

## 3D Printing Technology Overview

### 1. Aim

3D printing is an additive manufacturing process which creates a physical object from a digital design. It involves using layers of material, building the structures through construction of layers of materials to grow the structure from bottom upwards. 3D printing technology has been around for quite a while, however, recently it has expanded its usage into many different applications, services, products and manufacturers. This article will introduce the history and concept of 3D printing, compare the advantages and disadvantages of the 3D technology. Then, it will explain the mechanisms of the different 3D printing technologies. Furthermore, based on the requirements of IT Innovation Center, we will recommend which model of 3D printer could be adopted, and suggest any potential experiment or 3D printing service from the IT Innovation Centre.

### 2. Brief history of 3D Printing

3D printing started in the 1980s. At that time it used to be referred to as rapid prototyping where companies were able to use it to visualize the shape of the component. The market for enterprise 3D printers continues to expand with an explosion in the number of new vendors, services, products and uses. This explosion was due to two main reasons. First, during the last ten years the technology has evolved from the prototyping level to the manufacturing level, specifically when it started to move from plastics to metallic materials. 3D printing materials now support plastic, sand, ceramic to metal, with different colours available too, this much widen the usages of 3D printing. Second, the patent for fused deposition modelling (FDM) – one of the most common 3D printing technology expired in 2009, which contributed a lot to boost the consumer 3D printer market. RepRap ( <http://reprap.org/> ) is humanity's first general-purpose self-replicating manufacturing machine. RepRap takes the form of a free desktop 3D printer capable of printing plastic objects. Since many parts of RepRap are made from plastic and RepRap prints those parts, RepRap self-replicates by making a kit of itself. Through RepRap project's mission to build a self-replicating machine, the first desktop 3D printer was born. As more and more manufacturers followed, the consumer 3D printing market took off in 2009.

#### 2.1 Pros and Cons of 3D Printing

3D printing is a rapidly developing technology, it has the following benefits:

- It can create complex designs and parts which are not easily created by conventional manufacturing methods.
- It allows to customize every item to user's requirement without additional manufacturing costs.
- It does not need for tools and moulds, so it requires lower fixed costs.
- It is speedy and cost effective for quick prototyping.
- There is less waste in the materials.

Comparing with the conventional manufacturing, 3D printing currently has the following limitations:

- It needs higher cost for large quantity production.
- There are fewer options in terms of materials, colours and finishes.
- Parts printed by 3D printers are often weaker than the traditional manufactured parts due to the layer-by-layer process.
- 3D printing technology has a precision limit based on the layer thickness, at the moment it cannot print objects requiring very fine details, for instance, the iPhone switch.

### 3. 3D Printing Technology

All 3D printing technology creates physical objects from digital design layer by layer, but each using its own proprietary method. Currently the available 3D printing technologies are divided into seven groups. This section will give an overview of the mainstream 3D printing technologies.

### 3.1 Material Extrusion

Material Extrusion is also called Fused Deposition Modelling (FDM), which is the most common technology for desktop 3D printing. Material Extrusion uses a solid material called the filament. The line of filament is guided from a reel attached to the 3D printer to a heated nozzle on the 3D printer which melts the material. These melted materials can be extruded on a specific and a predefined path created by the software on the computer, once it cools down and solidifies, which provides the foundation for the next layer of material until the entire object is manufactured.

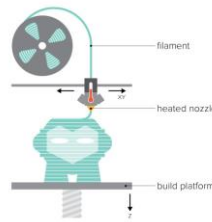


Figure 1 Schematic of Material Extrusion

Material Extrusion is one of the cheapest 3D printing technology on the market. It also supports a wide range of plastic materials in various colors including Acrylonitrile Butadiene Styrene (ABS), (Poly Lactic Acid) PLA and nylon etc.

### 3.2 VAT Photopolymerization

VAT Photopolymerization is also called Stereolithography (SLA) and Digital Light Processing (DLP). A vat of liquid photopolymer resin is cured through selective exposure to light (via a laser or projector) which then initiates polymerization and converts the exposed areas to a solid part. To create a 3D printed object, a build platform is submerged into a translucent tank filled with liquid resin. Once the build platform is submerged, a light located inside the machine maps each layer of the object through the bottom of the tank, thus solidifying the material. After the layer has been mapped and solidified by the light source, the platform lifts up and lets a new layer of resin flow beneath the object once again. This process is repeated layer by layer until the desired object has been completed. There are two common methods today, differentiated by the light source: SLA uses a laser, whereas DLP employs a projector.

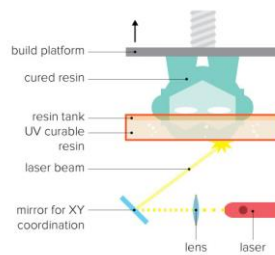


Figure 2 Schematic of VAT Photopolymerization

VAT Photopolymerization technology can print 3D object with high level of accuracy and complexity with a smooth surface finish, and it is possible to accommodate large build areas.

### 3.3 Power Bed Fusion

Power Bed Fusion (PBF) is also called Selective Laser Sintering (SLS), which uses a laser to melt and solidify layers of powdered material into finished objects. These printers have two beds that are called the pistons. When the printing process begins, a laser maps the first layer of the object in the powder, which selectively melts – or sinters – the material. Once a layer has been solidified, the print bed moves down slightly as the other bed containing the powder moves up; and a roller spreads a new layer of powder atop the object. This process is repeated, and the laser melts successive layers one by one until the desired object has been completed.

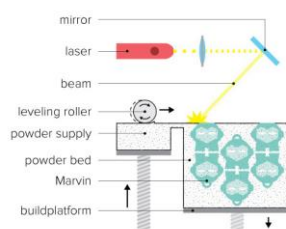


Figure 3 Schematic of Power Bed Fusion

PBF is mostly used for industrial 3D printing applications, it can print 3D objects of high level of complexity. And it can use a wide range of materials including metal and ceramic powders, sand, and various plastics such as polyamides (nylon), polystyrenes and thermoplastic elastomers.

### 3.4 Binder Jetting

Binder jetting is similar to PBF in the way that the printer uses thin layers of powdered material to build up an object, but instead of using a laser that sinters the layer together, these printers use a binding agent extruded from a nozzle to bind the powder together. The process starts with a nozzle spreading the binding agent across the first layer of the object and binding the powder together. Once the first layer has been fused with the binding agent, the printing bed moves down slightly and a thin layer of new powder is spread atop the object. This process repeats until the desired object has been fully formed. After it is removed from the print bed, the object is cleaned from excess powder and coated with an adhesive glue to give it strength and to make it resistant to discoloration.

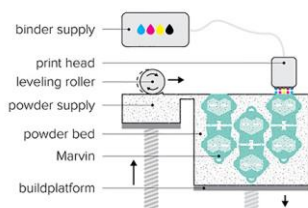


Figure 4 Schematic of Binder Jetting

Binder Jetting uses a wide range of materials including metal, ceramics, glass, sand and powdered plastic. It allows for full color printing and high productivity.

### 3.5 Material Jetting

Material Jetting is also called Stratasys PolyJet and 3D systems MultiJet Modelling. These 3D printers jet layers of liquid photopolymer onto a build tray and cure them instantly using UV light. The build process begins when the printer jets the liquid material onto the build tray. These jets are followed by UV light, which instantly cures the tiny droplets of liquid photopolymer. As the process is repeated, these thin layers accumulate on the build tray to create a precise object. Where overhangs or complex shapes require support, the printer jets a removable gel-like support material that is used temporarily, but can be removed after the print is completed.

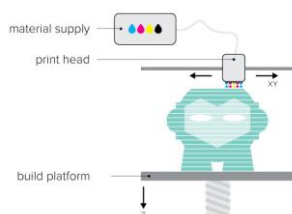


Figure 5 Schematic of Material Jetting

Material Jetting is used in industrial 3D printers. It uses materials, including photopolymers, polymers, and waxes. It can create 3D models with fine details and full color, and it is the most precise 3D printing technology today.

### 3.6 Sheet Lamination

Sheet Lamination is a group of processes that create a layer by cutting the contours of the layer, which includes ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM). Sheets of material are stacked and laminated together to form an object. The lamination method can be adhesives or chemical (paper/plastics), ultrasonic welding, or brazing (metals). Unneeded regions are cut out layer by layer and removed after the object is built. The UAM process uses sheets or ribbons of metal, which are bound together using ultrasonic welding. LOM uses a similar layer by layer approach, but uses special paper as material and adhesive instead of welding.

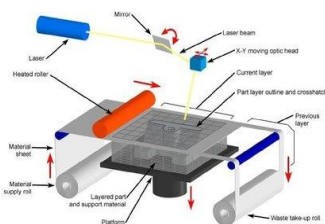


Figure 6 Schematic of Sheet Lamination

Sheet Lamination uses a range of material including paper, plastic sheets, and metallic foils/tapes. It can be used in high volume builds, and it allows for combinations of metal foils, including embedding components.

### 3.7 Directed Energy Deposition

Direct Energy Deposition (DED) is a group of processes where the material is directly deposited on the final location in the product. Powder or wire is fed into a melt pool which has been generated on the surface of the part where it adheres to the underlying part or layers by using an energy source such as a laser or electron beam. This is essentially a form of automated build-up welding. A typical DED machine consists of a nozzle mounted on a multi axis arm, which deposits melted material onto the specified surface, where it solidifies. The process is similar in principle to material extrusion, but the nozzle can move in multiple directions and is not fixed to a specific axis. The material, which can be deposited from any angle, is melted upon deposition with a laser or electron beam.

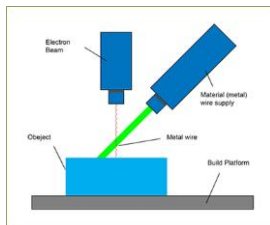


Figure 7 Schematic of Direct Energy Deposition

DED uses materials including polymers, ceramics, more typically is metals in the form of either powder or wire. DED is not limited by the direction or axis and it can control the object structure to a high degree, so it is effective in repairs and adding new features to parts. It can also use multiple materials in a single part.

## 4. 3D Printing Process

To start with 3D printing, users will need a 3D model - a mathematical representation of any three-dimensional surface of an object. There are different ways to create a 3D model:

- Find a 3D design online: there is a wide range of 3D designs available online, which is also a good starting point.
- Use specialised software tools: there are many computer-aided design (CAD) tools available on the market, including Autodesk, AutoCAD, SketchUp, Blender, etc. Depends on the functionality, some of these software are free, others are paid licensed.
- Create 3D models from 3D scanners: 3D models created by 3D scanners may need some degree of conversion. For instance, using Meshlab to convert the 3D meshes created by the 3D scanners into the U3D format which can be recognized by many of the 3D printers.

All these three options can be tried to create 3D models. Using the 3D designs available online can help us to get familiar with the concept of 3D models. IT Innovation Centre has an HP Sprout computer which has the 3D scanning capabilities. We can use HP Sprout to scan objects and create 3D models. Those specialised software tools such as SketchUp can be used to create 3D models and to refine the scanned 3D objects. 3D model is the starting point of 3D printing.

## 5. Recommendation

### 5.1 3D Printer for IT Innovation Centre

To do 3D printing, we would also need access to 3D printing technologies. Although there are 3D printing online services available, the cost is very high and there is always a lead time for 3D printing and delivery too. Therefore, it is proposed to buy a 3D printer in the IT Innovation Centre. As mentioned in the section 3 of this article, there are many different 3D printing technologies available now. However, to suit our experiment needs, a desktop 3D printer using FDM technology will be fit for purpose. I compared the market and two models of 3D printers from branded 3D printer manufacturers are selected. The key specifications are listed in the following table, both are strong competitors in the desktop 3D printers.

	MakerBot Replicator+	Ultimaker 2+
Price range	£2673.93 Amazon	£2976.51 Amazon
Dimensions	16.2 by 20.8 by 17.4 inches	23.1 by 19.9 by 13.4 inches

Weight	40.4 lbs	24 lbs
Maximum Building Area	6.5 by 11.6 by 7.6 inches (HWD)	8.1 by 8.8 by 8.8 inches (HWD)
Frame	Open	Open
LED/LCD screen	Yes	Yes
3D printing Technology	Fused Deposition Modelling (FDM)	Fused Deposition Modelling (FDM)
Number of Extruders	1	1
Number of Colors	1	1
3D Printing Resolutions (the lower the better)	100 microns	20 microns
Ports	USB 2.0	USB 2.0
SD Card Slot	No	Yes
USB Type A Port	Yes	No
Wireless connectivity	802.11b/g/n	None
Materials Supported	AGS, PLA	ABS, PLA

According to the specifications table, both printers support USB 2.0, so users can load the 3D models via USB. MakerBot Replicator+ supports wireless connection, which is more flexible in connectivity. While Ultimaker 2+ has a slightly bigger building area and a better 3D printing resolution. 3D printing material is also an important factor to consider when buying a 3D printer. Both of the 3D printers support a wide range of materials. It is not necessary to have the material from the same 3D printer supplier, although the same brand will work better in terms of compatibility. The widely used ABS material costs £30 ex VAT per 750g from the Ultimaker official website, while MakerBot PLA is only available in big bundles, costing €451.00 per bundle from the MakerBot official website. It is possible to buy MakerBot PLA from other suppliers, for example, MakerBot PLA costs £59 per 900g from the Amazon website. Comparing these two models of 3D printers, building area, 3D print resolution, and material cost are more important factors, so IT Innovation Centre decided to purchase an Ultimaker 2+ 3D printer.

## 5.2 3D Printing Projects for IT Innovation Center

Besides from experiment purposes, IT Innovation Centre can use 3D printers for student projects. In the Emerging Technology Competition 2016, one of the students' initiatives is to use a 3D printer to print modular parts to assemble drones. Potentially IT Innovation Centre can provide 3D printing as a new service to research staff and students too, which will give staff and students access to this new technology.