Exploration of 3D Printing

Lin Zeyu
Bachelor's Thesis

___.___.______ ______________________________

Bachelor’ s degree (UAS)

Abstract

Field of Study Technology, Communication and Transport			
Degree Programme Degree Programme in Industrial Management			
Author(s) Lin Zeyu			
Title of Thesis Exploration of 3D Printing			
Date	31.03.2014	Pages/Appendices	39
Supervisor(s) Seppo Ryynänen, Senior lecturer			
Client Organisation/Partner			

Abstract

3D printing technology is introduced and defined in this Thesis. Some methods of 3D printing are illustrated and their principles are explained with pictures. Most of the essential parts are presented with pictures and their effects are explained within the whole system.

Problems on Up! Plus 3D printer are solved and a DIY product is made with this machine. The processes of making product are recorded and the items which need to be noticed during the process are the highlight in this thesis.

There is also a combination of 3D printing technology and Lean production system chapter in this thesis. And what is the future tendency of 3D printing technology development is predicted.

Keywords

3D printing technology, 3D printing methods, RepRap, Up! Puls, Lean production.

CONTENT

SYMBOLS AND ABBREVIATIONS

SLA	Stereolithography
SLS	Selective Laser Sintering
FDM	Fused Deposition Modeling
FFF	Fused Filament Fabrication
J-P	Polyjet or Jetted Photopolymer
UV	Ultraviolet
STL	Sterolithography File Format
D-I-Y	Do-It-Yourself
ABS	Acrylonitrile Butadiene Styrene
PC	Polycarbonate
PEI	Polyetherimide
ISO	International Organization for Standardization
USP	the United States Pharmacopeia
PPSF/PPSU	Polyphenylsulfone
PEEK	Polyetheretherketone
PTFE	Polytetrafluoroethylene

1 Introduction

There has been vast of hype about 3D printing technology these years. From 3D guns, 3D cars to 3D jaw and 3D houses, this technology is certainly capturing lots of headlines in many newspapers, scientific journals etc. Many predict that 3D printing technology will completely change not only the industry field, but also our entire way of life in the future. (Armstrong L., Dec. 2013) Even many authoritative media claimed that 3D printing would be the Third Industrial Revolution. However, what is 3D printing, how does it works, and how is this 3D printing so meaningful to the human beings? This is definitely an attractive topic that needs to be explored.

1.1 Definition

3D printing, also called additive manufacturing, or known as rapid prototyping, is a process of making a three-dimensional solid object of virtually any shape from a digital model. 3D printing is achieved using an additive process where successive layers of material are laid down in different shapes.（ 3D printer Technology - Animation of layering, create it real, 2012） 3D printing has a contrary process compared to the traditional manufacturing methods by adding layer by layer instead of removing the materials by cutting or boring.

1.2 History

The start of 3D printing can be traced back to 1976, when the inkjet printer was invented. In 1984, adaptations and development on the inkjet concept morphed this technology from printing the ink to printing the materials. In the decades since then, a variety of applications of 3D printing technology have been developed across several industrial fields. （Maxey K., The history of 3D printing, 09, 2013）

The first 3D printer was created by Charles Hull in 1984, which enabled the tangible 3D object to be created from digital data. By using this technology, a design can be tested before investing in mass production.

During the 90s, the first SLA (Stereolithographic apparatus) machine was produced by 3D System. It proved that highly complex parts could be manufactured overnight. On the other hand, this technology has been engaged in the medical area. The first lab-grown organ was implanted in human when young patient underwent urinary bladder augmentation using 3D synthetic scaffold coated with his own cells.

After entering the 21st Century, 3D printing technology has been used in the more and more fields, such as medical, manufacturing, automotive, aviation, jewellery and so on. Especially in the last decades, the world's first 3D printed robotic aircraft was built in seven days in 2011. And the world's first 3D printed car was built in the same year. It is estimated to retail for $ 10,000 to $ 50,000 if it becomes commercially viable. (Maxey K., The history of 3D printing, 09, 2013) It has more reasons for us to believe that it will have a bright situation in the future.

2 The category of 3D printer

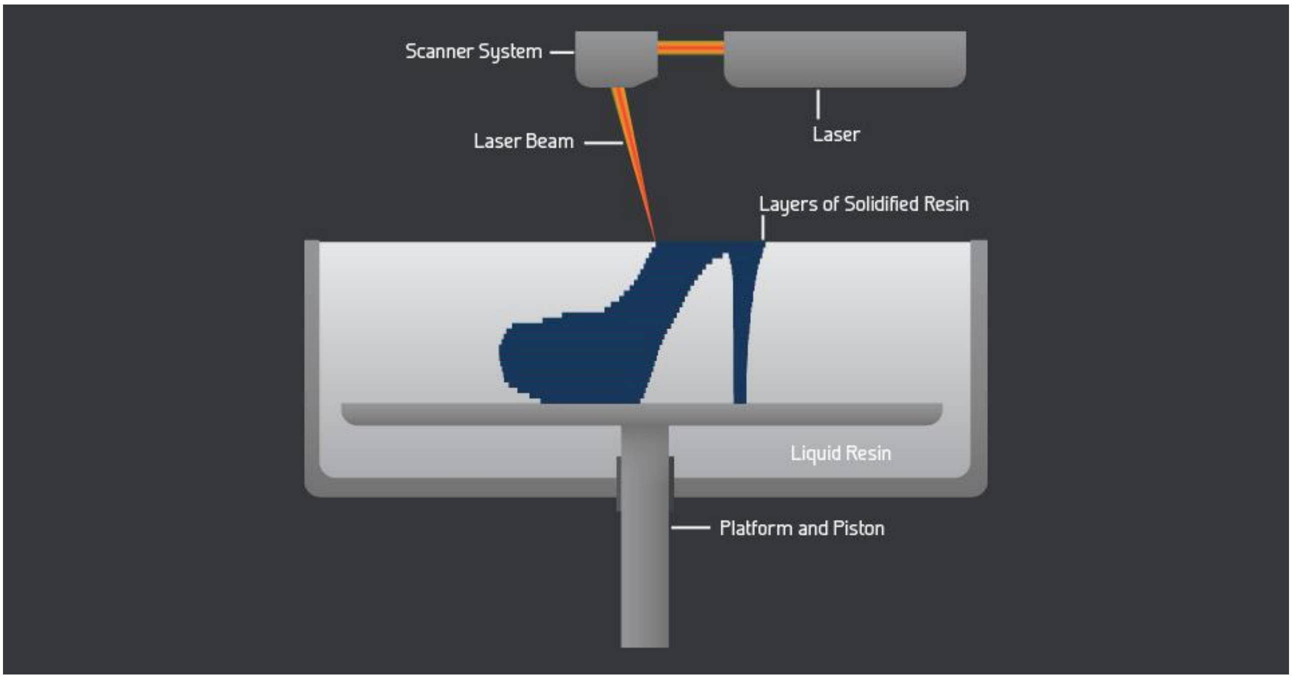
Many people have the misunderstanding about 3D printing that it is just one certain kind of manufacturing technology based on the powder method, which was created by MIT. In fact, 3D printing is an umbrella term, which includes many kinds of distinct manufacturing technologies. All these processes belong to “Additive Manufacturing” which creates objects by adding material in thin layer until the object is completed. In the following chapter various kinds of 3D printers will be introduced according to their manufacturing methods.

2.1 Stereolithography (SLA)

Using the property of the liquid photocurable resin can be solidified by the certain wavelength of an ultraviolet, a SLA 3D printer works by concentrating a beam of UV light onto the surface of a vat filled with liquid photocurable resin. One thin layer is drawn out by UV beam at one time and one object will be completed by layer and layer boned together created by the laser. After that, a full and extremely high-resolution three-dimensional model will be lifted out of the vat. The unused resin can be recollected for the next work. This method was being used in the first commercially available 3D printer invented by Charles Hull in 1986 even it was not called a 3D printer at that time. It can be used to demonstrate ideas and test designs.

Functional prototypes and assemblies, casting patterns, vacuum form patterns and end-use parts can be built by using this method. However, the materials it used only can be rigid or flexible epoxy polymers, so there is relatively narrow range for choosing the material.

The picture 1 shows the necessary construction of the SLA 3D printer, which are the UV laser, scanner system, photocurable liquid resin, platform and piston. After entering a model to the printer, on each layer, the laser beam tracks a part cross-section pattern on the surface of the liquid resin. The piston controls the platform that goes up and down to assist the layers construction until the object is complete. And then, the object model needs to be cleaned up, for instance, removing the support constructions and hardening the model by putting the part into UV oven for curing. Then the raw object is finished and ready for finishing and assembly.

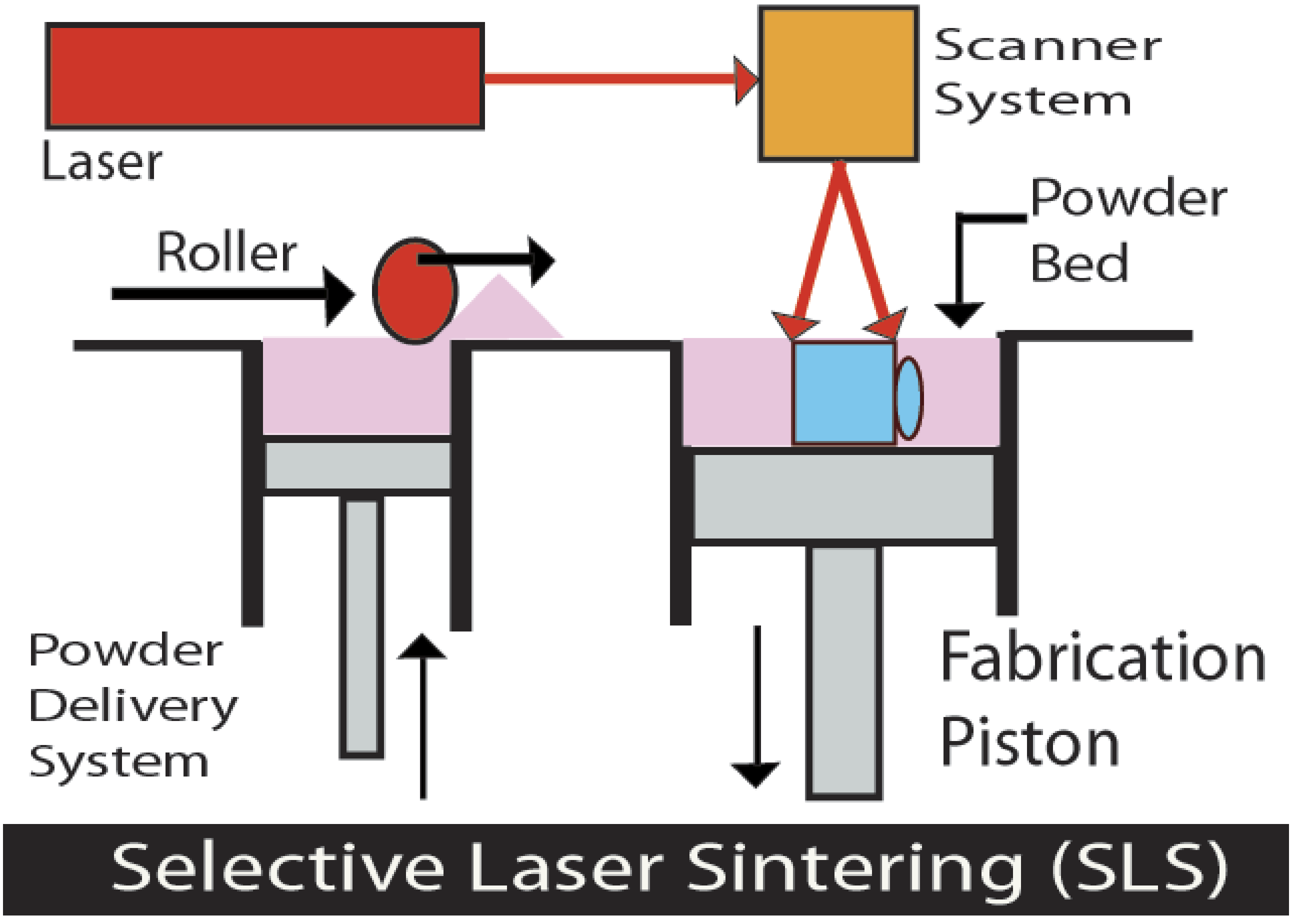


Picture1: The construction of the SLA printer, From: proto 3000

2.2 Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is an excellent combination of 3D printing and lasers. The whole process is similar to the SLA except the UV beam is replaced by lasers and the vat of resin is replaced by the powdered base, such as polystyrene, ceramics, glass, nylon, even the metals like steel, titanium, aluminium, and silver. This is also the major benefit of SLS because it has the ability to produce the parts in a variety of materials. This method use laser heats the powder and the powder is fused at the certain point (sintered). All the unsintered powder would become the support structure for the part and remain as it was. There is no extra waste when the object is completed. The rest of the material can be used next time. Selective Laser Sintering (SLS) was invented by Carl Deckard and his colleagues at the University of Texas in Austin in1980.

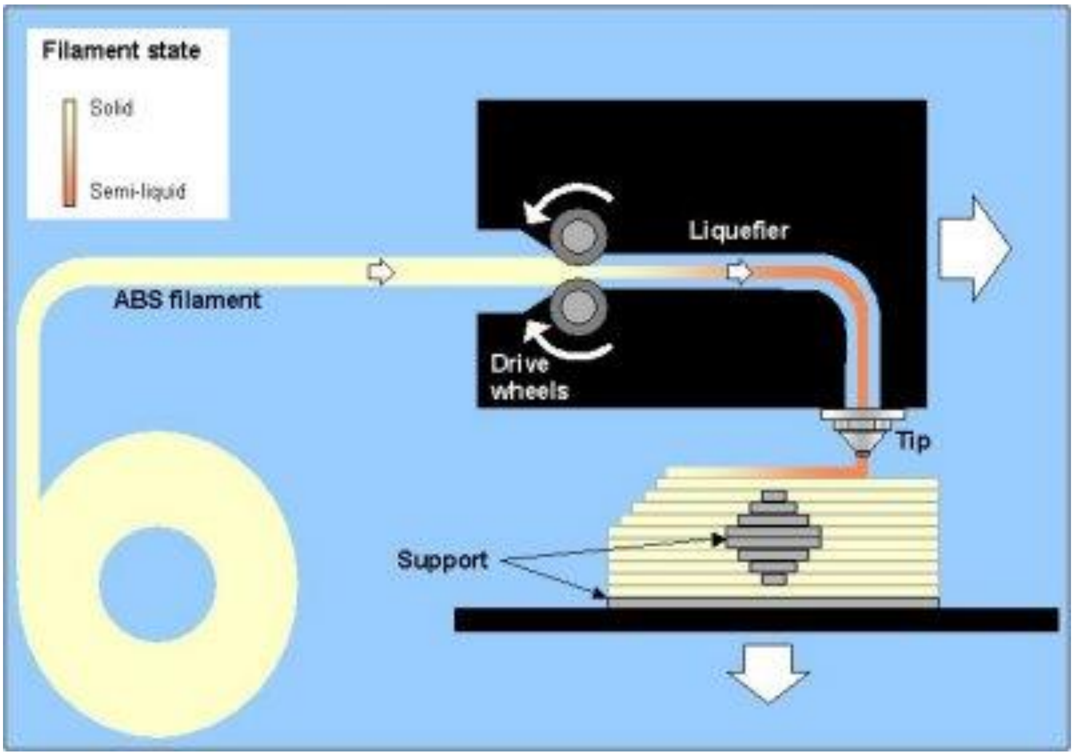
Picture 2 below illustrates the construction of the SLS 3D printer. Apart from the lasers, scanner system, platform and piston, because of the material properties of powder, there is one more set for feeding the materials. This configuration consists of one powder platform, a piston and a roller as show in the picture. The fabrication piston goes down during the process while the powder delivery piston goes to the opposite direction. The roller on the top carries the powder to the fabrication section for feeding until the object is fabricated. Inside of an SLS machine is the oven used to heat the material to a few degree lower than the melting temperature. These nearly melted materials will be selectively melted by the beam of laser before stick it together. When the object is finished, wait until the material cools down, and brush the needless material away that sticks the surface of the object. Then the part is ready to use.



Picture 2: The construction of the SLS printer， From: Martello

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

As the most seen 3D printer, it does have the big advantage compared to other methods, which is the cheapest price. And also it seems that this method is the most promising for the cheap home use 3D printers. With this method, a filament of melted thermoplastic material is extruded from the nozzle forms the layers to create the objects. Each new layer will stack on the top and fuse with the previous layers when the material hardens almost immediately after squirt out forms the extrusion nozzle. Usually FDM/FFF printers use ABS plastic, PLA (Polylactic acid) and biodegradable polymers, some of them can use concrete, chocolate and sugar and other food. This method was invented in the 1980s by Scott Crump who is also the founder of Stratasys, the leading company in 3D industry. FDM, which is the abbreviation of the Fused Deposition Modelling are trademarked by the Stratasys while the similar process Fused Filament Fabrication and its abbreviation FFF cannot step on the trademark. With FFF, a spool of filament instead of nozzle feeds the material during the process.



Picture 3: The principle of FDM/FFF printer, From: Fused Deposition Modelling

Picture 2 above shows the basic configuration of the FDM 3D printer. The layer stacks one by one is extruded through the tip of the extruder. The ABS filament feed by the drive wheels and the filament is liquefied during the period in the extruder.

2.4 Polyjet or Jetted Photopolymer (J-P)

This is much like traditional inkjet printer deposit ink. The photopolymer liquid is jetted out precisely and hardened with a UV light. The layers are stacked successively until the object is completed. This method has several advantages e.g. it can create rubber-like objects and it allows the use of various materials and colours to be incorporated into a single object at a high resolution. This technology is developed by Objet, which has been acquired by Stratasys now.

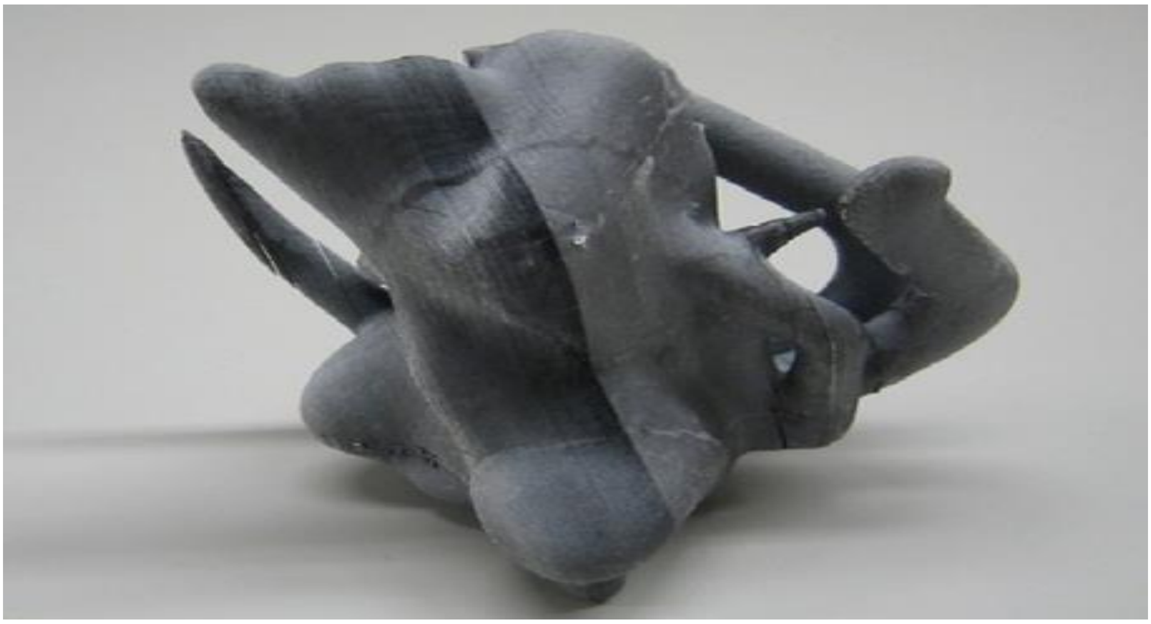
Picture 4: The product of the J-P, From: 3D Printed Instructions

Picture 4 above shows the characters of the product produced by J-P method. The product is rubber-like and different colours used are very distinctive compared to the other method.

2.5 The others

There is a variety of 3D method in the world apart from the four types illustrated above. For example, syringe extrusion can be used in the 3D printer depend on almost every material has a creamy viscosity whenever it heats or not. Thus, chocolate, cheese, clay and cement can be used as the material of this method. There is another kind of method called Selective Laser Melting (SLM), which is similar to the SLS while it fully melts the powder instead of just fuses the powder granules at a low temperature. This is similar to Electron Beam Melting (EBM), which uses an electron beam instead of a UV laser during the process. The difference is exacting and capability of producing implants grade parts to be used in orthopaedic surgery. And there is a completely different method named Laminated Object Manufacturing (LOM), where thousands of sheets of layers made of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter. The object can get wood-like properties by simulating the year ring.

In the picture 5, there is a product produced by using LOM, due to the different method of manufacturing, the product shows the wood-like properties as the faultage of sheet simulating the year ring.



Picture 5: The product of LOM, From : 3D printed Instructions

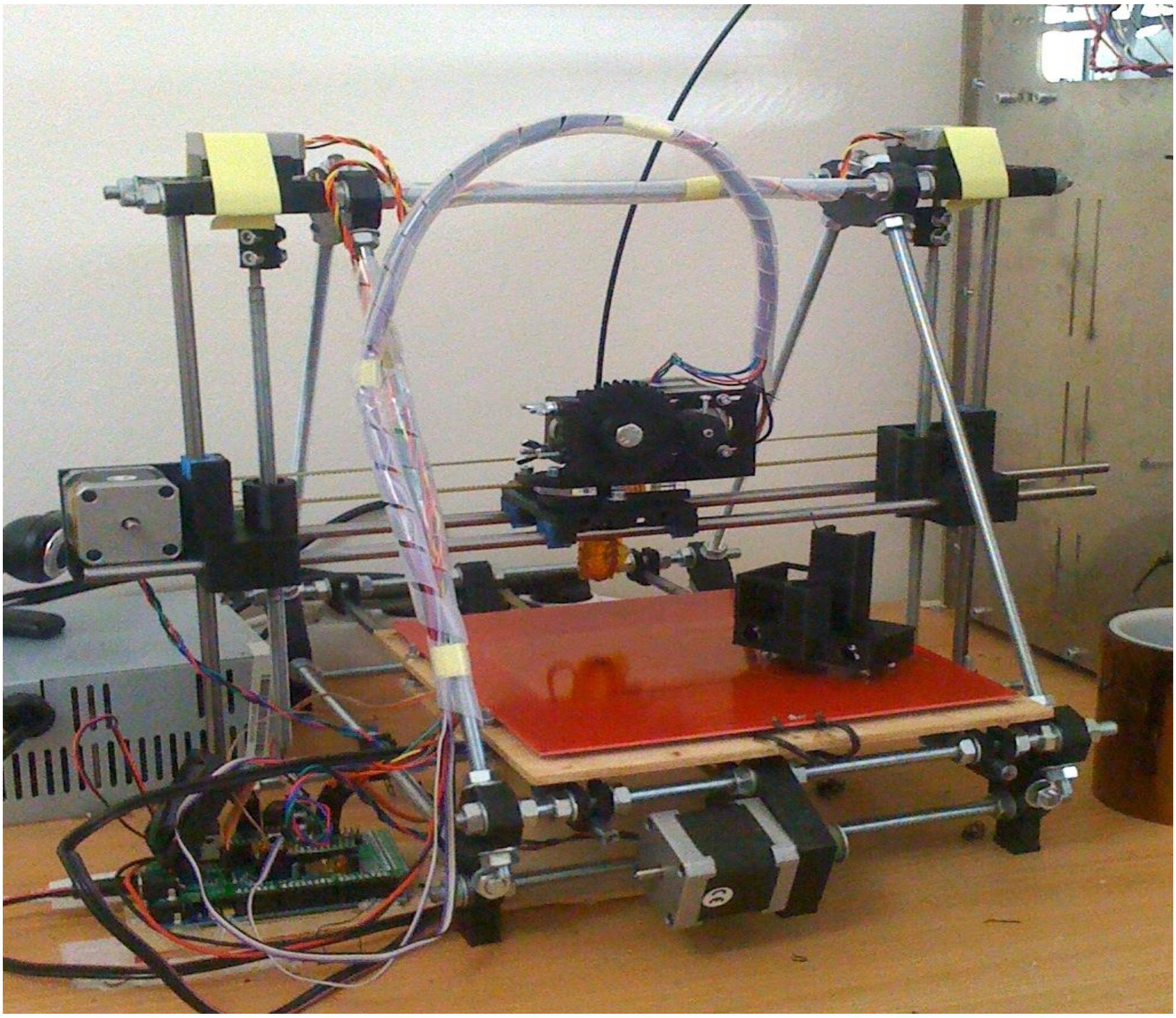
3 The most common 3D printing method-FDM

3.1 Parts of the printer

In this chapter, the necessary and elementary parts are introduced, and the RepRap 3D printer is an example machine because it is one of the simplest 3D printers in the world, additionally, it is relatively representative. But first what is RepRap printer is going to be introduced.

RepRap is the abbreviation of self-replicating manufacturing machine. It can print the normal useful plastic objects and also make a kit for itself, which can be assembled to create another RepRap.

RepRap is the sort of desktop 3D printer, and it was the first low cost 3D printer in the world, started the open source revolution of 3D printers as well. RepRap was founded in 2005 by Dr Adrian Bowyer, a Senior Lecturer in mechanical engineering at the University of Bath of the United Kingdom.



Picture 6: The picture of working RepRap Prusa Mendel 3D printer. From: Steven Devijer

In the picture 6 above is showing the construction and parts of the RepRap Prusa Mendel 3D printer. As it can be seen, there are several stepper motors, frame, extruder, electronics, end stops and other parts in the picture, which will be introduced more specifically in the following.

Hardware

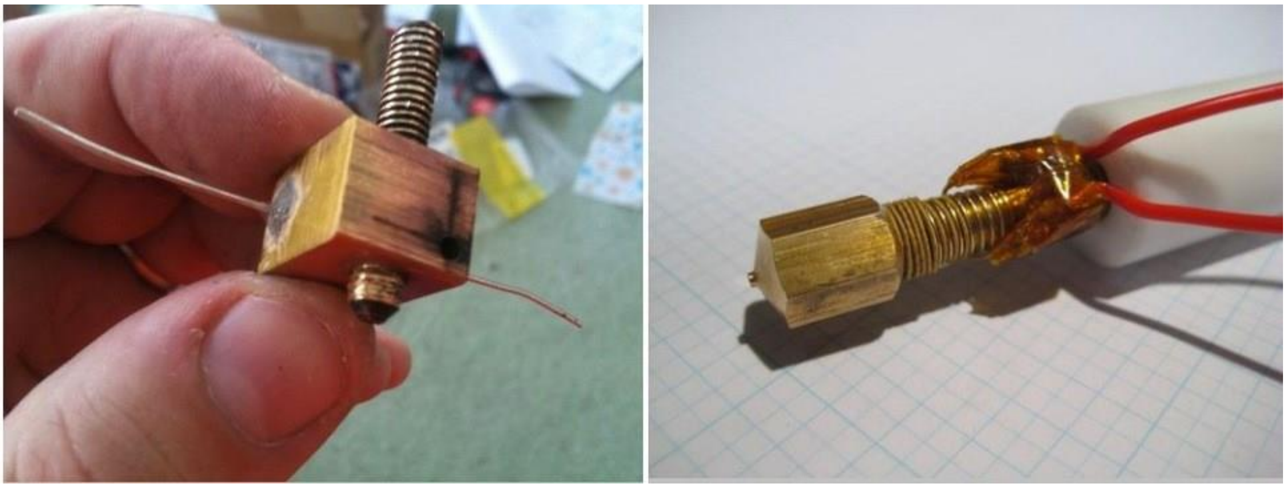
The frame has the function of support because all the three axes will be added, and the most necessary property should be the stiffness. Usually, the frame is made from aluminium or steel. Sometimes, wood construction can be used also. But, the thickness of the frame material should be at least 6 mm or more.

The RepRap itself can make all the parts, which are plastic. They are bushings, bearings and gears and so on. They can be printed by the RepRap machine according to the size.

Extruder is very important in the 3D printer like the pan to the cook. Wade's gear extruder is wisely used in the FDM machine especially in the RepRap Prusa Mendel. It includes two parts, which are cold part in the up， which feeds the filament to the extruder; the other part is hot bottom part that melts the filament and extrudes the material to the platform. In terms of the cold part, it has a large gear driven by a stepper motor that uses friction to pull the filaments into the cold part and push them into the hot part. In the picture 7 below, there is a typical Wade's gear extruder.

Picture 7: Wade's geared extruder, from: Steven Devijer

The hot part consists of a brass bolt with a hole drilling down its vertical axel, a thermistor to measure the temperature, a heat barrel to separate the two parts and a nozzle where the material flows out. As can be seen in the picture 8 below, there are two methods to heat the hot end. One is the resistor and the other is NiChrome wire. In the comparison of these the two methods, NiChrome method is more recommended to use in this case because there is only one heat barrel that needs to be heated. Besides, the thermistor and the NiChrome or Resistor should be connected to the electrons that allow the measurement of the electrons measuring and controlling of the temperature of the heat barrel.



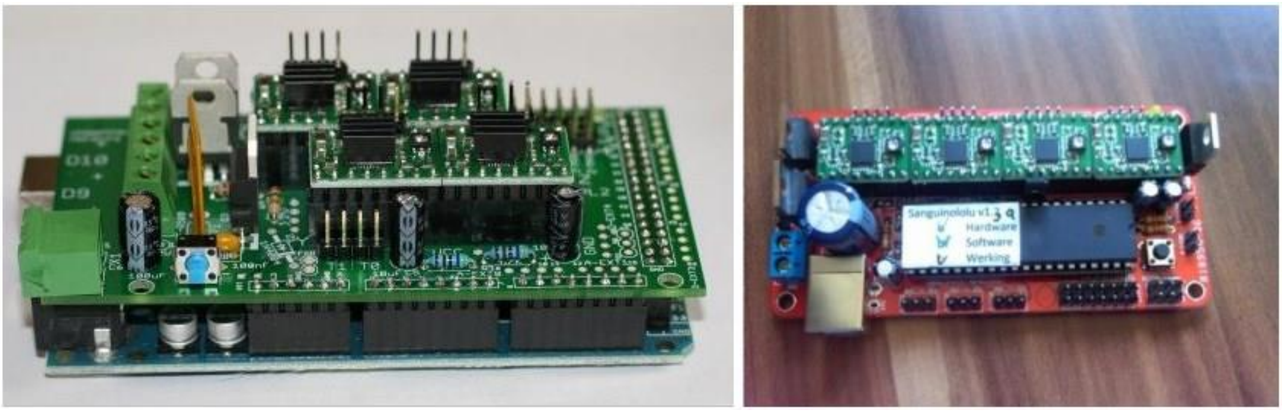
Picture 8: Left: Resistor method, Right: NiChorme method, From: Steven Devijer

The effect of the heat barrel is to prevent transferring too much heat to the cold part, which determines the quality of the material of the heat barrel which can resist high temperature while transfer little heat. Here PEEK is a suitable material for this purpose, however, its high price and need of a PTFE tube inside the heat barrel become its biggest disadvantages.

PEEK is one of the strong and stiff thermoplastic materials that are often used where the performance at elevated temperatures is needed. It also has excellent chemical and mechanical resistance as well as resistance of hot water and stream. PTFE is a low friction, soft fluoropolymer with outstanding chemical resistance and weathering resistance. It is stable at the temperatures up to 250 °C therefore it is usually used in the high temperature circumstance. Moreover, it has excellent electrical insulating properties. (From: Curbell plastics, technical resource)

Electronics boards are important in the 3D printer to control the crucial steps of the process. The function of the electronics is to process the G-code instructions, control the stepper motors, monitor and control the temperature of the hot part of the extruder as well as control and monitor the temperature of the platform etc.

There are several choices for the RepRap here because these are open source. However, the other 3D printers may have their own options in their machine. Here some currently popular electronics boards will be mentioned. The first one is RAMP, which is a DIY shield board for Arduino Mega. The other one is the Sanguinololu that is an all-in-one DIY board with a microprocessor. But both of the electronics boards need to be connected to the PC using an USB-to-serial converter. The Arduino used with the RAMPS board has such a converter built-in, so does the Sanguinololu board. The price of the RAMP with an Arduino Mega board will be a little more expensive than the Sanguinololu. The picture 9 below shows both the assembled RAMP board and assembled Sanguinololu board.



Picture 9: Left: an assembled RAMP mounted on the Arduino Mega board with four stepper motors controller installed, Right: assembled Sanguinololu board with four stepper motor controller installed, From: Steven Devijer

In general, there are six stepper motors used in a 3D printer, first one is controlling X-axis, the second one is controlling the Y-axis, the third one is controlling the extruder, two control the Z-axis, the last one is controlling the feed of the filament. Normally all six stepper motors are of the same type but not essentially except the two stepper motors, which control the Z-axis. In fact, the most wanted aspect of the stepper motor is its torque. However, the amount of torque that stepper motor will actually supply is controlled by the stepper motor controller in some degree. The stepper motor used in the printer is actually bipolar stepper motor that is more complicated to control than the unipolar stepper, yet it provides more torque at the same size.

End stops play a very important role in the Cartesian robot, which help achieving the three axes, which will stay at the zero position at the start of the printer job nor go beyond the limits. Each axis will have one end stop installed at beyond where the axes shouldn’t move. For instance, X axis will have it at the left hand side limit, Y axis will have it on the back side limit and Z axis will have it to keep the platform not hit the nozzle. There are also two kinds of end stops, which are very popular right now, the mechanical switch and optical switch. However, the mechanical switch is highly recommended because it is much cheaper, works as well as the optical one and is easier to install.

3.2 General process and materials

There have been several kinds of 3D printing methods since the starting of 1980s, and they have become the fastest and most affordable equipment for modelling, prototyping and production application. However, most of them are still too expensive for the normal use except the most wisely used 3D printing method known as Fused Deposition Modelling, which is normally called FDM.

Process

With the manufacturing process of FDM, it is relative easy to make the objects which is one of the advantages for its popularization. It starts with the help of Computer-Aided Design. Usually the idea of the object is created and presented by the CAD files. But, before the printing work, the files need to be converted to the format which is understandable for the 3D printer, for FDM, the most common format is STL. The object will be mathematically sliced and oriented for the printing process, and if required, the supporting constructions will be generated. The object will also be analysed for achieving the designed goals, for instance, the different colours of the same material can be used to construct the objects. The file gets converted to the G-code that is the most widely used numerical control program language and sent to the electrons to control the movements.

During the printing process, the materials, which are continuously from a coil, are going through the pathway that is designed at a controlled rate and fed through the excursion nozzle. The nozzle is heated to melt the materials and extrude them onto a base, which is called the platform or table in the 3D printer. There is a numerically controlled mechanism that is the computer-aided manufacturing (CAM) software package for controlling the nozzle and the platform which translates the dimensions of the object through the coordinates in the X-axial, Y-axial and Z-axial as we familiar know as Cartesian Coordinate system. The three axes together with the extruder form the Cartesian Robot. And the whole process will start building from the bottom up.

In a normal FDM printing system, the nozzle can be moved both in horizontal and vertical directions over the platform to build the object. And the nozzle head is controlled by the stepper motor or servomechanism. New thin layer is binding to the old ones when it cools down and hardens immediately after extruding from the nozzle. The platform will go down to create room for the next layer; in general, the distance would be 0.2-0.4 mm. Although the FDM printing technology is flexible, there are still some restrictions for making the overhangs. Even the small overhangs can get help of the lower layers.

Once the building process of an object is completed, its support materials can be removed by soaking the object in water and detergent solution or in the case of thermoplastic supports, snapping the support material off by hand. Objects can be sanded, milled, painted or plated to improve their function and appearance. (Fused Deposition Modeling: Most Common 3D printing method, Elizabeth Palermo, 09,2013)

3.3 Materials for consuming

As it has been mentioned above, the purposes of using FDM are various. For the company, mostly it is used for product development, prototyping and production process. The applications for the personal user are normal for their hobbies, inventions and D-I-Y products. Therefore, it is important to choose the right material depending on its properties and purpose.

For now, thermoplastics are still the most used materials for the FDM. Because thermoplastics can endure heat, chemical corrosion and mechanical stress, they are the ideal materials for making the prototypes that must withstand some kind of testing, especially for the particularly small detailed parts and the specialized manufacturing tools. Moreover, this kind of material is not harmful to the human that is a valueable property. Somehow the thermoplastics can even make contribution to the prevalence of the FDM because they can be used in food and drugs packages sometimes which make the FDM more popular in this area. Last but not least, this material is relatively cheap to use which is the most important strength for its popularization.

The most common used material for FDM printer is acrylonitrile butadiene styrene (ABS), which is known as a widely used thermoplastic used to make many consumer products. For instance, the LEGO bricks and the white water pipes are made of this material. Apart from the ABS, some other thermoplastics can be used in the FDM printer also, like polycarbonate (PC) or polyetherimide (PEI) and PPSF/PPSU (polyphenylsulfone). As most end products are using these materials, their properties are closely matched to many real end products. (Fused Deposition Modeling: Most Common 3D printing method, Elizabeth Palermo, 09,2013)

Actually, there are more specific categories for certain types of thermoplastics in order to make them more suitable for the end products' properties. They will be illustrated below.

Regarding to the ABS group, normally there are five types that are commonly used. They are ABSplus, ABSi, ABS-M30 , ABS-M30i, and ABS-ESD7.

The products which are made from ABSplus are mechanically strong and stable over time. The reason is that this material works with soluable support materials, removel support is hands-free, and it does need extra effort to construct the conplex shapes and deep cavities.

When the product needs to be made beyond the tough and opaque, the designers need this ABSi to work with. This material is used when light transmission or flow monitoring is important. Especially, this material is pretty useful in the automative industy, aerospace and medical-device manufacturing.

ABS-M30 and ABS-M30i are similar with the ABS plus that they have good mechanical strength, offer soluable support materials and suport removel hands-free and efficiency. The difference between ABS-M30 and ABS-M30i is that the ABS-M30i complies with ISO 10993 and USP Class IV.

ABS-ESD7 is designed for applications where a static charge could damage the components, impair performance, or cause an explosion. Because this material has static dissipation with a target surface resistance of 107 ohms.

The toughest material in this industry is nylon 12, which is exhibiting 100-300% better elongation at break and excellent fatigue resistance. Nylon gives great chemical resistance and superior Z-axis lamination as well as highest impact strength to the parts.

As most people know, PC is one of the most wisely used industrial thermoplastic depending on its reliability, high tensile and flexural strength. It is also an ideal material for the FDM manufacturing which is demanding fast speed and it is endurable for use. Its property makes it very suitable for making functional prototypes, tooling and end-use products. Moreover, breakaway or soluble support materials are both available for PC.

One unique material that needs to be mentioned is PC-ABS, which shows the best features of these two excellent FDM manufacturing materials that can be seen from the name. It inherits the good strength and heat resistance from the PC and inherits the flexibility from the ABS. Not only these, the PC-ABS gets its unique property on the surface finish.

PC-ISO is the strongest, most heat resistance biocompatible material which is used on FDM manufacturing. Generally, it is used in medical, pharmaceutical, and food packaging area because it is gamma and Ethylene Oxide sterilizable and complies with the ISO 10993 and USP Class IV. This thermoplastic material can work with the breakaway support material.

PPSF/PPSU can endure the highest heat among these FDM thermoplastic materials. Moreover, it has good mechanical strength and resistance to petroleum and solvents. It is gamma and Ethylene Oxide and autoclave sterilizable as well. It works with the breakaway support material and it can produce under-the-hood automotive prototypes, sterilizable medical devices and tools for house using and so on.

Last but not least, ULTEM 9085 has the reputation of reliability and high performance because it possesses all the excellent properties on the thermal, mechanical and chemical aspects makes it ideal material to be used in aerospace, automotive and military applications. ULTEM 9085 works with breakaway support material. The picture below illustrates the comparison of these materials. (Stratasy Official Website/ materials)

The picture 10 below shows the categories and the comparison of these materials mentioned above. It includes the thickness of these materials, available color, tensile of strength and elongation, stress, impact ability and their unique properties.

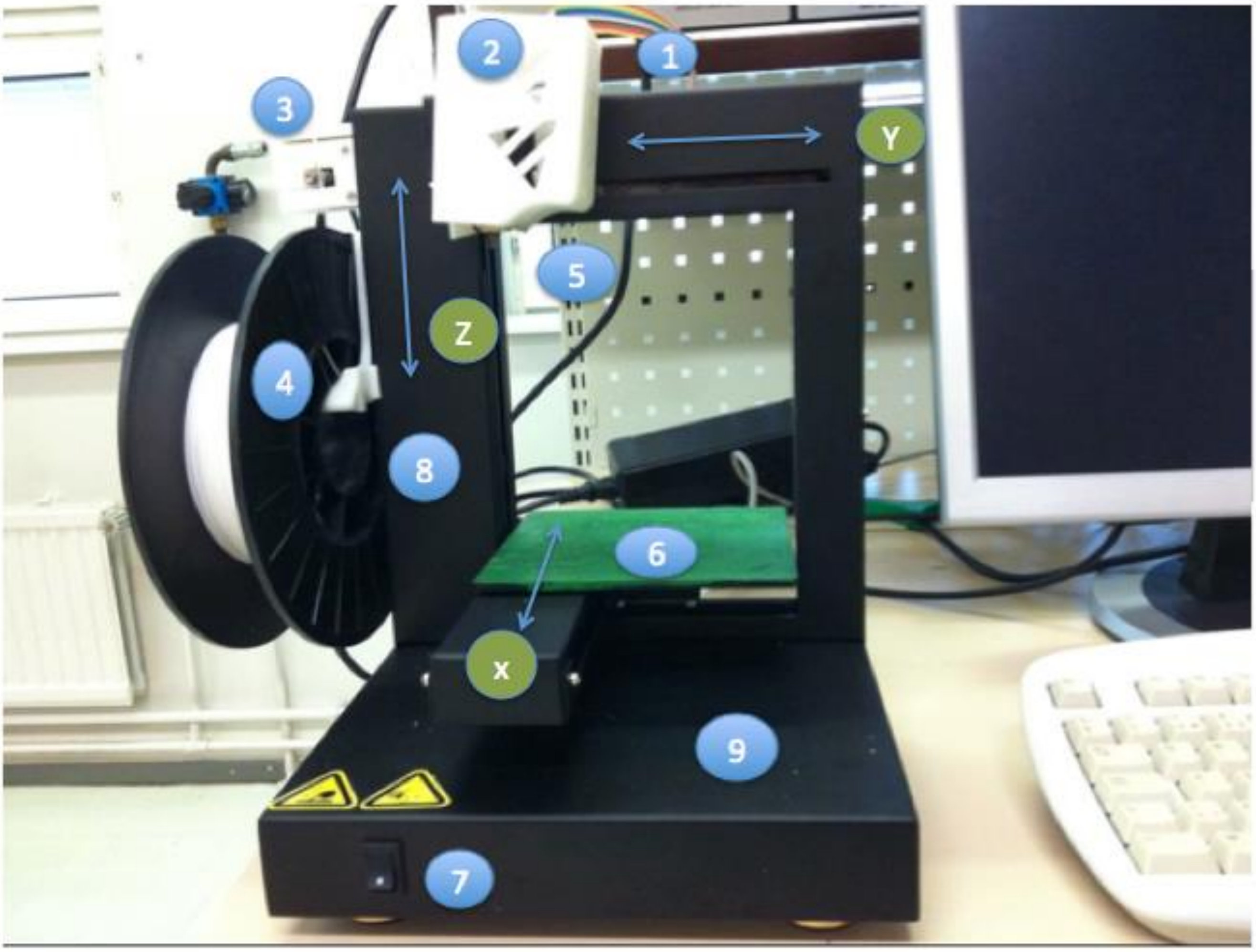
Material:	ABSplus-P430	ABSi	ABS-M30	ABS-M30i	ABS-ESD7	PC-ABS	PC-ISO	PC	NYLON 12	ULTEM™ 9085	PPSF
System Availability	Fortus 250mc	Fortus 400mc Fortus 900mc	Fortus 360mc Fortus 400mc Fortus 900mc	Fortus 400mc Fortus 900mc	Fortus 400mc Fortus 900mc	Fortus 360mc Fortus 400mc Fortus 900mc	Fortus 400mc Fortus 900mc	Fortus 360mc Fortus 400mc Fortus 900mc	Fortus 360mc Fortus 400mc Fortus 900mc	Fortus 400mc Fortus 900mc	Fortus 400mc Fortus 900mc
Layer Thickness:											
0.013 inch (0.330 mm)	X	X	X	X		X	X	X	X	X[3]	X[4]
0.010 inch (0.254 mm)	X	X	X	X	X	X	X	X	X	X	X
0.007 inch (0.178 mm)	X	X	X	X	X	X	X	X	X		
0.005 inch (0.127 mm)		X[1]	X[1]	X[1]		X[1]		X[1, 6]			
Support Structure	Soluble	Soluble	Soluble	Soluble	Soluble	Soluble	BASS	BASS, Soluble	Soluble	BASS	BASS
Available Colors	Ivory White Black Dark Grey Red Blue Olive Green Nectarine Fluorescent Yellow Custom Colors	Translucent Natural Translucent Amber Translucent Red	Ivory White Black Dark Grey Red Blue	Ivory	Black	Black	White Translucent Natural	White	Black	Tan Black	Tan
Tensile Strength[2]	5,300 psi (37 MPa)	5,400 psi (37 MPa)	5,200 psi (36 MPa)	5,200 psi (36 MPa)	5,200 psi (36 MPa)	5,900 psi (41 MPa)	8,265 psi (57 MPa)	9,800 psi (68 MPa)	7,000 psi (48 MPa)	10,390 psi (72 MPa)	8,000 psi (55 MPa)
Tensile Elongation[2]	3.0%	4.4%	4.0%	4.0%	3.0%	6.0%	4.3%	4.8%	30%	5.9%	3.0%
Flexural Stress	7,600 psi (53 MPa)	8,980 psi (62 MPa)	8,800 psi (61 MPa)	8,800 psi (61 MPa)	8,800 psi (61 MPa)	9,800 psi (68 MPa)	13,089 psi (90 MPa)	15,100 psi (104 MPa)	10,000 psi (69 MPa)	16,700 psi (115 MPa)	15,900 psi (110 MPa)
IZOD Impact, notched	2.0 ft-lb/in (106 J/m)	1.8 ft-lb/in (96 J/m)	2.6 ft-lb/in (139 J/m)	2.6 ft-lb/in (139 J/m)	2.1 ft-lb/in (111 J/m)	3.7 ft-lb/in (196 J/m)	1.6 ft-lb/in (86 J/m)	1.0 ft-lb/in (53 J/m)	3.74 ft-lb/in (200 J/m)	2.0 ft-lb/in (106 J/m)	1.1 ft-lb/in (59 J/m)
Heat Deflection	204°F (96°C)	188°F (87°C)	204°F (96°C)	204°F (96°C)	204°F (96°C)	230°F (110°C)	271°F (133°C)	280°F (138°C)	180° F (82°C)	333°F (167°C)	372°F (189°C)
Unique Properties	Variety of color options	Translucent material	Variety of color options	ISO 10993 USP Class VI[5]	Static dissipative, target surface resistance of 10^7 ohms[7]	Highest impact resistance	ISO 10993 USP Class VI[5]	Highest tensile strength	Fatigue resistant, high elongation at break	Flame, smoke, toxicity (FST) certified	Highest heat and chemical resistance

Picture 10: Comparison of the FDM manufacturing materials From: Stratasys's Fortus 3D production system brochure

3.4 FDM Printer Example: UP! Plus

This 3D printer is designed and made by the 3D systems company. This machine is perfect blend of portability and precision that is suitable for personal and office use. The printer needs an easy assembly and can print the object in 15 minutes when taken out of the box. The best accuracy is 0.2 mm, which enables the part to serve either as end product or assembles use. As user loads the pattern to the computer, the computer will generate the support for your design automatically no matter how complicated the design is, and just by peeling off the support constructions after the model is finished can get a precise, high quality product. Because the printer is usually used at home or office, thus this printer has heat and wind shield protection for the users.

Appearance and parts



Picture 11: Photography of UP! Plus, From Lin Zeyu

As the picture shows, ① is ribbon cable, ② is head of the machine, ③ is feed guide, ④ spool of roll,⑤ is the nozzle, ⑥ is the platform, ⑦ is the initialize switch, ⑧ is roll holder, ⑨ is main structure of the machine.

Technical Specifications

Build platform: 140 mm width 140 mm depth 135 mm height.
Selectable Z resolution: 0.2 mm, 0.25 mm, 0.3 mm and 0.4 mm. Depending on the model.
Support Material: Smart Supports. Intelligent snap off support material, printed in the same material, printed at a lower density and built automatically by the included 3D print software.
Dimensions: 245 mm width, 260 mm depth, 350 mm height

Weight: 5 kg

Shipping Weight: 10 kg

Power input: 100-240 VAC, 50-60 Hz, 220 W

Power output: 20 VDC 11 amp

Connectivity: USB (Print job stored and spooled to Printer, ability to turn off computer during printing.)

Consumables: 1.75 mm ABS Plastic Filament or PLA (corn starch) Filament

Warranty: 12 month via UP! Distributor

Software: STL 3D layout and printing software included free for Windows and MAC 10.7 Beta

Operating System: Windows XP, Vista, Windows 7, OSX 10.7 beta

Unboxing time to print: 15 minutes

Printer speed: 10-100 cm3/h

Input format: STL or UP3

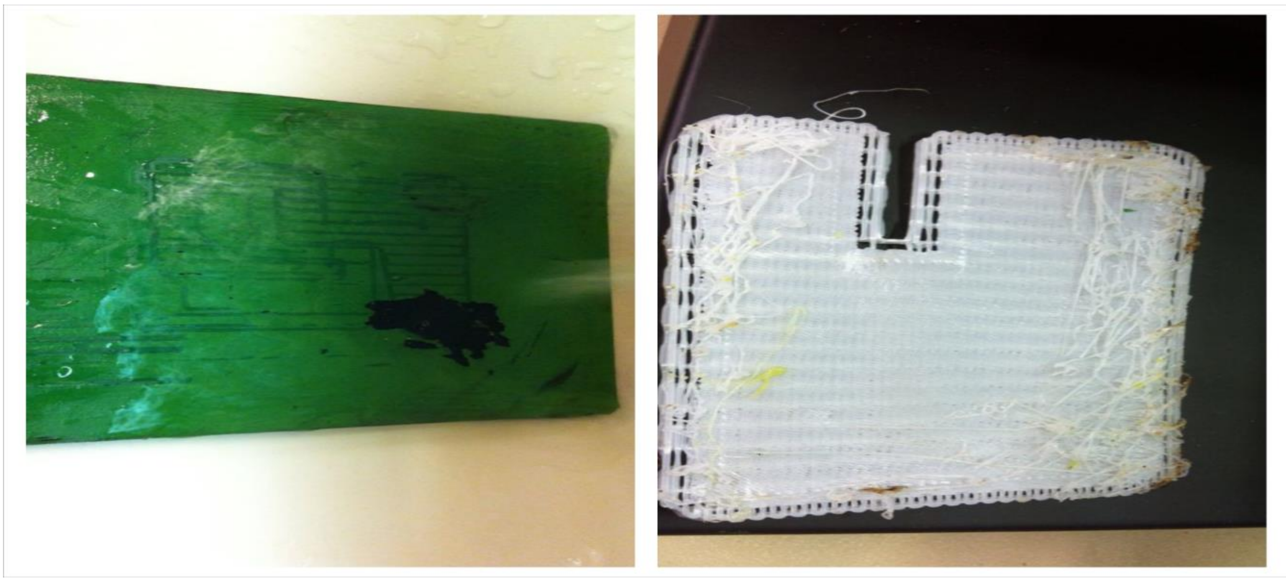
Ambient temperature: 15 °C~30 °C

Relative Humidity: 20 %-50 %

(User Manual – UP! Start Plus 3D Printer)

3.4.1Problem study and solving

This machine malfunctioned when it was used for the first time. There were several problems: 1, the feeding configuration in the extruder failed to work; 2, the platform was broken and out of use, 3, the extruder was blocked and couldn't extrude normally; 4, the materials were burnt when extruded from the nozzle. And the picture 12 below shows the problem on the platform and the extruded materials.



Picture 12: Left: the problem with the platform, Right: the bad quality of object printed by UP! From: Lin Zeyu

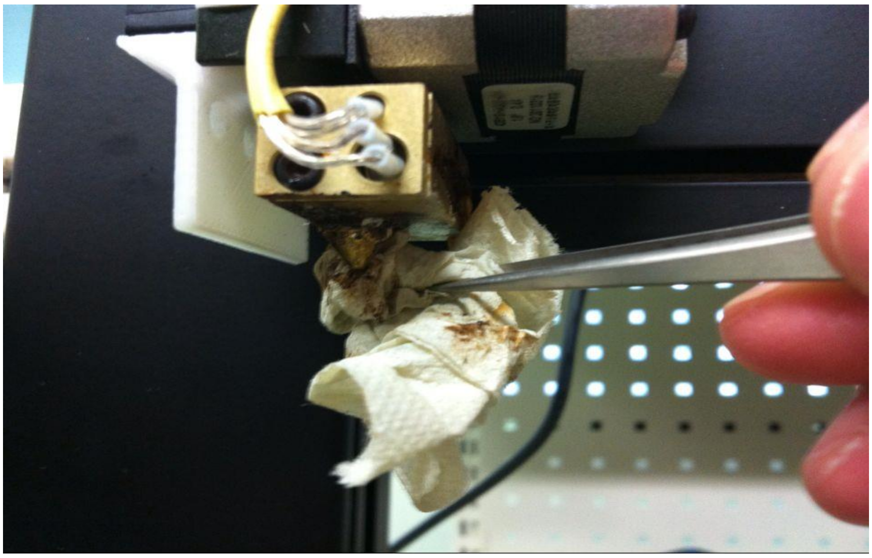
Feeding system's malfunction is confronted by most FDM machines. The feeding system was analysed and the reason was deduced on the stepper motor in the extruder and the end part of the extruder. Because the feeding force is provided by the friction of the gear controlled by the stepper motor and the end part maybe blocked by the previous melted material and increase the difficulty for extruding the filament. For feeding force missing, the reason is that the friction between gear and filament is relatively low. For end part of the extruder, the previous melted material has accumulated at the end part and it obstructs the new material to be extruded through.

In order to solve this kind of situation, the extruder was taken apart and the original reason was found that the accumulated powder of the filament becomes lubricant between the gear and the filament, thus the gear cannot provide enough friction force. Therefore, cleaning the plastic powder is the most crucial step to get the gear work normally. Here the gear and the stepper motor were cleaned with a brush with blowing a little wind. Afterwards, it worked very well as the original design. For the end part of the extruder, firstly the nozzle was removed by a plier and then it was heated using a lighter. The accumulated melted material was taken out by using a long tweezers. Actually, the nozzle is glued to the end part that is not fixed by a thread. It cannot stick to the end part in very hot circumstances by glue although many methods were used, which were supposed to endure very high temperature. So that, screws and the metal ring were used to get it fixed, like the picture shows below. Problem 1, problem 3 and 4 were solved at this step.

Picture 13: Left up: stepper motor with powder lubricant, Right up: the nozzle heated by lighter, Left down: nozzle fixed by metal ring with screws, Right down: fixed nozzle. From: Lin Zeyu

The problem with the platform was relatively easy to fix, the method was to soak the platform in hot water for several hours, using tweezers and hand to get the green paint out. The front side was broken because the people had used wrong way to get the printed models out and that scratched the surface by knifes already. Thus, the sides were changed and brush was used to paint the surface.

To improve quality of the objects, this kind of maintenance work is essential for the Up! In fact, every machine needs maintenance. For instance, using tweezers to clean the nozzle is daily work for the maintenance.

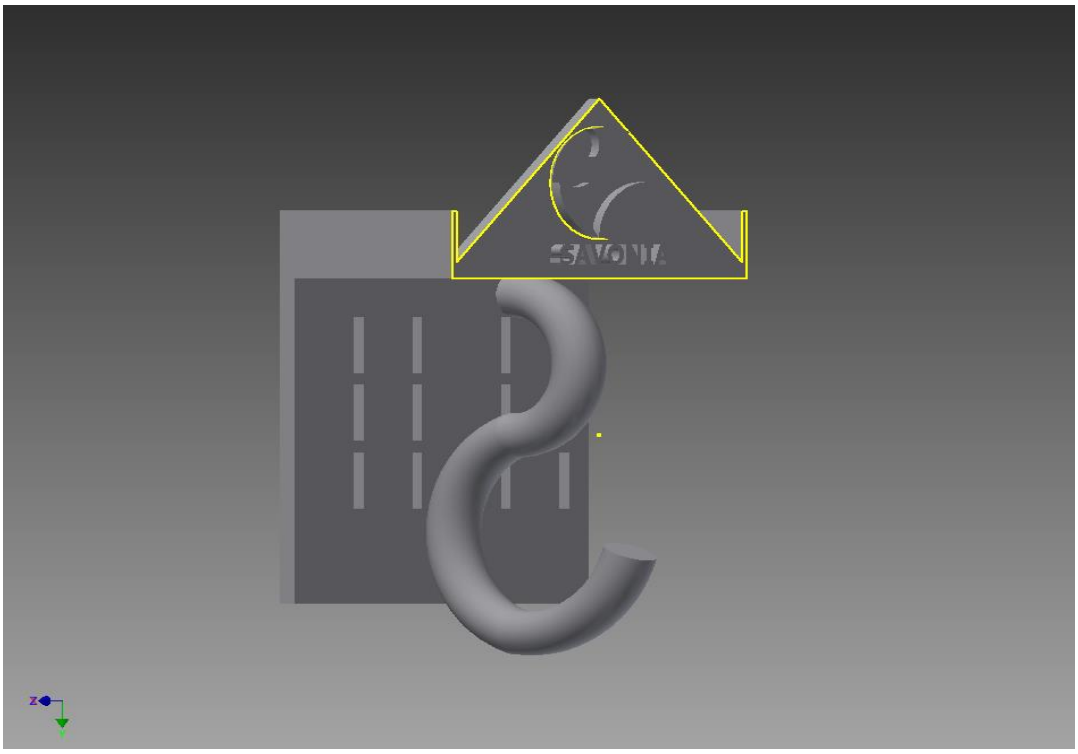


Picture 14: Clean the nozzle with soft paper. From: Lin Zeyu

Picture 14 above shows the method for cleaning the extruder, and it is important to use a soft paper instead of hard one. So far, the main problems were solved and the printer could work in a normal condition. The next step was to use UP! to make a true object.

3.4.2 Starting to print with Up!

Before printing the object, the model file is necessary. This file can be downloaded from the Internet or can be designed and made by software users. Here the file was made in Autodesk Inventor 2014, and the file is in ipt format when it is done in this software, but it is easy to export the file to the STL format using the export to the CAD format function and you will find the STL in it.



Picture 15: The image of the hook, from: Lin Zeyu

Description of the hook:

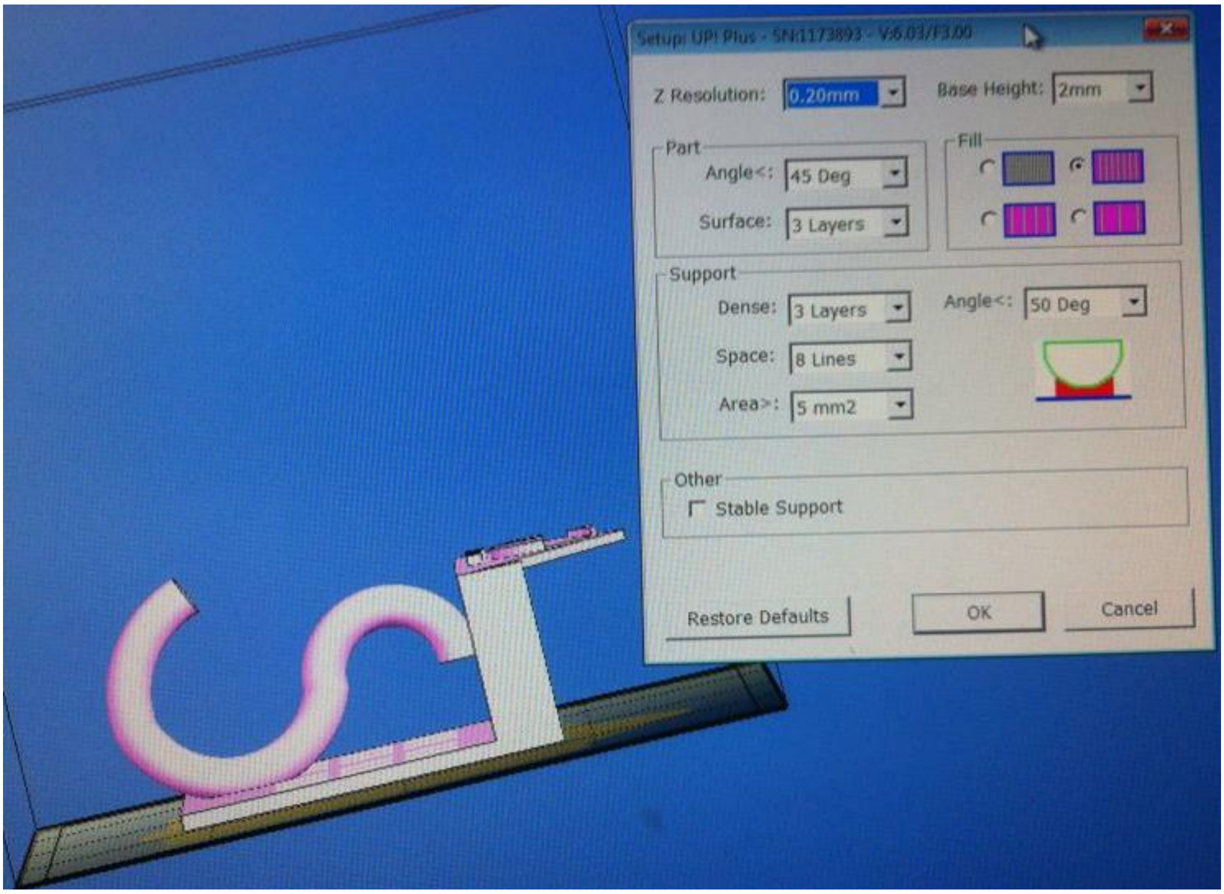
This hook is a business gift designed for this work and can be used at the house and in office. This hook not only has the school badge on it, but also a S-shape hook represents the Savonia University of Applied Sciences. The whole shape is like the C building of our school with the twelve windows on it. On the top of the hook, car keys and USB memory disc can be fastened. In this design, most of the basic functions are used during the process, and software-using skills are also been practiced.

Preparing for work

Before every printing work, initializing the printer is necessary. It will make all the movable parts to the zero position that make convenience for the following operations and this step should be the first step every time when using the printer. The next step is setting the nozzle height if the platform has been moved from last setting. It is very crucial because it will determine the success and the quality of the work. Generally, the nozzle should start the work at 0.2 mm above the platform that is the resolution of the Z-axis. Too much distance between nozzle and platform will reduce the accuracy of extrusion and too less distance will block the nozzle to extrude the material. Regarding to the method of setting nozzle height, it has been illustrated in the user manual of Up!

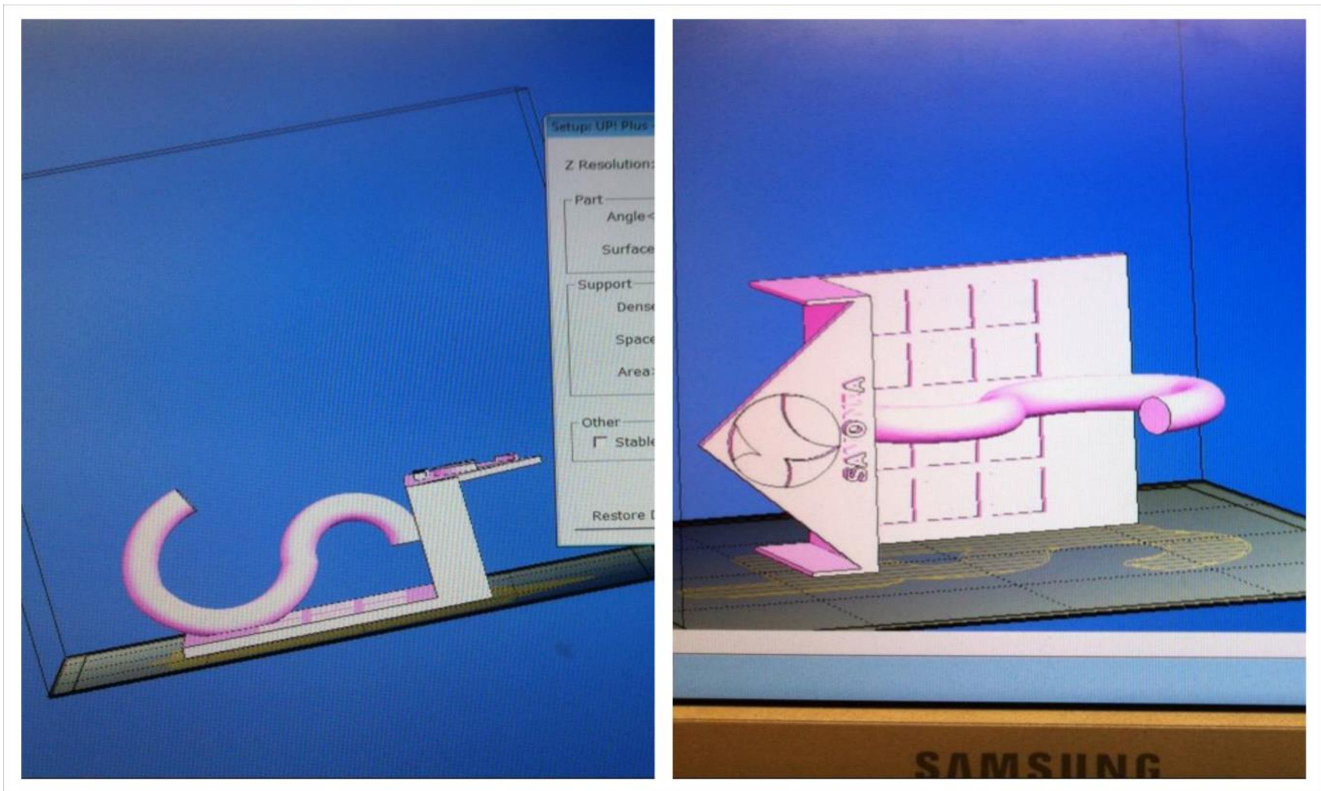
Starting the printing work

After the file has been opened and the design model has been loaded to the working window used for Up!, choosing the preference is also important for making a successful object. There are four kinds of modes for printing interior of the objects that are solid, semi solid, semi hollow and hollow. They are the most important options for choosing what kind of quality you want and how much material you want to use. Moreover, it is also vital to choose the other preferences for the object that determine the accuracy and the quality of the object in some degree. Of course, some of them will have two sides, for instance the option stable support would decrease the distorting while the support construction is harder to remove, and higher density will cost more material. The picture 16 below shows what kind of preference I chose for the hook.



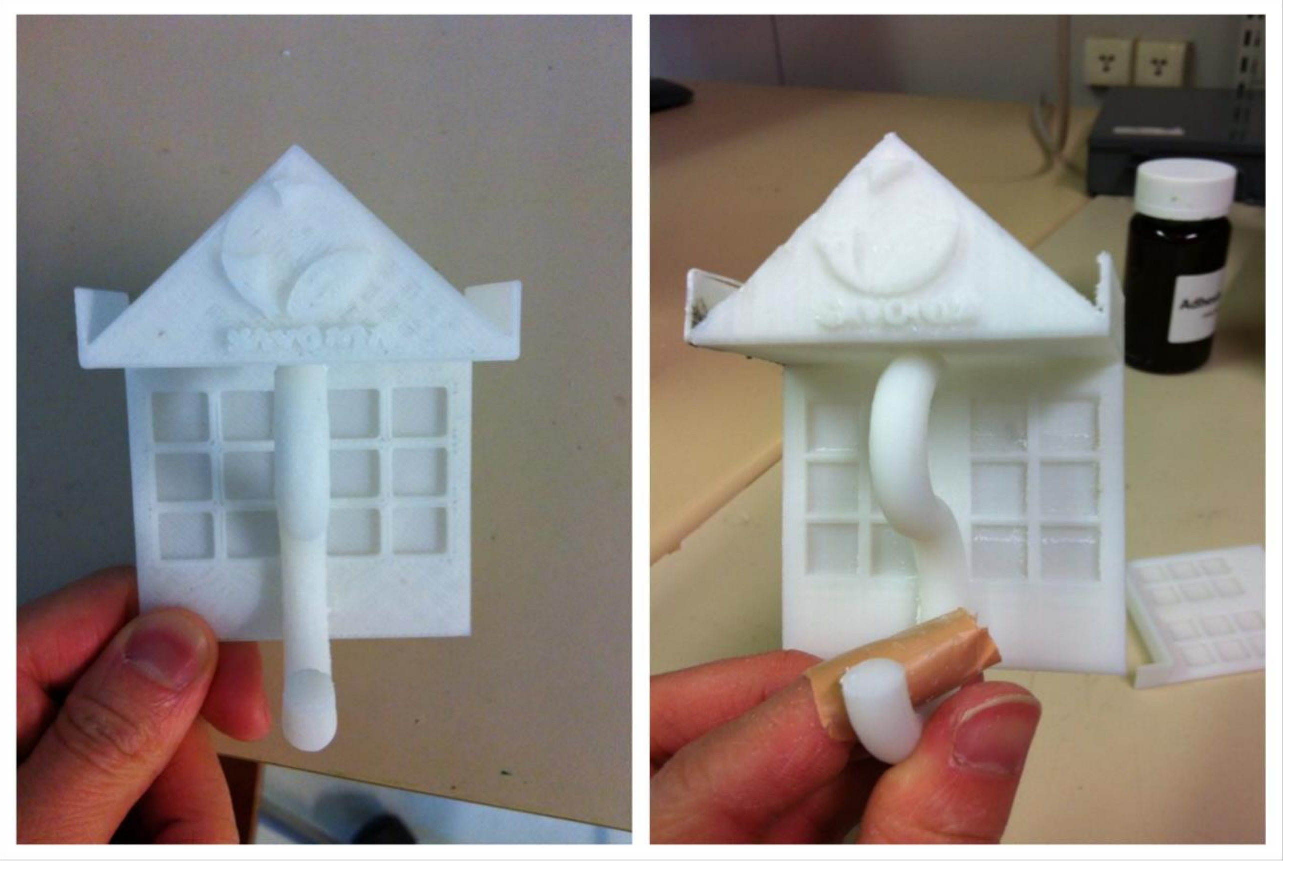
Picture 16: Preference chosen for the hook, From: Lin Zeyu

The chosen of preference is important, while the layout of the model is more crucial to get high quality objects. There are some reasons to explain its importance. First, it will save more material because difference layout would need different support construction, good layout will need less support. Second, good layout will save time while extruding less support material. Third, the support construction will be easy to remove without damage of the object. Last one is good layout will produce a better quality objects. Two models were printed, the first one using the plain layout, the other is lean layout way, and the material usage, time consumption and the quality of the objects were compared. It shows in the picture 17 below.



Picture 17: Comparison of two layouts model, From: Lin Zeyu

From the data collected during the experiment, plain layout would extrude two hundred and thirty-six layers, and the time cost one hour and forty-three minutes; the material needed is around twenty-six grams. The lean layout needs extrude two hundreds and forty-three layers, which costs two hours and sixteen minutes, and the material needed is around twenty-nine grams. Compared to the quality, from the result of the printed work, obviously, the quality of plain layout is better than lean layout. It mainly shows in the elaboration of the object, and the difficulty of removing support construction as well as the strength of the object.



Picture 18: Comparison of two products with different layout, Left: printing in a plain layout, Right: printing in a lean layout, From: Lin Zeyu

The picture 18 implies that the first object is more elaborate. It shows that the edges of the object are more smooth, the words on the badge are more clear, and it is easier to get the support construction removed, the strength of the object is higher as well. In the second picture, there are still some supporting materials, which cannot be removed even take longer time to deal with. One side on the top was already broken off when the support part was removed. It can be easily recognized the left side has been glued to the body as shown in the picture. And the difficulty of removing the support part is higher.

In a conclusion, it is not easy to make a successful 3D product. First, it is necessary to know the machine well, get acquainted with the preference and have a thought about how to make a high quality product while saving time and material. Then, have a good design model, avoid the difficult work for the printer, for example the manufacture of hanged construction. Last but not least, do the preparing work and maintenance carefully and regularly, moreover, truly understand the details determining success or failure. Accumulating the experience from every failure and defect, and make a great progress.

4 3D printing technology in Lean Production

In this chapter, the current situation about the relationship between 3D printing technology and the Lean production line will be illustrated with examples and explained how it works in the a situation.

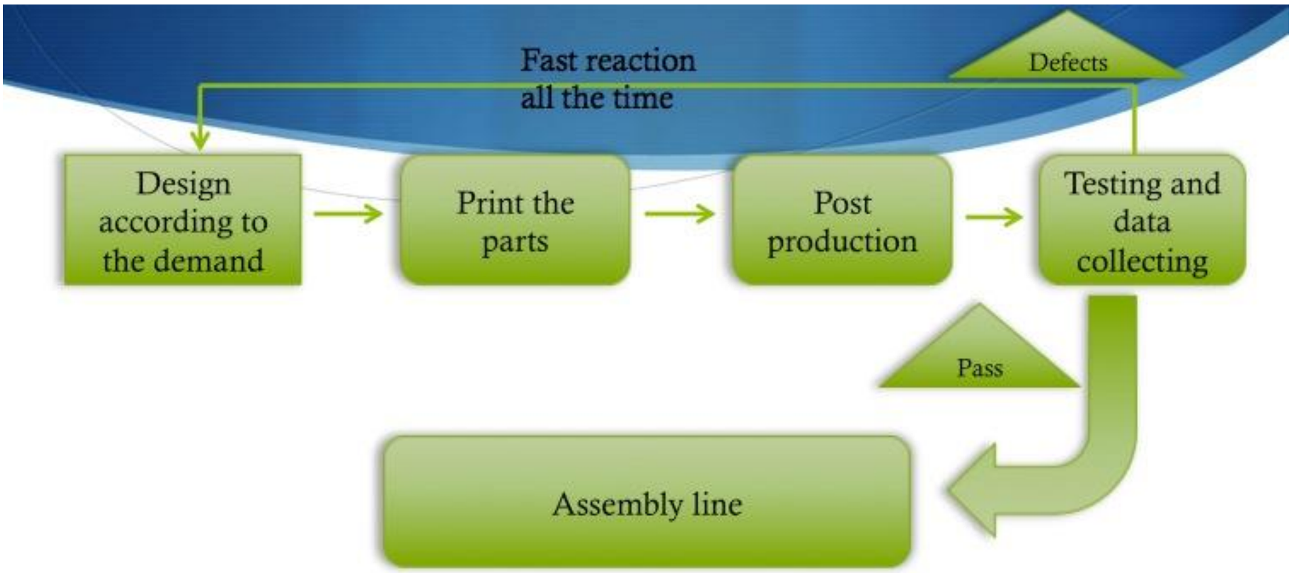
As everybody knows, 3D printing is known as additive manufacturing. It makes the part by adding the material which is total reverse process with the traditional manufacturing method, for instance milling, boring and machining. Using this method is definitely a boon for Lean manufacturing because individual part can be created in a very few amount rather than a batch or make a very complicated molds for the parts in the mass production. Compared to the traditional method, no tools are needed, 3D printing manufacturing is a totally new approach.

In addtion, why 3D printing can be used in Lean production is vital also. Here are some reasons summarized that why 3D printing technology could be used in Lean prduction and how it revolutionized the industrial field.

3D printing techonology will definitely increase the production speed whilst reducing the time and costs. The 3D model design in the computer design is easier than making the molds for the production. And assmebly lines will not be the center of the production process like today, due to the 3D printing technology can make the assemebly directly on the machine. That will save the manufacturing time, labor needed, distribution and handling cost.

Customization and the reaction speed will improve a lot. With the demanding diversity and the high level requirements from the customer, customization will have more influence on production that is also the competition of speed. 3D printing technology has significant advantage for these, and provides much options for customization.

Additionally, 3D printing changes the replenishing the stock from the distance to the “near-source” and decreases world wide transportation. It would save the logistic fee and time sharply. Parts can be produced only as required while the setup needs very little. After the customer sends an order, the components can be produced immediately, no inventory of parts is needed and immediate assembly or shipping. (Danielle M., Why 3D Printing Could Be A Manufacturing And Logistics Game Changer, 10,2013)



Picture 19: Example flow chart of 3D printing technology within the production, From: Lin Zeyu

In the graph above, the processes of 3D printing technology working line are explained. The start process is designing the object according to the demand, and then manufacturing the parts by using 3D printer. Post production will finish the surface of the parts and do the special treatment to improve its precision and durable. Testing and data collecting is very crucial for the quality inspection and design modification. It will determine the utilize of the parts and make the database for the future design. If the part is defective, analyze the reason and make the change on the new part. Finally, send it to the assembly line for the production.

The future of 3D printing techonoly in Lean Production

Considering 3D printing technology within Lean manufacturing, there is minimum waste and the potential for cost reduction in the production development. It will also reduce the production time sharply and offer the customization capabilities for diverse demands. Moverover, 3D printing technology can be used in every field of industry even in households. For now, 3D printing technology has been used in famous enterprises like GE and Ford, but mostly used for testing projects in a small scale. With the cost of 3D printer declining, now is the time to begin thinking about how we can use this technology to become more efficient and wide.

5 Conclusion

This 3D printing technology was the first phrase caming to my mind when I chose the topic for my Thesis. From my point of view, this topic refers to many subjects we had learned in the graduate study, for example properities of materials, construction of mechanism, computer-aided design and maintenance. Due to the limited of time and resources, this study cannot be all-around about 3D printing technology. However, it cannot deny the bright future of 3D printing technology. It is a completely a different approach, and it will be the game changer in the new world.

From this thesis, the whole construction and vital parts of 3D have been studied, and the whole process of using 3D printer for printing a object was manipulated. More important, all methods for 3D printing have been introduced. It gives me a comprehensive knowledge about 3D printing technology, and it would be a solid base for my future study. Not only the certain field of knowledge, but also the method of study that benefit me a lot.

Reagading to me, it is an life-devoting work. In the current situation, 3D printing technology is still in the beginning state in every industrial field, and it remains much potential for me to excavate.
And I wish I will make more and more great products draws out from 3D printing technology.

References

Network documents

Lucas Armstrong: Is 3D printing ushering in the third Industrial Revolution? 12,2013

Available at: http://www.marsdd.com/2013/12/16/is-3d-printing-ushering-in-the-third-industrial-revolution/ (Accessed 12.01.2014)

3D printer Technology- Animation of layering, create it real, 2012

Available at: http://www.createitreal.com/index.php/technology/process (Accessed 12.01.2014)

Kyle Maxey: The history of 3D printing, 09,2013

Available at: http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/6262/Infographic-The-History-of-3D-Printing.aspx (Accessed 12.01.2014)

Proto 3000, Stereolithography Rapid Prototyping Solutions

Available at: http://proto3000.com/stereolithography-sla-rapid-prototyping-process.php (Accessed 16.01.2014)

Martello Website,

Available at: http://www.martello.co.uk/rapid_prototyping.htm (Accessed 18.01.2014)

Fused Deposition Modelling,

Available at: http://www.cs.cmu.edu/~rapidproto/students.03/rarevalo/project2/Process.html (Accessed 20.01.2014)

3D printed Instructions,

Available at: http://3dprintedinstruments.wikidot.com/methods (Accessed 20.01.2014)

Steven Devijer, Building your own 3D printer, 2011

Available at: http://reprapbook.appspot.com/ (Accessed 23.01.2014)

Curbell Plastics, Technical Resource,

Available at: http://www.curbellplastics.com/technical-resources/ (Accessed 28.01.2014)

Fused Deposition Modeling: Most Common 3D printing method, Elizabeth Palermo, 09,2013
Available at: http://www.livescience.com/39810-fused-deposition-modeling.html
(Accessed 05.02.2014)

Stratasy Official Website/ materials
Available at: http://www.stratasys.com/materials (Accessed 08.02.2014)

Stratasys's Fortus 3D production system brochure,
Available at:
http://www.stratasys.com/~/media/en/3D%20Printers/Production%20Series/FortusSystemsMaterialsOverview-English.pdf (Accessed 08.02.2014)

User Manual – UP! Start Plus 3D Printer,
Available at: http://www.robotshop.com/media/files/pdf/user-manual-up-plus.pdf
(Accessed 15.02.2014)

Danielle M., Why 3D Printing Could Be A Manufacturing And Logistics Game Changer, 10,2013
Available at: http://www.manufacturing.net/blogs/2013/10/why-3d-printing-could-be-a-manufacturing-and-logistics-game-changer
(Accessed 05.03.2014)