DESIGN AND DEVELOPMENT OF HYPERCUBE 3D PRINTER

By

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I hereby declare that this thesis contains literature survey and original research work by the undersigned, as a part of Master of Production Engineering studies.

All information in this document have been obtained and presented in accordance with the academic rules and ethical conduct.

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Chapter 1: INTRODUCTION

1.1 CONCEPT OF ADDITIVE MANUFACTURING

3D Printing or Additive Manufacturing (AM) is any of various processes for making a 3-dimensional processes in which successive layers of material are laid down under computer control . A 3D printer is a type of industrial robot. Early AM equipment and materials where developed in the 1980s, chuck hull of 3D system corps, invented a process known as stereo lithography employing UV lasers to cure photopolymers. Hall also developed the STL file format widely accepted by 3D printing software, as well as the digital slicing and infilling strategy common to many process today. Also during the 1980s , the metal sintering forms of AM were being developed (such as selective laser sintering and direct metal laser sintering),although they were not yet called 3D printing or AM at that time .In 1990, the plastic extrusion technology most widely associated with the term “3D Printing “ was commercialized by strategy under the name fused deposition modeling (FDM). In 1995 , Z corporation commercialized an MIT -developed additive process under the trademark 3D printing (3DP), referring at that time to a proprietary process in jet deposition of liquid binder on powder AM technologies found application starting in the 1980’s in product development data visualization, rapid prototyping and specialized manufacturing. There expansion into production (job production, mass production and distributing manufacturing) has been under development in the decades since. Industrial production roles within the metal working industries achieved significant scale for the first time in the early 2010’s. Since the start of the 21st century there has been a large growth in the scales of AM machines and their price has dropped substantially. According to Wohlers Associates, consultancy, the market for 3D printers and service was worth $2.2 billion worldwide in 2012, up 29% from 2011. Applications are many, including architecture, construction (AEC), industrial design, automotive, aerospace, military, engineering, dental & medical industries, biotech(human tissue replacement), fashion, footwear, jewelry, eyewear, education, geographic information system, food & many other fields.

3D printing called as desktop fabrication. It is a rapid prototyping process whereby a real object can be created from a 3D design. A 3D printer machine uses a CAD model for rapid prototyping process.

1.2 HISTORY AND DEVELOPMENT PHASES OF ADDITIVE MANUFACTURING

a) **1981:** Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two additive methods for fabricating three-dimensional plastic models with photo-hardening thermoset polymer, where the UV exposure area is controlled by a mask pattern or a scanning fiber transmitter.

b) **1984**: On 16 July 1984, Alain Le Méhauté, Olivier de Witte, and Jean Claude André filed their patent for the stereo lithography process.

c) **1988**: The technology used by most 3D printers to date—especially hobbyist and consumer-oriented models—is fused deposition modeling, a special application of plastic extrusion, developed in 1988 by S. Scott Crump and commercialized by his company Stratasys, which marketed its first FDM machine in 1992.

d) **1993**: The term *3D printing* originally referred to a powder bed process employing standard and custom inkjet print heads, developed at MIT in 1993 and commercialized by Soligen Technologies, Extrude Hone Corporation, and Z Corporation.

e) **1995**: In 1995 the Fraunhofer Institute developed the selective laser melting process.

f) **2009**: Fused Deposition Modeling (FDM) printing process patents expired in 2009.

g) **2012:** Filabot develops a system for closing the loop with plastic and allows for any FDM or FFF 3D printer to be able to print with a wider range of plastics.

h) **2014:** Georgia Institute of Technology Dr. Benjamin S. Cook, and Dr. Manos M. Tentzeris demonstrate the first multi-material, vertically integrated printed electronics additive manufacturing platform (VIPRE) which enabled 3D printing of functional electronics operating up to 40GHz.

1.3 DIFFERENCE BETWEEN ADDITIVE AND SUBTRACTIVE MANUFACTURING

Additive Manufacturing	**Subtractive Manufacturing**
Involves adding layers of material to create an object.	Removes material from the object.
Processes include 3D printing, direct digital manufacturing, rapid prototyping or additive and layered fabrication.	The process is either by: manual removal, traditional machining or CNC machining
Uses computers and specialist 3D printing equipment to create products and prototype.	Uses computers and robotics to assist standard machining processes, e.g., turning, drilling or milling
The layering often leaves a slightly 'stepped' or rough surface which needs to be finished post-printing by sanding or blowing.	A variety of surface finishes can be machined including smooth, stepped, mottled etc.
Intricate and hollow objects can easily be built up in layers.	Milling undercuts and intricate shapes can be difficult.
Best suited for smaller items or parts, especially in plastic.	Best suited for manufacturing voluminous items and parts, especially in metal.
Depending on the size of the object, 3D can be a slow process.	Relatively fast process.
Software is available to directly link the design to a 3D printer, so a machine operator isn't necessary.	A CNC machinist is required to operate the mill or machine and oversee the production. However, new automated software means that programming machine-executable code is no longer needed.

Overall, 3D printing is a fairly cheap process.	Generally, more expensive than additive manufacturing.

1.4 APPLICATIONS OF ADDITIVE MANUFACTURING

Three dimensional printing makes it as cheap to create single items as it is to produce thousands and thus undermines economies of scale. it may have as profound an impact on the world as the coming of the factory did just as nobody could have predicted the impact of the steam engine in 1750 or the printing press in 1450, or the transistor in 1950. It is impossible to foresee the long-term impact of 3d printing but the technology is coming, and it is likely to disrupt every field it touches.

a) MANUFACTURING APPLICATION

1. Cloud-based additive manufacturing: Additive manufacturing in combination with cloud computing technologies allows decentralized and geographically independent distributed production. Cloud-based additive manufacturing refers to a service-oriented networked manufacturing model in which service consumers are able to build parts through Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), Hardware-as-a-Service (HaaS), and Software-as-a-Service (SaaS). Distributed manufacturing as such is carried out by some enterprises; there is also a services like 3D Hubs that put people needing 3D printing in contact with owners of printers.
2. Mass customization: Companies have created services where consumers can customize objects using simplified web based customization software, and order the resulting items as 3D printed unique objects. This now allows consumers to create custom cases for their mobile phones. Nokia has released the 3D designs for its case so that owners can customize their own case and have it 3D printed.
3. Rapid manufacturing:_Advances in RP technology have introduced materials that are appropriate for final manufacture, which has in turn introduced the possibility of directly manufacturing finished components. One advantage of 3D printing for rapid manufacturing lies in the relatively inexpensive production of small numbers of parts.

4. Rapid Prototyping: Industrial 3D printers have existed since the early 1980s and have been used extensively for rapid prototyping and research purposes. These are generally larger machines that use proprietary powdered metals, casting media (e.g. sand), plastics, paper or cartridges, and are used for rapid prototyping by universities and commercial companies.

b) MEDICAL APPLICATIONS

Surgical uses of 3D printing-centric therapies have a history beginning in the mid-1990s with anatomical modeling for bony reconstructive surgery planning. By practicing on a tactile model before surgery, surgeons were more prepared and patients received better care. Patient-matched implants were a natural extension of this work, leading to truly personalized implants that fit one unique individual. Virtual planning of surgery and guidance using 3D printed, personalized instruments have been applied to many areas of surgery including total joint replacement and craniomaxillofacial reconstruction with great success. Further study of the use of models for planning heart and solid organ surgery has led to increased use in these areas. Hospital-based 3D printing is now of great interest and many institutions are pursuing adding this specialty within individual radiology departments. The technology is being used to create unique, patient-matched devices for rare illnesses. One example of this is the bioresorbable trachial splint to treat newborns with tracheobronchomalacia developed at the University of Michigan. Several devices manufacturers have also begin using 3D printing for patient-matched surgical guides (polymers). The use of additive manufacturing for serialized production of orthopedic implants (metals) is also increasing due to the ability to efficiently create porous surface structures that facilitate osseointegration. Printed casts for broken bones can be custom-fitted and open, letting the wearer scratch any itches, wash and ventilate the damaged area. They can also be recycled.

Fused filament fabrication (FFF) has been used to create microstructures with a three-dimensional internal geometry. Sacrificial structures or additional support materials are not needed. Structure using polylactic acid (PLA) can have fully controllable porosity in the range 20%–60%. Such scaffolds could serve as biomedical templates for cell culturing, or biodegradable implants for tissue engineering.

c) INDUSTRIAL APPLICATION

1. Apparel
2. Industrial art and jewellery
3. Automotive industry
4. Construction
5. Fire arms
6. Computer and robots
7. Soft sensors and actuators.

d) SOCIO CULTURAL APPLICATIONS

1. Art and jewelry
2. Communication
3. Domestic use
4. Education and research
5. Cultural heritage.

1.5 ADVANTAGES OF 3D PRINTER

a) Anything with great geometrical complexity.

b) Ability to personalize every product with individual customer need.

c) Produce products which involve greate level of complexity that simply could not be produce physically in any other way.

d) Additive manufacturing can eliminate the need for tool production and therefore reduces the cost, lead time, and labour associated with it.

e) 3D printing is an energy efficient technology.

f) Additive manufacturing use up to 90% of standard materials and therefore creating less waste.

g) Lighter and stronger products can be printed.

h) Increase operating life for the products**.**

i) Production has been brought closer to the end user or consumer.

j) Spare parts can be printed on site which will eliminate shipping cost.

k) Wider adoption of 3d printing would likely cause re-invention of a number of already invented products.

l) 3D printing can create new industries and complete new profession.

m) Printing 3d organs can revolutionaries the medical industry.

1.6 DISADVANTAGES OF 3D PRINTER

a) High Energy Consumption

According to research by Loughborough University, 3D printers consume approximately 50 to 100 times more energy than injection molding, when melting plastic with heat or lasers. In 2009, studies at The Environmentally Benign Manufacturing, a research group dedicated to investigating the environmental impacts related to product manufacturing, showed that direct laser metal deposition uses 100 times as much electrical energy as traditional manufacturing. For mass production, 3D printers consume a lot of energy and are therefore better suited for small batch production runs.

b) 3D Printing Technology is Expensive

3D printing equipment and materials cost make the technology expensive. Industrial grade 3D printers are still expensive costing hundreds of thousands of dollar, which makes the initial expenses of using the technology very high. For a single machine, capital investment starts in the tens of thousands of dollars, and can increase to as high as hundreds of thousands of dollars or more. Also, the materials used in commercial grade 3D printers are costly compared to product materials used in traditional manufacturing.

c) Limited Materials

While 3D printing is a significant manufacturing breakthrough, materials that can be used are still limited, and some are still under development. For example, the 3D printing material of choice is plastic. Plastic is preferred as it can quickly and easily be deposited down in melted layers to form the final product. However, plastic may vary in strength capacity and may not be the best for some components. Some companies offer metal as a material, but final product parts are often not fully dense. Other specialized materials including glass and gold are being used but are yet to be commercialized.

d) 3D Printers Aren’t that User-friendly

Because of the excitement and potential around 3D printing technology, 3D printers have come across as easy to use and also sound more useful than they really are. The truth is 3D printers use high-voltage power supplies, specialized equipment, and parts which makes them difficult to use and manage. Some have low resolution and can’t even connect to Wi-Fi. Improvements have been made here and it’s getting easier to 3D print day by day.

e) Harmful Emissions

3D printers used in enclosed places such as homes can generate potentially toxic emissions and carcinogenic particles according to researchers at the Illinois Institute of Technology. Their 2013 research study showed that 3D desktop computers could emit large numbers of ultrafine particles and some hazardous volatile organic compounds during printing. The printers emitted 20 billion ultrafine particles per minute using PLA filament, and the ABS emitted up to 200 billion particles per minute. Emitted radiations are similar to burning a cigarette, and may settle in the bloodstream or lungs posing health risks including cancer and other ailments.

f) Too Much Reliance on Plastic

Popular and cheap 3D printers use a plastic filament. Although using raw plastic reduces waste generation, the machines still leave unused or excess plastic in the print beds. PLA is biodegradable, but ABS filament is still the most commonly used type of plastic. The plastic byproduct ends up in landfills negatively affecting the environment. Furthermore, plastic limits the type of products that can be created from the material. Future 3D printers will need to use other materials such as metal (as some currently do) or carbon composites to become more useful to manufacturers and consumers alike.

g) 3D Printers are Slow

While 3D printers are limitless for mass customization, they are slow when it comes to manufacturing many objects. Depending on printer size and quality, it can take several hours to days to print. The more the work involved with product development, the slower the printers. Companies that receive orders to customize and make 3D prints using a variety of products can take up several weeks to print depending on the materials used.

h) Production of Dangerous Weaponry

With 3D printers, it is easy to create 3D knives, guns, explosives, and any other dangerous items. Criminals and terrorists can, therefore, make such weapons without being detected. Some criminal organizations have already used 3D printing technology to create card readers for bank machines. As time goes on, 3D technology will become more user-friendly and cost-effective, and it is possible that design and production of unlicensed weaponry will increase.

i) Copyright Infringements

Counterfeiting is one the most significant disadvantages of 3D printing. Anyone with a product blueprint can forge products very quickly. Patent violations will increasingly become more common, and identifying counterfeited items will become practically impossible. As 3D printing technology evolves, patents, and copyright holders will have a harder time protecting their rights and companies manufacturing unique products will be significantly affected.

j) Manufacturing Job Losses

3D printing technology can make product designs and prototypes in a matter of hours as it uses only one single step. It eliminates a lot of stages that are used in subtractive manufacturing. As a result it doesn’t require a lot of labor cost. As such, adopting 3D printing may decrease manufacturing jobs. For countries that rely on a large number of low skill jobs, the decline in manufacturing jobs could dramatically affect the economy. It’s likely that robotics will have a much larger impact here.

1.7 CLASSIFICATION OF ADDITIVE MANUFACTURING

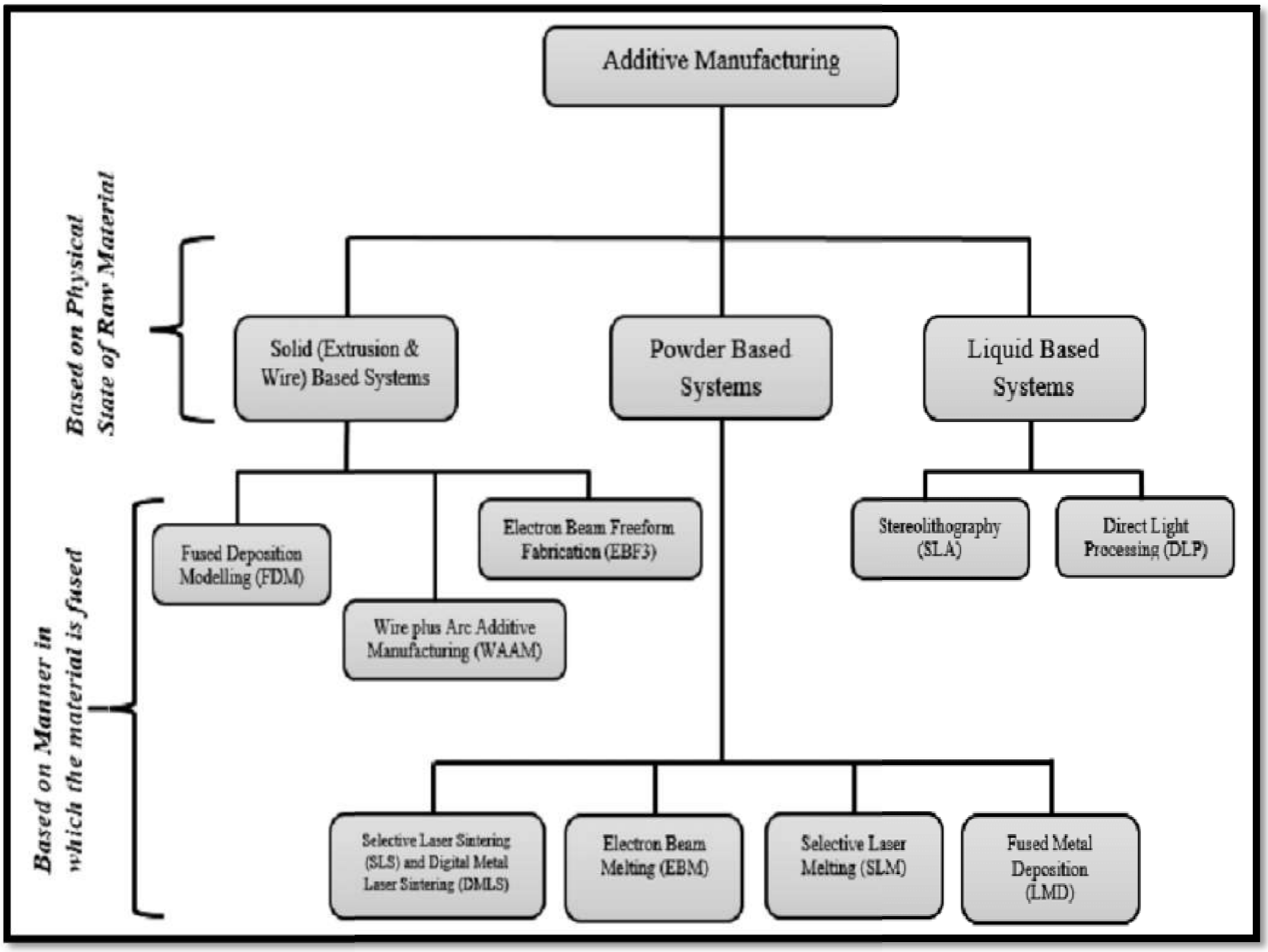


Fig 1.1: Classification of additive manufacturing.

1.8 IMPORTANT ADDITIVE MANUFACTURING TECHNOLOGIES

1. Selective laser sintering.

Selective laser sintering (SLS) is an additive manufacturing (AM) technique that uses a laser as the power source to sinter powdered material (typically nylon/polyamide), aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure. It is similar to Selective Laser

Melting (SLM); the two are instantiations of the same concept but differ in technical details. Selective laser melting (SLM) uses a comparable concept, but in SLM the material is fully melted rather than sintered, allowing different properties (crystal structure, porosity, and so on). SLS (as well as the other mentioned AM techniques) is a relatively new technology that so far has mainly been used for rapid prototyping and for low-volume production of component parts. Production roles are expanding as the commercialization of AM technology improves.

Technology: An additive manufacturing layer technology, SLS involves the use of a high power laser (for example, carbon dioxide) 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.

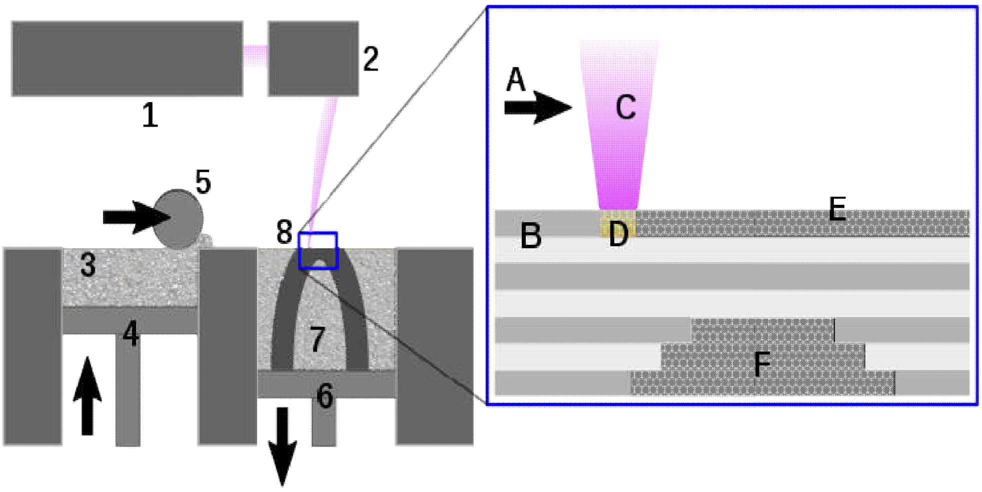


Fig 1.2: Selective Laser Sintering Process

1. Laser.
2. Scanner system.
3. Powder delivery system.

4. Powder delivery piston.
5. Roller.
6. Fabrication piston.
7. Fabrication powder base.
8. Object being fabricated.
   A. Laser scanning direction.
   B. Sintered powder particles (brown state)
   C. Laser beam.
   D. Laser sintering.
   E. Pre-placed powder base.

2. Fused Deposition Modeling.

Fused filament fabrication (***FFF***), also known under the trademarked term **fused deposition modeling** (***FDM***), sometimes also called *filament freeform fabrication*, is a 3D printing process that uses a continuous filament of a thermoplastic material.Filament is fed from a large coil through a moving, heated printer extruder head, and is deposited on the growing work. The print head is moved under computer control to define the printed shape. Usually the head moves in two dimensions to deposit one horizontal plane, or layer, at a time; the work or the print head is then moved vertically by a small amount to begin a new layer. The speed of the extruder head may also be controlled to stop and start deposition and form an interrupted plane without stringing or dribbling between sections. "Fused filament fabrication" was coined by the members of the RepRap project to give a phrase that would be legally unconstrained in its use, given trademarks covering "fused deposition modeling".

Fused filament printing is now the most popular process (by number of machines) for hobbyist-grade 3D printing. Other techniques such as photopolymerisation and powder sintering may offer better results, but they are much more costly.

The 3D printer head or 3D printer extruder is a part in material extrusion additive manufacturing responsible for raw material melting and forming it into a continuous profile. A wide variety of filament materials are extruded, including thermoplastics such as acrylonitrile butadiene styrene (ABS), polylactic acid(PLA), high-impact polystyrene (HIPS), thermoplastic polyurethane(TPU) and aliphatic polyamides (nylon).

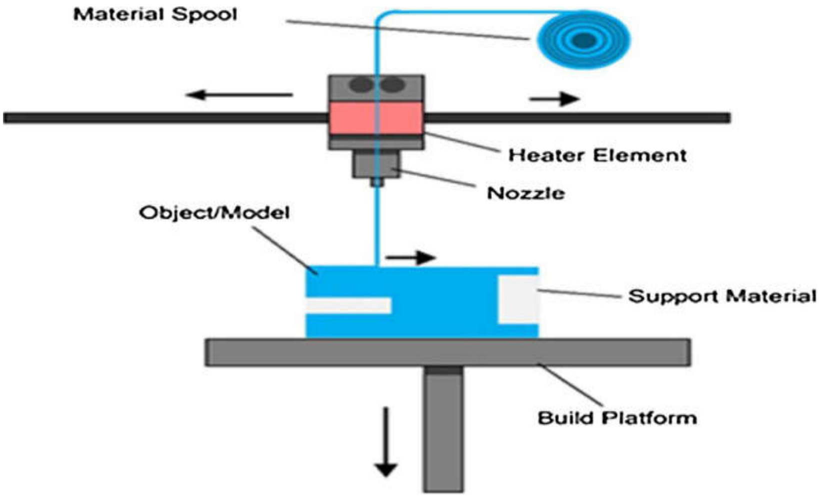


Fig 1.3: Fused Deposition Modeling.

3. Stereo-lithography.

Stereolithography (SLA also known as stereolithography apparatus, optical fabrication, photo-solidification, or resin printing) is a form of 3D printing technology used for creating models, prototypes, patterns, and production parts in a layer by layer fashion using photochemical processes by which light causes chemical monomers to link together to form polymers. Those polymers then make up the body of a three-dimensional solid. Research in the area had been conducted during the 1970s, but the term was coined by Chuck Hull in 1984 when he applied for a patent on the process, which was granted in 1986. Stereolithography can be used to create prototypes for products in development, medical models, and computer hardware, as well as in many other applications. While stereolithography is fast and can produce almost any design, it can be expensive.

Stereolithography is an additive manufacturing process that, in its most common form, works by focusing an ultraviolet (UV) laser on to a vat of photopolymer resin. With the help of computer aided manufacturing or computer-aided design (CAM/CAD) software, the UV laser is used to draw a pre-programmed design or shape on to the surface of the photopolymer vat.

Photopolymers are sensitive to ultraviolet light, so the resin is photochemically solidified and forms a single layer of the desired 3D object. Then, the build platform lowers one layer and a blade recoats the top of the tank with resin. This process is repeated for each layer of the design until the 3D object is complete. Completed parts must be washed with a solvent to clean wet resin off their surfaces.

It is also possible to print objects "bottom up" by using a vat with a transparent bottom and focusing the UV or deep-blue polymerization laser upward through the bottom of the vat. An inverted stereolithography machine starts a print by lowering the build platform to touch the bottom of the resin-filled vat, then moving upward the height of one layer. The UV laser then writes the bottom-most layer of the desired part through the transparent vat bottom. Then the vat is "rocked", flexing and peeling the bottom of the vat away from the hardened photopolymer; the hardened material detaches from the bottom of the vat and stays attached to the rising build platform, and new liquid photopolymer flows in from the edges of the partially built part. The UV laser then writes the second-from-bottom layer and repeats the process. An advantage of this bottom-up mode is that the build volume can be much bigger than the vat itself, and only enough photopolymer is needed to keep the bottom of the build vat continuously full of photopolymer. This approach is typical of desktop SLA printers, while the right-side-up approach is more common in industrial systems.

Stereolithography requires the use of supporting structures which attach to the elevator platform to prevent deflection due to gravity, resist lateral pressure from the resin-filled blade, or retain newly created sections during the "vat rocking" of bottom up printing. Supports are typically created automatically during the preparation of CAD models and can also be made manually. In either situation, the supports must be removed manually after printing.

Other forms of stereolithography build each layer by LCD masking, or using a DLP projector

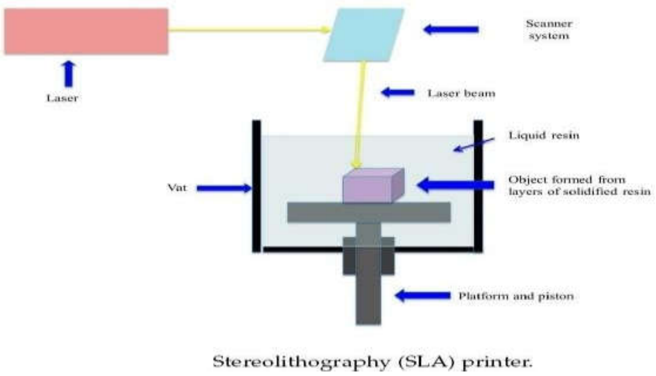


Fig 1.4: Stereo-lithograpghy printer.

4. Laminated object manufacturing.

Laminated object manufacturing (**LOM**) is a rapid prototyping system developed by Helisys Inc. (Cubic Technologies is now the successor organization of Helisys) In it, layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter. Objects printed with this technique may be additionally modified by machining or drilling after printing. Typical layer resolution for this process is defined by the material feedstock and usually ranges in thickness from one to a few sheets of copy paper.

The process is performed as follows:

a) Sheet is adhered to a substrate with a heated roller.

b) Laser traces desired dimensions of prototype.

c) Laser cross hatches non-part area to facilitate waste removal.

d) Platform with completed layer moves down out of the way.

e) Fresh sheet of material is rolled into position.

f) Platform downs into new position to receive next layer.

g) The process is repeated until full model or prototype prepared.

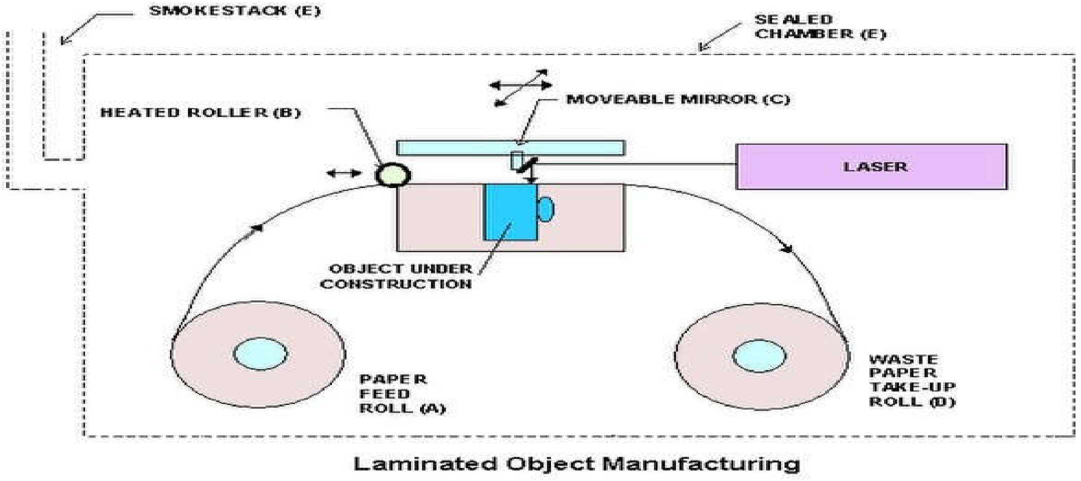


Fig 1.5: Laminated object manufacturing.

5. Ink-jet printer.

This method uses a single jet each for a plastic build material and a wax-like support material, which are held in a melted liquid state in reservoirs. The liquids are fed to individual jetting heads which squirt tiny droplets of the materials as they are moved in X-Y fashion in the required pattern to form a layer of the object. The materials harden by rapidly dropping in temperature as they are deposited. After an entire layer of the object is formed by jetting, a milling head is passed over the layer to make it a uniform thickness. Particles are vacuumed away and are captured in a filter. The process is repeated to form the entire object. After the object is completed, the wax support material is either melted or dissolved away. The most outstanding characteristic of the Solid-scape system is the ability to produce extremely fine resolution and surface finishes, essentially equivalent to CNC machines. The technique is very slow for large objects. Materials selection is very limited. Other manufacturers use considerably different inkjet techniques, but all rely on squirting a build material in a liquid or melted state which cools or otherwise hardens to form a solid on impact. 3D Systems produces an inkjet machine called the Thermo-Jet Modeler (TM) which utilizes several hundred nozzles in a wide head configuration. It uses a hair-like matrix of build material to provide support for overhangs which can be easily brushed off once the object is complete. This machine is much faster than the Solid-scape approach, but doesn't offer as good a surface finish or resolution.

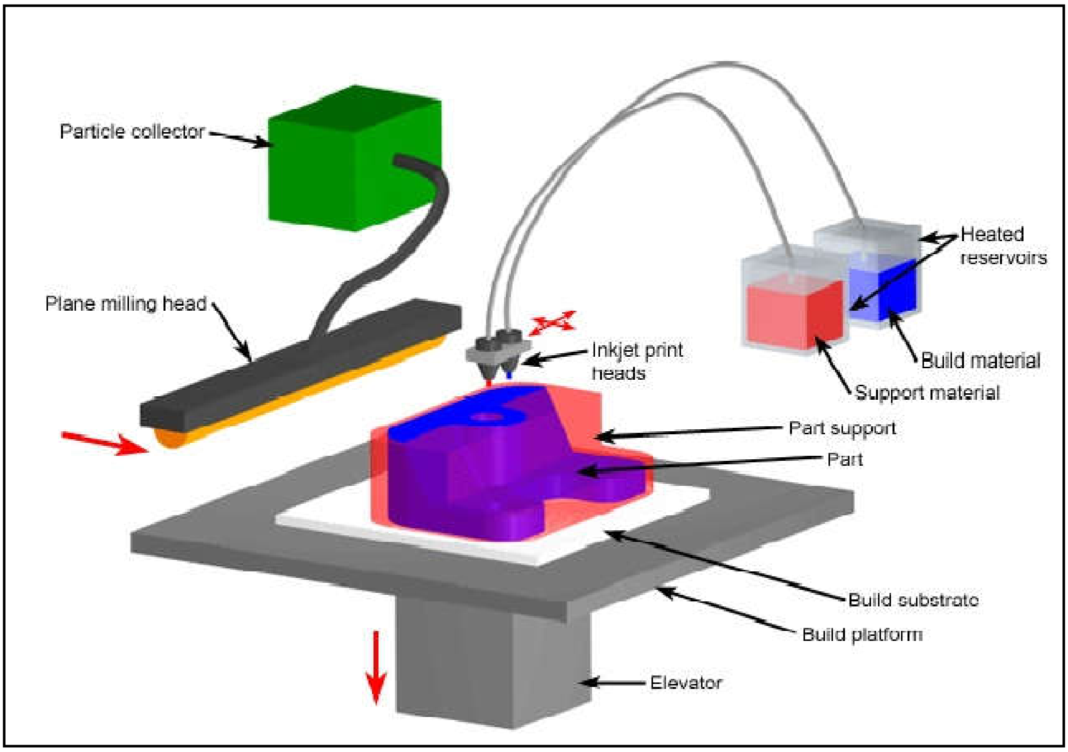


Fig 1.6: Ink-jet Printer.

6. Selective Laser Melting.

Selective laser melting (**SLM**), also known as **direct metal laser sintering** (**DMLS**) or **laser powder bed fusion** (**LPBF**), is a rapid prototyping, 3D printing, or additive manufacturing (AM) technique designed to use a high power-density laser to melt and fuse metallic powders together. In many SLM is considered to be a subcategory of selective laser sintering (SLS). The SLM process has the ability to fully melt the metal material into a solid three-dimensional part unlike SLS.

DMLS uses a variety of alloys, allowing prototypes to be functional hardware made out of the same material as production components. Since the components are built layer by layer, it is possible to design organic geometries, internal features and challenging passages that could not be cast or otherwise machined. DMLS produces strong, durable metal parts that work well as both functional prototypes or end-use production parts.

The process starts by slicing the 3D CAD file data into layers, usually from 20 to 100 micrometers thick, creating a 2D image of each layer; this file format is the industry standard .stl file used on most layer-based 3D printing or stereolithography technologies. This file is then loaded into a file preparation software package that assigns parameters, values and physical supports that allow the file to be interpreted and built by different types of additive manufacturing machines.

With selective laser melting, thin layers of atomized fine metal powder are evenly distributed using a coating mechanism onto a substrate plate, usually metal, that is fastened to an indexing table that moves in the vertical (Z) axis. This takes place inside a chamber containing a tightly controlled atmosphere of inert gas, either argon or nitrogen at oxygen levels below 500 parts per million. Once each layer has been distributed, each 2D slice of the part geometry is fused by selectively melting the powder. This is accomplished with a high-power laser beam, usually an ytterbium fiber laser with hundreds of watts. The laser beam is directed in the X and Y directions with two high frequency scanning mirrors. The laser energy is intense enough to permit full melting (welding) of the particles to form solid metal. The process is repeated layer after layer until the part is complete.

The DMLS machine uses a high-powered 200 watt Yb-fiber optic laser. Inside the build chamber area, there is a material dispensing platform and a build platform along with a recoater blade used to move new powder over the build platform. The technology fuses metal powder into a solid part by melting it locally using the focused laser beam. Parts are built up additively layer by layer, typically using layers 20 micrometers thick.

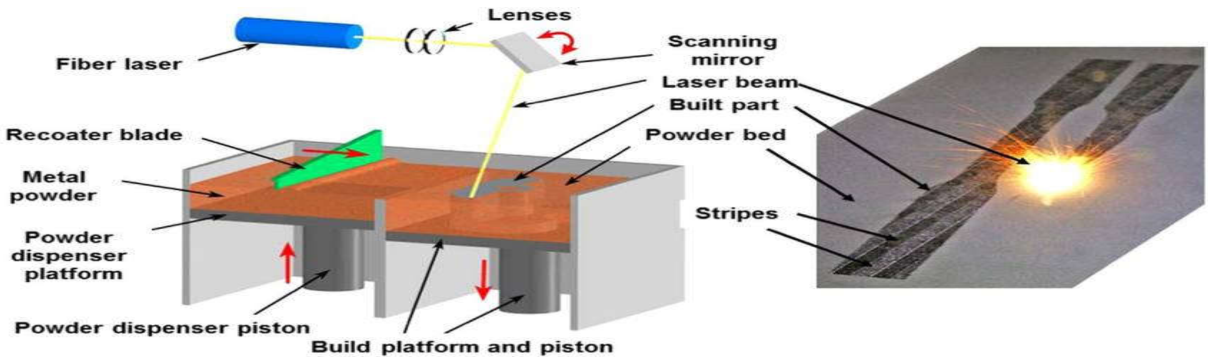


Fig 1.7: Selective laser melting.

1.9 LITERATURE REVIEW

Jason A. Inzana, Diana Olvera[1] used phosphoric acid-based binder solution concentration to 8.75% to maximize cytocompatibility and mechanical strength, with a supplementation of Tween 80 to improve 3D printing of collagen. To further enhance the formulation, collagen was dissolved into the binder solution to fabricate collagen-calcium phosphate composites. Reducing the viscosity and surface tension through a physicologic heat treatment and Tween 80, respectively, enabled reliable thermal inkjet printing of the collagen solutions. Supplementing the binder solution with 1-2wt% collagen significantly improved maximum flexural strength and cell viability. To access the bone healing performance, they implanted 3D printed scaffolds into a critically sized murine femoral defect for 9 weeks. The implants were confirmed to be osteoconductive, with new bone growth incorporating the degrading scaffold materials. Overall, their study demonstrated optimization of material parameters for 3D printing calcium phosphate scaffolds and enhancement of material properties by volumetric collagen incorporation via inkjet printing.

Anh-Vu Do, Dehnoush Khorsand[2] analysed the criteria for viable printing scaffolds materials and 3-D printing technologies for tissue engineering. They developed the 3-D printed scaffolds that closely resemble the micro-environment properties at the site of implantation, such as ECM properties, load bearing mechanical properties, pore size arrangements to allow nutrient diffusion and cell mitigation, and appropriate growth factor milieu for promotion of angiogenesis and/or osteogenesis. As new material and “bioinks” are synthesized and novel printing methods are discovered, the 3D scaffolds to be used in tissue engineering continues to become more sophisticated and effective. The 3D printing techniques and materials discussed in their review are likely to contribute to improve approaches to generating functional tissue for replacement and repair.

Andrew Pfister, Rudiger Landers[3] compared two important rapid-prototyping technologies that is 3D printing and 3D bio-plotting with respect to the computer-aided design and free-form fabrication of biodegradable polyurethane scaffolds meeting the demands of tissue-engineering applications. Aliphatic polyurethanes were based on lysine ethyl ester di-isocyanate and isophorone diisocyanate. Layer-by-layer construction of the scaffolds was performed by 3D printing, that is, bonding together starch particles followed by infiltration and partial crosslinking of starch with lysine ethyl ester diisocyanate. Alternatively, the 3D Bioplotting process permitted 3D dispensing and ethylene oxide and glycerol. The scaffolds were characterized with X-Rays microtomography, scanning electron microscopy and mechanical testing. Osteoblast-like cells were seeded on such scaffolds to demonstrate their potential in tissue engineering.

Susmita Bose, Sahar Vahabzadeh and Amit Bandyopadhyay[4] focused on recent advances in 3D printed bone tissue engineering scaffolds along with current challenges and future directions. It also emphasises on the recent development in the field of 3D printing. Many applications benefited from the faster processing of products without the need for specific tooling or dies. However, the performance criteria and concerns related to reproducibility and part quality, when new technologies are in their infancy. However, the use of additive manufacturing technology options, three dimensional printing is becoming popular due to the ability to directly print porous scaffolds with designed shape, controlled chemistry and interconnected porosity. Some of these inorganic scaffolds are biodegradable and have proven ideal for bone tissue engineering, sometimes even with site specific growth factor/drug delivery abilities.

Barbara Leukers, Stephan H.Irsen, Stefen Milz[5] focused on scaffold design for historical evaluation of seeded scaffolds, optimize seeding efficiency and observe the cell proliferation into the inner structure with a special design of the scaffolds. Nowadays, there is a significant need for synthetic bone replacement materials used in bone tissue engineering (BTE). Rapid prototyping and especially 3D printing is suitable technique to create custom implants based on medical data sets. 3D printing allows fabricating scaffolds based on Hydroxyapatite with complex internal structures and high resolution. To determine the in-vitro behaviour of the cells cultivated on the scaffolds, they designed a special test-part. MC3T3-E1 cells were seeded on the scaffolds and cultivated under the dynamic setups. Histological evaluation was carried out to characterise the cell growth. In summary, the dynamic cultivation method lead to a stronger population compared to the static cultivation method. The cells proliferated deep into the structure forming close contact to Hydroxyapatite.

F.Rengier, A.Mehndiratta[6] generated graspable three dimensional objects applied for surgical planning, prosthetics and related application using 3D printing or rapid prototyping. Graspable 3D objects overcome the limitations of 3D visualisations which can only be displayed on flat screens.3D objects can be produced based on CT or MRI volumetric medical images. Using dedicated post-processing algorithms, a spatial model can be extracted from image data sets and exported to machine-readable data. That spatial model data is utilized by special printers for generating the final prototype model. Patient-clinician interation, surgical training, mediacl research and education may require graspable 3D objects. The limitation of rapid prototyping include cost and complexity, as well as the need for specialized equipments and consumables such as photoresist resins. Medical application of rapid prototyping is feasible for specialized surgical planning and prosthetics applications and has significant potential for development of new medical applications.

Thomas A. Chambell, Olga S.Ivanova[7] discussed the possibilities of adding nanometre like carbon nanotubes, nanowires and quantum dots to host matrices such as polymers and ceramics via Addictive Manufacturing(AM) to enhance greater capabilities in nanocomposities production. Additive manufacturing holds strong potential for the formation of a new class of multifunctional nanocomposites. With the ability to print complex 3D objects layer by layer, additive manufacturing with nanomaterials could be leveraged in new ways toward greater control over material properties across part dimensions. Multifunctionality through embedding of nanomaterials can further extend capabilities of nanocomposites to properties such as gradients in thermal and electrical conductivity, photonic emissions tunable wavelength, increased strength and reduced weight.

Collin Ladd, Ju-Hee So, John Muth[8] demonstrated the possibilities to direct write structures composed of a low viscosity liquid with metallic conductivity at room temperature using binary eutectic alloy of Gallium and Indium. The liquid metal is useful for soft, stretchable or shape reconfigurable electronics. The liquid metal exhibits a negligible vapour pressure and low toxicity. They present free standing liquid metal structures such as wires, fibres, interconnects and stacks and arrays of droplets using four separate yet related direct write patterning methods. They elucidated the mechanism by which these structures form and present a working proof-of-concept flexible circuit using liquid metals wire bonds.

Carl Schubert, Mark C van Langeveld[9] discussed the applications and limitations of 3D printing and production process by producing a set of eyeglass frames from 3D blueprints. 3D printing is a method of manufacturing i which materials, such as plastic or metal, are deposited onto one another in layers to produce a three dimensional object, such as a pair of eye glasses or the other 3D objects. This process contrasts with traditional ink-based printers which produce a two dimensional object (ink or paper). To date, 3D printing has primarily been used in engineering to create engineering prototypes. However, recent advances in printing materials have now enabled 3D printers to make objects that are comparable with traditionally manufactured items. In contrast with conventional printers, 3D printing has the potential to enable mass customisation of goods on a large scale and has relevance in medicine including ophthalmology. 3D printing has already been proved viable in several medical applications including the manufacture of eyeglasses, custom prosthetic devices and dental implants.

Helena N Chia and Benjamin M Wu [10] illustrated technologies in tissue engineering and key limitations to motivate future research and advance in field of advance manufacturing. 3D printing promises to produce complex biomedical devices according to computer design using patient-specific anatomical data. Since its initial use as pre-surgical visualisation models and tooling molds, 3D printing has slowly evolved to create one-of-a-kind devices, implants, scaffolds for tissue engineering, diagnostic platforms and drug delivery system. Fueled by the recent explosion in public interest and access to affordable printers, there is renewed interest to combine stem cells with custom 3D scaffolds for personalized regenerative medicine. Before 3D printing can be used routinely for the regeneration of complex tissues (e.g. bone, cartilage, muscles, vessels, nerves in the craniomaxillofacial complex), and complex organs with intricate 3D microarchitecture (e.g. liver, lymphoid organs), several technologies limitations must be addressed.

C.X.F. Lam, X.M.Mo, S.H. Teoh, D.W. Hutmacher[11] developed a unique blend of starch-based polymer powders(cornstarch, dextran and gelatine) for 3DP process and also fabricated the cylindrical scaffolds of five different designs and post processed to enhance the mechanical and chemical properties. Rapid prototyping(RP) techniques have been utilised by tissue engineers to produce three-dimensional porous scaffolds. RP technologies allow the design and fabrication of complex scaffold geometries with a fully interconnected pore network. Three-dimensional printing (3DP) techniques was used to fabricate scaffolds with a novel micro- and macro-architecture. The scaffolds properties were characterised by scanning electron microscopy (SEM), differential scanning calorimetry (DSC), porosity analysis and compression test.

Ke Sun, Teng-Sing Wei, Bok Yeop Ahn[12] exhibited high areal energy and power densities. Printed high aspect ratio, multilayer electrodes onto a glass substrate by depositing inks through 30 µm cylindrical nozzles. To print high aspect ratio electrode architectures, the composition and rheology of each ink must be optimized to ensure reliable flow through fine deposition nozzles, promote adhesion between the printed features, and provide the structural integrity needed to withstand drying and sintering without delamination or distortion.

David Espalin, Danny W. Muse, Eric MacDonald[13] compared and contrasted stereolithography used for 3D-printed electronics with the FDM-based system through experimental results and demonstrate an automated FDM-based process for producing features not achievable with FDM alone.

Matt Zarek, Michael Layani, Ido Cooperstein [14] described a general and facile method based on 3D printing methacrylated macro monomers to fabricate shape memory objects that can be used in flexible and responsive electric circuits. Heat-activated shape memory polymers (SMPs) have enjoyed a long history of interest and academic development because of the expectation that they could impart structural responsiveness and ultimately, autonomous deployment in otherwise in accessible places, such as the human body and space. The particular focus on SMPs stems from the board tunable range of mechanical, thermal and optical properties and from their low density at low cost compared to shape memory alloys. Until now, SMPs were not used in the field of flexible electronics due to inadequate nature of the present processing techniques

Elena Bassoli [15] verified the feasibility and evaluated the dimensional accuracy of two rapid casting (RC) solutions based on 3D printing technology: Investment casting starting from 3D-printed starch patterns and ZCast process for the production of cavities for light alloys casting. The research assessed the feasibility and dimensional performances of two RC solutions, providing data that are extremely useful for the industrial application of the considered technologies. Her paper deals with experimental work on innovative techniques on which data are still lacking in literature. In particular, an original contribution to the determination tolerances and the investigation on the predictive performances of commercial CAE software is provided.

Brett G.Compton and Jennifer A. Lewis[16] showed the methods for 3D printing using light weight cellular composites of oriented fibre-filled epoxy with exceptional mechanical properties. Because alignment of high aspect ratio fillers occurs along the print direction, the build path itself can be used to spatially control their orientation within the part. The capability adds an entirely new dimension to engineering design and optimization, where composition, stiffness and toughness within bulk 3D object can be digitally integrated with component design to achieve a highly optimized structure. For example, reinforcements could be aligned around geometric stress concentrators or stiffness could be graded near fixture points to minimize damage. In additional to creating structures that mimic balsa wood, their approach is ideally suited to fabricated a wide range of bio-inspired composites structures with controlled architecture and mechanical properties.

Jacques Cali, Dan A. Calian, Cristina Amati[17] proposed a method for converting 3D models into a printable, functional, non-assembly models with internal friction. They have also designed an intuitive work-flow that takes an appropriately rigged 3D model, automatically fits novel 3D printable and posable joints, and provides an interface for specifying rotational constraints. Those developing materials to be utilised for 3D printing must take into account variety, composition, strength and finishing procedures in order to increase the versatility of the technology. Currently, the variety of materials is limited to the ability of the material to be powder-based or have low enough viscosities to be extruded from the printing head. Many manufacturers require proprietary materials to be used in their 3D printers or risk forfeiting the warranty.

Ardino Ambrosi and Martin Pumera[18] provided a general overview of the most commonly available 3D-printing methods along with a review of recent electrochemistry related studies adopting 3D-printing as possible rapid prototyping fabrication tool. Since its conception during the 80s, 3D-printing, also known as additive manufacturing, has been receiving unprecedented levels of attention and interest from industry and research laboratories. This is in addition to end users, who have benefited from the pervasiveness of desktop-size and relatively cheap printing machines available. 3D printing enables almost infinite possibilities for rapid prototyping. Therefore, it has been considered for applications in numerous research fields, ranging from mechanical engineering, medicine, and materials science to chemistry. Electrochemistry is another branch of science that can certainly benefit from 3D printing technologies, paving the way for the design and fabrication of cheaper, higher performing and ubiquitously available electronics devices.

Zhong Xun Khoo, Joanne EE Mai Teoh, Yong Liu[19] reviewed the major progresses in 4D printing including 3D printing of smart nanocomposites, shape memory alloys, shape memory polymers, actuators for soft robotics, self evolving structures, anti-counterfeiting system, active orgami and controlled sequential folding, and some research activities on 4D bio-printing followed by discussions on challenges, applications, research directions and future trends of 4D printing. Additive manufacturing (AM), commonly known as three-dimensional printing or rapid prototyping, has been introduced since the late 1980s. Although a considerable amount of work progress has been made in this field, there is still a lot of challenges of research work to be done in order to overcome the various challenges remained. Recently, one of the actively researched areas lies in the additive manufacturing of smart materials and structures. Smart materials are those materials that have the ability to change their shape or properties under the influence of external stimuli. With the introduction of smart materials, the AM-fabricated components are able to alter their shape or properties over time (the 4th dimension) as a response to the applied external stimuli. Hence, this gives rise to a new term called '4 D printing' to include the structural reconfiguration over time.

Bethany C. Gross, Jayda L. Erkal, Sarah Y. Lockwood[20] evaluated 3D printing and its potential impact on Biotechnology and the chemical sciences. Those developing materials to be utilised for 3D printing must take into account variety, composition, strength and finishing procedures in order to increase the versatility of the technology. Currently, the variety of materials is limited to the ability of the material to be powder-based or have low enough viscosities to be extruded from the printing head. Many manufacturers require proprietary materials to be used in their 3D printers or risk forfeiting the warranty.

Jodi L. Connell, Eric T. Ritschdorff, Marvin Whiteley[21] described a laser writing approach, based on multiphoton lithography, for fashioning microscopic 3D bacteria chambers from bovine serum albumin (BSA), a highly soluble protein that can be crossed linked into porous, rugged and biocompatible hydrogels. Bacteria communicate via short range physical and chemical signals, interactions known to mediate quorum sensing, sporulation and other adaptive phenotypes. Although most in-vitro studies examine bacterial properties averaged over large populations, the levels of key molecular determinants of bacterial fitness and pathogenicity (e.g. oxygen, quorum-sensing signals) may vary over micrometer scales within small, dense celluler aggregates believed to play key roles in disease transmission. A detailed understanding of how cell-cell interactions contribute to pathogenicity in natural, complex environments will require a new level of control in constructing more relevant cellular models for assessing bacterial phenotypes.

Nirveek Bhattacharjee, Arturo Urrios[22] reviewed past and recent efforts in 3D printing of microfluid systems, compared the silent features of poly(dimethylsiloxane) (PDMS) molding with those of 3D printing and gave an overview of the critical barriers that have prevented the adoption of 3D printing by microfluidic developers. The vast majority of microfluidic system have been built in poly(dimethylsiloxane) (PDMS) by soft lithography, a techniques based on PDMS micromoulding. A long list of PDMS properties have contributed to the success of soft lithography: PDMS is biocompatible, elastomeric, transparent, gas-permeable, water-imperable, fairly inexpensive, copyright-free and rapidly prototyped with high precision using simple procedures. However, the fabrication process typically involves substantial human labor which tends to make PDMS devices difficult to disseminate outside of research lans, and the layered molding limits the 3D complexibility of the devices that can be produced.

Paul G. McMenamin, Michelle R. Quayle[23] used a combination of imaging acquisition technology, image processing and colored 3D printing, they had demonstrated that accurate 3D printed colour copies of dissected human anatomical specimens can be rapidly and economically reproduced. The teaching of anatomy has consistently been the subject of societal controversy, especially in the context of employing cadaveric materials in professional medical and allied health professional training. The reduction in dissection-based teaching in medical and allied health professional training programs, accessing human cadavers and concerns with health and safety considerations for students and staff exposed to formalin-containing embalming fluids.

Dimitris Mitsouras, Peter Liacouras[24] described the imaging, postprocessing and equipment requirements to make a 3D-printed model from standard radiologic images and also discuss the existing literature and evidence base on the use of 3D printed models in medicine and describe future applications of 3D medical printing. While use of advanced visualisation in radiology is instrumental in diagnosis and communication with referring clinicians, there is and unmet need to render Digitally Imaging and Communications in Medicine (DICOM) images as three dimensional printed models capable of providing both tactile feedback and tangible depth information about anatomic and pathologic states. Three dimensional printed models, already entrenched in the non medical sciences, are rapidly being embraced in medicine as well as in the lay community.

Karl D.D. Willis, Eric Brockmeyer[25] presented an approach to 3D printing custom optical elements for interactive devices labelled Printed Optics and also explore the possibilities for this vision afforded by fabrication of custom optical elements using today’s 3D printing technology. Printed optics enable sensing, display and illumination elements to be directly embedded int he casing or mechanical structure of an interactive device. Using these elements, unique display surfaces, novel illumination techniques, custom optical sensors and embedded optoelectronics components can be digitally fabricated for rapid, high fidelity, highly customized interactive devices. Printed optics is part of their long term vision for interactive devices that are 3D printed in their entirety.

Carl Schubert, Mark C van Langeveld[26] discussed the potential for 3D printing to revolutionize conventional printing, the applications and limitations of 3D printing and the production process demonstrated by producing a set of eyeglass frame from 3D blueprints.

Alvaro Goyanes, Asma B.M. Buanz, Abdul W. Basit[27] discussed that FF3DP has the potential to offer a new solution for fabrication personalized-dose medicines or unit dosage forms with controlled-release profiles. The use of fused-filamed 3D printing (FF 3DP) to fabricate individual tablets is demonstrated. The technology permits the manufacture of tablets containing drug dose tailored to individual patients, or to fabricate of tablets with specific drug profiles. Commercially produced polyvinyl alcohol (PVA) filament was loaded with a model drug (fluorescein) by swelling of the polymer in ethanoic drug solution. It was found that changing the degree of infill percentage in the printer software varied the weight and volume of the printed tablets. The tablets were mechanically strong and no thermal degradation of the active occurred during printing. Dissolution tests were conducted in modified Hank's buffer. The results showed release profiles were dependent on the infill percentage used t print the tablets.

Thierry Rayna, Ludmila Striukova[28] showed that 3D printing technologies have the potential to change the way business model innovation, by enabling adaptive business models and by bringing the 'rapid prototyping' paradigm to business model innovation itself. There is a growing consensus that 3D printing technologies will be one of the next major technological revolution. While a lot off work has already been carried out as to what these technologies will bring in terms of product and process innovation, little has been done on their impact on business models and business model innovation. Yet, history has shown that technologies revolution without adequate business model evolution is a pitfall for many businesses.

Joseph T. Muth, Daniel M. Vogt[29] embedded 3D printing of strain sensors within Highly stretchable Elastomers. Due to the disparate mechanical properties of soft objects and conventional rigid electronics, integration electronics devices within highly stretchable matrices have been proven difficult. Soft sensors are typically composed of deformable conducting material patterned onto, attached to, or encapsulated within an active stretchable material. To create the desired sensing geometry, a number of processing methods have been employed to date, including lithographic, planar printing, coating and microchanneling moulding, filling and lamination.

Christian Weller, Robin Kleer[30] proposed that in a monopoly, the adoption of AM allows a firm to increase profits by capturing consumer surplus when flexibly producing customized products. Additive manufacturing, colloquially known as 3D printing, is currently being promoted as the spark of a new industrial revolution. The technology allows one to make customized products without incurring any cost penalties in manufacturing as neither tools nor molds are required. Moreover, AM enables the production of complex and integrated functional designs in a one-step process, thereby also potentially reducing the need for assembly work.

1.10 OBJECTIVE OF THE PRESENT WORK

It has been observed that most of the commercially available 3D printers are of having a print volume of 220x220x200 mm^3 and with the increase of printing speed they fail to print with very good accuracy as the structural rigidity of that printers are low. Most of these kinds of printers are based upon Prusa Mendel structure.

Some of the commercially available printers which have high structural rigidity and bigger print volume are very costly. These printers are also limited to certain materials and cannot be modified for research purpose on variety of materials.

Keeping in view the above problems, there is a need for inhouse design and development of a low cost 3D printers that are capable of 3D printing with a high accuracy, having high structural rigidity and bigger print volume and having the flexibilty to accommodate further modification as per future research requirement.

Based upon the above requirements, the objectives of present research work have been framed as follows

a) To study about different types of 3D printer and their configurations.
b) To design a Hypercube 3D printer with a relatively bigger print volume for Laboratory use and future research studies.
c) To 3D print the necessary parts for development of HyperCube 3D printer.
d) To develop a Hypercube 3D printer.

Chapter 2: FUNDAMENTALS OF 3D PRINTING

2.1 PARTS OF 3D PRINTERS

a) **Controller Board:** The controller board, also referred to as the motherboard or main board, is the brain of the 3D printer. It's the one responsible for the core operation, directing the motion components based on commands sent from a computer and interpreting input from the sensors. The controller board's quality has a major effect on the overall performance of the 3D printer. A machine made of high-end parts from top to bottom won't be able to print as well as it should if the controller board is not good.

b) **Filament:** The filament is the material used to print objects on a 3D printer. It's the equivalent of the ink used on a regular office 2D printer. It comes in a spool, which is loaded into the spool holder of the 3D printer, with the end of the filament inserted into the extruder. There are different kinds of filaments, each with their own properties and pros and cons.

c) **Frame:** The frame is the chassis of the 3D printer. It holds the other components together and is directly responsible for the stability and durability of the machine. These days, 3D printer frames are made of either acrylic or metal, but in the early days of consumer-level 3D printers, wood is often the go-to frame material.

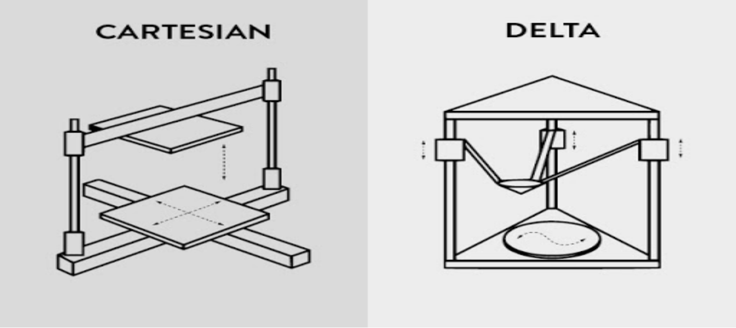


Fig 2.1: 3D Printer Frames

d) **Motion Components:** The motion components are the parts responsible for the movement of the 3D printer in the three axes. They are the ones that move the print bed and the print head. Basically, the controller board directs how the 3D printer should move while the motion components are the ones that do the actual moving.

e) **Stepper Motors:** The stepper motors, which are run by stepper drivers, are the keys to the mechanical movement of a 3D printer. Stepper motors are connected to all three axes and drive the print bed, the print head, and the threaded rods or leadscrews. They make a full rotation in increments or steps, hence the name, making them more suited for 3D printers than a normal DC motor. The print head also comes with a stepper motor that drives the extruder feeding movement.

Fig 2.2: Stepper Motor

f) **Belts:** In a Cartesian 3D printer, the belts, which are connected to motors, move the X-axis and the Y-axis from side to side and are integral to the overall print speed and precision. In a delta 3D printer, belts are often used to drive the movement on the Z-axis. A loose belt can ruin an entire print. That's why many 3D printers come with tensioners. Belt tensioning devices keep the belts in optimum tightness and provide an easy way to adjust the belt tightness.

Fig 2.3: Belt Drive

g) **Threaded Rods/Lead Screws:** In the Z-axis, the movement relies on threaded rods, which are also connected to stepper motors. As the threaded rod rotates, the print head moves up or down. In the case of the Ultimaker 3 and other similar 3D printers, the print bed is the one that moves. Some people confuse a threaded rod with a leadscrew. While both have the same function and are similar in appearance, they have different characteristics. A leadscrew offers a smoother movement but has a higher price on average.

Fig 2.4: Leadscrew

h) **End Stops:** Simply put, end stops are like markers that allow the 3D printer to identify its location along the three axes, preventing it from moving past its range, which can result in hardware damages. While many 3D printers use mechanical end stops, there are also those who use optical end stops.

www.pololu.com

Fig 2.5: Endstop

i) **Power Supply Unit:** The power supply unit supplies power to the entire 3D printer. No need for an elaborate explanation for this component. The PSU is either mounted on the frame or housed in a separate controller box together with the user interface. It's a lot better if the PSU is mounted on the frame as it translates to a smaller overall machine footprint.

Fig 2.6: Power Supply Unit

j) **Print Bed:** The print bed is where the extruder deposits the filament to form a solid object. Calling back to the 2D printer analogy earlier, the print bed is the equivalent of a piece of paper. It's either heated or non-heated, with the latter being common among starter 3D. A non-heated print bed is good enough for PLA, but for high-temperature materials, a heated print bed is a must in order to cut down on warping issues, improving the overall print quality.

Fig 2.7: Print Bed

k) **Print Bed Surface**: As the name suggests, the print bed surface or build surface is what goes on top of the print bed. It helps the object being printed stick to the platform and allows for easier removal of completed objects.

Fig 2.8: Print Bed Surface

l) **Extruder**: The print head or the extruder is the component that turns the filament into a 3D model. It's separated into two sections: a cold end and a hot end. To put it simply, the cold end clamps the filament and pushes it down to the hot end while the hot end, which ends with a nozzle, melts the filament and deposits it onto the build platform.

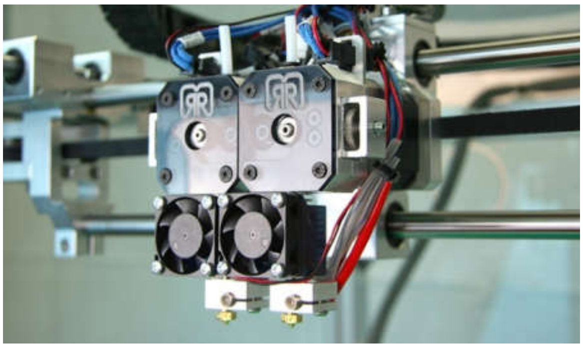


Fig 2.9: Extruder

2.2 PROCESS OF 3D PRINTING

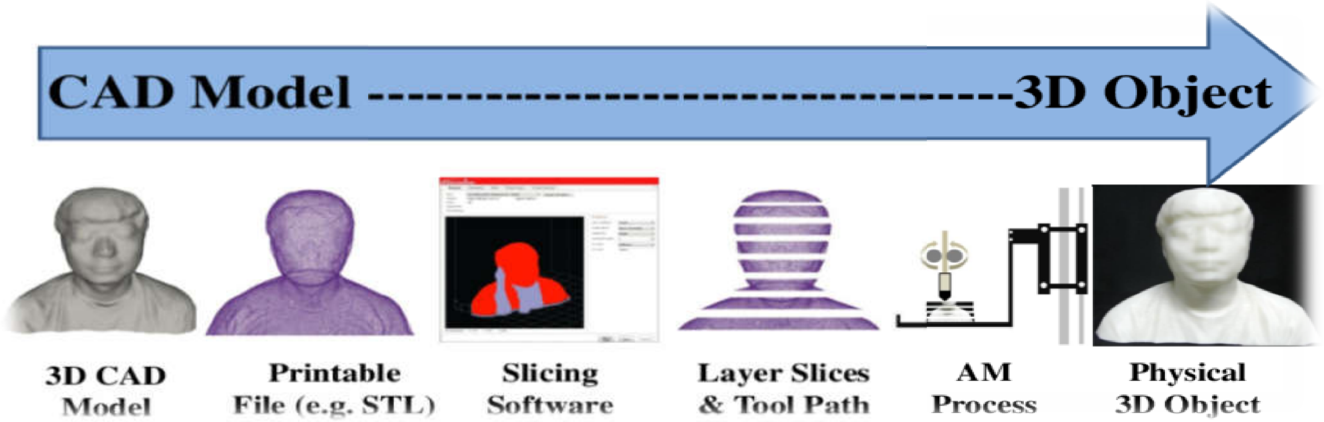
3D Printing process can be described and defined in following steps:-

a) ***CAD Model Creation***: Initially, the item to be 3D printed is designed utilizing a Designing Software. Solid work modellers, for example, CATIA and Solid works have a tendency to represent 3D objects more precisely than wire-frame modellers like AutoCAD. This procedure is comparatively for the majority of Rapid prototyping building methods.

b) ***Conversion to STL Format***: The different designing softwares use methods to present solid parts. To have consistency, the standard triangular format has been followed as the standard of the 3D printing industry.

c) ***Slicing of STL file:*** A pre-processing computer program is done which readies the STL format going to be built. Numerous programs are there, which permit the user to tweak the model. The pre-processing program cuts the Standard Triangular Language (STL) model into numerous layers from 0.01mm to 0.7 mm thickness, in view of building method. The program likewise makes an auxiliary structure to help the model admist of building. Sophisticated structures are bound to use auxiliary support.

d) ***Layer by Layer Construction***: The fourth step is the actual construction of the part. Using one of various techniques RP machines build one layer at a time from polymers, or powered metal.



2.3 DESIGNING SOFTWARES

a) **Autodesk Fusion 360:** This is a unique addition to the list of 3d printing software tools. Fusion 360 is a cloud-based 3D CAD program that utilizes the power of the cloud to bring design teams together and collaborate on complex projects. Another advantage of the cloud platform is that Fusion stores the entire history of the model including the changes to it. Numerous design options are available, including freeform, solid, and mesh modeling.

b) **SolidWorks:** Solidworks tends towards the industrial side of things. It is practical and detailed. While most software, mimic curves through gently inclining flat structures, Solidworks uses a system of nubs that create averages of the edges to produce fantastically detailed curvatures. It only does away with polygonal modelling, opting instead for dimensional sketching. As a result, resizing becomes far less of a hassle.

c) **Rhino3D:** The company behind this software markets it as the world's most versatile 3D-modeler. The software is available for download in a variety of bundles on their website at various prices. The program uses a precise and mathematical model known as NURB, allowing you to manipulate points, curves, meshes, surfaces, solids, and more in all sorts of ways. Ultimately, given the range of design features available with Rhino3D, it's hard to argue against its claims about unrivaled versatility in creating complex 3D models.

d) **123Design:** This is a powerful yet accessible piece of software to help create and edit 3D designs. We can take photos of objects and make 3D models from these photos, and the software is also available on smartphones. Many newer printer models are supported.

e) **SketchUp:** SketchUp is another good modeling software because it maintains that balance between usability and functionality, making it ideal for most skill levels. The software has an easy learning curve and there are advanced features available for professionals at an extra cost. It is especially good for designing interior and exterior architectural projects but also has tools for a diverse range of other purposes.

f) **FreeCAD**: A parametric 3D modeling tool that is open-source and enables you to design real-life objects of any size. The parametric component makes editing your design a piece of cake. Simply go to your model history and change the parameters, and you'll have a different model. As the name suggest, it is in fact totally free. The upside of this is that none of the tools are blocked behind a pay wall, so you can tweak your models to your heart's desire.

g) **TinkerCAD**: This is an online 3D design app geared towards beginners. The software features an intuitive block-building concept, allowing you to develop models from a set of basic shapes. TinkerCAD is full of tutorials and guides to aid any aspiring novices get the designs they're looking for. It even allows you to share and export files with ease.

h) **3D Slash:** 3D Slash focuses on providing design software with a uniquely fun user interface and enough advanced features to work with a high level of precision. We can also make logos and 3D text with this software. 3D Slash is free to use and ideal for beginners, however there a range of price packages that add in features for cooperative use or commercial use depending on the needs of the consumer. Additionally, the free versions have limitations in terms of functions, higher resolutions and colours we can apply. It's intuitive interface with a block cutting style to create shapes makes it simple enough for anyone to use.

i) **Blender:** In essence, Blender covers many facets of 3D creation, including modeling, animation, and simulation amongst others. This open-source software has a steep learning curve and is ideal for users who feel ready to transition to designing complex 3D models.

2.4 SLICING SOFTWARE AND 3D PRINTER HOST

a) Cura: Cura is the benchmark slicer software for all Ultimaker 3D printers, but it can be used with most other 3D printers. It's fully open source and can be extended via a plugin system.

b) **MatterControl 2.0**: Recently revamped to version 2.0, MatterControl is a CAD and 3D printing software for desktop computer. Featuring printer host functionality that lets us directly control and monitor printing when connected via USB, we can also slice STLs for export to SD card for offline printing and even generate designs in the CAD section of the software.

c) **3DPrinterOS**: A cloud-based solution to 3D printer management, 3DPrinterOS is a comprehensive suite that encompasses print job queuing and delegation, printer control and an app-based plug-in system that allows for STL analysis and repair, plus in-cloud slicing.

d) **KISSlicer:** Don't be fooled by the acronym of this program. It may be called " Keep It simple slicer" but it is actually a pretty sophisticated 3D printing software tool. Some have hailed it as a worthy alternative to the other 3D slicer software tools, other complain about the confusing interface.

e) **Slic3r:** Slic3r is open source slicer software with a reputation for adding bleeding edge features that can't be found anywhere else.

f) **SlicerCraft**: From the brains behind IceSL, SliceCraft is a browser-based slicer. With a simple dialogue to upload STLs or paste web links to pull STLs for slicing, you can quickly and conveniently prepare g-code for printing using the vast majority of options afforded to you by IceSL itself.

g) **IceSL:** IceSL is a remarkable piece of 3D printing software. It is not merely a 3D slicer software, but also a 3D modelling tool. In the left window, you can edit your model directly via scripting in a Lua-based language. At first glance, this may seem like a frightening prospect but it enables some nifty parametric modelling. The center window is a live preview.

h) **OctoPrint:** Octoprint is a 'pure' web-based 3D printer host that allows you to exercise complete control over our printing jobs and printer itself. Combined with a wif enabled device- such as a Rasberry Pi- that is hooked up to our printer, we can dial in and control our machine remotely via OctoPrint's web interface.

i) **Repetier-Host:** The Repetier is open source and highly capable software for 3D printer control and slicing. Straddling the intermediate to advanced user spectrum, Repetier is pitched as an all-in-one solution, offering multi-extruder support (up to 16 extruders), multi-slicer support via plugins and support for virtually any FDM 3D printer on the market.

j) **AstroPrint:** Akin to 3DprinterOS, AstroPrint is another cloud-based solution that allows users to monitor and manage our 3D printers, as well as our slicer settings printer profiles and material profiles. With a free AstroPrint Cloud account, we can restore virtually all of the information needed to achieve a successful print. Better yet, these settings can be accessed via our browser or the AstroPrint mobile app.

2.5 G AND M CODES FOR 3D PRINTING:

Table1: G and M codes

G Codes	
G0	Rapid Movement
G1	Linear Coordinated movement
G2	Clockwise ARC movement.
G3	Clockwise ARC movement.
G4	Dwell.
G10	Retract filament
G11	Retract recover filament.
G28	Home all axis.
G29	Detailed Z-Probe, probes the bed at 3 or more points. Will fail if you have not homed yet.
G30	Single Z probe, probes bed at current XY location.
G31	Dock sled(Z probe sled only)
G32	Undock sled
G90	Use Absolute Coordinates.
G91	Use Relative Coordinates.

M CODES	
M0	Unconditional Stop
M1	Same M0
M17	Enable/Power all stepper motors
M18	Disable all the Stepper Motors.
M20	List SD card
M21	Initiate SD card.
M22	Release SD card.
M23	Select SD file.
M24	Start/Resume SD print.
M25	Pause SD print.
M26	Set SD Position in bytes
M27	Report SD print status
M28	Start SD write
M29	Stop SD write
M30	Delete file from SD
M31	Output time since last M109
M32	Select file and start SD print
M42	Change Pin status via G codes
M80	Turn ON Power Supply
M81	Turn OFF Power Supply
M82	Set E codes absolute(default)
M83	Set E Codes relative while in Absolute Coordinates(G90)
M84	Disable steppers until next move
M85	Set inactivity shutdown timer with parameter
M92	Set Axis
M104	Set extruder target temperature.
M105	Read current temperature.
M106	Fan On.

M107	Fan Off.
M109	Wait for Extruder temp to reach target temp.
M112	Emergency stop
M114	Output current position to serial port.
M115	Capabilities String.
M117	Display Massage.
M119	Output Endstop status to serial.
M126	Solenoid Air Valve Open
M127	Solenoid Air valve close
M140	Set Bed Temperature
M150	Set Blink colour output
M190	Wait for Bed temperature to reach target temperature.
M200	Set filament diameter.
M201	Set Max acceleration for printer move.
M202	Set Max acceleration for travel move.
M203	Set maximum federate
M204	Set Default acceleration
M206	Set additional Homing offset.
M207	Set retract length S
M220	Set speed factor override percentage
M221	Set extruder factor percentage override
M700	Turn off print pressure to syringe 0
M701	Turn On print pressure to syringe 0
M702	Turn off purge pressure to syringe 0
M703	Turn On purge pressure to syringe 0
M750	Turn off vacuum pump
M751	Turn On vacuum pump.

2.6 3D PRINTING MATERIALS:

a) Poly Lactic Acid(PLA):

Colours : White
Extruder Temperature: 205±15˚C
Bed Temperature : 50±10˚C
Ventilation : Closed or Open Printer.
Bed Adhesion : Kapton Tape.

Along with ABS, PLA ae the two most plastics used in 3D printing and drawing. PLA is low-wrap and can be used in a variety of applications. As an added bonus PLA is made up from renewable biodegradables such sugarcane, grain crops, corn starch and soybean making it eco-friendly. It is by far the safest 3D filament to use with 3D pens for kids.

When it melts the smell is completely absent or there is a slightly sweetish smell similar to the smell of corn or honey. PLA is dissolved in dichloromethane.

b) Acrylonitrile Butadiene Styrene (ABS):

Colours : Most Primary colours.
Extruder Temperature: 230±10˚C
Bed Temperature : 100±15˚C
Ventilation : Only closed Printer
Bed Adhesion : Blue Painters Tape

ABS is the most commonly used 3D printing material. Parts made from the ABS are durable and able to withstand high temperatures. In comparison to PLA filament, ABS can be described as more supple and less brittle. It is also non-biodegradable. ABS can be treated with acetone to get a glossy finish. While printing with ABS filament, we must use a heated surface, as ABS plastic will contract if it touches a cold surface and the plastic will warp. Unlike PLA which is odourless when heated, ABS let's off the distinct smell of burning plastic when heated.

c) Nylon (Polyamide):

Colours : Large Palette Available.
Extruder Temperature : 255˚C
Bed Temperature : 115˚C
Ventilation : Only closed Printer
Bed Adhesion : PVA-Based Glue

Nylons is perhaps the strongest and most durable of the printing materials. The thin strands of Nylon adhere and give nylon great strength. Nylon filament prints naturally as a clear white colour and can absorb acid-based clothing dyes or synthetic cloth specific dyes allowing for a large colour palette. Nylon loves to absorb water Nylon should be printed (most hydrophilic plastic), which is not good news for 3D prints. Therefore must be stored in dry place.

d) Polyethtylene Terephthalate (PET):

Colours : Large Palette Available.
Extruder Temperature : 245±10 ˚C
Bed Temperature : 60±10 ˚C
Ventilation : Open or closed Printer
Bed Adhesion : Blue Painters Tape

PET is difficult to find in tis pure form, as most PET plastics tend to be co-polymers. PETG filament is the most commonly found, the G means it has glycol modification is an industrial strength filament with several great features. PET is available in any colour as it mixes with most dyes. PETG really provides the best of both worlds, this filament gives the durability and resilience of ABS, along with the compatibility and practically of PLA.

e) Thermoplastic Elastomer (TPE/TPU):

Colours : Few colour option.
Extruder Temperature : 220±10 ˚C
Bed Temperature : 30±10 ˚C
Ventilation : Open and closed Printer
Bed Adhesion : Blue Painters Tape

TPE and TPU is one of the more flexible 3D printing materials. TPE/TPU filament is mostly used for parts that need to flex or bend, such as springs and belts found in the automotive industry. If we have a phone cover, it’s most probably made from TPE. This is an highly flexible 3D printing material will allow us to create objects which have the typical characteristics of a plastic ruler, soft and flexible.

Thermplastic Polyethane (TPU) is the newer version of TPE and has some advantages over its sibling. It is more resistant to abrasion, and can be used with a wider range of 3D printers as it is slightly more rigid.

TPE/TPU cannot be used with 3D pens as it is too flexible and will jam inside the pen.

f) **Metal Infused PLA**:

Colours : Silver, Aluminium, Copper, Brass.
Extruder Temperature : 210±10 ˚C
Bed Temperature : 50±10 ˚C
Ventilation : Open or Closed Printer
Bed Adhesion : Glass

Metal Infused plastics are tough to print in comparison to normal PLA, but due to the metal mixed in with the PLA, prints made from these metal printing materials are heavier and will give a more authentic look and feel.

Finishing can be done with wire brushing, rock polishing or wheel polishing. The metal infusion does however, not make it stronger.

We can use these 3D printing materials to imitate jewellery and a whole other host of applications where we want to give the appearance of metal.

g) High Impact Polystyrene (HIPS):

Colours : Large Palette Available.
Extruder Temperature : 230±10 ˚C
Bed Temperature : 110±10 ˚C
Ventilation : Only Closed Printer
Bed Adhesion : Kapton Tape.

HIPS can be compared with ABS. It is often used together with ABS using a dual head printer, as the HIPS plastic can be dissolved afterwards using Limonene as solvent.

This property makes it a great option as support material when printing ABS with dual extrusion printer. Of all the 3D printing materials, HIPS is closet to ABS but it doesnot wrap nearly as easily.

h) PLA Conductive Filament:

Colours : Black or copper.
Extruder Temperature : 220±10 ˚C
Bed Temperature : 50±10 ˚C
Ventilation : Closed Printer
Bed Adhesion : Blue Painters Tape

Conductive PLA, designed for low voltage circuit applications. What we get with conductive PLA is material that’s less flexible than normal PLA but with better adhesion. This makes it ideal for a dual head printer to use both normal PLA and conductive filament, as the layer adhesion between the two plastics is excellent.

Chapter 3: DESIGN AND DEVELOPMENT OF HYPERCUBE 3D PRINTER

3.1 HYPERCUBE 3D PRINTER

The Hypercube 3D Printer is a high quality and robust design. The Hypercube printer is originally designed by Tech2C. The Hypercube 3D Printer follows the CoreXY philosophy with a bigger build volume. However, it is an extremely modular and expandable design which can be scaled up to 700*700*700 and beyond. It is commonly called **HyperCube 3D printer** as shown in the Fig 3.1.

In this project work, the build volume will be 500*500*500 mm^3.

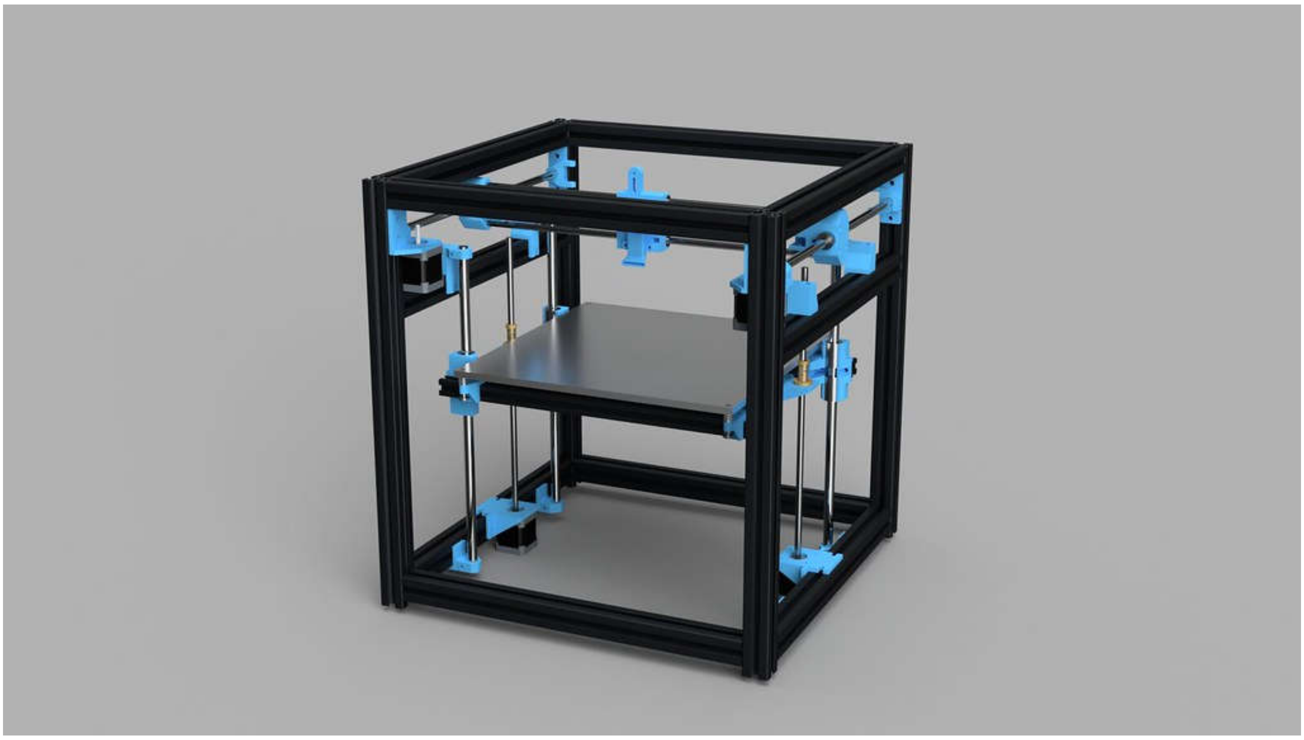


Fig 3.1: HyperCube Structure of 3D Printer.

3.2 PLAN OF WORK

a) CAD Design of a Hypercube FDM 3D Printer with Core XY arrangement with a print volume of 310x310x310 mm^3.

b) Selection of raw materials including mechanical hardware and electronics components for the fabrication part.

c) Purchasing of raw materials (mechanical hardware, electronics accessories).

d) Fabrication of the 3D printer.

e) Testing the print quality on the newly developed 3D printer.

3.3 CAD DESIGN OF HYPERCUBE 3D PRINTER FOR THE PRESENT PROJECT WORK

According to the project requirement and availability of the raw materials and for bigger print volume (310mm X 310mm X 310mm), a CAD model has been prepared in SOLIDWORKS as shown in the Fig 3.2.

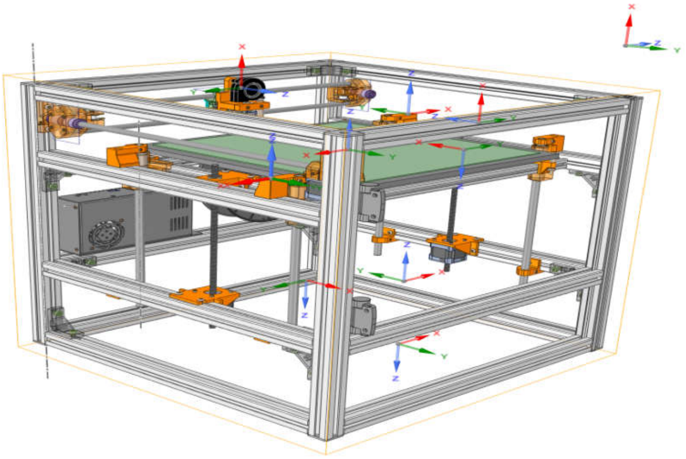


Fig 3.2: Solidworks model of 3D Printer.

3.4 DIFFERENT VIEWS OF HYPERCUBE 3D PRINTER

Fig 3.3 and 3.4 show the different views of Hypercube 3D printer.

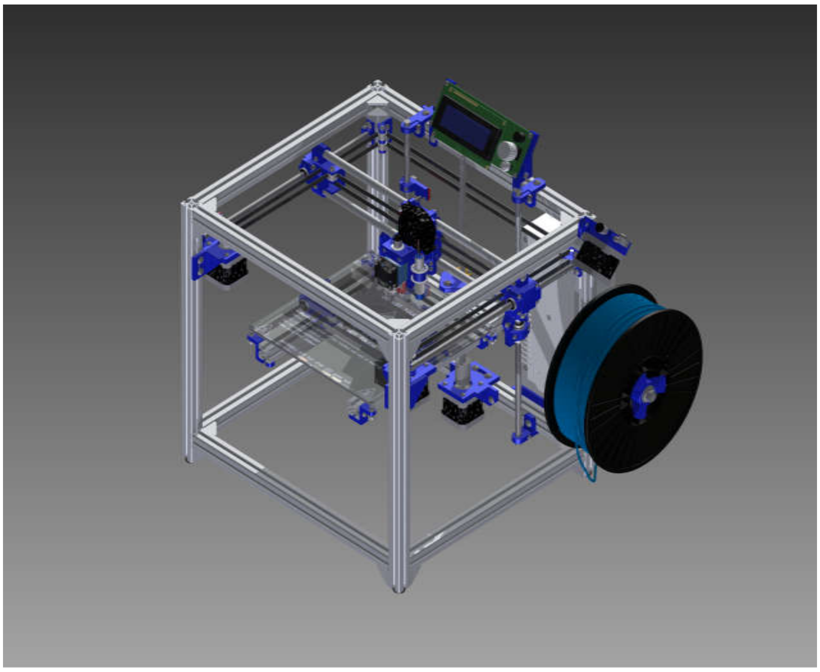


Fig 3.3: Isometric view.

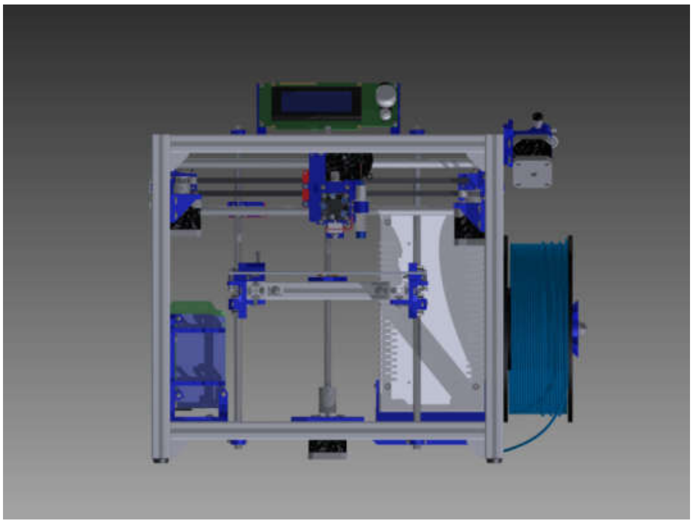


Fig 3.4: Front view of HyperCube 3D printer

3.5 RAW MATERIALS (MECHANICAL AND ELECTRONICS) LIST

Table 2: Raw Materials

Serial no.	Items	Specifications	Quantity
1	Alumunium Frame	2020 and 3030	
2	45° Angle bracket	2020 and 3030 Supporting	
3	Stepper Motor	NEMA 17	04
4	Extruder	MK8	01
5	Hot End with Bowden Tube	V6 J-Head	01
6	Build Plate	Hot bed	
7	Lead Screw	8mm X 2mm X 500mm	02
8	Coupler	5mm x 8mm flexible coupler	02
9	Belt Pulley	GT-2 Timing Belt Pulley	6 Feet
10	Smooth Rod	1. 8mm x 500mm 2. 10mm x 500mm 3. 12 mm x 500 mm	2+2+2
11	Stepper Drive	DRV 8825	4
12	Motor Sheild	RAMPS 1.4	01
13	Display Panel	LCD Display	01
14	Screw, Nut Bolt etc		
15	Limit Switch		06

16	Power Supply	12V 20A	
17	Micro Controller	Arduino Mega 2560	01

3.6 3D PRINTER USED TO PRINTS THE PARTS OF HYPERCUBE

As shown in the Fig 3.5, this printer was used to print the parts of Hypercube 3D printer.

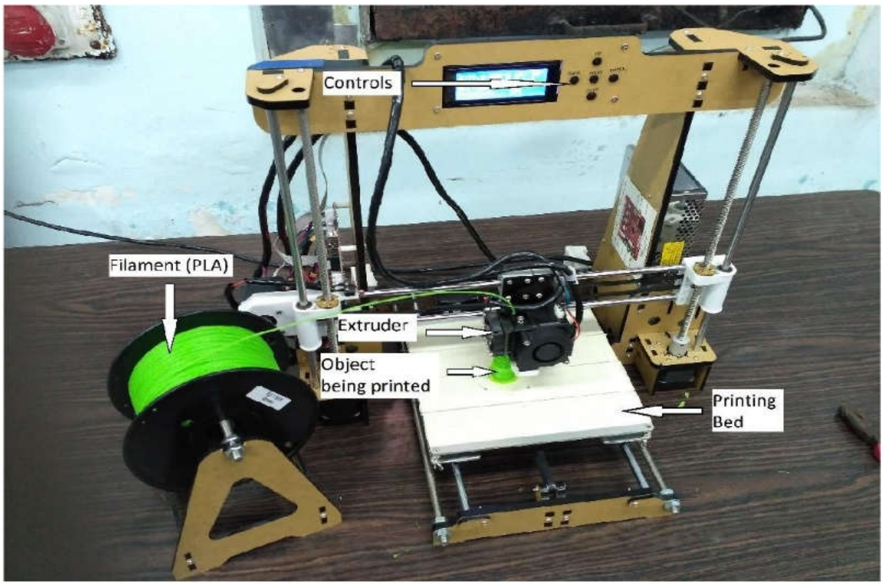


Fig 3.5: 3D printer.

3.7 LISTS OF PARTS TO BE 3D PRINTED

The .stl files for the parts which are to be 3D printed are downloaded from www.thingiverse.com.

Table 3: Parts to be 3D printed

Serial No.	**Part Name**	**Quantity**	**Print Time**
1.	Belt clamp	2	2* 15min
2.	Belt Tensioner.	2	2* 5min
3.	X-end stop flag	2	2* 7mins
4.	XY Idealer Mount Left	1	1* 1.5hrs
5.	XY Idealer Mount Right	1	1* 1.5hrs
6.	XY Stepper Mount Left	1	1* 4hrs
7.	XY Stepper Mount Right	1	1* 4hrs
8.	Y Carriage LM10UU	1	1* 5hrs
9.	Y End Stop Flag	1	1 *15min
10.	Z Axis Bearing Holder	4	4* 4.5hrs
11.	Z Axis Linear Rail Bracket Double Z Left	2	2* 3hrs
12.	Z Axis Linear Rail Bracket Double Z Right	2	2* 3hrs
13.	Z Axis Linear Rail Bracket Left	2	2* 1.5hrs
14.	Z Axis Linear Rail Bracket Right	2	2* 1.5hrs
15.	Z Motor Mount	2	2* 3hrs
16.	Y Carriage Clamps	2	2* 2hrs
17.	Retainer	1	1* 45 mins
18.	Z Nut Bracket	2	2* 2.5 hrs
19.	X Carriage	1	1* 4.5hrs
20.	Extruder Mount	1	1* 5hrs

Total Quantities: 34 Total Time : 80 hrs (approx).

3.8 3D PRINTED PARTS

a)

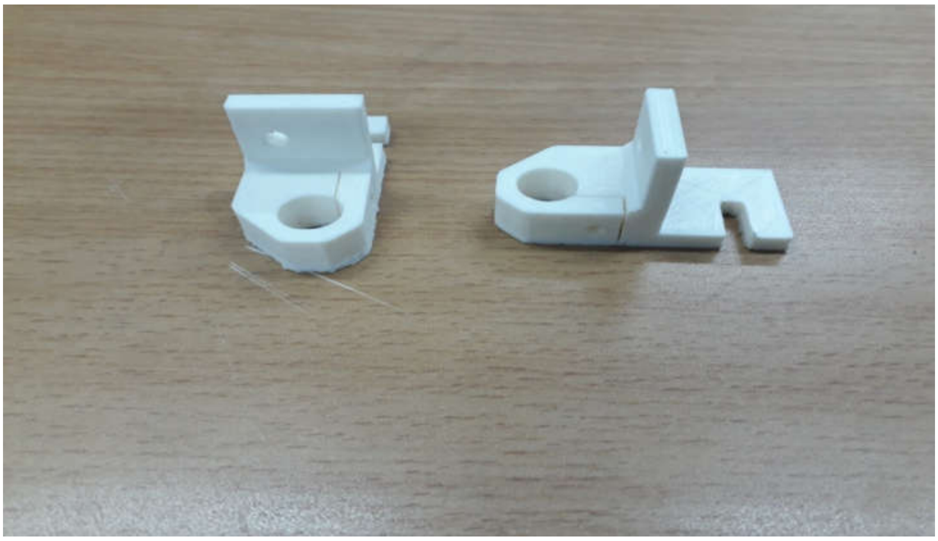


Fig 3.6: Z-axis Linear Rail Bracket Right.

b)

Fig 3.7 : Z-axis Linear Rail Bracker Double Left

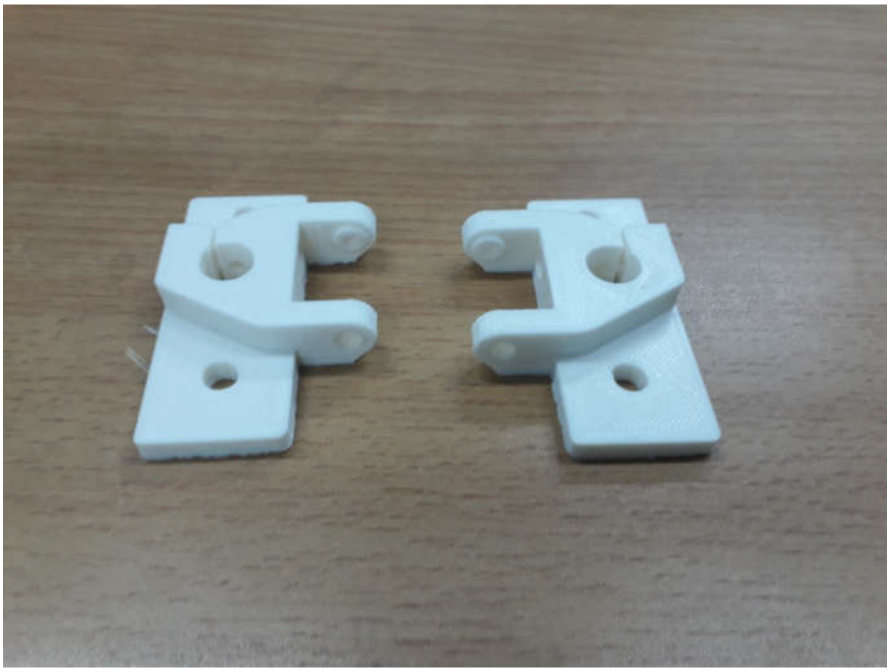


Fig 3.8: XY Idler Mount Left & Right

c)

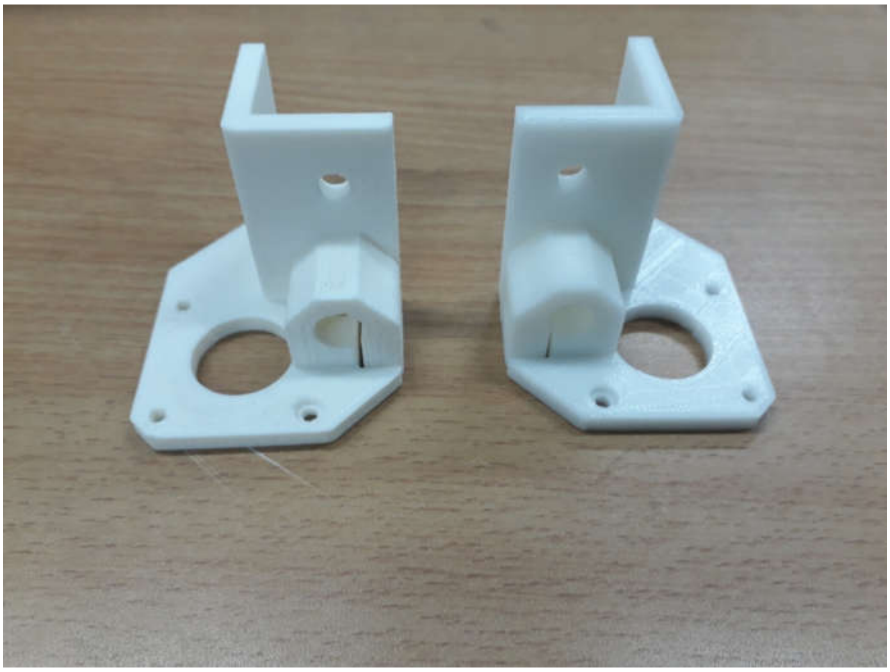


Fig 3.9: XY Stepper Mount Left & Right

d)

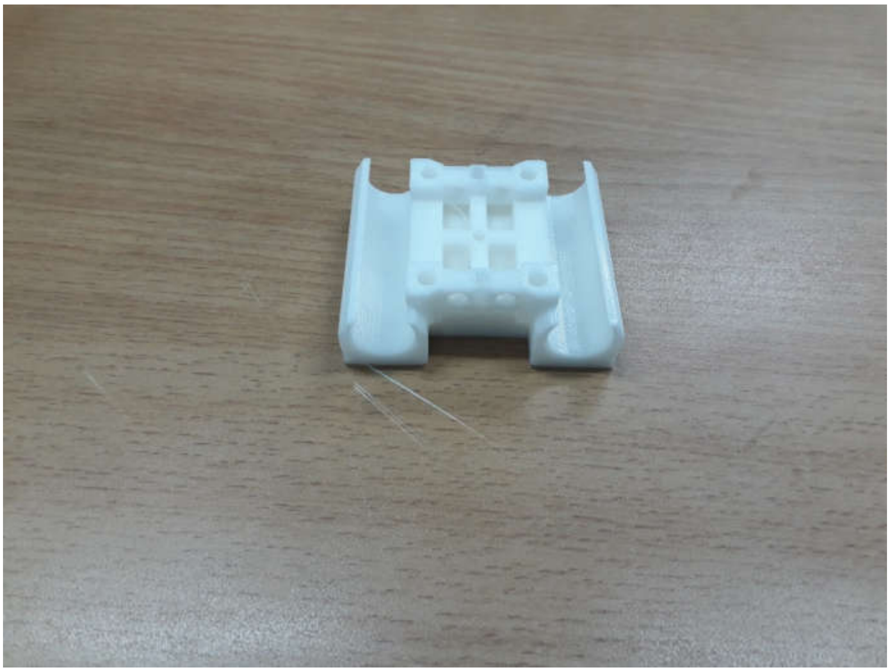


Fig 3.10: X-Carriage

e)

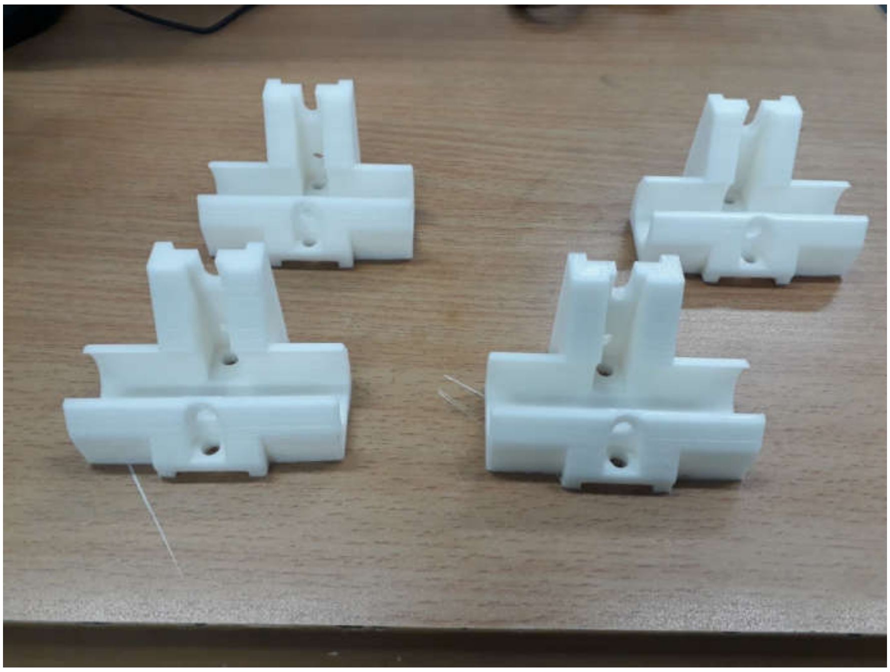


Fig 3.11: Z-axis Bearing holder

f)

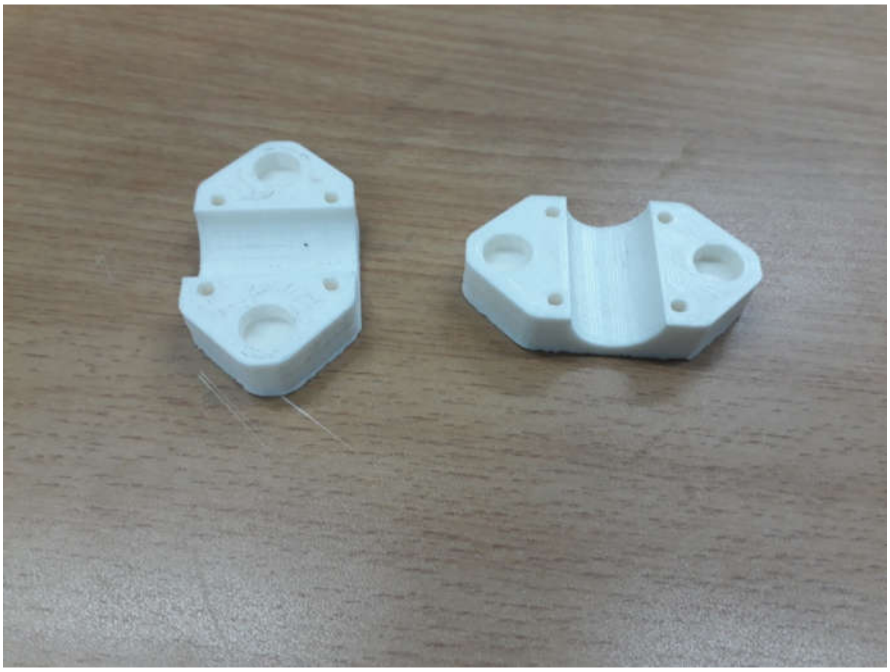


Fig 3.12: Y Carriage Clamp

g)

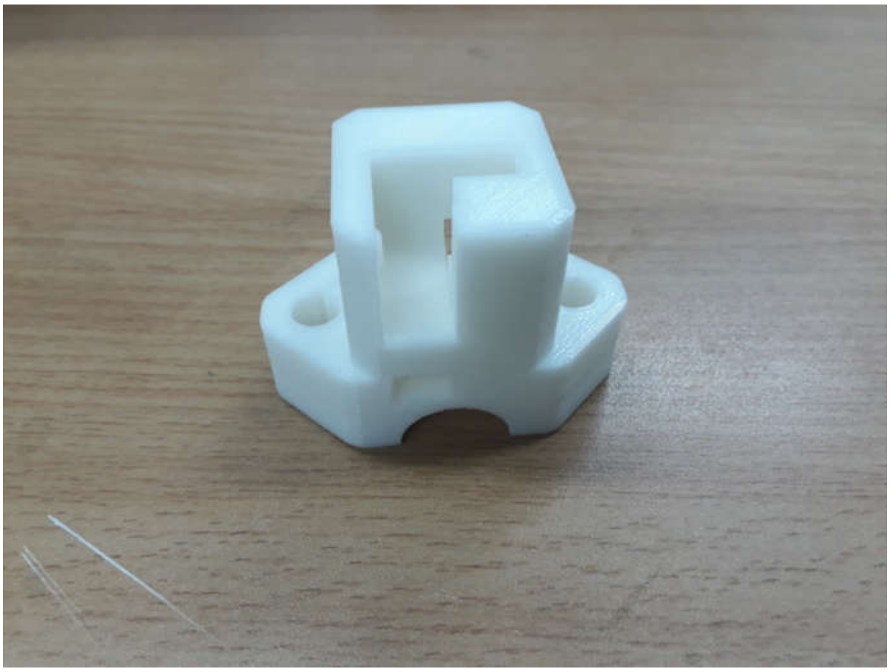


Fig 3.13: Y Carriage

h)

Fig 3.14: Retainer

i)

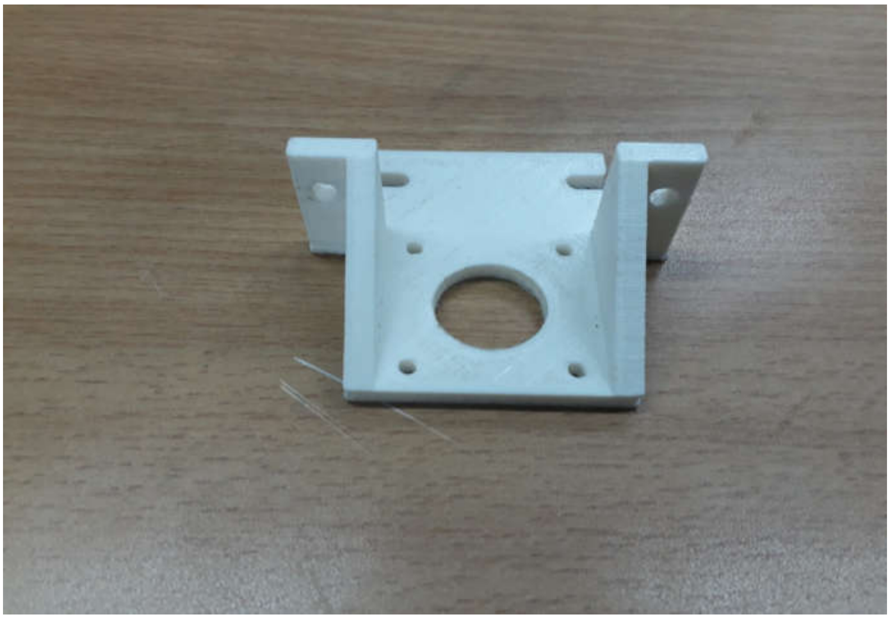


Fig 3.15: Z Motor Mount

j)

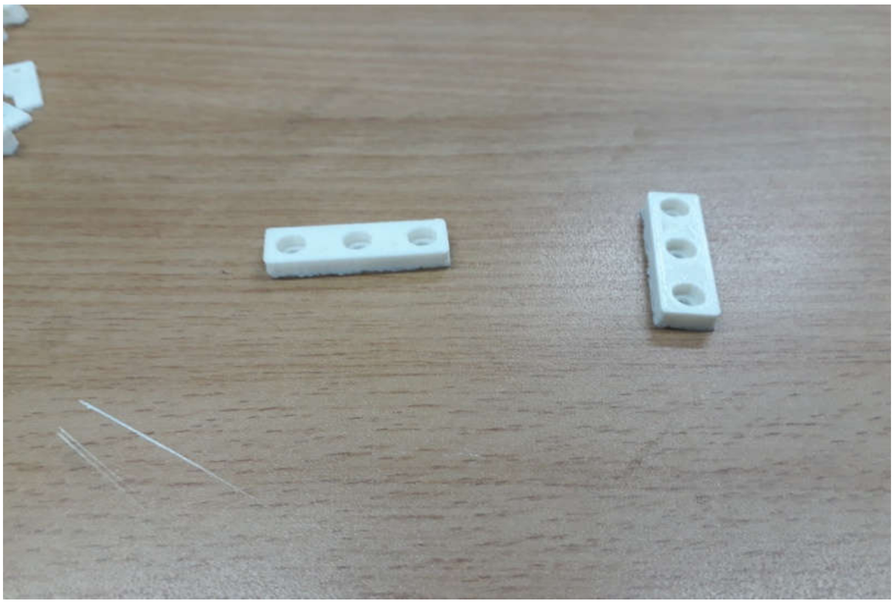


Fig 3.16: Belt Tensioner

k)

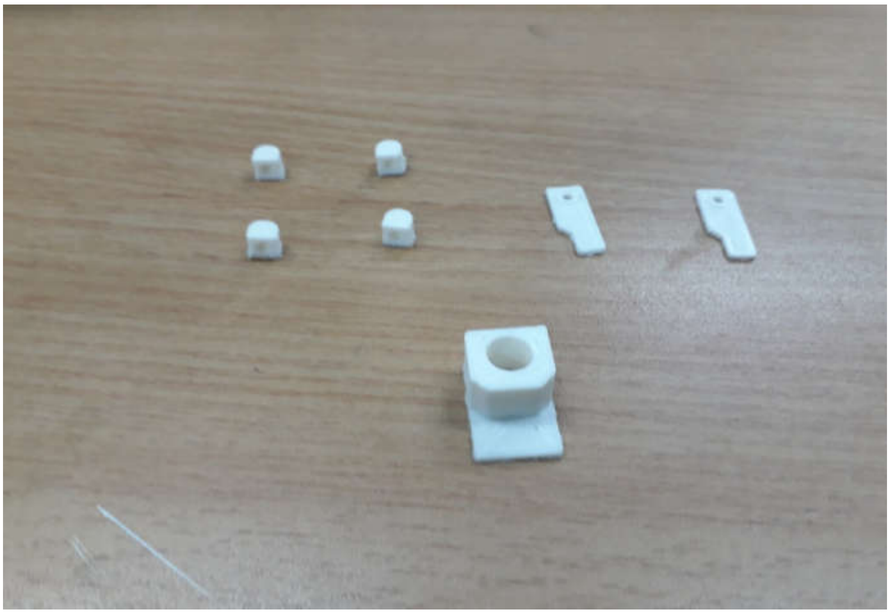


Fig 3.17: Belt clamp, X end stop flag, Belt tensioner.

m)

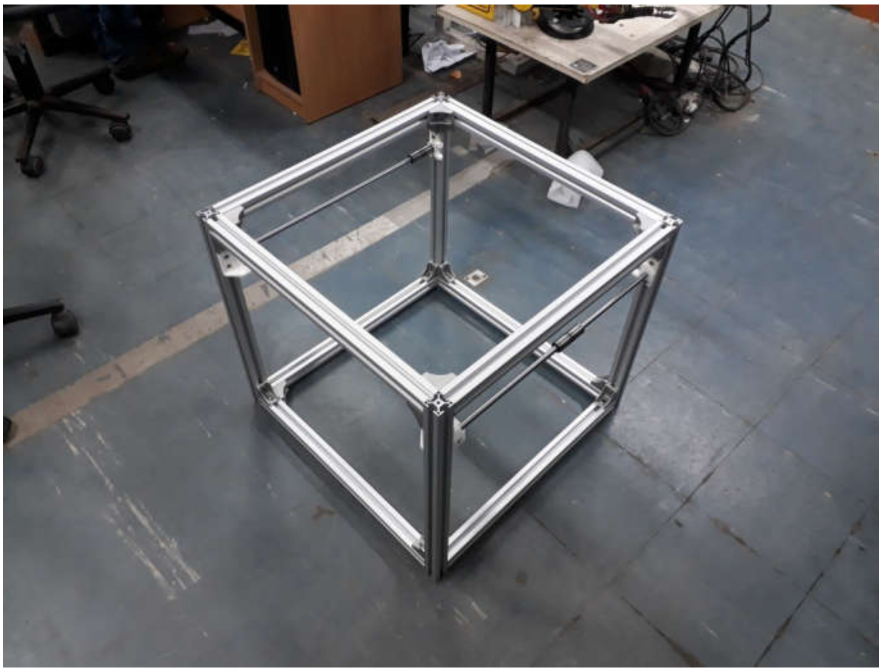


Fig 3.18: Structural Frame Work

3.9 ELECTRICAL AND ELECTRONICS CIRCUIT SETUP

Electrical equipments are basically stepper and the power supply. Stepper motors are mounted on X, Y and Z axis on 3D printed angle plate and this plate is attached to the frame with nut and bolt. There are two stepper motor coupled with the lead screw for Z axis movement. Each stepper motor consists of multiple wires. In this project, NEMA-17 is used which is a bipolar stepper motor and consists of four wires. Each of the two wires belongs to separate windings, wires (Red And Blue) are part of same winding and (Green And Black) are of the other. And after identifying the wires, they were joined in the stepper motor shield with jumper wire. After this the RAMPS 1.4 shield is mounted with the Arduino MEGA 2560 microcontroller and power is supplied to the RAMPS 1.4 from external power supply.

Circuit diagram of all electrical and electronics components are shown below:

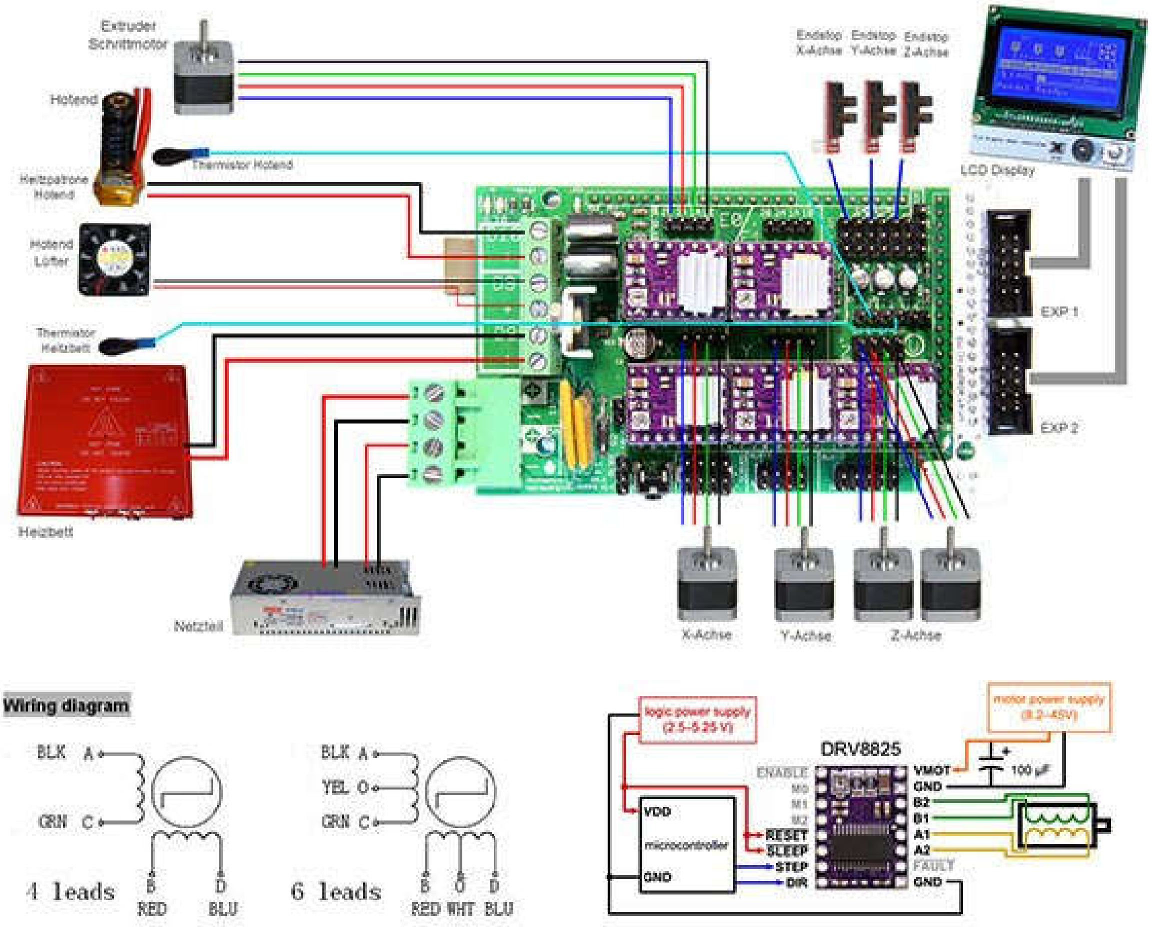


Fig 3.19: Detail circuit diagram of all electronics and electrical equipment.

3.10 SOFTWARE DESCRIPTION

Introduction

Computer software, or simply software, is that part of a computer system that consists of encoded information or computer instructions, in contrast to the physical hardware from which the system is built. The software used in this project comes under open source. Open-source software (OSS) is computer software with its source code made available with a license in which the copyright holder provides the rights to study, change, and distribute the software to anyone and for any purpose. Open-source software may be developed in a collaborative public manner. Open-source software is the most prominent example of open-source development.

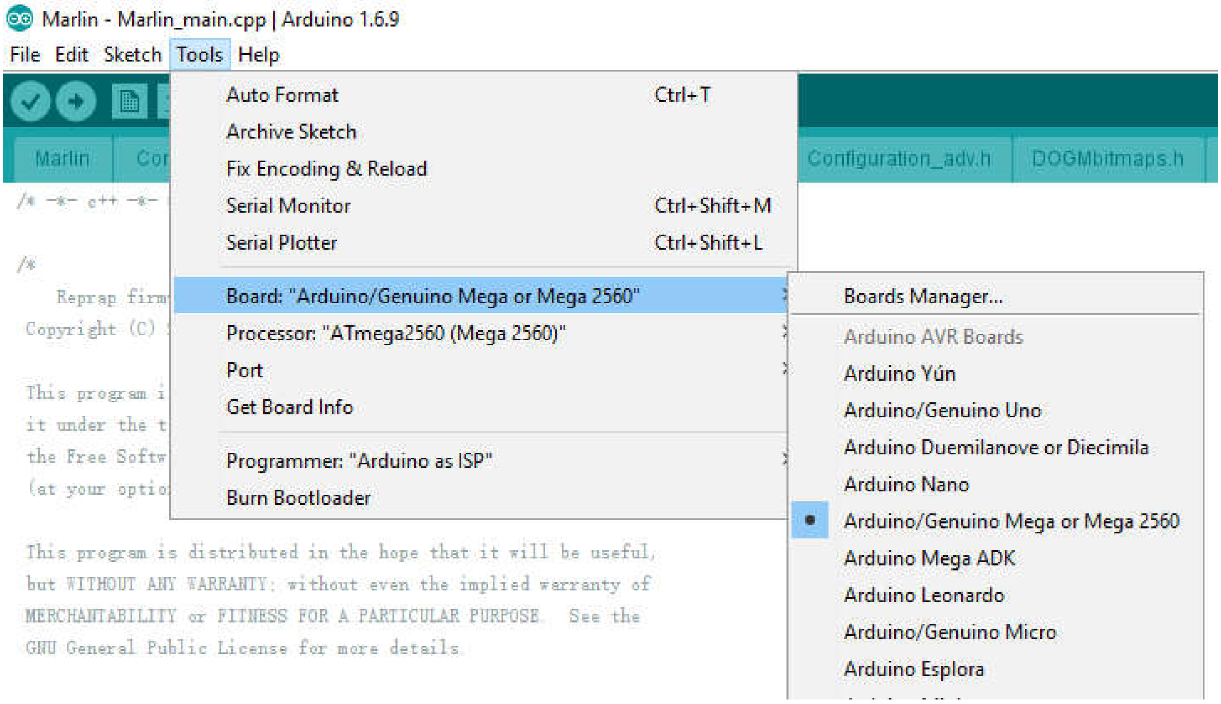
Arduino IDE :

The Arduino integrated development environment (IDE) is a cross-platform application (for Windows, macOS, Linux) that is written in the programming language Java. It originated from the IDE for the languages *Processing* and *Wiring*. It includes a code editor with features such as text cutting and pasting, searching and replacing text, automatic indenting, brace matching, and syntax highlighting, and provides simple *one-click* mechanisms to compile and upload programs to an Arduino board. It also contains a message area, a text console, a toolbar with buttons for common functions and a hierarchy of operation menus.

The Arduino IDE supports the languages C and C++ using special rules of code structuring. The Arduino IDE supplies a software library from the Wiring project, which provides many common input and output procedures. User-written code only requires two basic functions, for starting the sketch and the main program loop, that are compiled and linked with a program stub *main()* into an executable cyclic executive program with the GNU toolchain, also included with the IDE distribution. The Arduino IDE employs the program *avrdude* to convert the executable code into a text file in hexadecimal encoding that is loaded into the Arduino board by a loader program in the board's firmware.

Arduino IDE Initial Setup And Board Setup

This is the Arduino IDE once it’s been opened. It opens into a blank sketch where you can start programming immediately. First, we should configure the board and port settings to allow us to upload code. Connect your Arduino board to the PC via the USB cable.



Board: "Arduino/Genuino Mega or Mega 2560"

Processor: "ATmega2560 (Mega 2560)"

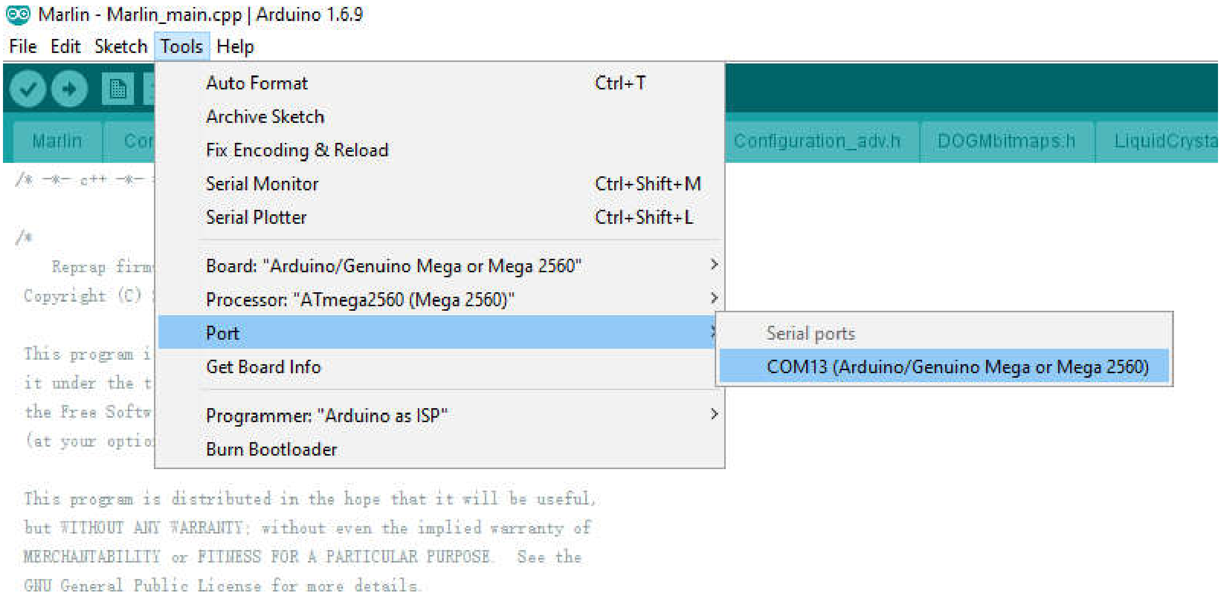
Programmer: "Arduino as ISP"

```
/* -*- c++ -*-

/*
   Reprap firm
  Copyright (C)

  This program i
  it under the t
  the Free Softw
  (at your optio

  This program is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.
```

Fig3.20: Initial setup and board setup

Com Port Setup

If we downloaded the Arduino IDE before plugging in our Arduino board, when it is plugged in the board, the USB drivers should have installed automatically. The most recent Arduino IDE should recognize connected boards and label them with which COM port they are using. Select the Tools pulldown menu and then Port. Here it should list all open COM ports, and if there is a recognized Arduino Board, it will also give its name. Select the Arduino board that you have connected to the PC. If the setup was successful, in the bottom right of the Arduino IDE, you should see the board type and COM number of the board you plan to program. At this point, your board should be set up for programming, and you can begin writing and uploading code.



```
/* -*- c++ -*-

/*
    Reprap firm
  Copyright (C)

  This program i
  it under the t
  the Free Softw
  (at your optio

  This program is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.
```

Fig. 3.21 : COM Port setup

Slic3r

Slic3r is the tool you need to convert a 3D model into printing instructions for your 3D printer. It cuts the model into horizontal slices (layers), generates toolpaths to fill them and calculates the amount of material to be extruded.

The Slic3r project was born in 2011 within the RepRap community as an effort to provide the growing 3D printing technology with an open and flexible toolchain. The code and the algorithms are not based on any other previous work. Readabilityand maintainability of the code are among the design goals. Slic3r, being a true non-profit community project, allowed the people to experiment with several original new features that have become common thereafter such as multiple extruders, brim, microlayering, bridge detection, command line slicing, variable layer heights, sequential printing (one object at time), honeycomb infill, mesh cutting, object splitting into parts, AMF support, avoid crossing perimeters, distinct extrusion widths, modifiers, and much more. All of these features were first introduced in Slic3r and are now part of the commercial software out there.

3.11 DIFFICULTIES FACED DURING PRINTING

a) The 3D printer requires frequent alinment adjustment. Sometimes even after a single print.

b) The Kapton tape on Heatbed forms bubbles, which distorts the base surface finish of the prints.

c) Care should be taken while loading the G-codes on the printer. Incomplete code will fetch incomplete print.

d) PLA being brittle sometimes tears of from the material spool. Operator must make sure it is well connected to the spool.

Chapter 4: SUMMARY AND GENERAL CONCLUSIONS

4.1 SUMMARY AND GENERAL CONCLUSION

In the present research study, attempt has been made to design and develop a low cost inhouse Hypercube 3D printer. The procedure adopted for design and development of 3D printer are as follow:-

1. 3D Printer has been designed for relatively bigger print volume 310×310×310mm^3 and accordingly the heat bed has been selected.
2. As per the design, extruded alumunium profiles have been selected and cut into appropiate length for making the basic hypercube structure.
3. All components like Z motor mount, X-carriage etc. have been manufactured using 3D printer.
4. Electronic circuits for stepper motors, drivers and controller have been fabricated and Merlin Software has been flashed and configured as per requirement.
5. Finally all the available parts have been assembled to develop the HyperCube 3D printer.

The developed 3D printer is quiet capable of producing large print volume and much cheaper compared to the commercial 3D printer available in the market. The maintenece cost of the printer is also much less. Apart from routine use, this printer can be modified easily as per the future research requirement.

In future the printer may be upgraded as per the requirements like followings:-

There are future possibilities of upgrading this Hypercube 3D printer as mentioned below:-

1) By adding GSM module, it can be operated remotely.
2) We can also add a smoke sensor, which will shut down its operation at the time of fire.
3) A bed levelling sensor may also be installed to align its bed automatically.
4) Multi-nozzle extruder may be added to make complicated structure and to add addition features like texture, colour to the 3D printed parts.
5) Different printing materials may be used to 3D print like dry cell (tissue), metals etc.
6) It may be made expandable as per the requirement.

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