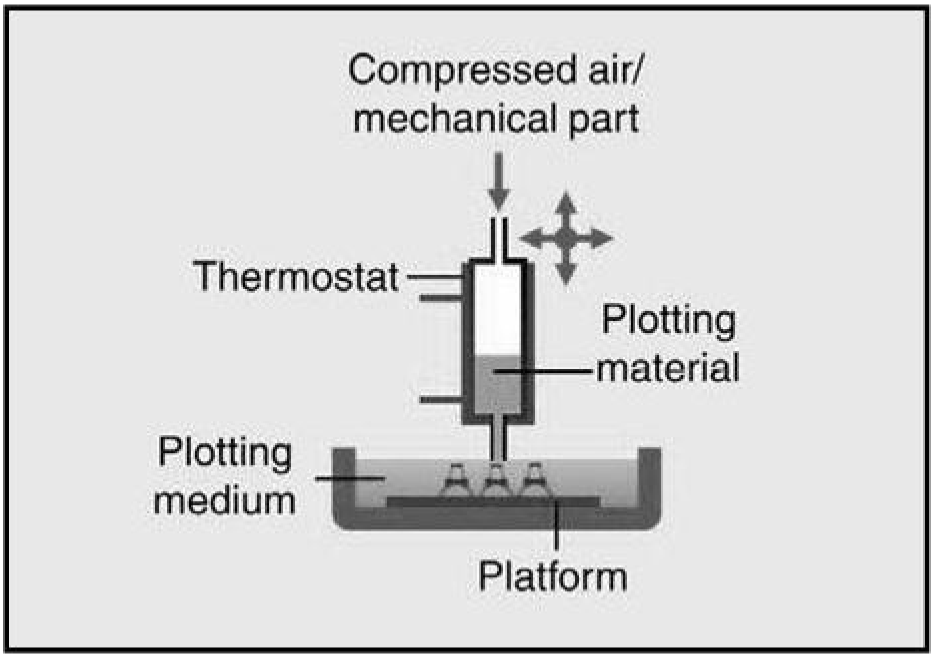

Plate 2.5 Direct Writing Assembly (C.W. Hull, 1986)

2.11.4 Materials jetting

According to ASTM Standards, material jetting is a 3D printing process in which drop by drop of build material are selectively deposited. In material jetting, a printhead dispenses droplets of a photosensitive material that solidifies, building a part layer-by-layer under ultraviolet (UV) light. At the same time, material jetting creates parts with a very smooth surface finish and high dimensional accuracy. Multi-material printing and a wide range of materials such as polymers, ceramics, composite, biologicals and hybrid are available in material jetting.

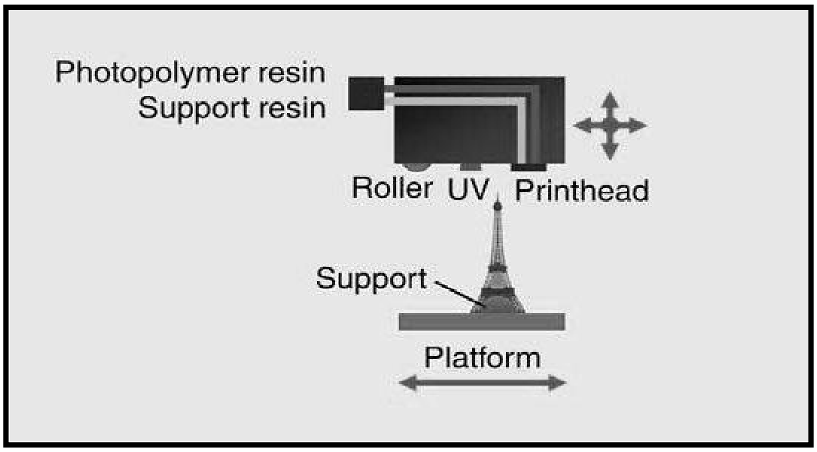

Plate 2.6 Material Jetting (C.W. Hull, 1986)

2.11.5 Powder bed fusion

The powder bed fusion process includes the electron beam melting (EBM), selective laser sintering (SLS) and selective heat sintering (SHS) printing technique. This method uses either an electron beam or laser to melt or fuse the material powder together. The example of the materials used in this process are metals, ceramics, polymers, composite and hybrid. Selective laser sintering (SLS) are the main example of powder based 3D printing technology. Carl Deckard developed selective laser sintering technology in 1987. Selective laser sintering is 3D printing technology that's functionally in fast speed, has high accuracy, and varies surface finish. Selective laser sintering can be used to create metal, plastic, and ceramic objects. Selective laser sintering used a high power laser to sinter polymer powders to generate a 3D product. Meanwhile, selective heat sintering technology is another part of 3D Printing technology uses a head thermal print in the process to melt the thermoplastic powder to create 3D printed object. Lastly electron beam melting enhances an energy source to heat up the material.

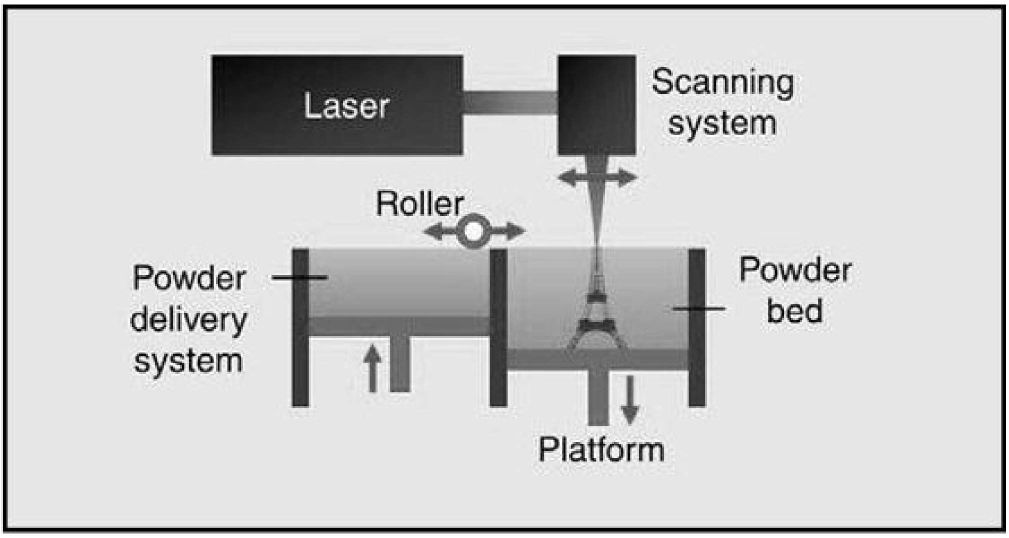

Plate 2.7 Selective Laser Sintering (C.W. Hull, 1986)

2.11.6 Sheet lamination

According to ASTM definition, sheet lamination is the 3D printing process in which sheet of materials are bond together to produce a part of object. The example of 3D printing technology that uses this process are laminated object manufacturing (LOM) and ultrasound additive manufacturing (UAM). The advantages of this process are sheet lamination can do full-colour prints, it relatively inexpensive, easy of material handling and excess material can be recycled. Laminated object manufacturing (LOM) is capable to manufacture complicated geometrical parts with lower cost of fabrication and less operational time. Ultrasound additive manufacturing (UAM) is an innovative process technology that uses sound to merge layers of metal drawn from featureless foil stock.

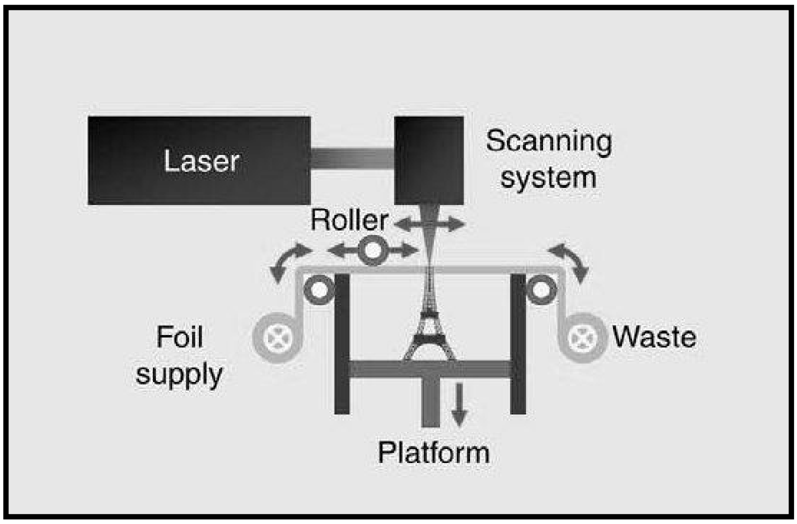

Plate 2.8 Laminated Object Manufacturing (C.W. Hull, 1986)

2.11.7 Vat Photopolymerization

The main 3D printing technique that frequently used is photopolymerization, which in general refers to the curing of photo-reactive polymers by using a laser, light or ultraviolet (UV). The example of 3D printing technologies by using photopolymerization is stereolithography (SLA) and digital light processing (DLP). In the stereolithography, it was influenced by the photo initiator and the irradiate exposure particular conditions as well as any dyes, pigments, or other added UV absorbers. Meanwhile, digital light processing is a similar process to Stereolithography that works with photopolymers. Light source is the major difference. Digital Light Process uses a more conventional light source, such as an arc lamp with a liquid crystal display panel. It can apply to the whole surface of the vat of photopolymer resin in a single pass, generally making it faster than Stereolithography. The important parameters of Vat Photopolymerization are the time of exposure, wavelength, and the amount of power supply. The materials used initially are liquid and it will harden when the liquid exposed to ultraviolet light. Photopolymerization is suitable for making a premium product with the good details and a high quality of surface.

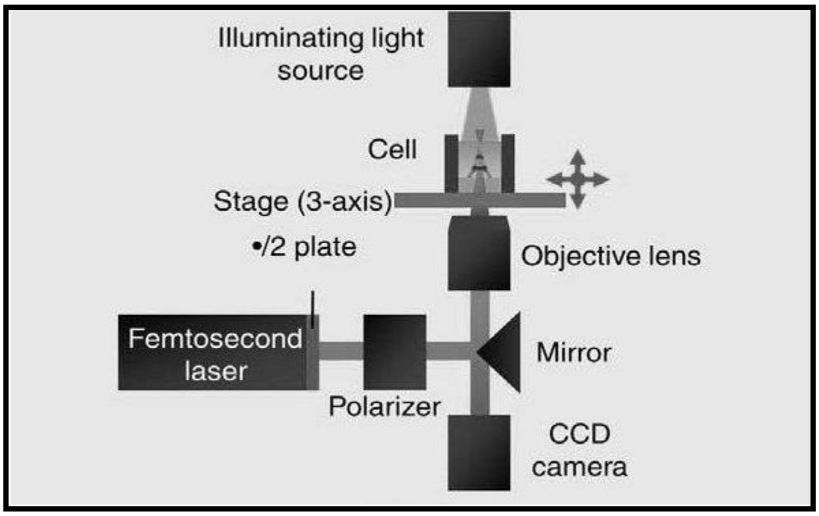

Plate 2.9 Two photon Polymerization (C.W. Hull, 1986)

2.12 Motion Configuration in 3D Printers

2.12.1 Cartesian configuration

Cartesian 3D printers are pretty much named after the coordinate system the X Y and Z axis which is used to determine where and how to move in three dimensions and the Cartesian 3D printers which have a heated bed which moves only in the Z axis. The extruder sits on the X-axis and Y-axis, where it can move in four directions on a gantry. This is the principle which can be seen in action on the models from Ultimaker and MakerBot. With the Printrbot Simple instead of moving the print head purely in XY space, one of the axes are changed by moving the print bed itself. This is a very easy and simple design, and therefore it will be easier to maintain, but at the sacrifice of printing speed

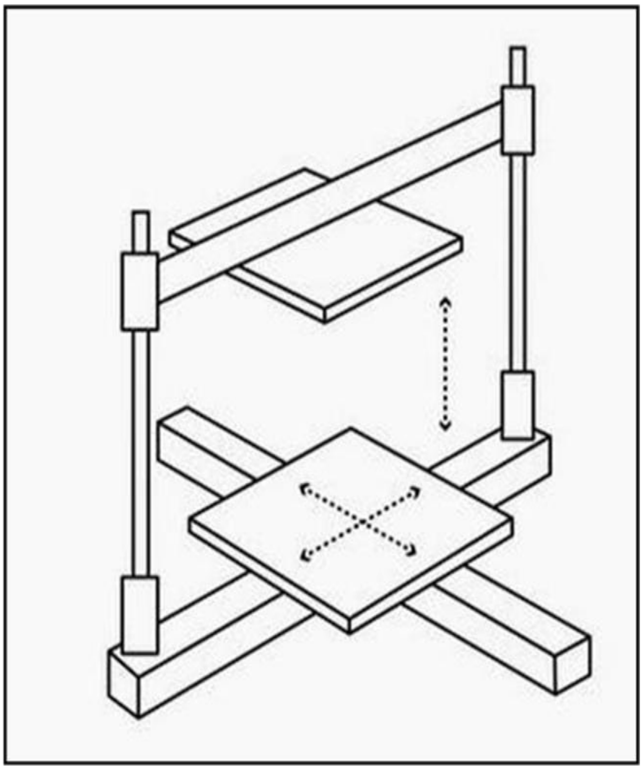

Plate 2.10 Cartesian Configuration (C.W. Hull, 1986)

2.12.2 Delta Configuration

Delta 3d printers feature a circular print bed. The extruder will be suspended above that by three arms in a triangular configuration thus the name “Delta” (Plate 2.15). These nifty robots were designed for speed and they also have the advantage of a print bed that does not move which could be advantageous for certain prints. The benefits which are obtained from the Delta configuration is that when the moving parts are lightweight it will be easier to travel. That results in faster printing with greater accuracy. Most "traditional" printers have a moving build platform. This means that the object you are printing is always moving which can lead to prints coming loose due to the constant jerks and to inaccurate prints especially when the prints get higher. Delta configuration are much better in building higher objects like a vase because the platform is fixed. They tend to be higher anyway which creates a bigger build volume. Because of the way they are build it is also fairly easy to make them bigger (not in width but certainly in height). When the overall construction is much less complicated and uses very less parts which will be reducing the maintenance and costs. Because of the arm construction it must be a lot taller than your build volume.

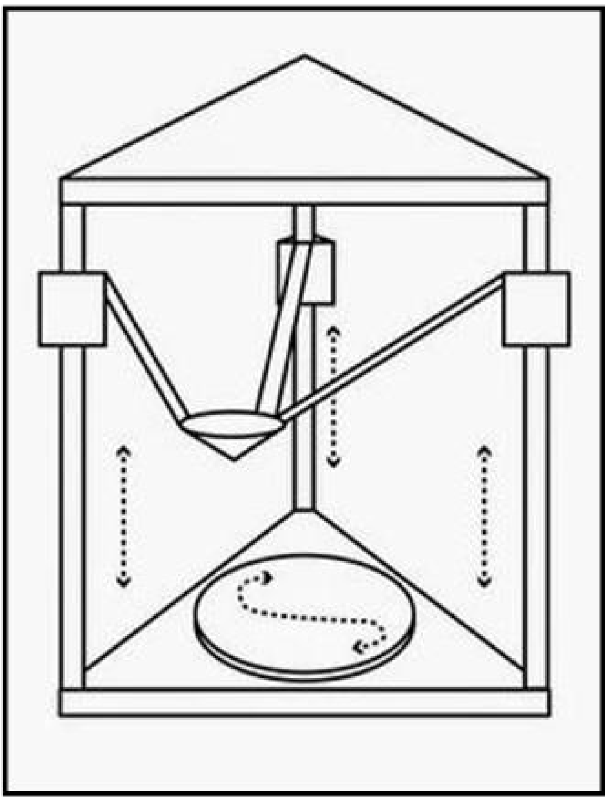

Plate 2.11 Delta Configuration (C.W. Hull, 1986)

2.12.3 SCARA configuration

Selective Compliance Assembly Robotic Arm abbreviated as SCARA type robotic system has three degrees of freedom and it is actuated by three servo motors to do one vertical and two horizontal motions. Feeding system for 3D printing is placed to back of robot and it is extended at the end of the robotic arm.

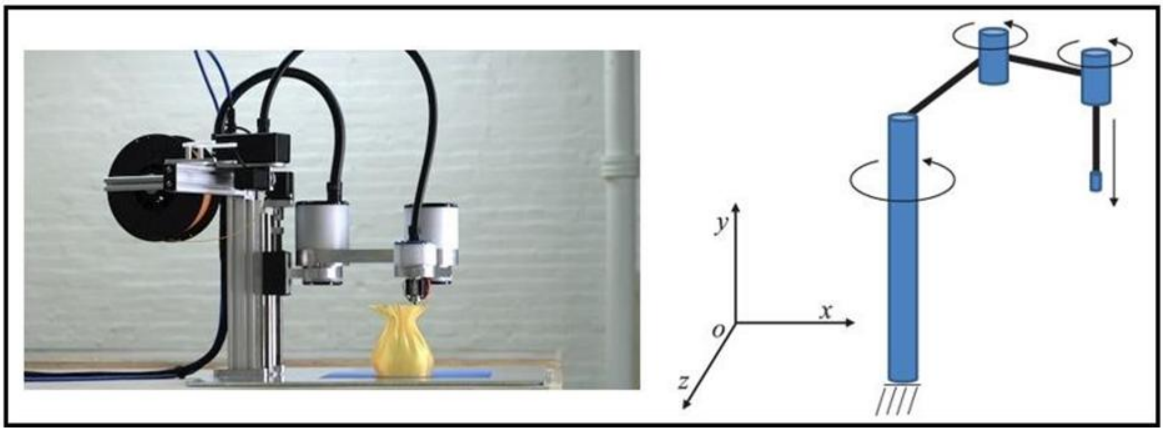

Plate 2.12 SCARA Configuration (C.W. Hull, 1986)

2.12.4 Polar configuration

This category uses a polar coordinate system. It is pretty much similar to that of Cartesian configuration except that the coordinate sets describe points on a circular grid rather than a square. All of which means that you can have a printer with a spinning bed, plus a print head that can move up and down. The biggest advantage of a polar configuration 3D printer is that the printer can easily function with only two stepper motors

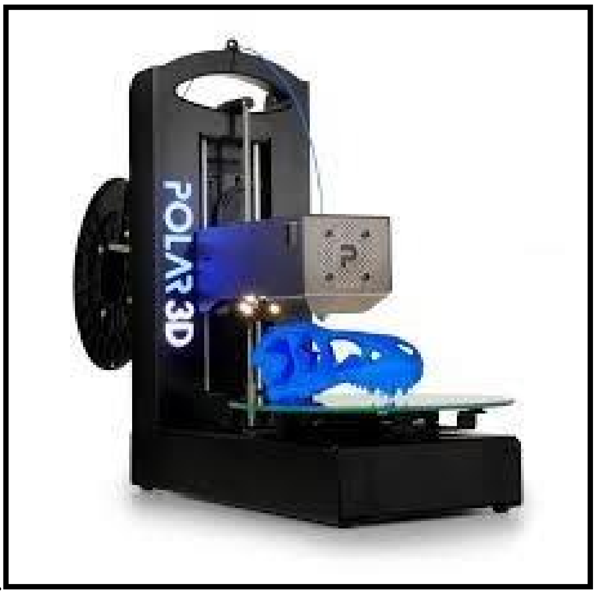

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Plate 2.13 Polar Configuration (C.W. Hull, 1986)

2.13 Materials Used for 3D Printing Technology in Manufacturing Industry

Like any manufacturing process, 3D printing needs high quality materials that meet consistent specifications to build consistent high-quality devices. To ensure this, procedures, requirements, and agreements of material controls are established between the suppliers, purchasers, and end-users of the material. 3D printing technology is capable to produce fully functional parts in a wide range of materials including ceramic, metallic, polymers and their combinations in form of hybrid, composites or functionally graded materials (FGMs).

2.13.1 Metals

Metal 3D printing technology gain many attentions in aerospace, automobile, medical application and manufacturing industry because the advantages existing by this process. The materials of metal have the excellent physical properties and this material can be used to complex manufacturer from printing human organs to aerospace parts. The examples of this materials are aluminium alloys, cobalt-based alloys, nickel-based alloys, stainless steels, and titanium alloys. Cobalt-based alloy is suitable to use in the 3D printed dental application. This is because, it has high specific stiffness, resilience, high recovery capacity, elongation and heat-treated conditions. Furthermore, 3D printing technology has capability to produce aerospace parts by using nickel base alloys. 3D-printed object produces using nickel base alloys can be used in dangerous environments. This is because, it has high corrosion resistance and the heat temperature can resistant up to 1200 °C. Lastly, 3D printing technology also can print out the object by using titanium alloys. Titanium alloy with have very exclusive properties, such as ductility, good corrosion, oxidation resistance and low density. It is used in high stresses and high operating temperatures and high stresses, for example in aerospace components and biomedical industry.

2.13.2 Polymers

3D printing technologies are widely used for the production of polymer components from prototypes to functional structures with difficult geometries. By using fused deposition modelling (FDM), it can form a 3D printed through the deposition of successive layers of extruded thermoplastic filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polypropylene (PP) or polyethylene (PE). Lately, thermoplastics filaments with higher melting temperatures can already be used as materials for 3D printing technology. 3D printing polymer materials in liquid state or with low melting point are widely used in 3D printing industry due to their low cost, low weight and processing flexibility. Mostly, the materials of polymers played important role in biomaterials and medical device products often as inert materials, by contributing to the efficient functioning of the devices as well as providing mechanical support in many orthopaedic implants.

2.13.3 Ceramics

Nowadays, 3D printing technology can produce 3D printed object by using ceramics and concrete without large pores or any cracks through optimization of the parameters and setup the good mechanical properties. Ceramic is strong, durable and fire resistant. Due to its fluid state before setting, ceramics can be applied in practically any geometry and shape and very suitable on the creation of future construction and building. Ceramics materials is useful in the dental and aerospace application. The examples of this materials are alumina, bioactive glasses and zirconia. Alumina powder for instance has the potential to be processes by 3D Printing technology. Alumina is an excellent ceramic oxide with a very wide range of applications, including catalyst, adsorbents, microelectronics, chemicals, aerospace industry and another high-technology industry. Alumina has great curing complexity. By using 3D printing technology, complex-shaped alumina parts with has a high density after sintering and also has high green density can be printed. Furthermore, in successive experiment, Stereolithographic (SLA) machine was used to process glass-ceramic and bioactive glass into dance part. It significantly improving the bending strength of this materials. The increasing of the mechanical strength will open up the potential for apply bioactive glass in relevant clinical structure such as scaffolds and bone. By using Stereolithographic Ceramic Manufacturing (SLCM), it is probable to produce solid bulk ceramics with high densities, very homogeneous microstructure, high compression strength and bending. Meanwhile, zirconia are the main construction materials in nuclear power sectors, using for element tubing. Hafnium-free zirconium is very suitable for this application because it has low susceptibility to radiation and also has low thermal neutron absorption.

2.13.4 Composites

Composite materials with the exceptional versatility, low weight, and tailorable properties have been revolutionizing high-performance industries. The examples of composite materials are carbon fibers reinforced polymer composites and glass fibers reinforced polymer composite. Carbon fiber reinforced polymers composite structures are widely used in aerospace industry because of their high specific stiffness, strength, good corrosion resistance and good fatigue performance. At the same time, glass fibers reinforced polymer composites are widely used for various applications in 3D printing application and has great potential applications due to the cost effectiveness and high-performance. Fiberglass have a high thermal conductivity and relatively low coefficient of thermal expansion. Furthermore, fiberglass cannot burn, and it not affected by curing temperatures used in manufacturing processes, therefore, it is very suitable for use in the 3D printing applicant.

2.13.5 Smart materials

Smart materials are defined as this material have the potential to alter the geometry and shape of object, influence by external condition such as heat and water. The example of 3D printed object produces by using smart materials are self-evolving structure and soft robotics system. Smart materials also can be classified as 4D printing materials. The examples of group smart materials are shape memory alloys and shape memory polymers. Some shape-memory alloys like nickel-titanium can be used in biomedical implants to microelectromechanical devices application. In the production of 3D printed products by using nickel-titanium, transformation temperatures, reproducibility of microstructure and density is the important issue. Meanwhile, Shape memory polymer (SMP) is a kind of functional material that responds to a stimulus like light, electricity heat, some types of chemical and so on. By using 3D printing technology, the complicated shape of shape memory polymer could be easily and conveniently to produce. The quality evaluation of this material is performed based on the dimensional accuracy, surface roughness and part density.

2.13.6 Specials materials

The examples of special materials are:

• Food 3D printing technology can process and produce the desired shape and geometry by using food materials like the chocolate, meat, candy, pizza, spaghetti, sauce and so on. 3D-food printing can produce healthy food because this process allows customers to adjust the ingredients of materials without reducing the nutrients and taste of the ingredients.

• Lumar dust 3D printing process has the capability to directly produce multi-layered parts out of lunar dust, which has potential applicability to future moon colonization.

• Textile with 3D printing technology, jewellery and clothing industry will be shine with the development on 3D textile printing. Some advantage of 3D printing technology in fashion industry are short processing time to make the product, reduced costs related with the packaging and reduce supply chain cost.

2.14 Softwares for 3D Printing

Design softwares:

✦ 123D Design

✦ Sketchup

✦ Sweet home 3D

✦ Meshmixer

✦ Style builder

Sampling softwares:

✦ Cura

✦ MakerBot

✦ Meshmixer

3D Scanning softwares:

✦ Skanect

✦ MakerWare for Digitzer

There are tons of softwares in the internet related to 3D printing, handpicked some of the best ones. Beginning with 123D design, Sketchup for designing, lots of tutorials are available in the internet which will helpful to get started within few hours of trying out those. Sweet home 3D is very user friendly, building your dream home with that software can be done at ease. 3D scanning softwares are very interesting to try out. A 3D scanner is required which is pretty expensive but still with household scanners like Kinect from X-Box 360 one, one can scan any object or even your own face and 3D print it. For Kinect using Skanect the objects can be 3D scanned and saved into different file formats. Once the 3D model is ready the next software which is required will be any slicing softwares like Cura. Slicing softwares (Pronterface or Cura), act as an interface between your 3D printer and your computer. They convert your 3D designs into a 3D readable format by slicing it layer by layer. The settings in these softwares will also impact on the final quality of your 3D printed object.

2.15 Industrial 3D Printing

The development of 3D printing systems for large-scale industrial applications follows familiar patterns in the manufacturing and related industries. Early inventions concerning 3D printing technologies came from individuals who subsequently created companies to commercialize their inventions, some of them more successfully than others. Currently, about 34 manufacturers produce and sell industrial 3D printing systems. Eighteen of these companies are located in Europe, seven in China, six in the U.S. and two in Japan. Nine of them sold more than 100 systems in 2013 (Wohlers Associates 2014). This also indicates that a large proportion of 3D printing companies in many countries are small or medium size enterprises. The 3D printing industry is a research-intensive industry. A survey among 3D printing system manufacturers revealed that average R&D spending was 19.1 % of 2013 revenues (Wohlers Associates 2014). The market is dominated by two large system manufacturers: Stratasys (based in Israel and the U.S.) and 3D Systems (based in the U.S.). Other important players include Beijing Tiertime (based in China), EOS and Envisiontec (both based in Germany). The industry has seen a certain degree of consolidation, exemplified by larger acquisitions (e.g. the acquisition of Solidscape by Stratasys in 2011 or of Z Corporation by 3D Systems in 2012).

As the 3D printing industry matured and diversified, standardization of terms, processes, interfaces and manufacturing technologies have become an important issue. The ASTM International Committee F42 on Additive Manufacturing Technologies was formed in January 2009 to address these challenges. It aims at developing consensus standards, thereby facilitating the adoption of 3D printing technologies into various industry sectors. Up to the present day, the committee has finished or is working on numerous standards for testing and evaluation, terminology, and properties of raw materials and processes used in 3D printing. In 2011, ASTM International also adopted a novel standard file format for transferring information between design programs and 3D printing systems. While the de facto industry standard STL, which has been in use since the 1980s, only enables the representation of information about a surface mesh, the new XML-based file format can also represent information about color, texture, material, substructure and other properties of an object. Participation in the standard setting body is voluntary, and non-members are able to interact with the standardization committee (Lipson and Kurman 2013). Standards are adopted by consensus, but voting privileges are limited to members. Some of ASTM's standards have been developed as joint standards together with the ISO Technical Committee 261 on Additive Manufacturing.

Standardization efforts are not restricted to the United States. In the European Union, the "Support Action for Standardization in Additive Manufacturing" was a project sponsored by the European Commission under its Seventh Framework Program from 2012 to 2014 to coordinate 3D printing standardization activities in Europe. The evolvement of 3D printing technologies has also had an impact on patent classifications. The U.S. Patent and Trademark Office has organized two additive manufacturing summits since 2012, bringing together interested parties from industry, academia and the patent world. In addition, the Cooperative Patent Classification, developed by the European Patent Office and the U.S. Patent and Trademark Office, now includes a special subclass for additive manufacturing and 3D printing in its patent classification (B33Y). This should make it easier to classify this technology in patent applications and to search for prior art in the future.

Funding for 3D printing companies and R&D activities comes from a variety of sources. Venture capital plays a certain role. Both manufacturers of 3D printing equipment and service providers have been successful in raising venture capital. Governments also provide significant funding for 3D printing technologies through various sources. Apart from general research channeled through national science foundations in various countries and the European Union's Seventh Framework Program, targeted government funding goes into 3D printing projects related to energy, military applications and outer space. The U.S. Department of Defense, for example, has been an active supporter of 3D printing research, as have been the U.S. National Laboratories (Wohlers Associates 2014). The U.S. Department of Energy's Advanced Research Project Agency-Energy (ARPA-E) has recently funded a project to produce a 30 kW induction motor using only 3D printing technologies. NASA is investigating the use of 3D printing technologies for the production of replacement parts in outer space missions, and the NASA Langley Research Center has been leading a U.S. government interagency 3D printing working group since 2010 (Wohlers Associates 2014).

3D printing is also increasingly the object of large-scale government initiatives. In 2012, for example, the U.S. government proposed a "National Network for Manufacturing Innovation" (NNMI). One of these institutes, "America Makes," focuses on 3D printing technologies. Its goal is to facilitate collaboration among the corporate and academic sector, as well as government agencies, to bring 3D printing technologies into mainstream manufacturing (http://americamakes.us). The institute is a public-private partnership, combining 50 companies, 28 universities and research labs, and 16 other organizations, and has been supported by the U.S. government with $ 50 million (Bechthold, Fischer et al. 2015). The European Union has funded 3D printing research with a total budget of € 225 million in its 7th Framework Program (2007-2013) and remains an active supporter in the follow-up "Horizon 2020" program (European Commission 2014). The German government granted about € 21 million in research funding for 3D printing between 2003 and 2013 (Bechthold, Fischer et al. 2015). China has reportedly made heavy strategic investments in 3D printing technologies. In China, government-funded activities are relatively more important than company-driven research and development (Expertenkommission Forschung und Innovation 2015).

3D printing is also an active area of research at many universities worldwide (Wohlers Associates 2014). Some universities, in particular MIT and the University of Texas, own considerable patent portfolios on 3D printing technology. As in other technology areas, 3D printing research and development has taken place both in companies and at universities. Nevertheless, with perhaps the exception of MIT and the licensing of its 3D printing patents, many commercially viable 3D printing patents seem to have emerged from the commercial sector. Key engineering personnel of important 3D printer manufacturers filed many of the early 3D printing patents, and 3D printing manufacturers are investing substantial amounts in their R&D activities. In the future, basic science research that is most relevant to 3D printing may occur in the development of new or refined 3D printing processes, or in the development of new raw materials for printing.

Looking at the development of 3D printing technologies in the commercial sector, it is interesting that many of the technological breakthroughs were achieved by start-up companies, rather than large established printing or engineering companies. Hewlett Packard entered into a short-lived agreement with Stratasys in 2010, according to which Stratasys would manufacture HP-branded 3D printers. The agreement was dissolved in 2012 (Wohlers Associates 2014). In late 2014, HP announced it would enter the industrial 3D printing market in 2016. Regardless of HP's technology and marketing capabilities, the company which once dominated the printer market is a latecomer to the 3D printing market. Similarly, the German Trumpf Group, a world leader in sheet metal fabrication machinery and industrial lasers, became active in 3D printing technologies in 2000, but stopped its activities a few years later. In 2014, the company re-entered the market by creating a joint venture with an Italian producer of high-precision laser machinery (Expertenkommission Forschung und Innovation 2015).

These two examples may echo a general observation that, in many industries, real breakthroughs often come from new entrants into the industry, rather than industry incumbents. For new entrants, patent protection may play an important role in order to protect themselves against industry incumbents and to signal to potential investors that they have a sound technology base to offer (Long 2006).

2.16 Personal 3D Printing

In addition to the industrial 3D printing sector, a vibrant market for 3D printing systems and services which are targeted towards the end consumer has developed over the last few years. This has led to an innovation ecosystem of its own. It consists of open source enthusiasts, hardware manufacturers, software programmers, service providers, novel funding methods and user innovators. Many of the personal 3D printers have their origins in the RepRap project. RepRap was started by Adrian Bowyer at the University of Bath as an open source project in 2005. The goal was to create a 3D printer which could replicate itself. All of the designs of the project have been released under the GNU General Public License (GPL). The project relies on about 25 core contributors and a large support community, which consists of enthusiasts, early adopters of emerging technologies, hackers and academic researchers (Jones, Haufe et al. 2011). For intellectual property scholars, RepRap is an interesting example illustrating that the open source idea may not only work for computer software, but also for the creation of physical products.

Personal 3D printers include RepRap and its derivatives, as well as printers sold by MakerBot, Delta Micro Factory, 3D Systems and many other companies. While some manufacturers operate both in the industrial and the personal 3D printing sector (e.g. 3D Systems), others focus only on the consumer market. Another open-source 3D printer project, Fab@Home, has developed a multi-material 3D printer which can print anything from chemical reactants to silicone sealant and chocolate.

Many members of the personal 3D printing movement are members of the RepRap community and embrace values of the open source community. This has also facilitated the creation of specialized 3D printing software programs, which are either licensed under open source licenses or under proprietary copyright licenses, but are provided for free. Open source slicer programs, such as Slic3R and Cura, convert STL descriptions of an object into so-called “G-code” file instructions tailored to specific 3D printers. They are often included in 3D printing clients such as Repetier-Host. Autodesk also offers various free 3D printing design software programs.

The emergence of the open source 3D printing community raises the question for intellectual property scholars why developers decide to invest considerable time, money and effort in creating open source 3D printers, without the ability to recoup their investment through the intellectual property system. The motivations of open source 3D printer developers may be similar to developers of other open source products (Lerner and Tirole 2002). In particular, personal needs, intrinsic motivation and reputational goals may be important driving factors for developers of open source 3D printer hard- and software (Jong and Bruijn 2013). In addition to open source hardware and software, the personal 3D printing market is characterized by specialized service providers which allow users to share 3D design files and/or use centralized 3D printing services to print 3D objects and have them shipped to the user. Companies such as Ponoko, Sculpteo and Shapeways operate marketplaces where producers of 3D objects can sell their models to consumers. The consumer can then either print the physical object at home or have it printed by the marketplace. The marketplace Shapeways, for example, was founded in 2008 as a spin-off from Royal Philips Electronics. The company operates a large 3D printing facility in Long Island City, NY. It shipped one million 3D-printed parts in 2012 (McKinsey Global Institute 2013). In 2014, the company featured nearly 500,000 3D objects, and 23,000 shop owners and products designers from 133 different countries.

Other platforms focus on the sharing of 3D design files. The platform Thingiverse, which is operated by MakerBot, for example, allows the uploading and sharing of user-created digital design files. It now features over 400,000 design files and is widely used by the RepRap and related communities. Empirical research is starting to explore user behavior on such platforms (Moilanen, Daly et al. 2015; Mendis and Secchi 2015). Furthermore, established companies from related industries are exploring entering the market for personal 3D printing services. Companies such as Office Depot, Staples and UPS are currently offering 3D printing services on a trial basis in a select number of their stores. In addition to novel service providers, the personal 3D printing community also benefits from novel funding mechanisms. Various personal 3D printing projects have benefited from crowdfunding platforms, such as Kickstarter. M3D raised $3.4 million, Formlabs $2.9 million and WobbleWorks $2.3 million on Kickstarter for 3D printing-related projects (Wikipedia 2015). Some of the crowdfunded projects may have proven popular on Kickstarter because of the media hype surrounding personal 3D printing technologies. But they also demonstrate the ability of this community to raise funds in novel ways.

Most importantly, the personal 3D printing market is characterized by many "user innovators" who are not mere consumers of a product, but who like to tinker with it. They may, thereby, explore new usage scenarios for 3D printers. As many of the personal 3D printers are based on open source software and hardware, sophisticated users are able to alter and improve upon existing hardware and software designs. In the personal 3D printing market, a particular interaction between companies and user innovators blurs the boundaries between producers/innovators and consumers ("maker movement") (Lipson and Kurman

2013; Bechthold, Fischer et al. 2015, Pearce 2012). The personal 3D printing market is, therefore, an example of a market in which user innovation plays an important role (Hippel 2005). It could lead to a world in which products are designed and produced based on commons-based peer-production models (Benkler 2002; Kostakis and Papachristou 2014).

2.17 Steps of 3D Printing

To develop a project via 3D printing, you need to perform the following steps (AZEVEDO, 2013; OLIVEIRA, 2016):

• Develop a project of the desired object in 3D CAD software, such as SolidWorks, Inventor, AutoCAD, among others;

• Convert the project to STL (Standard Tecelation Language) format. This format describes surfaces of an object through a set of triangles of different dimensions. The more triangles there are, the greater the project accuracy;

• The next step is to choose a reference plane from the STL file, and so the object will be divided into layers parallel to the chosen reference plane. The smaller the size of the layer, the more accurate the print will be;

• Each of these layers is described by a file called GCODE. This code has the numerical commands for the manufacture of each of the layers, possessing information of temperature, trajectory, speed, positioning, among others;

• Finally, printing is done using the GCODE code, which directs the printer to obtain the desired object.

2.18 Application

2.18.1 Education

New learning material: often you must want new teaching materials but may not be able to afford to budget for them. Now their resources can be made using a 3D printer, saving money on your department budget. When we will be Printing our own learning, materials are not only cheaper but it will be almost always quicker too. Even though students are traditionally taught through books and theory, kinesthetic learners prefer to learn through using aids and materials. 3D printing which also allows you to bring any of the subject matter to life as the physical aid to engage all of your students for a very long period of time increasing that their learning and improving their problem solving and critical thinking capabilities.

2.18.2 Apparel

3D printing has spread into the world of clothing with fashion designers experimenting with 3D-printed bikinis, shoes, and dresses. When we talk about the commercial production, Nike is using 3D printing to prototype and manufacture the very same football shoe for the American football players and the company New Balance is 3D manufacturing custom fit shoes for all the athletes. 3D printing has come to the point where companies are printing consumer grade eyewear with on demand custom fit and styling (although they cannot print the lenses). On demand customization of glasses is possible with rapid prototyping.

2.18.3 Construction

With the help of 3D printers, we are able to build civil models like prototype of building or plan structures. So that the customers can easily visualized the models.

2.18.4 Dental

With the help of 3D printers, we are able to print jaws it can be a prototype or it can be a jaw bone which can be transplanted as per the needs. An 83-year-old British woman recently underwent the first-ever custom transplant of a lower jaw made by a 3D printer.

2.18.5 Medical

Medical applications for 3D printing are expanding rapidly and are expected to revolutionize health care. Medical uses for 3D printing, both actual and potential, can be organized into several broad categories, including: tissue and organ fabrication; creation of customized prosthetics, implants, and anatomical models; and pharmaceutical research regarding drug dosage forms, delivery, and discovery. The application of 3D printing in medicine can provide many benefits, including: the customization and personalization of medical products, drugs, and equipment; cost-effectiveness; increased productivity; the democratization of design and manufacturing; and enhanced collaboration. However, it should be cautioned that despite recent significant and exciting medical advances involving 3D printing, notable scientific and regulatory challenges remain and the most transformative applications for this technology will need time to evolve

2.18.6 Domestic Use

The domestic market of the 3D printing was mainly practiced by hobbyists and enthusiasts and was very little used for many of the practical household applications which are inapplicable. A working clock was made and gears were printed for home woodworking machines among other purposes. 3D printing was also used for ornamental objects. Websites associated with home 3Dprintins include coat hooks, doorknobs etc.

2.19 Advantages of 3-D Printing

Quicker and Proximity to Market. The longer the product stays in design cycle, the lesser is the profit to the company. Thus there is a requirement of fast production units which also produce tools with precise measurement. Thus 3D printers can provide such a fast rate of production to the companies.

Cost Saving efficient and Economical. 3D printer uses mostly ABS plastic as a working material which reduces the cost of production to a great extent and also saves the raw materials which would be used in traditional method.

Increased Data Security. Having a 3D printer at home removes any worry about the misuse of the confidential STL files which can then be safely sent to the vendor.

More Rigorous Product Testing. Basically 3D printers were used only for printing models of the real objects which were much stronger and do not shrink or absorb moisture.

Early Feedback identifies design flaws, defects and Discontinuities. As the output generated by the CAD software is very fast therefore it gives enough time to the user to identify any flaw if found in the design.

Early Changes Saves Money. The cost of production increases if the changes are made in the later phase of the process. Thus it is necessary to communicate and collaborate with each other to reduce the cost of production

2.20 Impact

The commercialization of 3D printing technologies has already had a considerable impact on production processes in various industries. It has enabled rapid prototyping in many industries and transformed the production of product components in some industries. Forecasts on the potential impact of 3D printing technologies in the future range from cautiously optimistic to enthusiastic. 3D printing technologies could have a profound impact not only on manufacturing processes, but also on supply and distribution chains. They will play an increasingly important role not only in rapid prototyping, but also in the production of product components and finished products (Bechthold, Fischer et al. 2015). They may enable mass-scale customization of products, reduce inventory costs and optimize product design. They could also lead to a world of decentralized manufacturing, in which objects are produced close to the customer or, in the extreme, even by the customer himself. A decentralization of the production of physical objects, coupled with the ability of customer tailored product design, could have a deep impact on traditional production channels. By disentangling design information about an object from the production of the object, 3D printing technologies share common features with other digital technologies: as the creation of information about an object is separated from the production of the object, old business models become challenged and new business models for both parts of the production process appear on the horizon

(Lemley 2015). As a result, 3D printing has the potential to disrupt traditional manufacturing and supply chains, thereby leading to innovation in business models. It could also open access to new financial resources through crowdsourcing, enable efficient targeting of niche markets and integrate consumers into the value chain (Rayna and Striukova 2014, Ghilassene 2014).

Whether forecasts on the future impact of 3D printing will materialize will, among other things, depend on whether 3D printing can overcome some of its current technical challenges. The costs of industrial 3D printers is still very high, and the suitable raw material is considerably more expensive than raw material which can be used in traditional manufacturing processes. Furthermore, 3D printing is still a slow process, often requiring many hours or days of printing to finish an object. The future impact of personal 3D printers is also hard to predict. As personal 3D printers are becoming more reliable and their design and marketing are improving considerably, they have the potential to be attractive to consumers, both as far as lifecycle costs (Wittbrodt, Glover et al. 2013) and environmental impact (Kreiger and Pearce 2013; Bechthold, Fischer et al. 2015; Lipson and Kurman) are concerned. However, it is hard to predict the impact of 3D printing on end consumer markets, as this will depend on the future ease of use, the adoption of the technology beyond enthusiasts and hacker circles, and many other business factors.

CHAPTER THREE

METHODOLOGY

3.1 Production Process in 3D Printing

Hereunder, in this chapter, all the necessary processes and steps for, starting with a digital design, obtaining a real printed piece, are going to be described. It is important to mention that there is not just a single valid process for printing three dimensional pieces. What is explained in this guide are a certain number of steps that should be adapted to the type of piece, selected technology, type of machine, and even to the used software. Furthermore, the process that is described hereunder is mostly intended for fused deposition modelling (FDM) 3D printers. In the production process for 3D printing, experience, piece features, used machine, etc. have a lot of weight. It is for sure that someone with little or without experience will 3D print a lot of piece with failures, before he finds the key. The production process, generally speaking, is the following

3.2 Installation and Setting of the software

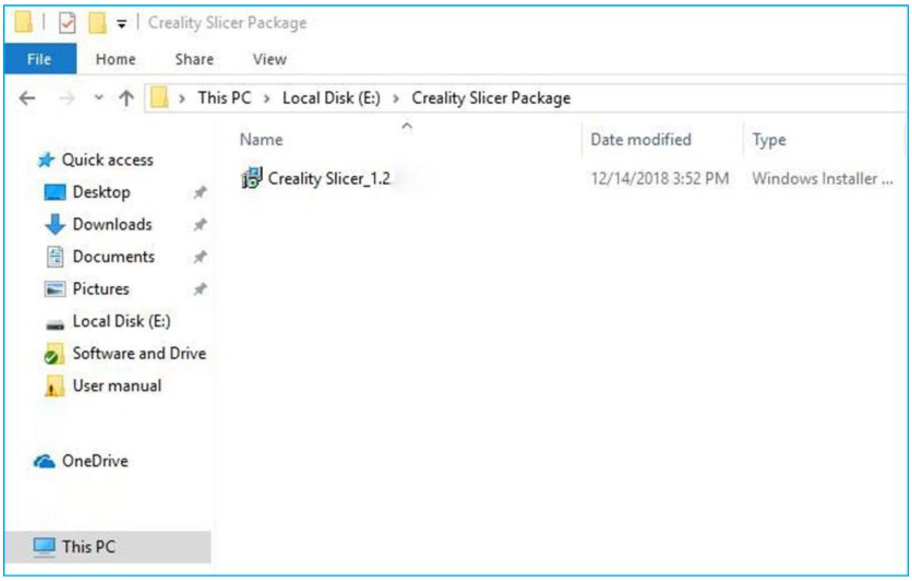

Plate 3.1 Double click Creality Slicer_1.2 (Shenzhen, 2018)

Plate 3.2 Choose “Next” to continue (Shenzhen, 2018)

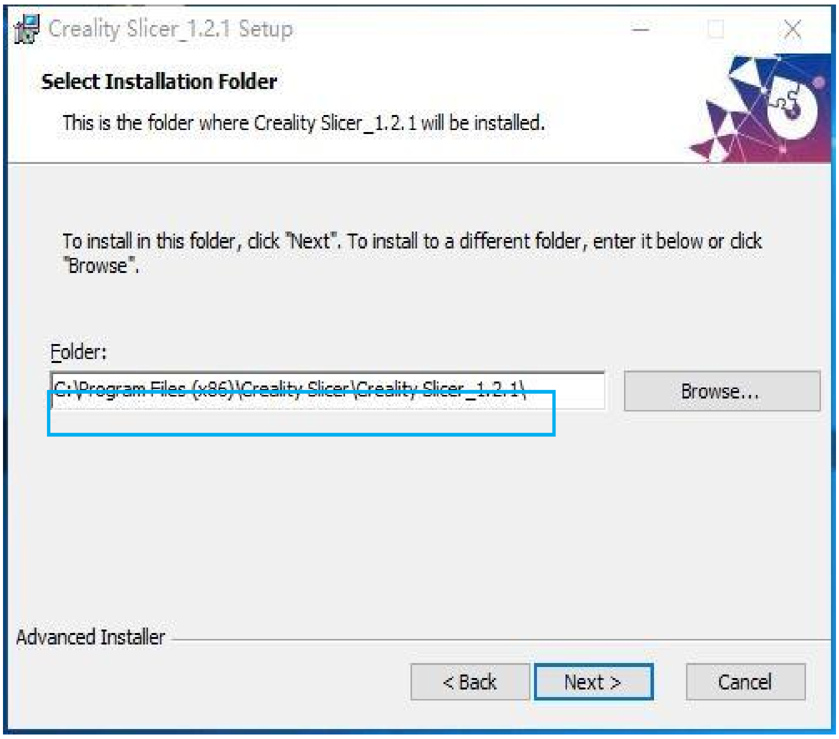

Plate 3.3 Choose the installation path, Default path（C:\Program Files(x86)\Creality Slicer) (Shenzhen, 2018)

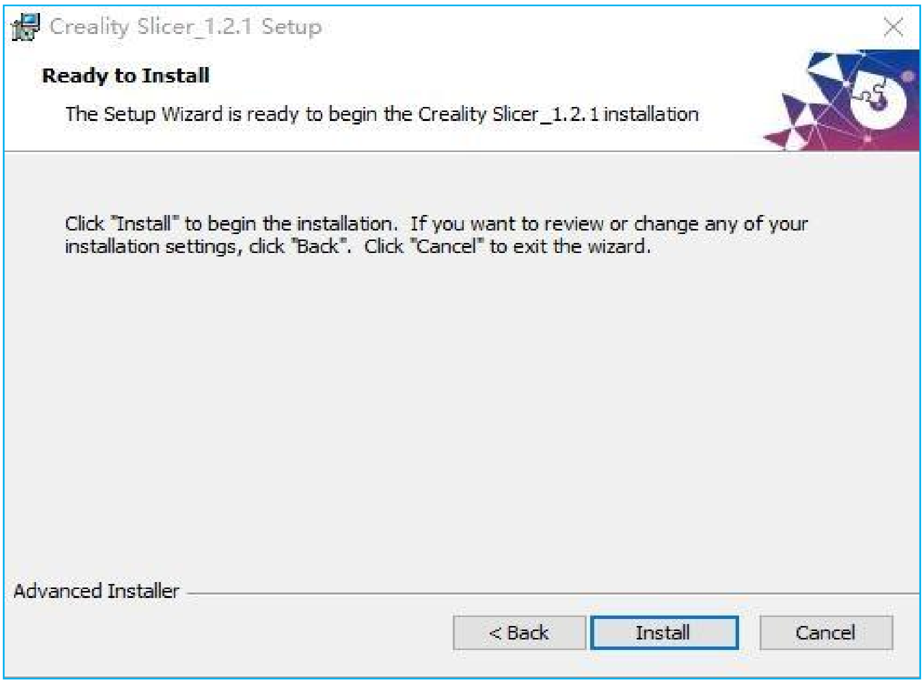

Plate 3.4 Click“Install”to install the software (Shenzhen, 2018)

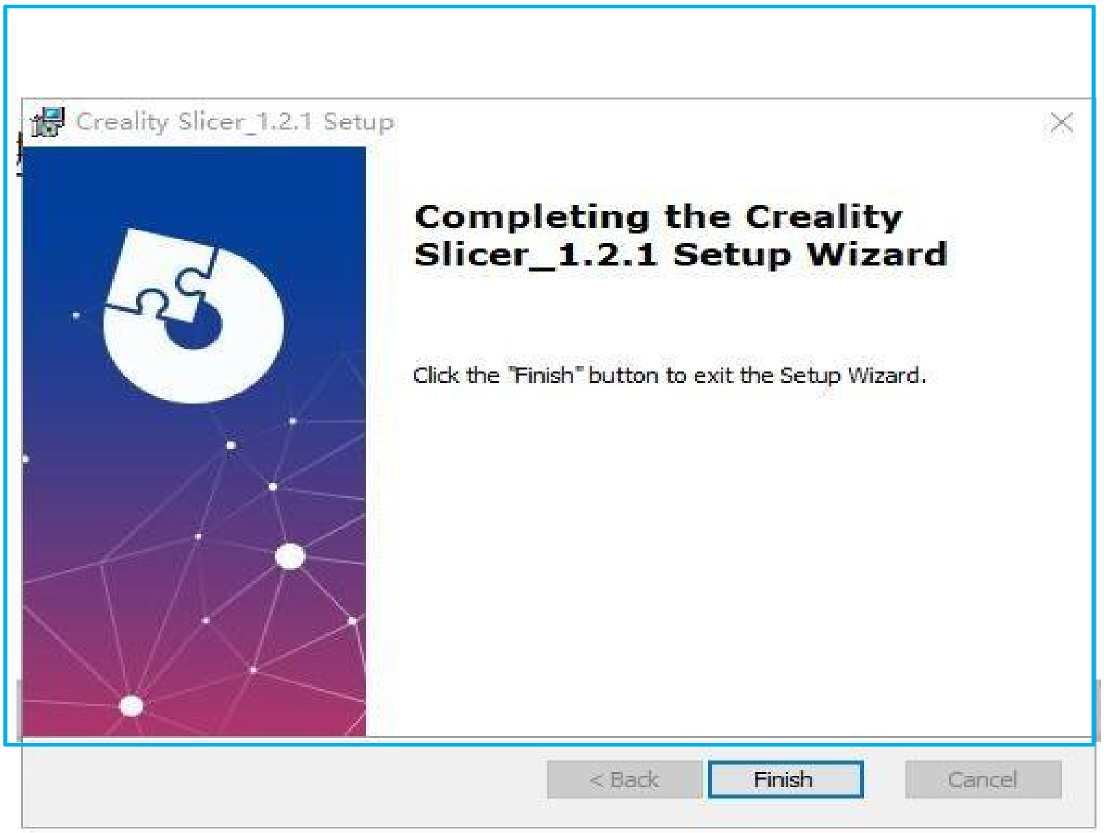

Plate 3.5 Wait some time, choose”Finish”to complete the installation (Shenzhen, 2018)

3.3 Choosing Language and Printers Model

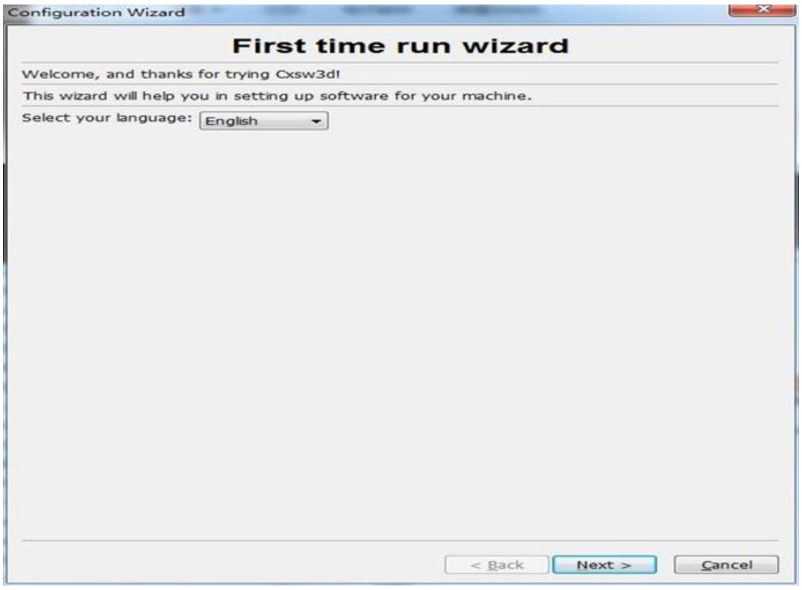

Plate 3.6 Select Language→Next (Shenzhen, 2018)

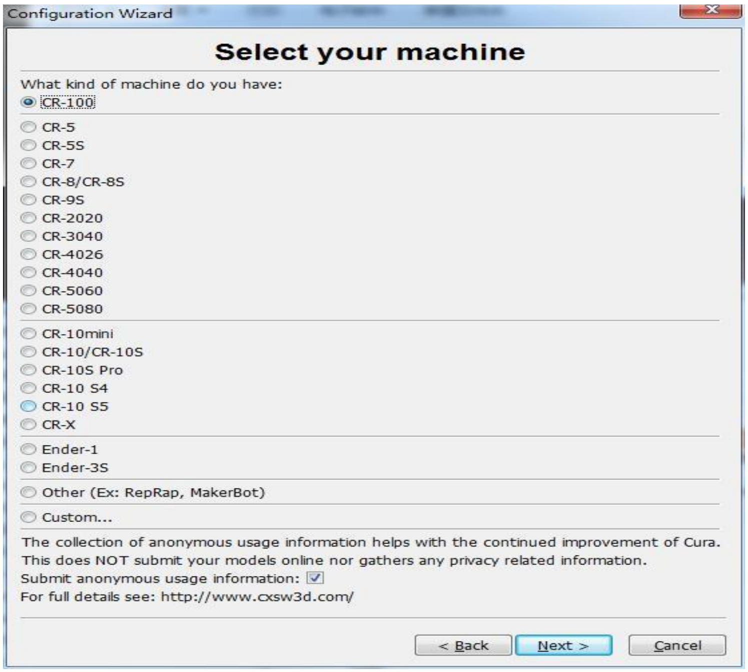

Plate 3.7 Choose Printer model name (you ordered) →Next (Shenzhen, 2018)

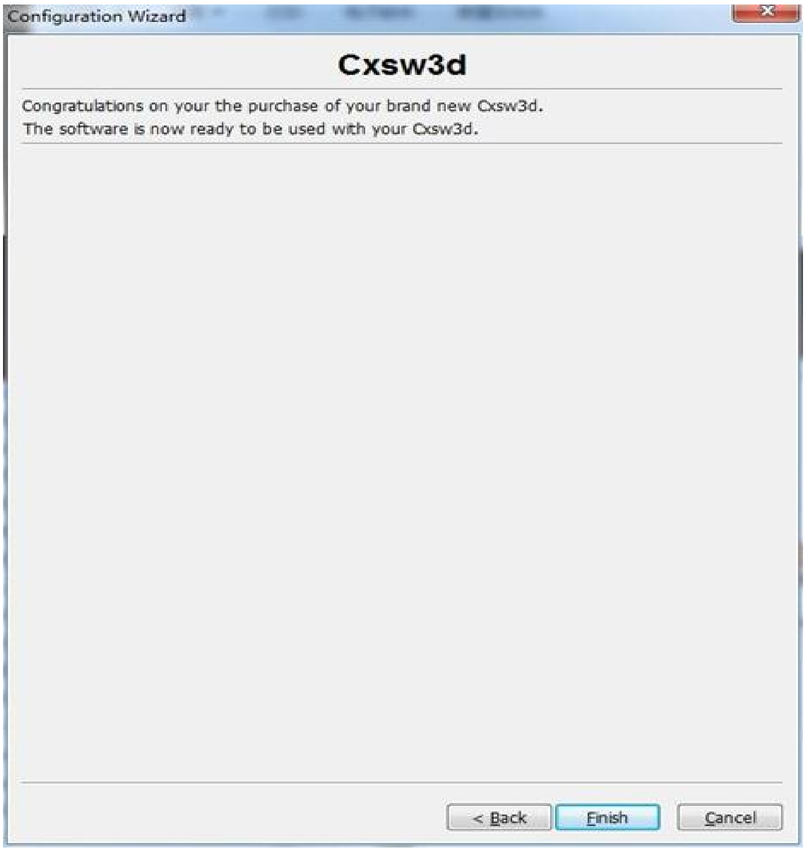

Plate 3.8 Finish the setting (Shenzhen, 2018)

3.4 Software Instructions

There are built-in instructions for the software, you can hover the mouse oneach parameter setting to view the detailed description

3.5 Electronics

3.5.1 Controller

The controller as shown below is the brains of 3D Printer. Almost all 3D Printer controllers are based on the of the Arduino microcontroller. While a lot of variations exist. they are exchangeable and basically all do the same thing. Now and then the controller is a remain solitary circuit load up with chips on it, in some cases the controller is an Arduino Mega with an extra board (called a "shield').

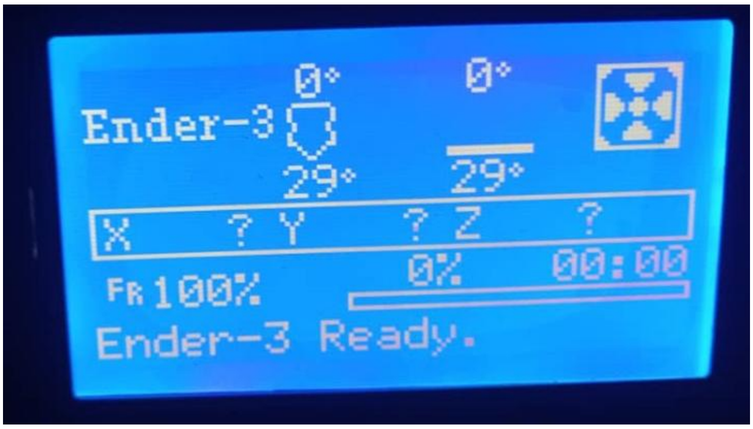

Plate 3.9 Controller (Shenzhen, 2018)

3.5.2 Stepper Motors

A stepper motor (or step motor) as shown below is a brushless DC electric motor that partitions a full pivot into a numerical of equivalent advances. The motor's position would then be able to be instructed to move and hold at one of these means with no criticism sensor, as long as the engine as deliberately measured to the application. Stepper motor moves a known break for each beat of vitality. This beat of vitality is given by a stepper driver and is suggested as a stage. As every movement moves the motor a known partition it makes them helpful gadgets for repeatable arranging. We will utilize stepper motor to move the bed carriage and different gatherings in their individually X - Axis, Y - Axis, Z-Axis.

Plate 3.10 Stepper Motors (Shenzhen, 2018)

3.5.3 Endstops

Mechanical switches are less complicated to implement and cheaper than optical end stops because they do not require a circuit board and only use 2 wires for connecting the switch. Resistors Pull up and down can put close to the main board. Contact-less magnetic switches are called read switches. They are proximity switches that close (or switch over) if a magnet comes close enough (usually 1 mm or less) and open if the magnet moves away. Reed switches are utilized as sensors in home caution frameworks to identify open windows and doors as shown in the plate below.

Plate 3.11 Endrops (Shenzhen, 2018)

3.5.4 Heated Bed

A heated build platform (HBP) as shown below improves in the printing quality of the 3d model by helping prevent warping. As extruded plastic cools it shrinks slightly. When this shrinking process does not occur throughout the printed part evenly, the result is the warped part. This warping is very commonly seen as corners being lifted off of the build platform. Printing on a warmed bed permits the printed part to remain warm amid the printing procedure and permit all the more notwithstanding contracting of the plastic as it cools underneath softening point. The warmth bed prompts higher complete quality that works with materials, for example, ABS and PLA. A HBP can likewise enable clients to print without rafts.

Plate 3.12 Heated Bed (Shenzhen, 2018)

3.5.5 Stepper Drives

A stepper driver is a motor that acts as the kind of intermediate person between a stepper motor and the controller. It streamlines the signs that should be sent to the stepper motor keeping in mind the end goal to motivate it to move. Here and there the stepper drivers are on independent circuit sheets that are connected to the controller through links. Now and then the stepper drivers are on little circuit sheets that connect straightforwardly to the controller itself. For this situation, the controller Will have space for no less than 4 of these little circuit sheets (one for every stepper motor). Finally, sometimes the stepper drivers are soldered right onto the controller itself.

3.6 Software

3.6.1 CAD Tools

Computer Aided Design are used to design 3D parts for printing. Computer aided design (CAD) is where we use the computer system to assist in the creation modification analysis or optimization of a design. Computer aided design software is utilized to expand the efficiency of the creator, enhance the nature of configuration, enhance interchanges through documentation, and to make a database for manufacturing.

Computer-aided design files in the most genuine sense are intended to enable you to effectively change and control parts in view of parameters. Now and then CAD files are alluded to as parametric records. The parts which are being represented as a tree of Boolean operations which are performed on primitive shapes such as cubes, spheres, cylinders, pyramids.

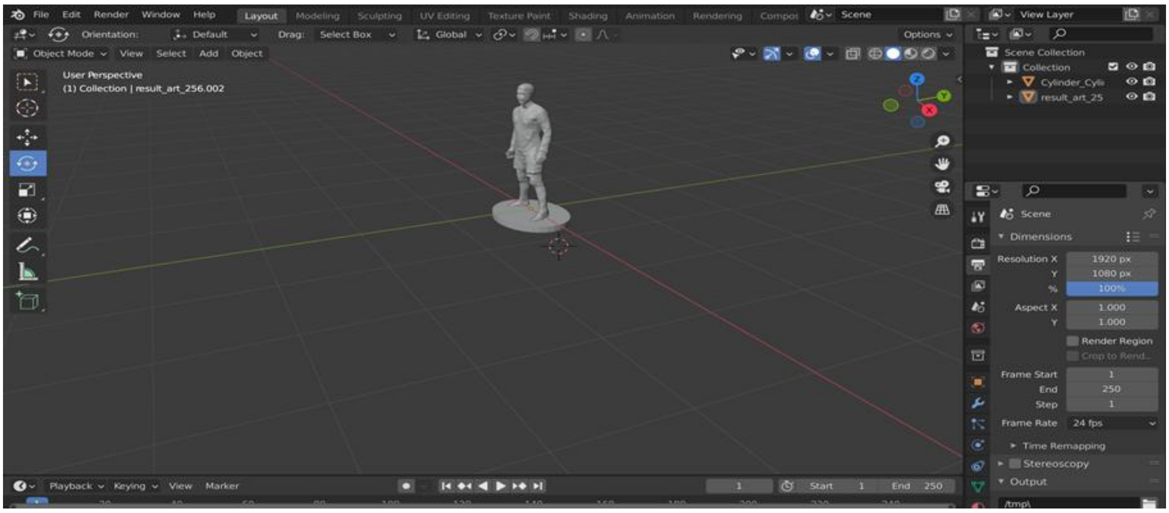

Plate 3.13 CAD Tools (Shenzhen, 2018)

3.6.2 CAM Tools

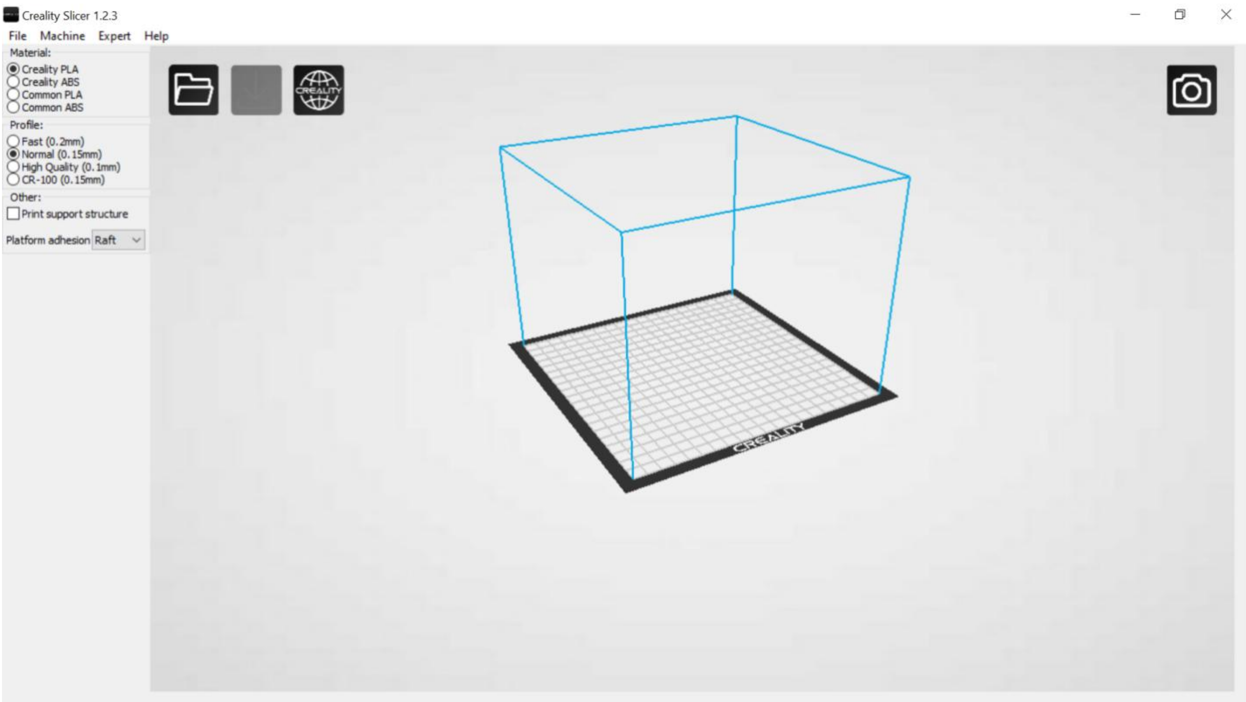

Plate 3.14 CAM Tools (Shenzhen, 2018)

Computer Aided Manufacturing, or CAM, tools handle the intermediate step of translating CAD files into a machine-friendly font used for our 3D printer electronics. Here we will be using a software which will be an integration of object slicing, Generation of G codes and M codes, Object Placement and other printer settings. Usually to turn a 3D part into a machine format, CAM software needs a STL file. The machine friendly format that is used for printing is called G-code.

3.6.3 Firmware

3D Printer electronics are controlled by an inexpensive CPU such as the Atmel AVR processor. Atmel processors are what Arduino-based microcontrollers use. These processors are exceptionally weak contrasted with even the normal 10 to 15-year-old PC you find in the landfill these days. However, these are CPUs so they do run primitive software. This primitive software they run is the firmware. The entire software chain that makes the 3D Printer work, the firmware portion of it is the closest you get to actual programming. In fact, the term for what you are doing with firmware is called cross compiling.

3.7 Processes of Fused Filament Fabrication

The 3D printers that are based on Fused Deposition Modeling (FDM) technology are also called as Fused Filament Fabrication (FFF), Plastic Jet Printing (PJP) or material extruding printers, which is the generic name for these 3D printers.

The 3D printers that work on FDM technology consist of a printer platform, a nozzle (also called as printer head) and the raw material in the form of a filament.

3.7.1 The Printer Platform

The printer platform or the bed is typically made of some metal, ceramic or hard plastic, and each successive layer is deposited on this platform.

3.7.2 The Nozzle / Printer Head

The nozzle of a fused deposition modeling printer as shown below is attached to a mechanical chassis which uses belt and or lead screw systems to move it. The entire extrusion assembly is allowed to move in X, Y AND Z dimensions by a motorized system. A fourth motor called as the stepper motor is used to advanced the thermoplastic material into the nozzle. All the movements of the head and the raw material are controlled by a computer.

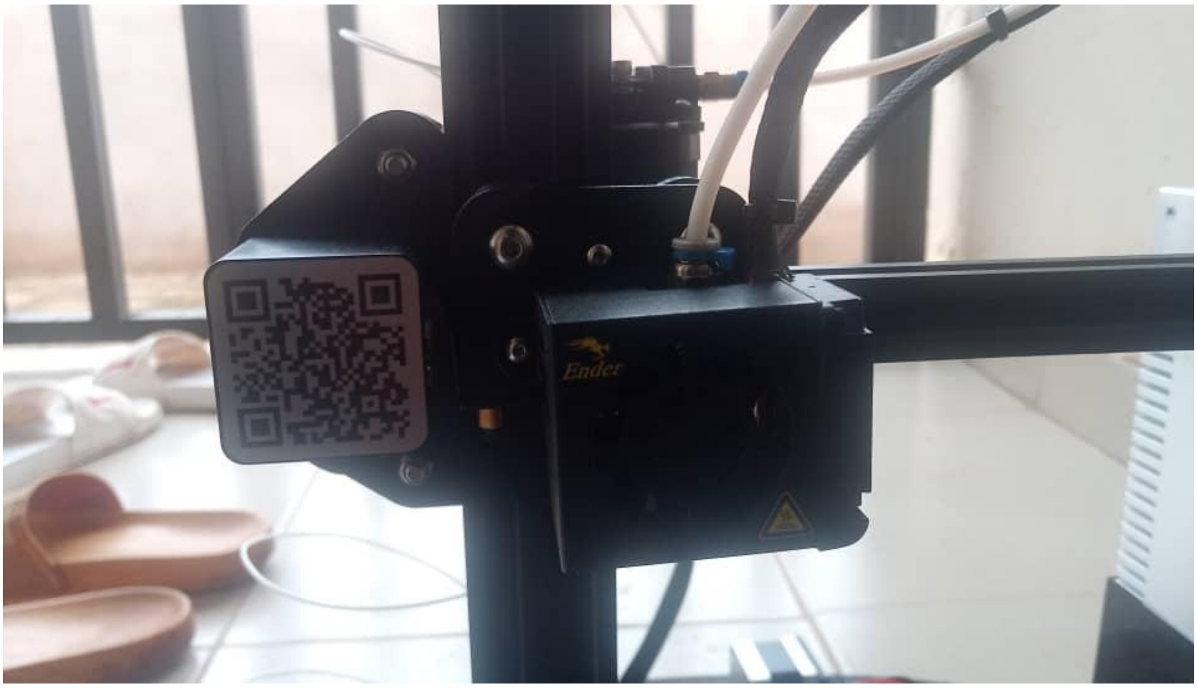

Plate 3.15 The Nozzle / Printer Head (Shenzhen, 2018)

3.7.3 The Raw Material

The raw material as shown below is typically production grade thermoplastics, though sometimes metal is used as well. The thermoplastic material is capable of being repeatedly melted when exposed to heat and re-solidified when the heat is withdrawn.

Plate 3.16 The Raw Material (Shenzhen, 2018)

3.8 Loading Filament

Method 1

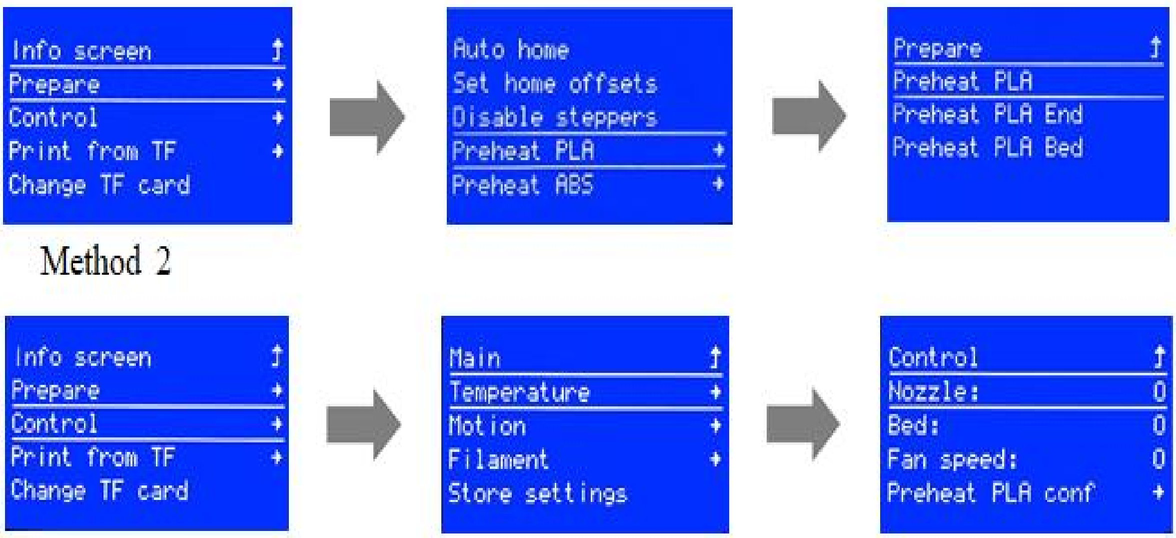

Plate 3.17 Preheat (Shenzhen, 2018)

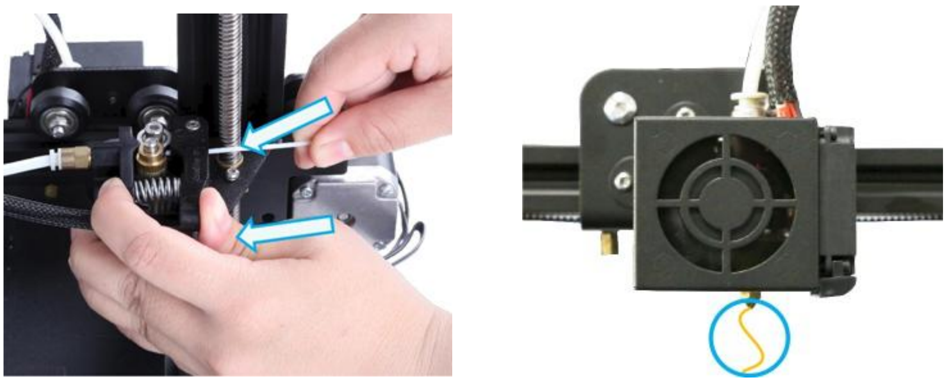

Plate 3.18 Feeding (Shenzhen, 2018)

Press and hold the extruder lever then insert 1.75mm filament through the small hole of the extruder. Continue feeding until you see filament out of the nozzle.

Tip: Replacing the Filament

1 Cutting filament near the Extruder and slowly feed new filament until the new filament get into the PTFE tube.

2 Preheating the nozzle,Press and hold the extruder, extract the filament, then feed the new filament.

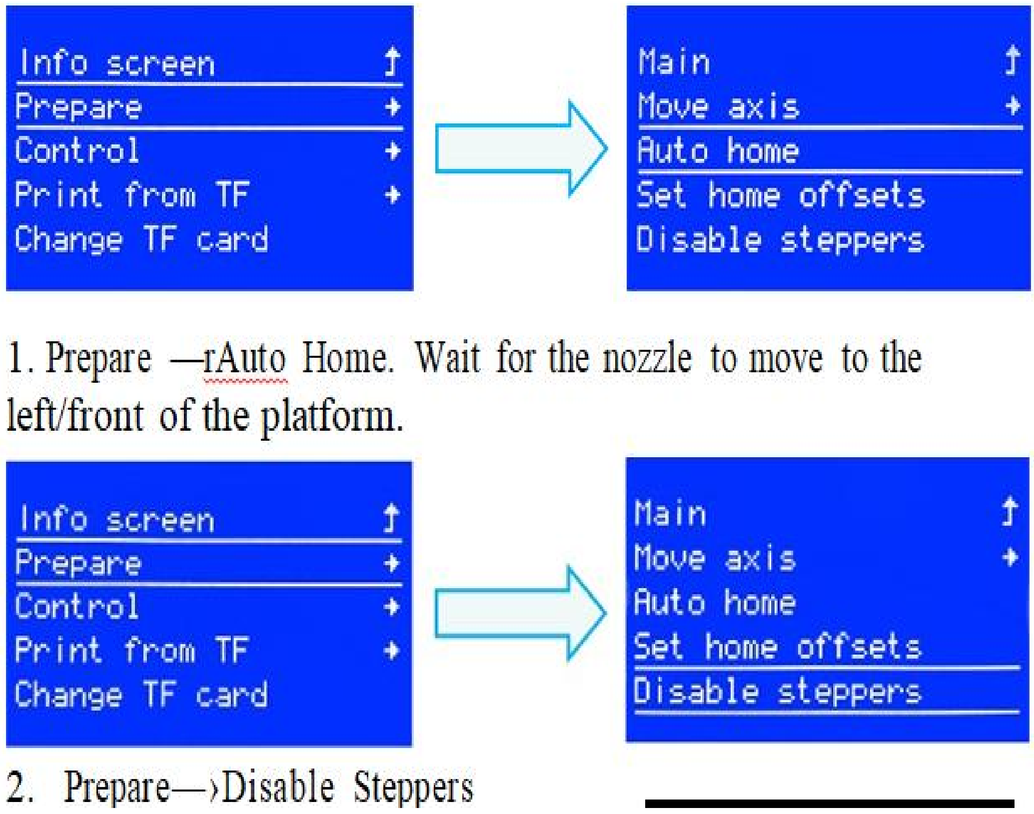

Plate 3.19 Bed Levelling (Shenzhen, 2018)

3. Move the nozzle to the front/left leveling screw and adjust the platform height by turning the knob underneath. Use a piece of A4 paper (standard printer paper) to assist with the adjustment, making sure that the nozzle lightly scratches the paper.

4. Complete the adjustment on all 4 corners

5. Repeat above steps 1-2 times if necessary.

3.9 Preparing to Print

Plate 3.20 Slicing (Shenzhen, 2018)

Open the software—+Load—+SeIect the file—•Wait for slicing to finish ,and save the gcode file to TF card.

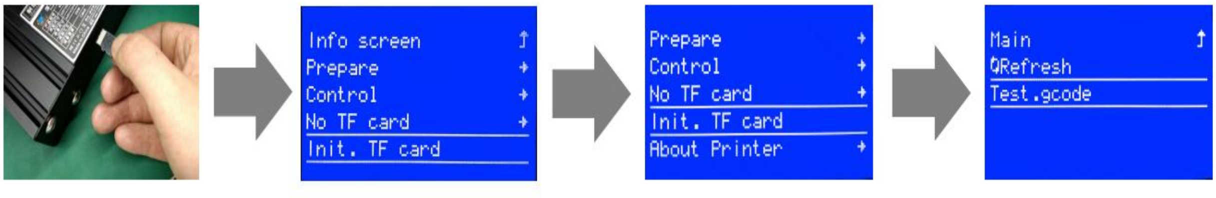

Plate 3.21 Printing (Shenzhen, 2018)

Insert the TF card—' Int. TF—Card —' Print from TF—'Select the file to be printed.

CHAPTER FOUR

RESULT AND DISSCUSSION

4.1 Result

The basic parameters for the Ender-3 Printer are:

- Molding Tech – FDM
- Printing Size – 220*220*250mm
- Printing Speed - $\leq$180mm/s, Normal 30 – 60mm/s
- Precision - +- 0.1mm
- Slice Thickness – 0.1mm – 0.4mm
- Nozzle Diameter – Standard 0.4mm
- Nozzle Number – 1
- Nozzle Temp - $\leq 250^{o}$c
- Bed Temp - $\leq 100^{o}$c
- Working Mode – Online or TF card Offline
- File Format – STL, OBJ, AMF
- Slice Software – Cura,Repetier-Host, Simplify3D
- Power Supply – Input:AC115/230V 50/60HZ, Output: DC 24V
- Total Power – 270W
- Filament – 1,75mm Pla
- Operating System – Windows XP/ Vista/7/10, MAC, LiNUX
- Language – English
- Resume Print – YES

The project was able to determine that it is possible to produce 5g football player figurines using a 3D printer, and that the main cost associated with this project would be the filament and the cost of labor. The cost of the 3D printer, shipping and handling was not included in this analysis as it was assumed that the printer had already been purchased.

Table 4.1 Cost of Material

ITEM	COST	SHIPPING & HANDLING FEES	IMPORT FEES	TOTAL

3D PRINTER	$165.00	$152.54	$27.42	$344.96
PLA FILAMENT 1KG	$18.99	$28.92	$0	$47.91

4.1.1 Electricity Cost

- 23 Nigerian naira per kilowatt hour, some 0.05 U.S. dollars for Household
- 36 NGN per kilowatt hour, roughly 0.08USD industrial electrical energy.

If it takes 30 minutes to print 5g of filament using the Ender-3 Printer, we can calculate the power consumption of the printer during the print.

To calculate the power consumption, we need to know the power of the printer and the time it takes to print the filament. The Ender-3 Printer has a power supply of DC 24V and a total power of 270W. The time it takes to print 5g of filament is 30 minutes.

We can calculate the energy consumption as follows: Energy Consumption (kWh) = Power (W) x Time (h) / 1000

Energy Consumption (kWh) = 270W x (30/60) h / 1000

Energy Consumption (kWh) = 0.675 kWh

So, it will take approximately 0.675 kilowatt per hour to print 5g of filament if it takes 30 minutes. Please note that this is an estimate based on the information provided, and actual power consumption may vary depending on the specific parameters of the print job.

4.1.2 Labour Cost

The cost of labor for producing the figurines would vary depending on the complexity of the design and the amount of time required to design and print the figurine. For a 5g (0.005kg) figurine design, the cost of labor may be around $5 to produce a dozen figurine. Here is the breakdown of costs associated with manufacturing one figurine using the Ender-3 printer, assuming a print time of 30 minutes and 1 United States Dollar equals 453.58 Nigerian Naira.

4.1.3 Materials

* The cost of 2.2lbs (1KG) of PLA filament is $18.99 and the cost of shipping and handling is $28.92, for

a total of $47.91 per 1KG of filament.

* Based on the weight of 5g of filament used to manufacture one figurine, the cost of materials for one figurine is $0.24 (5g of filament is around 0.011% of 1KG of filament)

* This cost is equivalent to 108.89 Nigerian Naira (0.24 * 453.58)

4.1.4 Equipment

* The 3D printer cost $344.96 including shipping. This cost is a one-time cost and is not associated with the production of one figurine.

* The cost of electricity is $0.08 per kilowatt hour.

* Based on the power consumption of 0.675 kilowatt per hour for one 5g filament, the cost of electricity for one figurine is $0.05

* This cost is equivalent to 22.68 Nigerian Naira (0.05 * 453.58) 50

4.1.5 Labor

* The cost of labor may be around $5 to produce a dozen figurines. * Based on the labor cost of $5 for 12 figurines, the cost of labor for one figurine is $0.41

* This cost is equivalent to 185.73 Nigerian Naira (0.41 * 453.58)

4.1.6 Cost to manufacture one figurine

* The total cost of materials for one figurine is 108.89 Nigerian Naira

* The total cost of equipment and electricity for one figurine is 22.68 Nigerian Naira * The total cost of labor for one figurine is 185.73 Nigerian Naira

* The total cost to manufacture one figurine is 108.89 + 22.68 + 185.73 = 317.30 Nigerian Naira The report shows that the cost of materials is still the most significant cost of manufacturing one figurine, accounting for 34.28% of the total cost. The cost of equipment and electricity is 7.14% of the total cost and the cost of labor is 58.57% of the total cost. It is important to note that these costs may vary depending on the specific parameters of the printing job, the cost of electricity in your area, and other factors. These costs are also subject to change over time, so it is important to regularly review and update them to ensure accuracy. In this scenario, the print time is shorter, which means that the power consumption is lower, and therefore the electricity cost is lower. As a result, the total cost to manufacture

one figurine is lower than the previous scenario where it takes 5 hours to print a 5g of filament. We expect that at the end of this research, we should have bridged the knowledge gap on 3D printing technology among production engineering student in the University of Benin. Through this research work, we hope to enhance the knowledge on the history of the additive technology, the economic benefit of the technology, the numerous advantages it has over the conventional subtractive manufacturing, its significance to production engineer and how the knowledge about it as an undergraduate can help in the manufacturing industry. At the end of this project, we will have a fully functioning Fused Deposition Modeling 3D printer in the Faculty of Engineering in the University of Benin. We will also not just have it but also use the knowledge gathered from this research to design and manufacture three- dimensional objects – players of soccer board games. We will know and see the advantages and disadvantages of using the proposed material for the manufacturing of Polylactic Acid (PLA) in filament form. We will also evaluate how we can improve on the technology and how we can harness its resources to further bring about technological development in the manufacturing industry of Nigeria.

Plate 4.1 Udosen's Soccer Board Game Figurine (James, 2021)

This study is to overview the types of 3D printing technologies, materials used for 3D printing technology in manufacturing industry and lastly, the applications of 3D printing technology. Therefore, 3D printing technology was applied in the designing of Udosen's Soccer Board Game Piece. In the future, researchers can do some study on the type of 3D printing machines and the suitable materials to be used by every type of machine. At present, 3D printing technology offers many benefits to the people, company and government. Therefore, more information is needed to progress on ways to enhance the adoption of 3D printing technology. The more information about 3D printing technology will help the company and government to upgrade and improve the infrastructure of 3D printing technology.

4.2 Discussion

According to the results and findings of this research, it is important to understand the strengths and the weaknesses of this technology. This section discusses the advantages and the disadvantages of applying 3D printing technology to a design. The research expected some results to be proved regarding the importance and usefulness of applying the new technology in Adoption of the higher education especially in the field of Architecture and Interior Design. There are many advantages of adopting 3D printing technology to design. The advantages of such a technology could be found in this study. The process of using additives in order to form solid 3D objects of form a digital model is called three-dimensional printing. 3D printing has worked into a number of markets that deals design with different kinds of applications. The paper is focused on the creating a game piece. It also has discussed the advantages of adding such a technology to the educational process that shall help students and faculty having professional models for their projects. An experiment that has concentrated on the importance and usefulness of this technology was done in order to clarify the differences between a hand-made model and a 3D-printed one. The results analysis has proven this technology's usefulness. This study result suggests the use of the new technological methods such as the 3D printing in the design process to show better representation for the design idea, this study explored the advantages of using the 3D printing in the teaching strategy for learners, in addition to other design considerations in the educational process.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The 3D-printer could drastically change the world in the ways mentioned, and with very few downsides, it certainly will. As long as the industry keeps making changes and price reductions, it could have an enormous influence on the future, and could easily save lives with the techniques mentioned. This paper has summarised the existing research that has been conducted into the application of 3D Printer which can be recommended in the educational system. It provides a state of the art review in answering the two questions of where and how 3D Printer is being used in the educational system. What is apparent from this review is that the use of 3D Printer in the educational system remains in its infancy, and the study of its application even moreso. This does not come as a surprise given the uncertainty and ambiguity that surrounds the technology’s capabilities and its future performance improvements, coupled with the financial limitations that educational institutions face.

In conclusion, the 3D printing of a football player figurine was a successful and educational project that demonstrated the capabilities of 3D printing technology. The use of a 3D modeling software and 3D printer allowed for the creation of a detailed and accurate figurine that accurately represented the chosen football player. Udosen's soccer board game appears to be an interesting and engaging board game that can provide hours of entertainment for players of all ages. The game's unique combination of strategic gameplay, player figurines, and customizable elements make it stand out from other soccer board games. The use of 3D printing to create player figurines adds a new level of immersion to the game, allowing players to feel more connected to their team and the game. The final product was one figurine of height 5cm and width of 3cm, and a time frame of 35mins which weighed 5g and cost 108.89 Nigerian Naira. Overall, I would recommend Udosen's soccer board game to anyone interested in soccer or strategic board games.

5.2 RECOMMENDATION

The game's customizable elements and engaging gameplay make it a great option for players looking to mix up their board game collection. In the future, 3D printing technology is likely to continue to advance and become more widespread, and its applications in the sports and athletics industry are likely to expand. The 3D printing of football player figurines is just one example of the many possibilities that this technology offers, and it is exciting to consider the potential for innovation and creativity in the field. Overall, the project was successful in achieving its objectives and has demonstrated the versatility and potential of 3D printing technology. While there were some challenges and limitations encountered during the design and printing process, these were overcome through careful planning and attention to detail. The project also highlighted the potential of 3D printing in the realm of sports and athletics, as it enables the creation of personalized and unique collectibles and displays

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