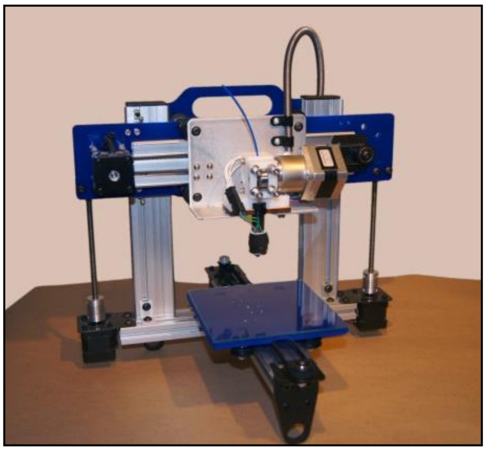
3D PRINTING

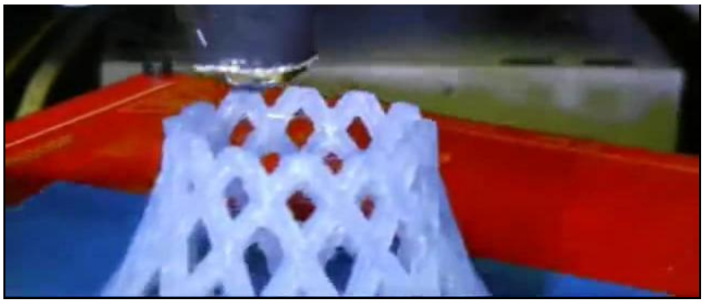
Introduction

Additive manufacturing or 3D printing is a process of making three dimensional solid objects from a digital model. 3D printing is achieved using additive processes, where an object is created by laying down successive layers of material. 3D printing is considered distinct from traditional machining techniques (subtractive processes) which mostly rely on the removal of material by drilling, cutting etc.

A 3D Printer



A hyperboloid object print (made of PLA) using a RepRap "Prusa Mendel" 3D printer for molten polymer deposition.



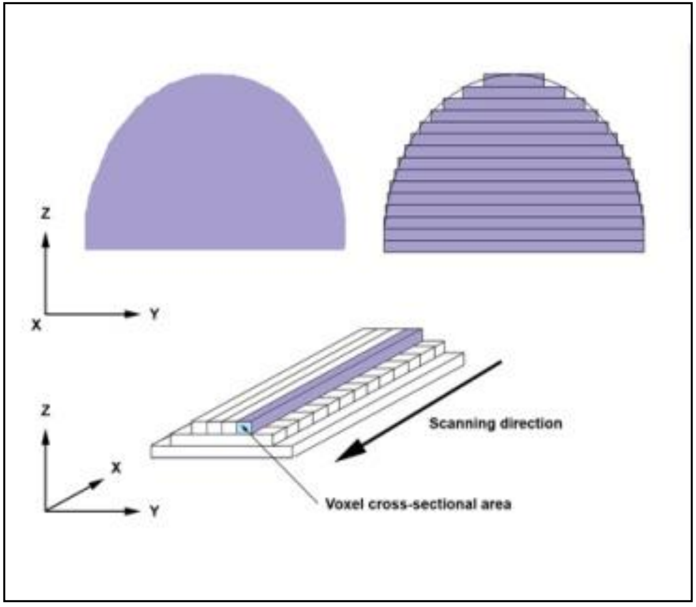
3D printing is usually performed by a materials printer using digital technology. Since the start of the twenty-first century there has been a large growth in the sales of these machines, and their price dropped substantially. The technology is used in the fields of jewellery, footwear, industrial design, architecture, engineering and construction (AEC), automotive, aerospace, dental and medical industries, education, geographic information systems, civil engineering, and many others**.**

History

Early examples of 3D printing occurred in the 1980s, though the printers then were large, expensive and highly limited in what they could produce.

- The term "3D printing" was coined at MIT in 1995 when then graduate students Jim Bredt and Tim Anderson modified an inkjet printer to extrude a binding solution onto a bed of powder, rather than ink onto paper. The ensuing patent led to the creation of modern 3D printing companies Z Corporation (founded by Bredt and Anderson) and ExOne.
- SLS was developed and patented by Dr. Carl Deckard at the University of Texas at Austin in the mid-1980s, under sponsorship of DARPA. A similar process was patented without being commercialized by R. F. Housholder in 1979.
- Stereolithography was patented in 1987 by Chuck Hull.
- fused deposition modelling was developed by S. Scott Crump in the late 1980s and was commercialized in 1990.

General Principles - 3D Model Slicing



The use of additive manufacturing takes virtual designs from computer aided design (CAD) or animation modeling software, transforms them into thin, virtual, horizontal cross-sections and then creates successive layers until the model is complete. It is a WYSIWYG (What You See Is What You Get) process where the virtual model and the physical model are almost identical.

With additive manufacturing, the machine reads in data from a CAD drawing and lays down successive layers of liquid, powder, or sheet material, and in this way builds up the model from a series of cross sections. These layers, which correspond to the virtual cross section from the CAD model, are joined together or fused automatically to create the final shape. The primary advantage to additive fabrication is its ability to create almost any shape or geometric feature.

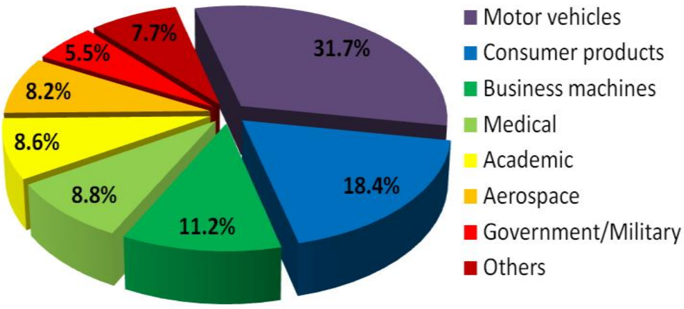
The standard data interface between CAD software and the machines is the STL file format. An STL file approximates the shape of a part or assembly using triangular facets. Smaller facets produce a higher quality surface. VRML (or WRL) files are often used as input for 3D printing technologies that are able to print in full colour.

Construction of a model with contemporary methods can take from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems can typically produce models in a few hours, although it can vary widely depending on the type of machine being used and the size and number of models being produced simultaneously.

Some additive manufacturing techniques use two materials in the course of constructing parts. The first material is the part material and the second is the support material (to support overhanging features during construction). The support material is later removed by heat or dissolved away with a solvent or water.

Traditional injection moulding can be less expensive for manufacturing polymer products in high quantities, but additive fabrication can be faster and less expensive when producing relatively small quantities of parts. 3D printers give designers and concept development teams the ability to produce parts and concept models using a desktop size printer.

Technologies Worldwide



The Audi RSQ alongside was made by Audi with rapid prototyping industrial KUKA robots

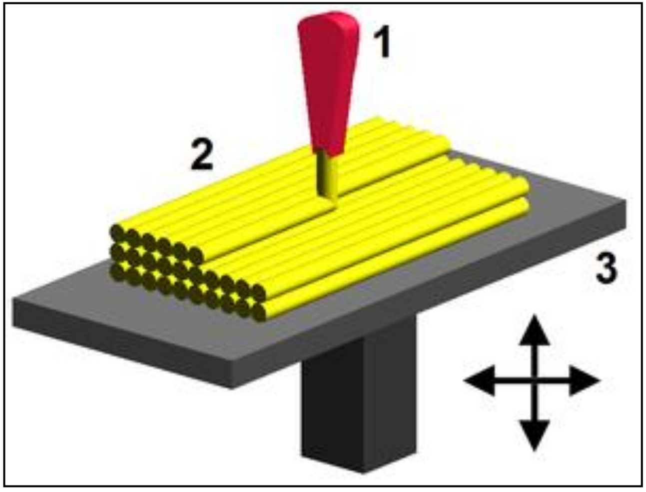
There are several technologies. All those available as of 2012 were additive, differing mainly in the way layers are built to create parts. Some melt or soften material to produce layers (SLS, FDM), while others lay liquid materials thermosets that are cured with different technologies. Lamination systems cut thin layers to shape and join them together.
As of 2005 conventional additive rapid prototype machines cost around £25,000.

Additive technologies	**Base materials**
Selective laser sintering (SLS)	Thermoplastics, metals powders, ceramic powders
Direct metal laser sintering (DMLS)	Almost any alloy metal
Fused deposition modeling (FDM)	Thermoplastics, eutectic metals
Stereolithography (SLA)	photopolymer
Digital Light Processing (DLP)	liquid resin
Fused Filament Fabrication (FFF)	PLA, ABS
Melted and Extrusion Modeling (MEM)	metal wire, plastic filament
Laminated object manufacturing (LOM)	Paper, foil, plastic film
Electron beam melting (EBM)	Titanium alloys
Selective Heat Sintering (SHS)	thermoplastic powder
Powder bed and inkjet head 3d printing Plaster-based 3D printing (PP)	Plaster, Colored Plaster

Methods and Materials

A number of competing technologies are available to do 3D printing. Their main differences are in the way layers are built to create parts, and the materials that can be used. Some methods use melting or softening material to produce the layers, e.g. selective laser sintering (SLS) and fused deposition modeling (FDM), while others lay liquid materials that are cured with different technologies, e.g. stereolithography (SLA). In the case of laminated object manufacturing (LOM), thin layers are cut to shape and joined together (e.g. paper, polymer, metal). Each method has its advantages and drawbacks, and consequently some companies offer a choice between powder and polymer as the material from which the object emerges. Generally, the main considerations are speed, cost of the printed prototype, cost of the 3D printer, choice and cost of materials and colour capabilities. Printers which work directly with metals are expensive. In some cases inexpensive printers have been used to make a part in plastic, which is then used as a mould to make a metal part.

Molten Polymer Deposition



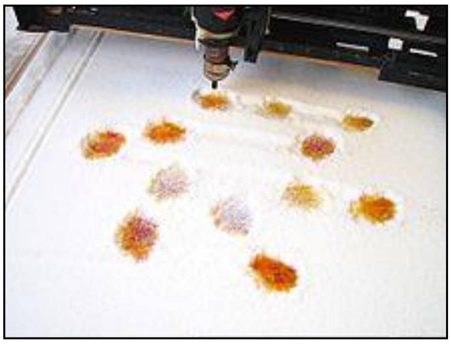
Fused deposition modeling: 1 - nozzle ejecting molten plastic, 2 - deposited material (modeled part), 3 - controlled movable table. Fused deposition modeling (FDM) is a technology used in traditional rapid prototyping developed by Stratasys in the late 1980s.

FDM works using a plastic filament or metal wire which is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package.

The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle. Stepper motors or servo motors are typically employed to move the extrusion head.

Various polymers are used, including acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polylactic acid (PLA), PC/ABS, and polyphenylsulfone (PPSU).

Granular materials binding



Like most granular systems CandyFab fuses parts of the layer, and then moves the working area downwards, and then adds another layer of granules and then repeats the process until the piece has built up

Another approach is selective fusing of print media in a granular bed. In this variation, the unfused media serves to support overhangs and thin walls in the part being produced, reducing the need for auxiliary temporary supports for the workpiece. Typically a laser is used to sinter the media and form the solid. Examples of this are selective laser sintering (SLS), using metals as well as polymers (e.g. PA, PA-GF, Rigid GF, PEEK, PS, Alumide, Carbonmide, elastomers), and direct metal laser sintering (DMLS).

Electron beam melting (EBM) is a similar type of additive manufacturing technology for metal parts (e.g. titanium alloys). EBM manufactures parts by melting metal powder layer by layer with an electron beam in a high vacuum. Unlike metal sintering techniques that operate below melting point, the parts are fully dense, void-free, and very strong.

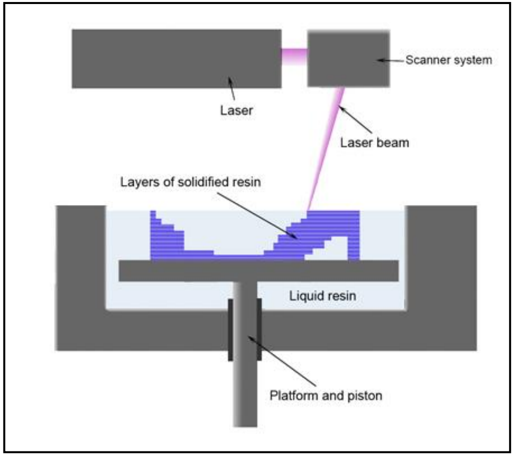
The CandyFab printing system uses heated air and granulated sugar. It can be used to produce food-grade art objects.

Another method consists of an inkjet 3D printing system. The printer creates the model one layer at a time by spreading a layer of powder (plaster, or resins) and inkjet printing a binder in the cross-section of the part. The process is repeated until every layer is printed. This technology allows for the printing of full colour prototypes and allows overhangs, as well as elastomer parts. Bonded powder prints can be further strengthened by wax or thermoset polymer impregnation.

Photopolymerization

The main technology in which photopolymerization is used to produce a solid part from a liquid is stereolithography (SLA).

Stereolithography apparatus



In digital light processing (DLP), a vat of liquid polymer is exposed to light from a DLP projector under safelight conditions. The exposed liquid polymer hardens. The build plate then moves down in small increments and the liquid polymer is again exposed to light. The process repeats until the model is built. The liquid polymer is then drained from the vat, leaving the solid model. The ZBuilder Ultra is an example of a DLP rapid prototyping system.

The Objet PolyJet system uses an inkjet printer to spray photopolymer materials in ultra-thin layers (16 micron) layer by layer onto a build tray until the part is completed. Each photopolymer layer is cured by UV light immediately after it is jetted, producing fully cured models that can be handled and used immediately, without post-curing. The gel-like support material, which is designed to support complicated geometries, is removed by hand and water jetting. Also suitable for elastomers.

Ultra-small features may be made by the 3D microfabrication technique of multiphoton photopolymerization. In this approach, the desired 3D object is traced out in a block of gel by a focused laser. The gel is cured to a solid only in the places where the laser was focused, because of the nonlinear nature of photoexcitation, and then the remaining gel is washed away. Feature sizes of under 100 nm are easily produced, as well as complex structures such as moving and interlocked parts.

Yet another approach uses a synthetic resin that is solidified using LEDs.

Resolution

Resolution is given in layer thickness and X-Y resolution in dpi Typical layer thickness is around 100 micrometres (0.1 mm), although some machines such as the Objet Connex series can print layers as thin as 16 micrometres. X-Y resolution is comparable to that of laser printers. The particles (3D dots) are around 50 to 100 micrometres (0.05-0.1 mm) in diameter.

The native resolution of a printer may be sufficient for some applications; if not, resolution and surface finish can be enhanced by printing an object slightly oversized in standard resolution, then removing material with a higher-resolution subtractive process.

Applications

“*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 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*”

- The Economist in a February 2011 leader

A model (left) was digitally acquired by using a 3D scanner, the scanned data processed using MeshLab, and the resulting 3D model used by a rapid prototyping machine to create a resin replica (right)

An example of 3D printed limited edition jewellery. This necklace is made of glassfibre-filled dyed nylon. It has rotating linkages that were produced in the same manufacturing step as the other parts.
Photography: Atelier Ted Noten**.**

Additive manufacturing's earliest applications have been on the toolroom end of the manufacturing spectrum. For example, rapid prototyping was one of the earliest additive variants, and its mission was to reduce the lead time and cost of developing prototypes of new parts and devices, which was earlier only done with subtractive toolroom methods (typically slowly and expensively). However, as the years go by and technology continually advances and disseminates into the business world, additive methods are moving ever further into the production end of manufacturing—sometimes even in ways that the pioneers of the techniques didn't foresee. Parts that formerly were the sole province of subtractive methods can now in some cases be made more profitably via additive ones.

Standard applications include design visualization, prototyping/CAD, metal casting, architecture, education, geospatial, healthcare and entertainment/retail.

Industrial Uses - Rapid prototyping

Full colour miniature face models produced on a Spectrum Z510 3D Printer

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 or cartridges, and are used for many rapid prototyping uses by universities and commercial companies. Industrial 3D printers are made by companies such as ExOne, Objet Geometries, Stratasys, 3D Systems, EOS GmbH, and Z Corporation.

Rapid manufacturing

Advances in RP technology have brought about the ability to use materials that are appropriate for final manufacture. These advances in material use have brought about the prospects of directly manufacturing finished components. The advantages of 3D printing in rapid manufacturing lie in the relatively inexpensive production of small numbers of parts.

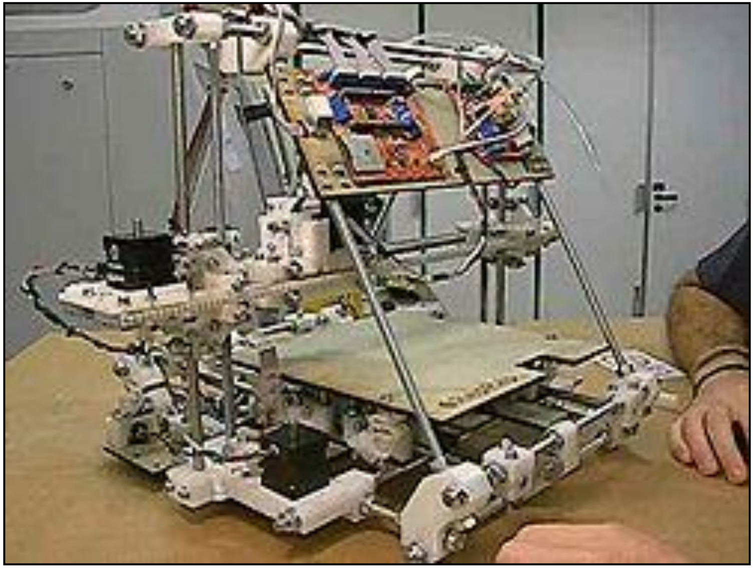
Rapid manufacturing is a new method of manufacturing, with many of its processes still unproven. 3D printing is now entering the field of rapid manufacturing; according to a 2009 report it was believed by many experts to be a "next level" technology Some of the most promising processes are adaptations of well established rapid prototyping methods such as laser sintering (LS). However, these techniques were still very much in their infancy as of 2006, with many obstacles to be overcome before RM could be considered a realistic manufacturing method.

Domestic and Hobbyist Uses

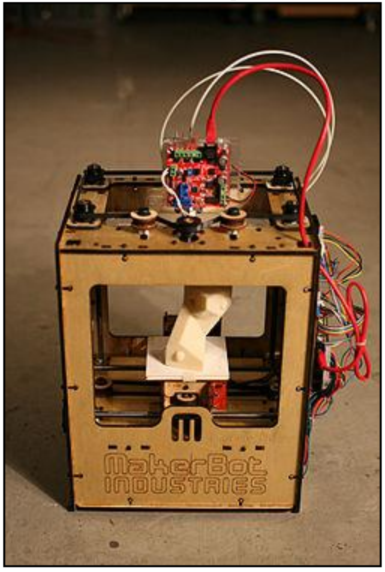
Domestic 3D printing is mainly for hobbyists and enthusiasts as of 2012, rather than practical household applications. Designs such as a working clock have been made, not as a practical, or particularly accurate timepiece, but as an interesting project. Gears have been printed for home woodworking machines and other purposes. 3D printing is also used for ornamental objects. One printer (the Fab@Home) makes a point of including chocolate amongst the materials that can be printed. Web sites associated with 3D printing tend to include backscratchers, coathooks, and so on. The RepRap Web site includes such examples. The Fab@Home gallery had many objects without practical application, but included examples of what is possible such as a flashlight/torch using conductive ink for the electrical circuit, a battery-powered motor, a case for an iPod, a silicone watch band, and a translucent cylinder completely enclosing a brown box, something difficult to fabricate any other way.

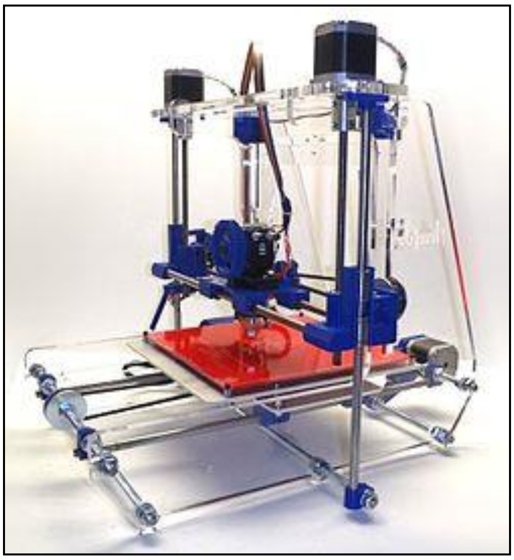
The open source Fab@Home project has developed printers for general use. They have been used in a research environment to produce chemical compounds with 3D printing technology, including new ones, initially without immediate application as proof of principle. The printer can print with anything that can be dispensed from a syringe as liquid or paste. The developers of the chemical application envisage that this technology could be used both in industry and for domestic use, so that "people in far-flung regions could make their own headache pills or detergent. The technique might also allow people to print and share recipes for niche substances that chemical or pharmaceutical companies don't make – because there aren't enough customers, or they simply haven't dreamed up those ideas."

Printers for domestic use. RepRap version 2.0 (Mendel)



MakerBot Cupcake CNC (Prusa) ***Airwolf 3D AW3D v.4***





There are several projects and companies making efforts to develop 3D printers suitable for desktop use at a price many households can afford, many of which are related. Much of this work was driven by and targeted to DIY/enthusiast/early_adopter communities, with links to both the academic and hacker communities.

The RepRap is a one of the longest running projects in the Desktop category. The RepRap project aims to produce a free and open source software (FOSS) 3D printer, whose full specifications are released under the GNU General Public License, and which can print many of its own parts (the printed parts) to create more machines. As of November 2010, the RepRap can print plastic parts, and requires motors, electronics, and some metal support rods to be completed. Research is under way to enable the device to print circuit boards, as well as metal parts. Several companies and individuals sell parts to build various RepRap designs, with prices starting at about €400/US$500 as of 2012.

Because of the FOSS aims of RepRap, many related projects have used their design for inspiration, creating an ecosystem of many related or derivative 3D printers, most of which are also Open Source designs. The availability of these open source designs means that variants of 3D printers are easy to invent; however, the quality and complexity of various printer designs, as well as the quality of kit or finished products, varies greatly from project to project.

This rapid development of open source 3D printers is gaining interest in both the developed as well as the developing world as it enables both hyper-customization and the use of designs in the public domain to fabricate open source appropriate technology through conduits such as Thingiverse. This technology can also assist in sustainable development as such technologies are easily and economically made from readily available resources by local communities to meet their needs.

The open source Fab@Home project has developed printers for general use which can use anything squirtable through a nozzle, from chocolate to silicon sealant and chemical reactants. Printers to the project's designs were available from suppliers in kit or assembled form at prices in the region of US$2000 as of 2012.

Many of these printers are available in kit form, and some are available fully assembled. The Solidoodle 2, a 6x6x6 inch printer is available fully assembled for US$499. Prices of printer kits vary from US$400 for the open source SeeMeCNC H-1, US$500 for the Printrbot, both derived from previous RepRap models, to over US$2000 for the Fab@Home 2.0 two-syringe system.

Printers for Commercial and Domestic Use

The development and hyper-customization of the RepRap-based 3D printers has produced a new category of printers suitable for both domestic and commercial use. The cheapest available machine in the assembled form is the Solidoodle 2, while the RepRapPro's Huxley DIY kit priced at around US$680 is one of the cheapest and most reliable. There are other high-end kits and fully assembled machines which are RepRap-based machines enhanced to print at high speed and high definition. Depending on application, the degree of printing resolution and speed of manufacturing lies between a personal printer and an industrial printer. A list of printers with pricing and other information is maintained.

3D Printing Services

Some companies offer an on-line 3D printing service open both to consumers and to industry. People upload their own 3D designs to a 3D printing service company website, designs are printed via industrial 3D printers and then shipped to the customer. Some examples of 3D printing services companies are Shapeways, Kraftwurx, i.materialise and Freedom Of Creation. Thingiverse of MakerBot Industries allows the sharing of 3D printing files and serves as a community resource.

Research Into New Applications

Other applications would include reconstructing fossils in paleontology, replicating ancient and priceless artifacts in archaeology, reconstructing bones and body parts in forensic pathology and reconstructing heavily damaged evidence acquired from crime scene investigations.

By 2005, academic journals had begun reporting on the possible artistic applications of 3D printing technology. By 2007 the mass media had followed, with an article in the Wall Street Journal and Time Magazine listing a 3D printed design among their 100 most influential designs of the year. During the 2011 London Design Festival, an installation, curated by Murray Moss and focused on 3D Printing, took place in the Victoria and Albert Museum (the V&A). The installation was called Industrial Revolution 2.0: How the Material World will Newly Materialise.

As of 2012 3D printing technology was being studied by biotechnology firms and academia for possible use in tissue engineering applications where organs and body parts are built using inkjet techniques. Layers of living cells are deposited onto a gel medium or sugar matrix and slowly built up to form three dimensional structures including vascular systems. Several terms have been used to refer to this field of research: organ printing, bio-printing, and computer-aided tissue engineering, among others. 3D printing can produce a personalized hip replacement in one pass, with the ball permanently inside the socket; at available printing resolutions the unit does not require polishing.

A proof-of-principle project at the University of Glasgow, UK, in 2012 has shown that it is possible to use 3D printing techniques to create chemical compounds, including new ones. They first print bespoke chemical reaction vessels, then use the printer to squirt reactants into them as "chemical inks" which then react. They have produced new compounds to verify the validity of the process, although not seeking anything with a particular application. They used the Fab@Home open source printer, at a stated cost of US$2,000.

The use of 3D scanning technologies allow the replication of real objects without the use of molding techniques that in many cases can be more expensive or more difficult, or too invasive to be performed, particularly for precious or delicate cultural heritage artifacts where the direct contact of the molding substances could harm the surface of the original object. Even a smartphone can be used as 3D scanner: at the 2012 Consumer Electronics Show, Sculpteo unveiled a mobile app that allows a 3D file to be generated directly with a smartphone.

Predictions for the future of commercial manufacturing, starting from today's already-begun infancy period, are that manufacturing firms will need to be flexible, ever-improving users of all available technologies in order to remain competitive. It is also predicted by some additive manufacturing advocates that this technological development arc will change the nature of commerce and globalisation, because end users will be able to do much of their own manufacturing rather than engaging in trade to buy products from other people and corporations. However, the real integration of the newer additive technologies into commercial production is essentially a matter of complementing traditional subtractive methods rather than displacing them entirely. As an example of a possible future application, an open source group emerged in the United States in 2012 that is attempting to design a firearm that may be downloaded from the internet and "printed" on a 3-D Printer. The weapon would however still need bullets fabricated by traditional methods. Calling itself Defense Distributed, the group wants to facilitate "a working plastic gun that could be downloaded and reproduced by anybody with a 3D printer." (*Only in America – Ed!)*

The South African publication, Business Day, recently reported that a joint venture between Aerosud and the Council for Scientific and Industrial Research's National Laser Centre are collaborating to build the world's fastest and largest prototype 3D printer which will use powdered titanium to make aircraft components. It is reported that the printer will be 10 times faster than anything in existence and will be able to produce components "46 times larger than anything other metal based 3D printers are able to produce".

The same article referred to the RepRap project. RepRap is short for replicating rapid prototype and is a 3D printer that can print most of its own components. Apparently NASA has taken the RepRap concept a step further with SpiderFab which proposes putting a large 3D printing machine in orbit around earth and delivering to it the raw materials required to build space station components, satellites, modules and eventually entire spacecraft in space, thereby reducing the cost of launching the completed article from the ground.

A practical example of 3D printing in a wildlife context is the fitting of a replacement nylon polymer beak to a bald eagle whose own beak had been shot off by a poacher. The bird concerned is now able to again fend for itself.

Concluding remarks

This article appeared in the Durban Society of Model Engineers Newsletter in 2014 and virtually the entire source of the material was Wikipedia. It is of course highly likely that technological advancements have been made since 2014.