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An Analysis on The Effect of DIY 3d Printer in The Manufacturing Industry: A Case Study of Lusaka Town- Zambia.

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ABSTRACT: The production of components such as neck rings, nozzles, sleeves, pins, flanges, pulleys and many other machine parts are having their headway to three-dimension (3D) printing. The 3D printer is also known as additive manufacturing; it produces component parts by adding material layer-by-layer.

Additive Manufacturing (AM) technologies are developing impressively and are expected to bring about the next revolution. AM is gradually replacing traditional manufacturing methods in some applications because of its unique properties of customizability and versatility more especially where prototyping is concerned.

Injection molding, machining and mould casting are common methods used in Zambia and other parts of the world to produce machine components. However, Computer Numerical Control (CNC) machines and the 3D printer are slowly being introduced by manufacturing companies both at commercial and small-scale level.

Furthermore, 3D printing considerably challenges mass production processes in the future. This type of printing is predicted to influence industries, like automotive, medical, education, equipment, consumer products industries and various businesses.

This paper, considered the history of the DIY 3D printer, its design and way of developing it with local material as well as its operating principle. It will briefly state other examples of DIY 3D printer types and mention various limitations of the DIY 3D printers and also give an explanation on the analytical effect it has made in the manufacturing industry.

KEYWORDS: 3d printer, CNC, DIY, additive and subtractive manufacturing, injection molding, casting

CHAPTER 1

Introduction

This chapter presents the history and background of the DIY 3D printer, problem statement and the problem analysis, justification of the study and the objectives of making the DIY 3D printer locally.

The project of study is a research based on the effect of the DIY 3D printer in the manufacturing industry of Mufulira.

1.1 History of the 3D printer machine

The word 3D printing means essentially, an umbrella that encompasses a group of 3D printing processes. Therefore, a 3D printer refers to a machine that prints three-dimensional solid objects using a digital file, typically by laying down many thin layers of material in succession. It is also known as Additive Manufacturing.
The first additive manufacturing equipment and its materials was developed in May, 1980 by Dr Kodama Hideo (a patent lawyer) from Nagoya Municipal Research Institute in Japan. He invented the Rapid Prototyping (RP) technology that involved the use of photopolymer material that harden when exposed to UV light. Unfortunately, he did not commercialize it.

In 1986, Chuck Hull- invented a Stereolithography Apparatus (SLA), a 3D printer machine that uses a technique of printing objects layer -by- layer by using lasers selectively causing chains of molecules to link together to form a polymer. Hull's invention of the SLA-1 opened doors to the renaissance of the world's commercial 3D printers. A year later, Carl Deckard, pioneered an alternative 3D printer machine known as Betsy that turned loose powder into a solid by involving a laser to bind the powder together to form a solid. The machine stood for some time, until 2006 when the first Selective Laser Sintering (SLS) 3D printers where commercially viable.

Nonetheless, a few years later in 1988, Scott. S. Crump along with his wife and other fellow inventors, developed a patent for a new additive manufacturing method called- Fused Deposition Modeling (FDM). This technique involved the melting of a polymer filament and deposit it into a substrate layer- by- layer to create a 3D object. Crump's ideas in this technology came earlier in 1988 when he attempted to create a toy frog for his daughter using a hot glue-gun loaded with a mixture of polyethylene and candle wax.

In the 2004, Adrian Bowyer a senior lecturer in Mechanical Engineering at the University of Bath in the United Kingdom, founded a 3D printer machine called the Rep-Rap which printed most of its own components. The first design Rep-Rap 3D printer was named Darwin. A few years later, in March 2007, other versions came on board such as, the Mendel, Prusa Mendel and Huxley. The initial Rep-Rap printers were named after a famous evolutionary biologist considering that the project was about replication and evolution.

Following the expiration of the main patent on the FDM technology in 2009, MakerBot launched another technology in the mainstream Additive Manufacturing by building a successive open source DIY 3D printer. The company allowed people to build their own 3D printer products and further created an on-line file library to enable users

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to submit and download 3D printable files. Later in the year 2013 the company was acquired by Stratasys to enhance its capacity.

Further innovations and improvements have been made over the years and new technologies are being invented and employed to improve on the DIY 3D printer by various scholars around the world. Additive manufacturing has moved from smaller print products to bigger transformations. For example, its use in the aircraft.

1.2. Background information

As earlier alluded to, the earliest 3D printers became noticeable in the late 1980s and they were believed to have been pioneered by Dr. Kodama, a credible Japanese Lawyer, and at that time, they were called Rapid Prototyping (RP) machines. 3D printer machines create digital images from a known material layer-by-layer until a solid object is formed. The working principle of 3D printer machines was derived from the 2D dimension dot matrix printer which only uses the X and Y movements (i.e. back-and-forth and side-to-side adjustments) and also from the configurations of the glue gun by smelting a filament. Arguably, the major breakthrough in the development of 3D printers can be traced back to 1983, when the first patent was issued by Charles Hull for Stereolithography Apparatus (SLA). After Charles Hull's 3D printers, many different types of 3D printer machines have emerged with unique printing processes which are all controlled by three-dimension digital data. For example, some processes use the extruder to heat the plastic filament into molten state and extrude it through a nozzle to deposit accurately onto a built platform. Additionally, other conventions use lasers to melt layers of powder material, yet some use ink-jet printer heads to deposit material into the shape of the designed component.

In Zambia, 3D printer machines have no traces of invention, but they are slowly existing in some parts of our country. They are bought on-line at prices ranging fromUS$454 - US$10 500 depending on the type and size of the printer. In this case, some of their components are made with the locally available material and attachments of few imported electronic components.

Problem statement and problem analysis

1.3.1. Problem statement

Traditional manufacturing stands to be one of the most outstanding methods of manufacturing products, components and items. Methods such as injection moulding, casting and machining are widely pronounced in the Zambian manufacturing industry. 3D printers are a form of Additive Manufacturing. These printers have given engineers and manufacturing industries the ability to prototype and equally manufacture products. The DIY3D printer's offer significant advantages over traditional manufacturing processes as they do not require any special tooling to make a part, products are made instantly with less time, furthermore, they promote mass customization, design freedom, reduced part assembly and give a low volume cost production; a variable that makes the cost effective on the whole.

To address the problem at hand, mostly locally available material will be used to make a DIY 3D printer and a small fraction of imported electronic components. This will provide opportunity to our

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local manufacturers and entrepreneurs to access DIY 3D printers.

1.3.2. Problem analysis

Zambia's manufacturing industry produces machine components through various processes that may include among others machining, injection molding, die casting and fabrication with respect to welding techniques. The challenges most consumers face with our locally manufactured products are that the required components or end products take time to be produced especially if machining processes are used. This is because a lot of processes are involved to have a finished product done. Sometimes, the components undertake one process or many processes depending on the complexity of the required part. For instance, making a flange with a key-way can take two processes where the piece is first shaped on the lathe machine and later, it is put on a shaper or milling machine for creating a key-way, hence, making the whole process laborious and costly on the part of the manufacturer and the end user. Furthermore, most consumers tend to compare local products with the foreign ones depending on what appeals most to them.

In this regard, it is observed that foreign products have a higher quality finish compared to the local products. In addition, it is perceived that such products are made with less errors and easier to replicate on mass production using low cost production capacities under economies of scale. This is because they employ highly skilled manpower, better tools and equipment and of course other factors such as less operation errors.

Figures 1: (a) Toss milling machine

Pictured by: Kalimanshi Winwright (Kalitony workroom – Mufulira)

(b) A Lathe Machine

Pictured by: Kalimanshi Winwright (Kalitony workroom – Mufulira)

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However, casting with mould and injection techniques are reliable for uniformity and are relatively less time consuming, but they may require some finishing processes such as sanding or machining.

It is in this regard that this paper presents the design and manufactured DIY 3D printer machine created from locally available material for a cohort of entrepreneurs and commercial manufacturers. This machine allows the creation of physical objects from three dimensional digital models by applying many thin layers of quick-drying material on top of each other. The figures below show a lathe machine and a 3D printer that are both used to manufacture objects with various specifications.

1.4. Situation analysis / inventory

This paper is designed with focus made to the findings drawn from the Mufulira Business Community, particular households within and in the periphery of the town, border areas near the Republic of Congo DR as well as statistics gathered from different parts of the Copperbelt Province of Zambia. Essentially, there are many activities that the local people of this town are engaged in, among them being farming, sole proprietary enterprises, small scale and medium enterprises, various allied business ventures, employment under different corporate entities, the mining industry as well as various Public Service Departments. Regardless of being a mining town, most people are out of employment due to retrenchments that have occurred in the mines, but a few lucky ones have ended up being employed by local contractors and a few manufacturing companies that supply manufactured products to the mines and other sectors.

The few schools like Northmead Secondary School, Munali Secondary that offer Design and Technology as a subject as well as engineering companies (that are in practical machining and fabrication for instance Labia Engineering Company, Discovery, Kalitony General Contractors) have little knowledge or none about the existence of DIY 3D printers or additive manufacturing. A few that are knowledgeable about this technology have limited financial capacity to purchase them.

1.5. Justification

This project of the DIY 3D printer machine was produced locally with the view to empower local manufacturers to produce parts that could be of relevance to the consumer. At the same time, parts such as the frame and others were locally made and other electronic components were imported making the machine cheaper compared to imported and assembled ones.

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1.6.0. Objectives

1.6.1. Broad objective

The broad objective of this project was to design and manufacture a DIY 3D printer that would manufacture components instantly and further promote rapid prototyping.

1.6.2. Specific objectives

The specific objectives include the following:

- To design a DIY 3D printer.
- To make a DIY 3D printer.
-

1.7.0. Statement of the scope

This project involves the designing and making of a 3D printer from the locally available material and a few imported electronic components. The said printer will be used to produce 3D objects by printing layer-by-layer to create tangible objects using 3D models, the blueprint (CAD file) of an object, say a cup, flower vessel, gears- all can be printed in three dimension, as opposed to use of traditional methods which rely on moulding and cutting technologies to produce a finite number of shapes and structures, with more complex hollow ones having to be created from several parts and assembled together. But 3D printing changes this altogether, it uses a plastic filament as a raw material. However, other 3D printer's use raw materials such as metal, wood, paper, resin, and glass. The 3D printer's nozzle can build an infinite number of complex figures that could only be limited by human imagination. This method provides for greater durability and higher structural integrity in its design.

The new technology creates higher chances of making both small scale entrepreneurs and big companies to reduce their manufacturing cost expenditures. This could be realized through reduced importation of components from overseas, use of lower labour costs and enterprise and promotion of use of cheaper and more accessible and reliable raw materials.

Additive manufacturing is certainly one of the most lucrative technologies to drive the 21st century. Its adoption has many benefits for our manufacturers which could be earned through Quick Production, less wastage of materials, promotion of better-quality outputs and allow for increased accessibility and sustainability of the prospects to mention a few.

1.8.0. Project Scope

The range of the project was restricted to the under listed machinery and materials:

1.8.1. Machines and tools used

- Angle grinder
- Pillar drilling machine
- Hand drilling machine
- Bench Angle grinder
- Rasp file (round and half round file)
- Tinsnips
- Phillips screw driver
- Spanner

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Materials/Parts/ Requirements

1.8.2. Electronics

- 3D Printer Kit Ramps 1.4 Boards
- Short Linear Bearing Bushing (LM12LUU 12 mm)
- NEMA 17 Bipolar Stepper Motors 76 oz
- Vertical ATX Power Supply
- MK8 Extruder Nozzle (1.75 mm Printer Head) or J-Head Hotend (1.75 mm) Filament Bowden Extruder Nozzle 0.4 mm
- Printer Kit RAMPS (1.4 Board + LCD 2004 + MEGA 2560 Module + 5 x A4988)
- Limit switch (10 X Micro)

1.8.3. Frame materials:

- Aluminum/Square tube mild steel (6 m x 20 mm x 20 mm with 1.5 mm thickness) for the framework
- Aluminum or steel Sheet metal (3 mm x 30 mm x 30 mm)
- Soft wood or Aluminum (12 mm x 3 mm x 5m)
- Linear Rail Shafts 12mm
- Linear Shaft Bearings 12mm
- A lot of Screws, Nuts and Washers
- Stepper Motor Mounts
- Arc threaded rod (diameter 8 x 160 mm)
- Printer filament 1.75mm 3mm ABS/PLA

1.8.4. Drive components

- Stepper Motors Nema
- Timing Belts GT2 6mm
- GT2 Timing Pulleys
- Screw Rods
- Aluminum Belt Pulley
- GT2 Timing Belt (10 meters)

Use unguided sketching and computer software (Google Sketch Up, AutoCAD, SolidWorks and Sketch Book) for design sketches and working drawings. Sketching, being the simplest and fastest way of expressing ideas and creativity will be used to illustrate concepts to other people before converting them into CAD drawings. The use of CAD software helps the designer working on 2D to immediately benefit from 3D images as it is being created. After all, it is possible to add a detail on a 3D model and evolve it into a creation that is built. Google Sketch Up, AutoCAD and Solid Works will be used for this purpose

1.8.5. Fabrication

The angle grinder was used for cutting and cleaning while the drilling machine was used for making holes in the DIY 3D printer frame and other parts.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 BENEFIT OF THE DIY 3D PRINTER

A 3D printing is a process of making three dimensional solid objects from a digital file. It is used in both rapid prototyping and additive manufacturing unlike subtractive manufacturing where materials are removed from the stock. 3D printing is sometimes referred to as additive manufacturing (AM) which builds a three-dimensional object from computer aided design (CAD) models or AMF files, usually built by successively adding filaments layer- by- layer.

Matthews et al., (2011), proposal seeks to discover the usefulness of rapid prototyping in the automotive industry. The fastest growing sections of 3D printing have been in aerospace and the medical discipline. An important note in the automobile industry is that weight is directly related to costs. Using subtractive manufacturing methods, there is up to 90% waste of raw materials, which is not attracted in3D printing. The parts can also be modified and manufactured faster with 3D printing. Impellers, fuel-injection nozzles, and door hinges can all be more cost effective to print via 3D methods.

Object Ltd. (2012) maintained that there are many benefits to 3D printing as a form of concept modeling. It can help sell ideas when a potential customer physically touches, feels, and sees the object. Suggestions made often provide a higher success rate when a physical prototypical design is presented.

Jim Wyman, an engineer, believed that an interpretation of a solid model communicates information ten times more easily than engineering drawings. 3D printing decreases costly demands that would be attracted otherwise. The more changes or mistakes that could be detected early on the design, the more money one would save in due course. 3D printed models allow you to see what you can't see in a computer model. Ideally, this convention is highly sensitive and in case of any undetected mistakes being made in the process of commanding prints under this model, one would end up suffering huge expenses or losses for the entire 3D printer project work to be done. Printing can also reduce the cost of the quote for the entire project. Many times, when a model is presented, quotes are lowered by ten percent because the buyer can visually see what the project capacity is thereby, making it cost effective.

Wohlers et al., (1996) observed that in the current market, twenty percent of 3D printers are now being used as a means of rapid manufacturing rather than just making prototypes. This is due to the lower costs and risks related with it, also 3D printing essentially removes the problem of economies of scale, because the price will be a concrete number.

The main difference between 3D printing and other rapid prototyping methods is the choice of materials, how these materials are deposited, fused, and solidified. 3D printing also enables items to be produced on a smaller scale, faster speed, less costly, and at a greater convenience than other additive manufacturing methods. Prior to purchasing a 3D printer, one must determine what the printed prototype will be used for, that is appearance, functional testing, fit, or characteristics.

Matthews (2011) remarked that besides Object and Stratasys manufactures, 3D Systems are also manufactured by Mcor Technologies and Z Corp. 3D Systems employs two types of technologies: multi-jet modeling and film transfer imaging technology. Mcor Technologies is one of the few companies to offer an eco-friendly 3D printer and primarily is used for woodcarvings. Z Corp offers a powder and binder process of inkjet printing. The powder is laid down, and the binder is applied to the areas of the model. This printer has multiple print heads and it has the ability to print more than one color a time.

Wichelecki (2009) asserts that, the usefulness in printing prototypes lies in testing structural properties such as strength-to-mass ratios and surface-to-volume ratios. Even in the past ten years, materials able to be printed have increased to glass, ceramics, and metal. Other advances in metal printing have led to the ability to print layers as thin as one micron.

Matthews (2009) remarked that utilizing 3D printing for electrically conductive prototypes is under extensive research and development. Rapid prototyping that uses 3D printing has several limitations when dealing with conductivity. First of all, there are few materials that can be utilized. If the model is not of the correct material, the extent of tests that can be performed on the model are limited. This affects medium and high voltage engineering products especially, because the shape and electric properties of the material will affect the distribution of electric fields which is critical for how the device will work.

Wohlers et al (1996) supports that as materials and printers develop, electronics look promising for 3D printing, however, 3D printing faces a few obstacles. First of all, factory workers are also fearful of losing jobs to these machines. Taxes used for public services may also see a decrease as a result of in-home printing capabilities. Another recent threat came with the passing of U.S. Patent number 8,286,236. These ten patents hold the rights to a method for secure manufacturing to control object production rights.

Hart (2012) these prices have dropped, but large-scale 3D printers can be quite costly. There are also components that can enhance the 3D printer, including 3D scanners and CAD software which can cost upwards of $4,000 depending on the number of licenses needed. However, there are cheaper, do-it-yourself 3D printers available for low costs. This presents an interesting scenario because users will be able to print whatever they want. This could enhance the economic status of 3rd world countries. It could also be a threat if people begin to print weapons. Based on these sources, it is clear that 3D printing has brought a new future to industrial manufacturing. 3D rapid prototyping can play an exceptional role in any of these industries, especially that of the automotive. It offers time, money, and convenience savings. The research and development of 3D printing is growing immensely. Overall, this is a worthwhile investment for any company where engineers and designers collaborate on new products on a regular basis.3D printers are great for mass customization, but are still too slow for manufacturing lots of objects. To

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change the manufacturing industry, the parts need to be printed in minutes, not hours. It currently takes anywhere from several hours to several days to print, depending on the size of the model and the quality of the printer. Receiving an order from Shape ways, the company that customizes and 3D prints a variety of products, can take up to two weeks, depending on the materials used.

Setting up a 3D printer will need to be as easy as hooking up a traditional HP printer. The 3D printer needs to have fewer wires than a television and fewer buttons than a computer for it to become a household electronic, and right now, that's not the case. The printers use high-voltage power supplies and specialized equipment and parts. Some of the cheapest printers can't even connect to Wi-Fi and most have low resolution.

2.2 OTHER TYPES OF 3D PRINTERS

It is imperative to recognize that the word 3D printing is essentially an umbrella term that encompasses a group of 3D printing processes. Therefore, this paper shall look at the other 3D printers that have been in existence by stating the materials used, their common applications, the strength and weaknesses in materials used and show the principle working diagrams.

It is well-known that seven different groups of additive manufacturing processes have been recognized and established. These seven 3D printing processes brought forth ten different types of 3D printing technologies in 3D printers used nowadays. Material Extrusion devices are the most frequently available and the cheapest types of 3D printing technology in the world. Some of example of the existing 3D printers include, the Stereolithography (SL), Digital Light Processing (DLP) just to mention a few.

2.3 Stereolithography

Stereolithography (SL) is widely recognized and was the first one to be commercialized. SL is a laser-based process that works with photopolymer resins that react with the laser and cure to form a solid in a very precise way to produce very accurate parts. It is a complex process, but simply put, the photopolymer resin is held in a vat with a movable platform inside. A laser beam is directed in the X-Y axes across the surface of the resin according to the 3D data supplied to the machine (the .STL file).

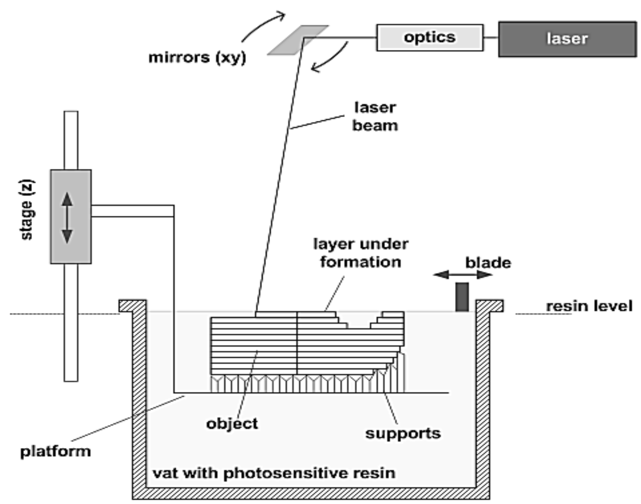

Figure 4: Sketch of the stereo lithography process.

Whereby the resin hardens precisely where the laser hits the surface. Once the layer is completed, the platform within the vat drops down by a fraction (in the Z axis) and the subsequent layer is traced out by the laser. This continues until the entire object is completed and the platform can be raised out of the vat for removal.

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Digital Light Processing

Digital Light Processing (DPL) is one of the examples of the commonly known 3D printers. It is a revolutionary new way to project and display information based on the Digital Micro mirror Device developed by Texas Instruments. DLP creates the final link to display digital visual information. This technology is being provided as subsystems or engines to market leaders in the consumer, business, and professional segments of the projection display industry. In the same way the compact disc revolutionized the audio industry.

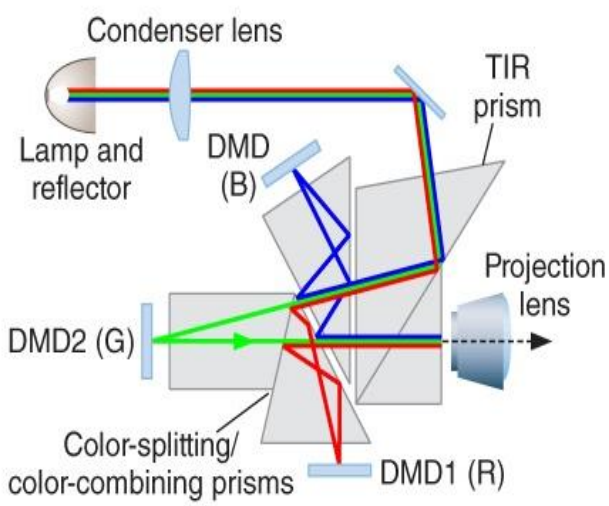

Figure 5: Digital Light Processing (DPL)

The DLP display technology digitally manipulates (or processes) light to produce film-like, all-digital images. It integrates a projection lamp and an electronic video signal from a source such as a VCR or computer and the processed light produces an all-digital picture.

The key to this complete digital process is the Digital Micro mirror Device (DMD), a thumbnail-size semiconductor light switch. The DMD consists of an array of thousands of microscopic-size mirrors, each mounted on a hinge structure so that it can be individually tilted back and forth. When a lamp and a projection lens are positioned in the right places in the system, DLP processes the input video signal and tilts the mirrors to generate a digital image.

Material Jetting

The other example of a 3D printer is Material Jetting. MJ is an additive manufacturing process that operates in a similar fashion to 2D printers. In material jetting, a print head (similar to the print heads used for standard inkjet printing) dispenses droplets of a photosensitive material that solidifies under ultraviolet (UV) light, building a part layer-by-layer. The materials used in MJ are thermo set photopolymers (acrylics) that come in a liquid form.

MJ creates parts of high dimensional accuracy with a very smooth surface finish. Multi-material printing and a wide range of materials (such as ABS-like, rubber-like and fully transparent materials) are available in Material Jetting. These characteristics make MJ a very attractive option for both visual prototypes and tooling manufacturing.

Selective laser sintering

Furthermore, Selective laser sintering is understood to be another form of 3D printer. SLS is an intelligent manufacturing process based on the use of powder-coated metal additives, a process generally used for rapid prototyping and instrumentation. A continuous Laser beams are used or animated as heating source for scanning and aligning particles in predetermined sizes and shapes

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of the layers. The geometry of the scanned layers corresponds to various sections of the models established by computer-aided design (CAD) or from files produced by stereo lithography (STL). After scanning the first layer, the scanning continues with the second layer which is placed over the first, repeating the process from the bottom to the top until the product is complete.

Recent advances in the fields of Computer Aided Drafting (CAD) and Rapid Prototyping (RP) have given designers the tools to rapidly generate an initial prototype from a concept, in 3D printing area the say that if you can draw it then you can make it. Additive manufacturing (AM) allows complex Parts to be built without the need for tooling, dies, or molds, using little human intervention. There are currently several different 3D technologies available as given in the examples above, each with its own unique set of competencies and limitations.

Fused Deposition Modeling

In this paper, we seek to characterize some of the properties a Fused Deposition Modeling (FDM) process, as well as the effects of varying some of the build parameters.

FDM is the commonly known 3D printer and is also referred to as Fused Filament Fabrication (FFF) printing process. It is one of the AM process that builds 3D shapes by taking filaments of thermoplastic polymer materials and driving them into a heated liquefier to be extruded through a small diameter nozzle onto a build platform. The technology of FDM is capable of processing metals, for example, electron beam melting, direct metal laser sintering, laser engineered net shaping and selective laser melting.

Figure 6: The exploded view of the Extruder Nozzle and a filament

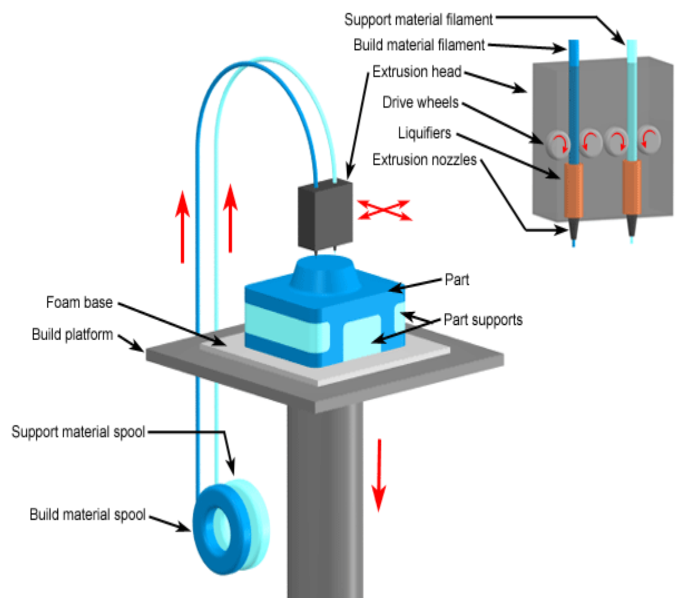

Figure 7: Schematic Representation of FDM Process
Source: Schematic Representation of FDM Process

Employing FDM technology to extrude metals poses advantages and disadvantages when compared to methods that currently build using metal alloys. An advantage of using FDM is the lack of expensive lasers equipped in sintering

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processes or an electron beam as is present in the electron beam melting process. Less expensive materials and systems are available that use FDM technology compared to sintering and melting technologies. A difference is also the ability to build using both thermoplastics and metals within the same build which is not possible with other direct metal systems. Additionally, it is ideally suited for the designers who demand part stability and strength.

FDM uses different materials for printing such as ABS plastic, polyamide (PLA), glass filled polyamide, Stereolithography materials (epoxy resins), silver, titanium, steel, PET, TPU, wax, photopolymers and polycarbonate.

S/No	**Name of material**	**Normal melting point**	**Temperature used in FDM**
1	ABS	105˚C	230˚C
2	PLA	65˚C	180˚C

Table 1: Properties of Materials

However, the first step in generating an FDM part is to create a three-dimensional solid model. This can be accomplished in many of the commonly available CAD packages. The part is then exported to the FDM Quick slice software via the Stereolithography (STL) format. This format reduces the part to a set a triangle by tessellating it. The advantage of this is that it is a common format that almost every CAD system can export, and reduces the part to its most basic components. The disadvantage is that the part loses some resolution, as only triangles, and not true arcs, splines, etc. now represent it. However, these approximations are acceptable as long as they are less than the inaccuracy inherent in the manufacturing process.

Once the STL file has been exported to Quick slice, it is then horizontally sliced into many thin sections. These sections represent the two-dimensional contours that the FDM process will generate which, when stacked upon one another, will closely resemble the original part three-dimensional part. This sectioning approach is common to all currently available Rapid Prototyping processes. It is a known fact that the thinner the sections, the more accurate the part.

Its working principle requires that a coil of filament is loaded into the 3D printer and fed through to a printer nozzle in the extrusion head. The printer nozzle is heated to an expected temperature, whereupon a motor pushes the filament through the heated nozzle, causing it to melt. The printer moves the extrusion head along specified coordinates, laying down the molten material onto the build plate where it cools down and solidifies. Once a layer is complete, the printer proceeds to lay down another layer. This process of printing cross-sections is repeated, building layer-upon-layer, until the object is fully shaped. Depending on the geometry of the object, it is sometimes essential to add support structures, for example if a model has steep overhanging parts.

The nozzle of the FDM printer has the most important jobs of all the mechanical systems. It is the last mechanical device that is used to build up a 3D object, the design and functionality is extremely important when it comes to the accuracy and build quality of the printer. The biggest contributor to the performance of the nozzle is its orifice size. Classically, the nozzle size used on many FDM

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printers are 0.4mm. This size is small enough to produce high quality parts while maintaining reasonable build times. Printers such as the MakerBot Replicator use this size nozzle. Depending on the overall goal of the part being printed however, these nozzles can be changed to larger diameters in order to increase the speed of the print job.

As with any emerging technology, 3D printing has disrupted the markets by transforming product development. Also known as additive manufacturing, 3D printing involves joining materials together, layer after layer to make objects from a 3D digital model. It differs from subtractive manufacturing (traditional manufacturing) which comprises cutting away unwanted parts from large pieces of solid material.

The 3D printing process eliminates many steps used in traditional manufacturing and facilitates the manufacture of complex structural components. These features have led to significant success in the areas of rapid prototyping and tool development.
As a result, 3D printing technology has opened new possibilities for industries by enabling faster product design, customization, cost reduction, tangible product testing, and more. For instance, its advances are increasingly becoming relevant in medical and dental industries where customization is essential.

2.3.0. Framing

Frame was made from steel square tube profiles of 20 mm x20 mm x 1.5 mm, thus, for the horizontal base and the vertical stand. It can also be made from aluminum flat bars 40 mm x10mm, 40 mm x8mm, 30 mm x10mm and aluminum or steel sheet of 3mm. The frame must be light enough to make it portable as well as to support the project being made.

CHAPTER 3

3.0 Design methodology

The procedures used in this design are in three steps; the first step elaborate the gathering of obtainable 3D printers which was purely done through internet. Followed by a procedure in designing an appropriate device from local available materials that was going to produce 3Dimention engineering parts and other objects, and the last step is to give an analysis on the effect of DIY 3d printer in the manufacturing industry and other fields.

Then again, scholar has been provided with access to computer software designing packages such as AutoCAD, SolidWorks and Google Sketch up for the purpose of creating drawings and animations.

3.1. Collection of data/needs

Data collection was over and done with internet, observation and interviewing. Having had a privilege to visit some local fabrication and machining companies in Mufulira industrial area such as Labia Machining and General Contractors, Newton General Contractor, Kalitony General Contractors and Mopani Copper Mine (Mufulira), this project observed and interviewed employees who were using the traditional manufacturing technologies, such as lathe machines, milling machine, shaper machine, drilling and other processes such casting to produce machine parts or components rather than them using additive

Manufacturing. The management states that they have no access to 3D printing machines hence, most of the engineering parts are ordered from outside the country which makes it more expensive and delay or low production due to the period spent before the parts are received.
In the making of DIY 3D printer using the local available materials I followed a video for Thomas Workshop from the internet. However, most electronics and electrical components where ordered from the internet as they are not accessible locally.

3.2 Design project

The project was aimed at designing and making an affordable, cheap, and portable DIY 3D printer using local available materials and some imported electrical components. This was basically to avail DIY 3D printers on the Zambian market; the printer would be useful in schools, colleges, homes and small-scale entrepreneurs for their various needs. For example, schools could equally use it as a teaching aid as well as allow learners to be creative in designing and making their own 3D printer products.
Various materials are used in DIY 3D printers, these include ceramic, metal and so forth, but our creation uses a filament plastic material that is controlled electrically. Its command print is determined from a computer running a supporting software such as AutoCAD, and solid works; normally the designs are saved in LTS format which when a command is made, the DIY 3D printer responds by printing a three dimension object layer-by- layer until the designed part is completed.

3.2.1. Design consideration

In the manipulative and building of a local DIY 3D printer, certain factors were considered to make it available and slightly cheaper and affordable on the Zambian market. Among the factors was the use of cheap local available material such as steel for the construction of the frame instead of aluminum which is slightly expensive in Zambia. The steel frame used was 20 mm x 20 mm x 1.5 mm in thickness, making the weight of the structure to be very light and portable enough to be moved around. Additionally, the use of wood in making DIY 3D printer parts makes it possible to be cheaper compared to use of plastic or aluminum. Other parts were steel supports instead of aluminum.
However, a lot of time and correct use of tools must be considered in order to come up with an accurate functional project.

3.2.2. METHOD OF ASSEMBLY

The DIY 3D printer assembly was first done by obtaining dimensions from Thomas workshop a pdf document, the dimensions where enlarged using AutoCAD and printed to correct scale, then the printed paper were glued to a piece of material being used and an angle grinder was used to cut pieces to correct size and debarred. Furthermore, a drilling machine was used in the making of holes to facilitate the assembly of the project

The first thing to assemble was a frame and later the electrical components, all the pieces were attached by method of screw and nuts

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3.2.3. WORKING PRINCIPLE

The working principle of a 3D printer was not so much different from two-dimension printers. In both, data comes from the computer and requires the printer to produce the results, except that in a two-dimension printer, the ink does not build up, whereas, in a 3D printer material builds up layer-by- layer.

However, 3D printable models may be created with a computer aided design (CAD) package, via a 3D scanner or by a plain digital camera and photogrammetry software. The manual modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

Before printing a 3D model from an STL file, it should first be examined for manifold errors. This step is called the fix up. Generally, STLs that have been produced from a model obtained through 3D scanning often have many manifold errors in them that need to be rectified. Examples of these errors are surfaces that do not connect and gaps in the models. Once that is done, the STL file is processed by a piece of software called a slicer which converts the model into a series of thin layers and produces a G-code file containing instructions tailored to a specific type of 3D printer (FDM printers). This G-code file can then be printed with 3D printing client software which loads the G - code, and uses it to instruct the 3D printer during the 3D printing process. Printer resolution describes layer thickness and X-Y resolution in dots per inch (dpi) or micrometers (µm). Typical layer thickness is around 100 µm (250 DPI), although some machines can print layers as thin as 16 µm (1,600 DPI).

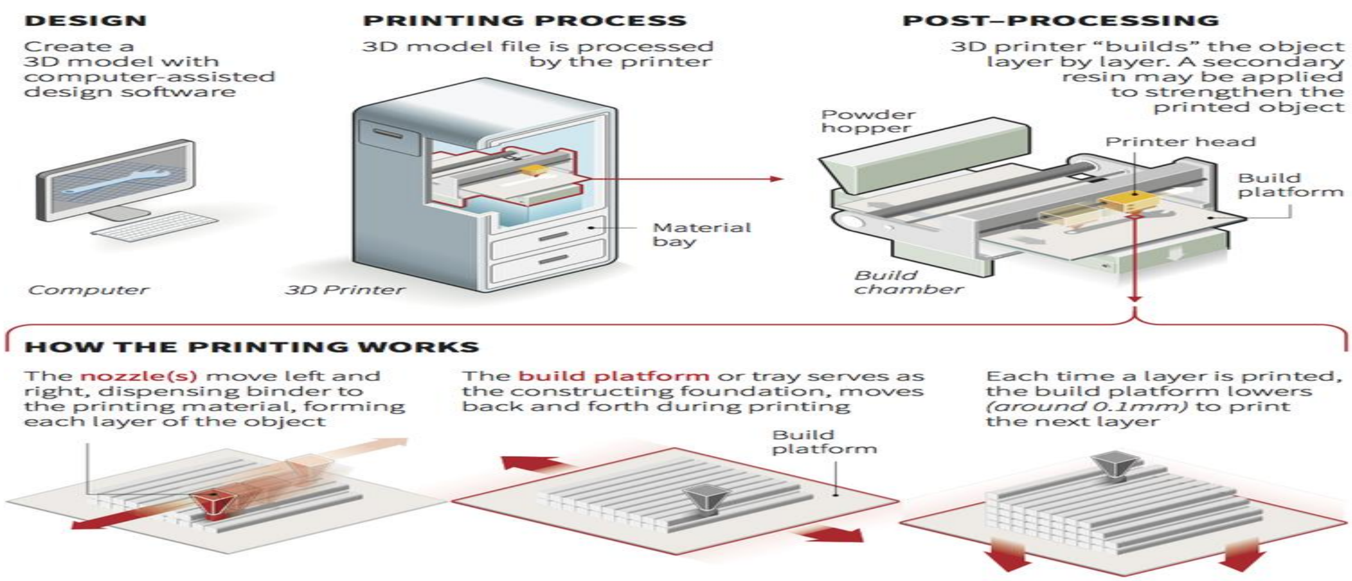

Figure 8: Working principle of Fused Deposition Modeling 3D printer.
Source: Hewlett-Packard; 3D systems; How Stuff Works; Engineering and Manufacturing

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Beaumont et al., (1958) states that, X-Y resolution are comparable to that of laser printers. The particles in form of 3D dots are around 50 to 100 µm (510 to 250 DPI) in diameter. Construction of a model with contemporary methods can be taken anywhere from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems can typically reduce this time to a few hours, although it varies widely depending on the type of machine used and the size and number of models being produced simultaneously. Traditional techniques like injection molding can be less expensive for manufacturing polymer products in high quantities, but additive manufacturing can be faster, more flexible and less expensive when producing relatively small quantities of parts. 3D printers give designers and concept development teams, the ability to produce parts and concept models using a desktop size printer.

Most printers have low resolutions on the product. Frick, et al., (2013) commented that a higher resolution subtractive process can achieve greater precision. Some printable polymers allow the surface finish to be smoothed and improved using chemical vapor processes. However, some additive manufacturing techniques are capable of using multiple materials in the course of constructing a part. These techniques are able to print in multiple colors and color combinations simultaneously. Some printing techniques require internal supports to be built for overhanging features during construction. These supports must be mechanically removed or dissolved upon completion of the print. All of the commercialized metal 3-D printers involve cutting the metal component off the metal substrate after deposition. A new process for the GMAW 3-D printing allows for substrate surface modifications to remove aluminum or steel (Amberlee et al., 2014).

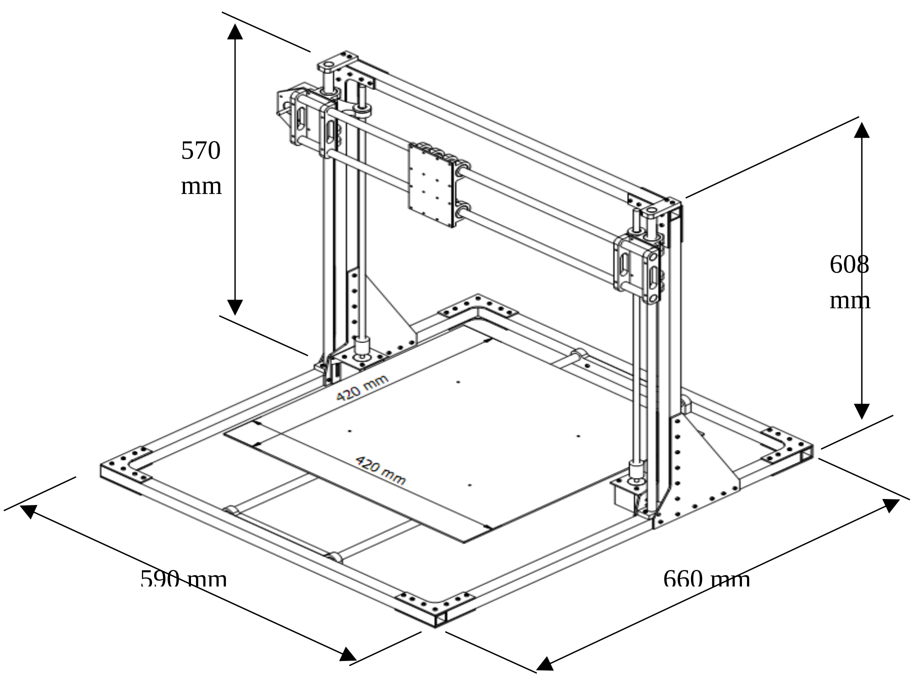

Figure 9: Frame dimensions

3.2.4.DESIGN SPECIFICATION OF THE FRAME

3.2.5. BUBBLE DIAGRAM

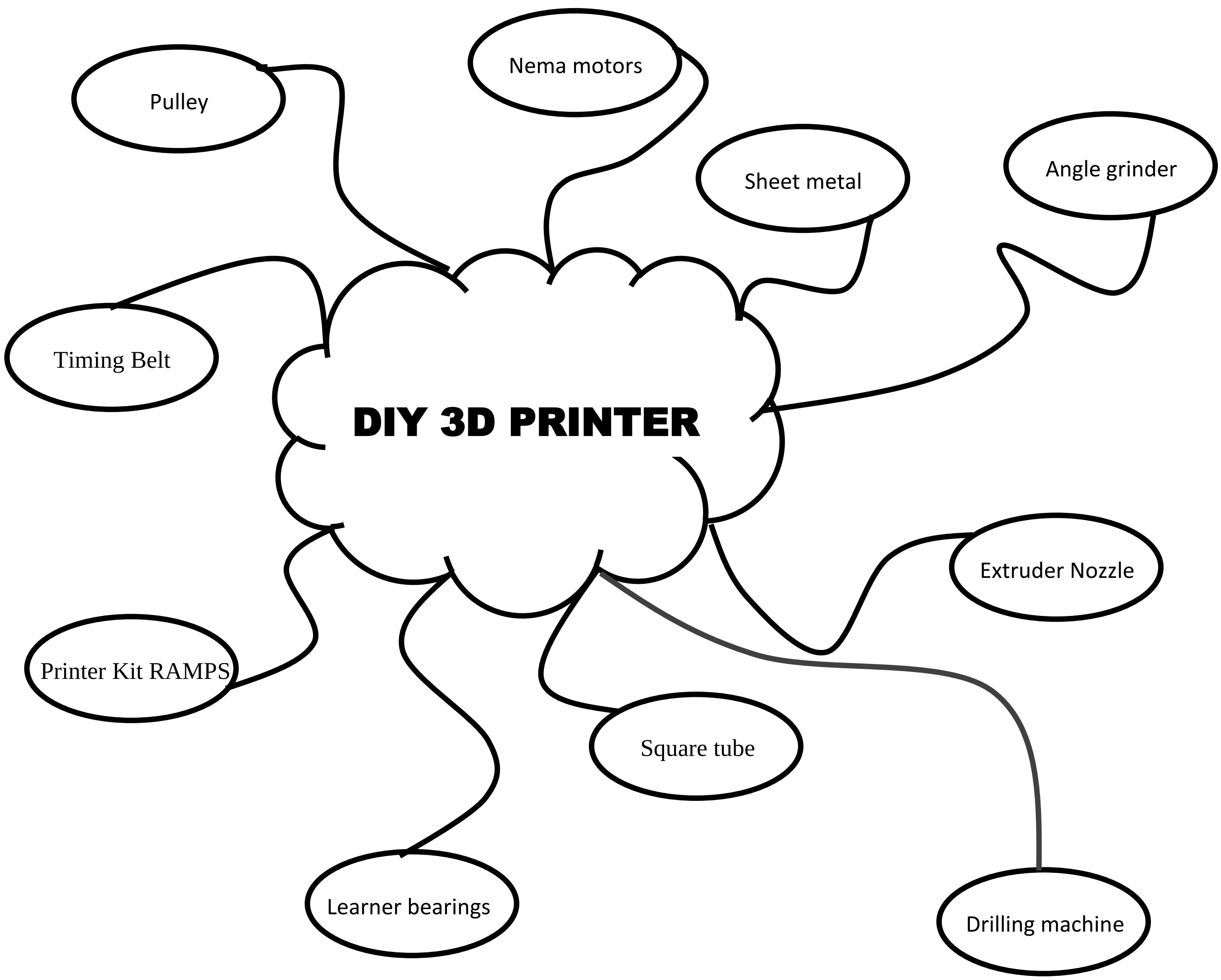

Figure 10: Bubble diagram,
Source: Kalimanshi Winwright, 2019

3.3.0. COMPONENTS OF THE DIY 3D PRINTER

The following below are a few components used in the making of the DIY 3D printer.

ELECTRONICS

3.3.13D PRINTER DIY KIT

The project opted to use scratch in built kit that contain most of the parts needed to assemble the printer. The kit contained:1 x 3D printer Controller RAMPS 1.4 board, 1 x Arduino-Compatible Mega 2560 R3, 5 x A4988 Step Stick Stepper Motor Drive Module, 1 x RAMPS LCD 12864 intelligent controller, 1 x Adapter, 2 Flat Festoon Cable and 1 x USB cable RAMPS 1.4 kit + Mega2560 + 5pcs A4988 + LCD 122864 Display for 3D printer Rep-Rap.

3.3.2. NEMA 17 STEPPER MOTOR

This was one of the components used in the project that make the DIY 3D printer to move in the X, Y and Z direction once in operation. The specifications of the motor are that, the shaft is 5mm diameter, Current per Phase: is2.0A, Holding Torque: 76 oz, Rated Voltage: 2.2V, Number of Phase: Two, Step Angle: 0.9° ± 5%, Resistance Per Phase: 1.1Ω± 10%, Inductance Per Phase: 3.0 mH ± 20%, Insulation Class: Class B, Dielectric Strength: 100Mohm, Operation Temp Range: -20 ~ +40° C, Lead Wire: 22AWG or 500mm.

3.3.3. LIQUID-CRYSTAL DISPLAY (LCD)

The LCD monitor on the local made 3D printer presents three-dimensional images without using goggles, the monitor is able switch between electrical flat display 2D and 3D dimensional modes, and furthermore, the monitor also display word processed data and spreadsheet files in 2D mode with the help of the computer graphics.

3.3.4. REPRAP ARDUINO MEGA POLOLU SHIELD 1.4 (RAMPS 1.4)

The RAMPS 1.4 board are used to fit the entire electronics part in the project, it consists of a RAMP 1.4 shield, an Arduino Mega 2560 board and a maximum of five Pololu stepper drivers. It has a very good interface and plenty of room for expansion. A number of Arduino expansion board can be added to the component as long as the main RAMP board is kept on top of the stack

HARDWARE'S

3.3.5. GT2 TIMING BELT

The GT2 timing belt with modified curvilinear tooth where used in the assembly because of their power grip, timing and quiet precision performance as compared to the conventional belt system.

3.3.6. ACME THREADED ROD

The ability of acme thread to work in power screwed machines regardless of their metric standard sand also their capability to withstand high tensional strength from large loads was used to make the Z movement in the project.

3.3.7. PULLEY

The aluminum pulley with less teeth was used in making the printer because, smaller pulley's gives more torque and good resolutions as compared to the pulley with more teeth.

3.3.8. EXTRUDER NOZZLE

The metal J-head Hotend extruder nozzle was used to eject the plastic material in liquid or semi-liquid form successive layer-by-layer during three dimensional prints.

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3.4.0. DESIGN ANALYSIS

3.4.1Other design considerations

There are a number of things to consider when designing and making a 3D printer. It is a known fact that all 3D printer machines print 3D objects. Regardless of this, printers have different capabilities and different design restrictions. There are a lot of things to consider when designing a DIY 3D printer locally, among them are the following: -

3.4.2. The filament types.

Currently, there are a number of different types of filaments used in DIY 3D printers. Therefore, it is important to consider the type of filament a particular machine uses to guarantee efficient operations. For example, the material for FDM and SLAcome in various colours and sizes.

3.4.4. The 3D printer DIY kit.

There are two types of do it yourself printer kits namely scratch built and kit-built type. The scratch built is preferred to the do it yourself in which individuals prefer to build things right from scratch by themselves, although they require some technical knowledge especially on the assembly part. For instance, knowing each and every nut and bolt involved in each design. The second one being the kit built which has no challenges compared to the latter. It is sold with easy instruction of assembly coupled with basic geometric instructions. However, it is important to know the kind of kit to purchase before making a DIY 3D printer.

3.4.4. Frame Material

The kind of materials to use in the making of the DIY 3D printer should be highly considered. Some material rust and others do not. For example, aluminum does not corrode, and other materials are lighter while others are heavier. If heavier material is used then the printer will not be so easily to be carried by an average person, portability will be a challenge.

3.5.5. Size of the printer

The other consideration is the printer size model, this will determine how long it will take in making especially on the frame assembly as well as printer settings. Smaller printer models have low quality settings but print in less time while bigger printer models have high quality products, but take several hours to print.

Chapter 4

4.0. THE EFFECT OF 3D PRINTERS

The locally designed and made DIY 3D printer will make a great effect in the education system, on entrepreneurs and the manufacturing industry in Zambia. The virtual framework of the DIY 3D printer used to manufacture real objects from a filament by slicing layer-by-layer has created a new perspective and promoted immense changes in the technology arena.

It is an obvious fact that the DIY 3D printer will make a huge contribution to the education sector. The Zambian Curriculum has included Information Communication Technology (ICT) and Design and Technology in its structure where learners will have to use various CAD packages. This printer will, therefore, be used by learners to produce real objects, hence promoting various skills and competencies among students in schools and colleges.

When the locally made 3D, printer gets on the Zambian market, it will make a lot of changes to small scale entrepreneurs, especially those that are in the field of designing and making of artifacts. A 3D printer is capable of making complicated parts to simple designs. For example, machine parts such as gears, hinges, impellers, bearing holders, just to mention a few that are of great relevance. SMEs would treasure to use a locally made 3D printer to make profit through a variety of products that they would churn or manufacture.

The other sectors that would benefit much from the locally made DIY 3D printer are companies dealing in machining and fabrication on a large scale. These industries use a lot of machinery in their operations. For example, Kalitony General Contractors, a company based in Mufulira that supplies spare parts to Mopani Copper Mines, African Explosives Limited and Chipolopolo Breweries Company as it engages in machining and fabrication of items such as nozzles, bushes, neck rings, flanges and pins. Most of its processes are in traditional manufacturing. Once acquired, the DIY 3D printer will shorten the process of production and reduce man power as well as increase its profit margins.

The conducted survey indicates that Mufulira town, has no 3D printer machine in existence so far, and evidently this technology is only promoted in the capital city of Zambia (Lusaka) and other industrialized parts of the country. However, Mufulira Mopani Copper Mines has benefited by acquiring a similar machine, i.e. Computer Numerical Control (CNC)profile machine cutter, which has made work easier by cutting sheet metal templates precisely as programmed from the computer for that cause.

3D printing has developed significantly over the past years and now allowing consumers and manufacturing companies to conduct rapid prototyping and even produce individual items at a profit. A new industrial revolution is coming up and commercial 3D printers are considerably smaller and more portable. As the cost of 3D printers has been decreasing drastically in the recent years, the technology has become accessible to businesses across the manufacturing industry.

Figure 33: CNC Profile Cutter – Mufulira Mopani Copper Mine workshop.

Despite not having DIY 3D printers in Mufulira town, this technology has made a lot of contributions to the manufacturing industry around the world. For instance, it makes consumers to be creative and innovative even where there is limited or marginal financial input, and less technological or human support from larger organisations.

Evidently, the acquisition of a 3D printer by manufacturing industries will reduce initial setting up costs in relation to plant creation, machinery acquisition and goes with less tooling costs. Quite naturally, the manufacturing industry has been the major user of 3D printing technology. Producing parts with low volumes or complex geometries, obtaining lighter parts, eliminating raw material wastage, increased gain of opportunities regarding testing and design, and customization are common reasons for employing 3D printing in the manufacturing business environment.

In the Education sector 3D printers have been used as an effective tool to improve educational practices, especially those related to Design and Technology and Physical Sciences. These 3D printers have not only enhanced educational activities in other areas, but also laid a foundation for accumulating knowledge on 3D printing technology. These could be supported by teacher training and related curriculum creation. 3D printing is now being integrated in the learning curriculum with its applications being utilised in printed molecular models and plastic gears (Jason Hidalgo et al: 2012). Students are now able to print their prototype models in 3D and this helps in the learning process of the students. Students are able to understand concepts better as it can be practically shown to them.

The other effect that 3D printer manufacturing has brought about to the medical fraternity is the creation of hearing aids (devices) and organ printing or human body imprints that are used as a form of implants of actual body parts (Athanasios et al: 2013). Body parts such as titanium pelvis, plastic tracheal splint, titanium jaws to mention but a few have been printed using 3D printing technology. Tissue engineering has made tremendous strides as it possible to engage in the printing of 3D blood vessels. People are getting 3D printed teeth customized for individuals. Dental Implants are being made on a commercial level making the whole process faster and more efficient in the contemporary world.

Being a promising technology, 3D printing has created great potential to bring about significant improvements to the manufacturing sector, particularly regarding designing, customization, and flexibility. 3D printing has also provided valuable opportunities for almost all areas by enhancing design and creation of objects in different ways. Furthermore, wide scale adoption of 3D printers by individuals seems to be on the horizon, which would crucially empower people to make a range of products.

Gravier M., et al (2016) observed that, supply chain constraints are found in traditional model industries, these include, efficiency on mass production, the need for low cost, high volume assembly of workers, and so forth. However, 3D printing bypasses these constraints by finding its value in low volume prints, thereby, providing customers with specific parts or components as desired. And in any case, these parts are of much greater complexity than possibly acquired through traditional manufacturing. This at once eliminates the need for both high volume production facilities and low-level assembly workers, thereby cutting

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out at least half of the supply chain in a single blow. From this point of view, it is no longer financially efficient to send products across the globe when manufacturing can be done almost anywhere at the same cost or lower. The raw materials today are digital files and the machines that make them are wired and connected, thus can be delivered faster and in more efficient patterns than ever before.

Additionally, the breadth and effect of AM continues to expand as the technology gains acceptance and functionality, making it a feasible means of production in a variety of industries. In the recent past, many companies have adopted AM and are beginning to reap the real benefits from this technology. Healthcare, automotive and aerospace industries are among the sectors with the greatest transformation potential in this light. AM technology has been pushed beyond the realm of prototyping and has become an effective means of advancing the way parts and tools are produced in the Aerospace industry. AM makes it possible to have objects printed in remote locations, as delivery of goods is no longer a restriction.

In order to benefit from the applications and opportunities of 3D printing, moving forward - companies in virtually every industry must be fast, flexible and capable of understanding the implications that 3D printing will have on the nature and scope of their businesses. Failing to do so will lead to a potential loss of market share, due to increased competition from new companies that create market changes and disruptive innovations. And competition won't stop there. As more and more individual consumers gain the ability to engineer and produce their own goods, and as 3D printing becomes a more efficient and cost-effective way to produce goods, there will be an opportunity for individuals to create new innovations, disrupt industries, and potentially generate new sources of wealth. As long as the technology is accessible, new businesses will continue to emerge. Although traditional manufacturing will likely to still hold a place in the competitive landscape in the years to come, the next years promise to reveal a rapid increase in the innovations made possible by 3D printing. To fully capitalize on these opportunities, governments may choose to make 3D printing widely accessible within free public service locations, such as schools and libraries. For the greater part, the private sector would equally be attracted to work towards embracing this technology as a platform for creation of new businesses, business models, products and services that push society forward by spurring the creation of this new source of global wealth.

One challenge could be that a 3D printed spare part could be made of a different material than the original and that the replacement needs to be fixed to the product especially if only a random piece of a component is considered.

Zambia has eight times less than the World Meteorological Organization's recommended number of weather stations needed to effectively monitor weather in a country. This is a problem for the developing country because its subsistence farmers rely on weather forecasts to manage their crops and its rural dwellers have little means of gaining knowledge of when a natural disaster would occur. To address this issue, scientists at the National Centre for Atmospheric Research (NCAR) have come up with a low-cost alternative to manage weather stations using 3D printing.

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Zambia's current weather stations equipment are outdated and need to be replaced with the new technology. The new technology total weather stations comprise 3D-printing frames and equipment that are of basic off-the-shelf sensors that monitor and store rainfall, detect temperature, relative humidity, air pressure data and wind speed. The whole system is powered by a single solar panel, and the plastic parts can easily be reproduced through use of a 3D printer when needed.

So far, in most of the weather stations in Zambia, meteorologists are working with the Zambian Meteorological Department to make the weather station's forecasts available to the citizens via radio and the web. To encourage the adoption of the project amongst the locals, the scientists intend to hand over the technology to their Zambian partners, who will be trained on how to read the data and how to build the machines. The goal here is to create a network of more than 100 weather stations that will offer enough data to start reading weather patterns in advance.

For the time being, the recently installed weather stations are providing much needed weather information for farmers and alerting communities about possible floods and other weather-related disasters.

Chapter 5

This chapter will give us a logical conclusion based on the objectives of the research and, thereafter, make relevant recommendations on improvements that could be done to the DIY 3D printer.

5.0. Conclusion and Recommendations

5.1. Conclusion.

Having designed and made the DIY 3D printer, I would with much pleasure and delight like to register that this is a simple and workable state of the art convention that should take center stage in this era of advancements in design and technology because of the following features that it comes with: For example, it uses a locally made frame from readily available materials compared to use of imported and highly expensive materials. At the same time the DIY printer kit comes with easy assembly instructions. Additionally, the material used for printing comes with a variety of colours at an affordable price for purchase. The use of a variety of filaments makes 3D printouts to be more attractive.

The printer can be made with less difficult if the right materials, tools and equipment are available in the workroom. It is highly beneficial to SMEs, manufacturers and schools as well. For example, the schools and colleges would greatly benefit from it as both a demonstrative and Teaching Aid and equally appreciate its efficiency in making designed project imprints from CAD. More so, it would serve as an important source of income to small medium entrepreneurs. Furthermore, it is renowned for cutting down the lengthy and laborious process used by traditional manufacturing processes in producing components.

5.2. Recommendations

From the experience obtained in designing and making of the DIY 3D printer locally in Zambia, it is recommended that: -

- When making the printer, precision in the mark out is cardinal and this is

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ensured by following the correct use of tools and equipment, there should be no short cuts in marking out. And if that is not carefully adhered to then the printer will be inaccurate in its operations.

- There should be trainings to educate people in electrical installations for DIY 3D printers. When people are skilled in electrical installation or wiring then the issues of maintenance would not be a problem to 3D printer uses.
- There should be much advocacy on the promotion of CAD packages in the Zambian school curriculum, so much that it is easily embraced at an early stage by scholars in the Design and Technology domain.
- The printer extruder nozzle needs to be multi-colour to accommodate variety filament colours and sizes so that there is beauty in finished printed objects.

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