Brief Report on machines available in the 3D Printers market and their characteristics

by

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Contenido

1. 3D PRINTING

The term "***3D printing***" received worldwide attention following an article published in THE ECONOMIST[1] in APRIL 2012.

In this article, a third industrial revolution was predicted, made possible by the virtue of layer-by-layer additive manufacturing technology.

In the near future, moulds and casting or costly machining or parts and products would no longer required.

Using 3D PRINTING, "on demand and on location production" could be done in the vicinity of the end user.

The software that drives the machines allows for designs to precisely meet the demands of the user.

Unused material is saved and used for the next production run, resulting in less waste and less pollution.

Also in large scale factories of the (near) future, digitalisation will have a disruptive effect. In short, The economist indicated that : "It will allow for things to be made economically in much smaller numbers, more flexibly and with much lower input of labour".

[1] The Economist (2012). The third industrial revolution. Retrieved April 21, 2012 from http://www.economist.com/node/21553017

2. 3D PRINTING: An overview

3D printing or additive manufacturing[2] 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.

This methodology differs from traditional machining, which relies on subtractive processes (the removal of material) by methods such as cutting or drilling.

1983 was the year that Charles Hull invented stereo lithography. He created the first working 3D printer in 1984 and in 1986 he founded 3D Systems[3].

Then, 3D printing is a 31 year old technology.

Technology became a trustworthy prototyping method. The term ***rapid prototyping*** was used, as the layer-by-layer manufacturing technique offered possibilities to quickly produce small scale models.

By 2004, the technology had madured so that even some end products could be produced. The term ***rapid manufacturing*** was born.

This quickly changed to ***additive manufacturing*** (AM) which to this day is the official terminology used in industrial and professional literature.

AM refers to the layer-by-layer method of building parts. Whether it involves the curing or hardening of a new layer of powder of fluid or the deposition of a new layer of material, all the production methods falling under the umbrella of AM use this layer-by-layer technique.

As one of the many production techniques (*see 3. Current materials and production methods*) 3D printing has lately become the term widely used. It immediately indicates the essence of additive manufacturing, as a methodology by which you basically produce parts and products by printing one layer on top of the other.

The main reason why 3D printing has received major attention over the past six years is that new production techniques, new process and design software and new materials have emerged, which have dramatically increased the range of possibilities for use. Furthermore, production costs have fallen quite substantially, although not so much with regard to the materials, which are still relatively expensive compared to

[2] Excell, J. & Nathan, S. (2010, May 24) The rise of additive manufacturing. The engineer. Retrieved October 30, 2013 from: http://www.theengineer.co.uk/in-depth/the-big-story/the-rise-of-additive-manufacturing/1002560.article

[3] 3D Systems (2013). A journey or a lifetime. Retrieved, Feb 8, 2015, from: http://www.3dsystems.com/30-years-innovation

mass production material costs. But price of 3D printing machines has dropped significantly and the availability or easy to use and cheap design software has exploted.

On the one hand, this has set off an enormous growth in the sales of home use machines.

Te iconic "sub 1000€ printer" is the RepRap[4], short for replicating rapid prototyper, a 3D printer that prints most of its own components.

The "family tree" of the RepRap has over 200 siblings, including well known 3D printers from Ultimaker, 3d Builder, AMR Europe and Leapfrog.

[4] RepRap (2013, October 13) RepRap. Retrieved, Feb 8, 2015, from: http://reprap.org/wiki/

3. Current materials and production methods

Every 3D printer has a designed production method and every production method has a range of materials which it can process. In the following overview[5], we show the various additive manufacturing processes, the materials and the applications for which it can be used.

TYPE	ACRONYM	MATERIALS	APPLICATIONS	MATERIAL COST	TECHNOLOGY COST
Stereolithography	SLA	Thermoplastics (elastomers)	Form/fit testing, functional testing, rapid tooling patterns, snap fits, very detailed parts, presentation models, high temperature	100 € per Kilo	>200.000 €
Fused deposition modelling	FDM	Thermoplastics such as: -Abs -Polycarbonate -Polyphenylsufone -Elastomers	Form/fit testing, functional testing, rapid tooling patterns, small detailed parts, presentation models, patient/food applications, high temperature	Between 80 & 150 € per kilo for others	>50000€ for others
Selective laser sintering	SLS	Thermoplastics such as: -Nylon -Polyamide -Polystyrene - Elastomers - Composites	Form/fit testing, functional testing, rapid tooling patterns, less detailed parts, parts with snap-fits & living hinges, high temperature	Between 80 & 150 € per kilo	>300.000 €
Direct metal laser sintering	DMLS	Ferrous metals such as: -Steel alloys -Stainless steel -Tool Steel Non Ferrous metals: -Aluminium -Bronze	Form/fit testing, functional testing, rapid tooling, high temperature, medical implants, aerospace parts.	Up of 400 € per kilo	>300.000 €

[5] CustomPartNet (n.d.) Additive Fabrication. Retrieved Feb 8, 2015 from : http://www.cuestompartnet.com/wu/additive-fabrication

		-Colbalt-chrome -Titanium -Ceramics			
3D PRINTING	3DP	Ferrous metals such as: -Stainless steel Non Ferrous metals: -Bronze -Elastomers -Composites -Ceramics	Concept models, limited functional testing, architectural & landscape models, coloured industrial design models, consumer goods & packaging	<40 € per kilo	<1000 €
INKJET PRINTING / DIRECT LIGHT PROCESSING	INKP / DLP	Thermoplastics such as: -Polyester	Form/fit testing, very detailed parts, rapid tooling patterns, jewellery and fine items, medical devices	Up of 100 € per kilo	>100.000 €
JETTED PHOTOPOLYMER		Thermoplastics such as: -Acrylic (Elastomers)	Form/fit testing, very detailed parts, rapid tooling patterns, presentation models, jewellery and fine items	Up of 300 € per kilo	>300.000 €
LAMINATED OBJECT MANUFACTURING	LOM	Thermoplastics such as: -PVC Paper Composites Also ferrous metals, non-ferrous metals, and ceramics	Form/fit testing, Less detailed parts, rapid tooling patterns	<40 € per kilo	<40.000 €

4. Overview of production methods

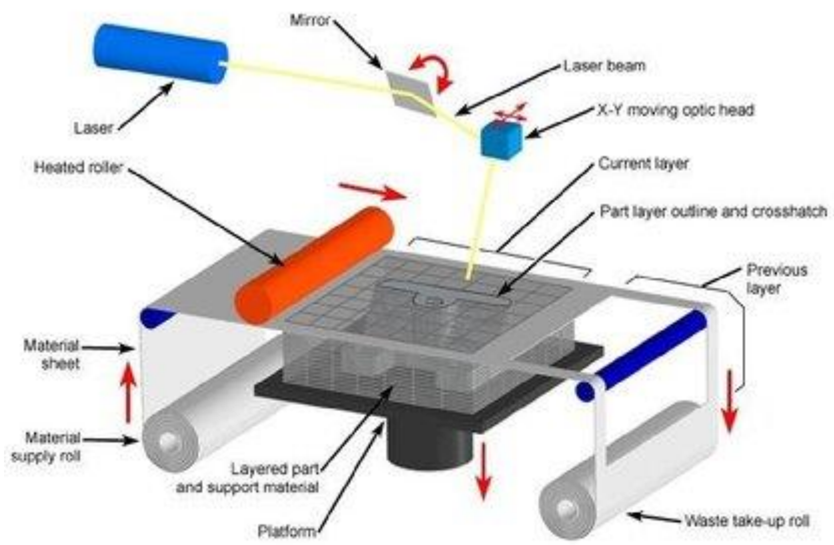
4.1 Power bed fusion

Thermal energy selectively fuses regions of a powder bed. The Powder Bed Fusion process includes the following commonly used printing techniques: Direct metal laser sintering (DMLS), Electron beam melting (EBM), Selective heat sintering (SHS), Selective laser melting (SLM) and Selective laser sintering (SLS).

Powder bed fusion (PBF) methods use either a laser or electron beam to melt and fuse material powder together. Electron beam melting (EBM), methods require a vacuum but can be used with metals and alloys in the creation of functional parts. All PBF processes involve the spreading of the powder material over previous layers. There are different mechanisms to enable this, including a roller or a blade. A hopper or a reservoir below of aside the bed provides fresh material supply. Direct metal laser sintering (DMLS) is the same as SLS, but with the use of metals and not plastics. The process sinters the powder, layer by layer. Selective Heat Sintering differs from other processes by way of using a heated thermal print head to fuse powder material together. As before, layers are added with a roller in between fusion of layers. A platform lowers the model accordingly.

Powder Bed Fusion – Step by Step

1. A layer, typically 0.1mm thick of material is spread over the build platform.
2. A laser fuses the first layer or first cross section of the model.
3. A new layer of powder is spread across the previous layer using a roller.
4. Further layers or cross sections are fused and added.
5. The process repeats until the entire model is created. Loose, unfused powder is remains in position but is removed during post processing.



4.2 Directed Energy Deposition

Simultaneous introduction of material and focused thermal energy fuse material by melting, during the process of deposition. "Focus thermal energy" means that an energy source (e.g., laser, electron beam, or plasma arc) is focused to melt the materials being deposited.

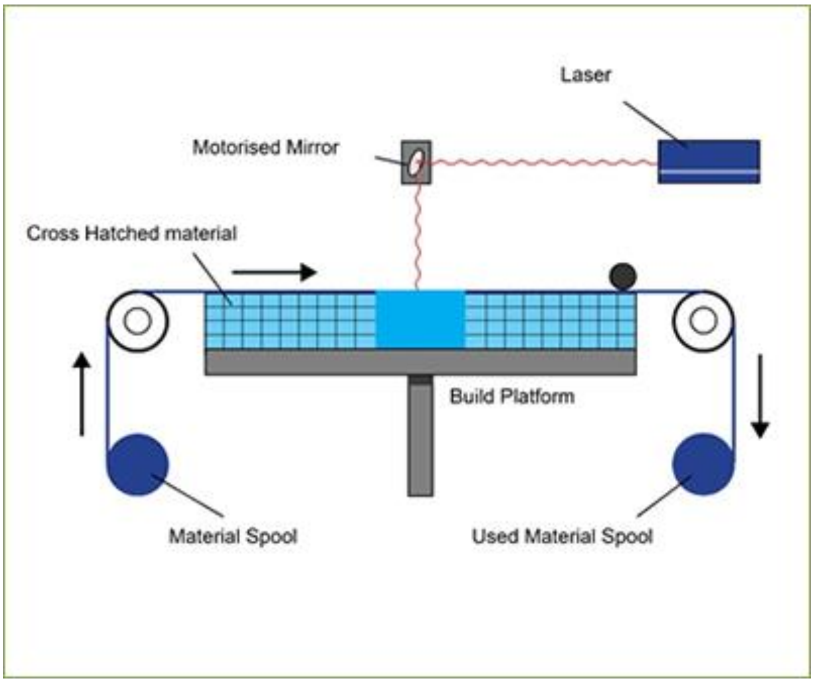
Directed Energy Deposition (DED) covers a range of terminology: 'Laser engineered net shaping, directed light fabrication, direct metal deposition, 3D laser cladding' It is a more complex printing process commonly used to repair or add additional material to existing components (Gibson et al., 2010).

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 due to 4 and 5 axis machines, is melted upon deposition with a laser or electron beam. The process can be used with polymers, ceramics but is typically used with metals, in the form of either powder or wire.

Typical applications include repairing and maintaining structural parts.

Direct Energy Deposition – Step by Step

1. A4 or 5 axis arm with nozzle moves around a fixed object.
2. Material is deposited from the nozzle onto existing surfaces of the object.
3. Material is either provided in wire or powder form.
4. Material is melted using a laser, electron beam or plasma arc upon deposition.
5. Further material is added layer by layer and solidifies, creating or repairing new material features on the existing object.



4.3 Sheet lamination

Sheet of material are bonded to form an object.

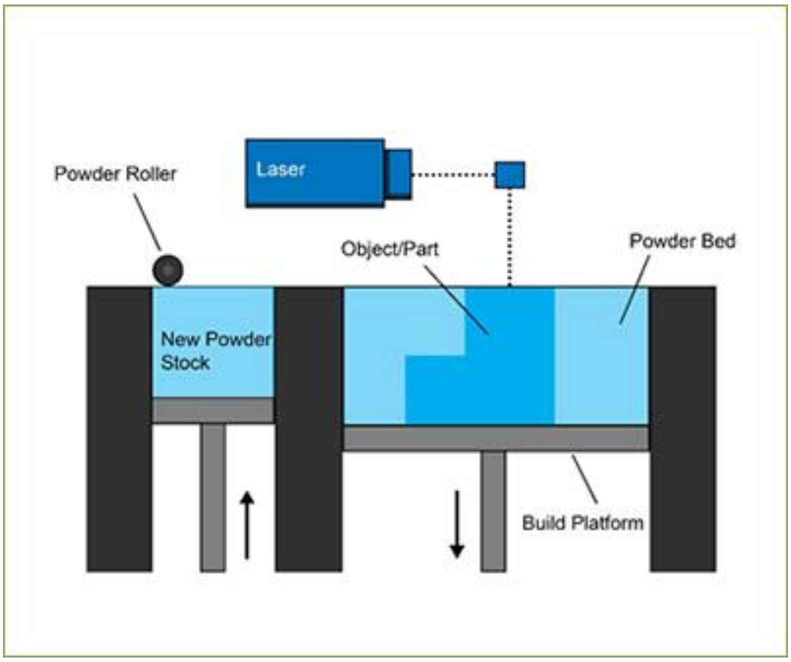
Sheet lamination processes include ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM). The Ultrasonic Additive Manufacturing process uses sheets or ribbons of metal, which are bound together using ultrasonic welding. The process does require additional CNC machining and removal of the unbound metal, often during the welding process.

Laminated object manufacturing (LOM) uses a similar layer by layer approach but uses paper as material and adhesive instead of welding. The LOM process uses a cross hatching method during the printing process to allow for easy removal post build. Laminated objects are often used for aesthetic and visual models and are not suitable for structural use. UAM uses metals and includes aluminium, copper, stainless steel and titanium (Ultrasonic Additive Manufacturing Overview, 2014).

The process is low temperature and allows for internal geometries to be created. The process can bond different materials and requires relatively little energy, as the metal is not melted.

Sheet Lamination – Step by Step

1. The material is positioned in place on the cutting bed.
2. The material is bonded in place, over the previous layer, using the adhesive.
3. The required shape is then cut from the layer, by laser or knife.
4. The next layer is added.
5. Steps two and three can be reversed and alternatively, the material can be cut before being positioned and bonded.



4.4 Binder and Material Jetting

Materials are selectively deposited for joining.
Binder Jetting is when a liquid bonding agent is selectively deposited to join powder materials.

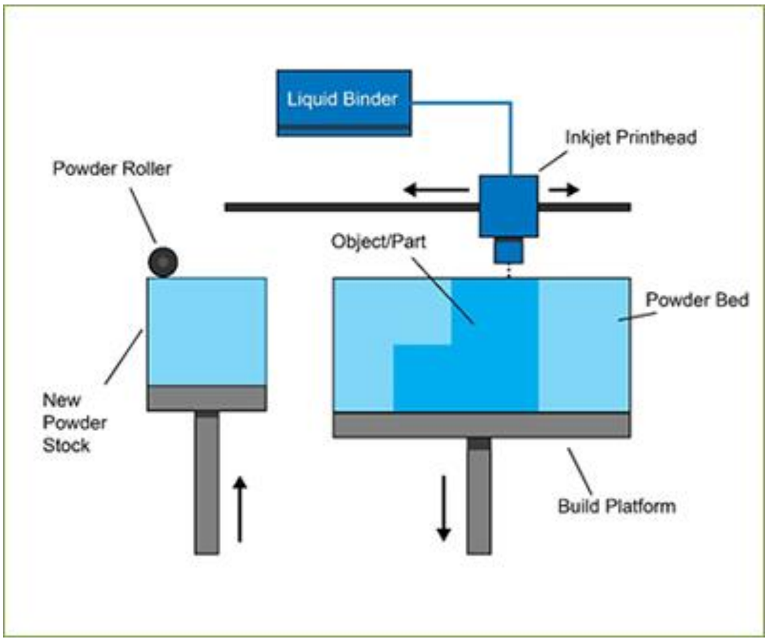
The binder jetting process uses two materials; a powder based material and a binder. The binder acts as an adhesive between powder layers. The binder is usually in liquid form and the build material in powder form. A print head moves horizontally along the x and y axes of the machine and deposits alternating layers of the build material and the binding material. After each layer, the object being printed is lowered on its build platform.

Due to the method of binding, the material characteristics are not always suitable for structural parts and despite the relative speed of printing, additional post processing (see below) can add significant time to the overall process.

As with other powder based manufacturing methods, the object being printed is self-supported within the powder bed and is removed from the unbound powder once completed. The technology is often referred to as 3DP technology and is copyrighted under this name.

Binder Jetting – Step by Step

1. Powder material is spread over the build platform using a roller.
2. The print head deposits the binder adhesive on top of the powder where required.
3. The build platform is lowered by the model's layer thickness.
4. Another layer of powder is spread over the previous layer. The object is formed where the powder is bound to the liquid.
5. Unbound powder remains in position surrounding the object.
6. The process is repeated until the entire object has been made.



4.5 Material Extrusion

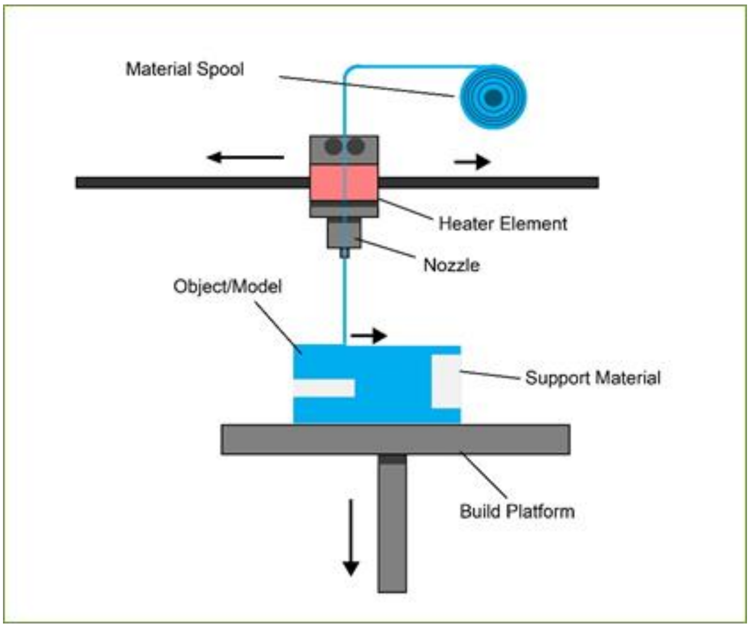
A continuous filament material is heated (usually to a semi-molten state) and then selectively dispensed through a nozzle or orifice.

Fuse deposition modelling (FDM) is a common material extrusion process and is trademarked by the company Stratasys. Material is drawn through a nozzle, where it is heated and is then deposited layer by layer. The nozzle can move horizontally and a platform moves up and down vertically after each new layer is deposited. It is a commonly used technique used on many inexpensive, domestic and hobby 3D printers.

The process has many factors that influence the final model quality but has great potential and viability when these factors are controlled successfully. Whilst FDM is similar to all other 3D printing processes, as it builds layer by layer, it varies in the fact that material is added through a nozzle under constant pressure and in a continuous stream. This pressure must be kept steady and at a constant speed to enable accurate results (Gibson et al., 2010). Material layers can be bonded by temperature control or through the use of chemical agents. Material is often added to the machine in spool form as shown in the diagram.

Material Extrusion – Step by Step

1. First layer is built as nozzle deposits material where required onto the cross sectional area of first object slice.
2. The following layers are added on top of previous layers.
3. Layers are fused together upon deposition as the material is in a melted state.



4.6 Vat Photo Polymerization

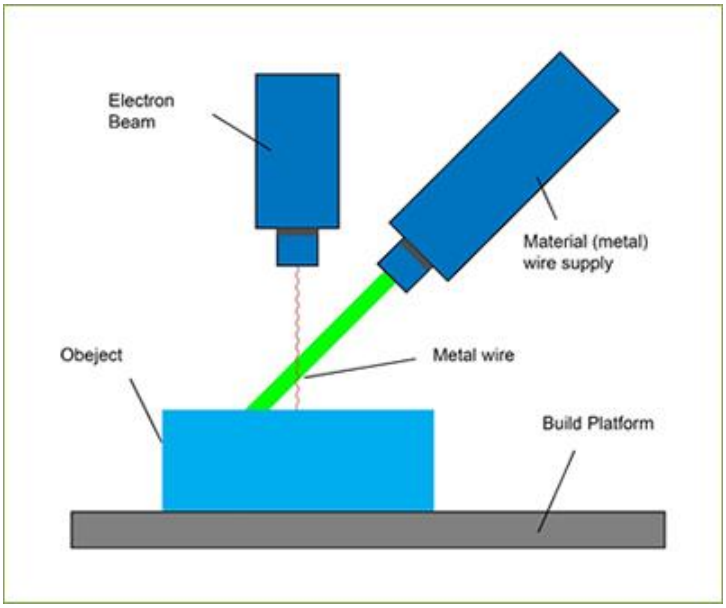
Liquid photopolymer in a vat is selectively cured by light-activated polymerization.

Vat polymerisation uses a vat of liquid photopolymer resin, out of which the model is constructed layer by layer. An ultraviolet (UV) light is used to cure or harden the resin where required, whilst a platform moves the object being made downwards after each new layer is cured.

As the process uses liquid to form objects, there is no structural support from the material during the build phase., unlike powder based methods, where support is given from the unbound material. In this case, support structures will often need to be added. Resins are cured using a process of photo polymerisation (Gibson et al., 2010) or UV light, where the light is directed across the surface of the resin with the use of motor controlled mirrors (Grenda, 2009). Where the resin comes in contact with the light, it cures or hardens.

Photopolymerisation – Step by Step

1. The build platform is lowered from the top of the resin vat downwards by the layer thickness.
2. A UV light cures the resin layer by layer. The platform continues to move downwards and additional layers are built on top of the previous.
3. Some machines use a blade which moves between layers in order to provide a smooth resin base to build the next layer on.
4. After completion, the vat is drained of resin and the object removed.



5. Overview of materials

Three types of materials can be used in additive manufacturing: polymers, ceramics and metals. All six individual AM processes, cover the use of these materials, although polymers are most commonly used and some additive techniques lend themselves towards the use of certain materials over others. Materials are often produced in powder form or in wire feedstock.

Other materials used include adhesive papers, paper, chocolate, and polymer/adhesive sheets for LOM.

It is essentially feasible to print any material in this layer by layer method, but the final quality will be largely determined by the material. The processes above can also change the microstructure of a material due to high temperatures and pressures, therefore material characteristics may not always be completely similar post manufacture, when compared to other manufacturing processes.

5.1Polimers

Common plastics can be used in 3D printing, including ABS and PC. The common structural polymers can also be used, as well as a number of waxes and epoxy based resins. Mixing different polymer powders can create a wide range of structural and aesthetic materials.

The following polymers can be used:

- ABS (Acrylonitrile butadiene styrene)
- PLA (polylactide), including soft PLA
- PC (polycarbonate)
- Polyamide (Nylon)
- Nylon 12 (Tensile strength 45 Mpa)
- Glass filled nylon (12.48 Mpa)
- Epoxy resin
- Wax
- Photopolymer resins

5.2 Metals

A range of metals can be used, including a number of options suitable for structural and integral component parts. Common metals used: Steel, TItanium, Aluminium, Cobalt Chrome Alloy (DMLS materials, 2014).

- Maraging steel 1.2709 (Tensile Strength 1100 Mpa)
- Titanium alloy Ti6AI4V (Tensile Strength: 1150 Mpa)
- 15-5ph stainless steel (Tensile Strength: 1150 Mpa)
- Cobalt chrome alloy, Co28Cr6Mo (Tensile Strength 1300 Mpa)
- Aluminium alsi10mg (Tensile Strength 445mpa)
- Gold and Silver

5.3 Ceramics

Ceramic powders can be printed, including:

- Silica/Glass
- Porcelain
- Silicon-Carbide