

Idiot's Guide to 3D Printing

Introduction

When looking through the many resources I was given, I narrowed down my field of interest to engineering, more specifically 3D printing. 3D printing is the process by which objects are formed layer by layer using different materials that bind them together. I find this topic to be very interesting because it has transformed the manufacturing industry by making the production of items quicker and more cost effective. This technology is used by the government, in corporations, small businesses as well as for personal use.

Basics/History

Additive manufacturing or rapid prototyping commonly referred to as 3D printing is the process in which different objects are made through the layering and binding of materials. This process has existed for the last few decades and is only now beginning to become popular. This technology was invented in the 1980's in order to expedite the manufacturing process. The efficiencies gained through using this process had a positive effect of reducing the carbon footprint. During the late 1980's to early 1990's large quantities of volatile organic compounds (VOC's) were emitted into the atmosphere. These compounds are bonds of carbon hydrogen and oxygen that evaporate at room temperature. They are used in products such as paints, varnishes, waxes, cleaning products, or cosmetic products, which are emitted into the air. VOCs become harmful when they are absorbed into the body. Effects of VOCs are headache, loss of coordination, nausea, and damage to vital organs, such as the liver or kidney. In an effort to lower the risks, in 1984 Charles Hull of the University of Texas, invented the first rapid prototyping system. In 1986 his patent gave him the ability to commercialize this system. His

rapid prototyping system uses a range of techniques to assemble objects quickly and cost effectively by using CAD (computer aided design) software with the 3D printers.

The Revolution



Figure 1: 3D Printed Jewelry (necklace) (ThisNext, 2012)

3D printing is starting to become more popular as the manufacturing industry is continually changing. The procedure is rapid, allows creators to have design freedom, and produces less waste, which makes it more environmentally friendly. Giving people creative freedom allows them to design custom items. In all these areas, the cost of manufacturing decreases while the speed of production and revenue increases. Even architects are using 3D printing. In order to create multiple models that are

distribute to clients or co-workers and small business owners use this technology

to create personalized items/gadgets on a larger scale. Many of the things a printer can produce are jewelry, art, toys, or parts for dishwashers. The



Figure 2: 3D Printed Art (sculpture) (Kahn, 2012)

medical industry has found a great use for 3D printing by producing prosthetic limbs or braces, etc. The finished products are fitted for the specific client providing greater user satisfaction.

Charles Hull

Charles Hull developed 3D Printing in 1984. Since that time he has acquired over 60 US patents in the fields of rapid prototyping and optics. The patent for Stereolithography, a 3D printing method, is his main contribution to the 3D printing industry. It was issued on March 11th, 1986 and was named “Apparatus for Production of Three-Dimensional Object by Stereolithography.” Based on his prior research, Hull was able to construct the first commercial 3D Printing Machine. Then in 1996 His success enabled him to start his own 3D Printing company, called 3D Systems located in Valencia, California.

United States Patent [19] Patent Number: **5,569,431**
Hull [45] Date of Patent: **Oct. 29, 1996**

[54] **METHOD AND APPARATUS FOR PRODUCTION OF THREE-DIMENSIONAL OBJECTS BY STEREO LITHOGRAPHY**

[73] Inventor: Charles W. Hull, Arcadia, Calif.

[21] Appl. No.: 484,749

[22] Filed: Jan. 7, 1995

Foreign Patent Documents

2,775,738 12/0586 Marx 15/058 X
 2,368,545 10/0589 Top 20/022 X
 (List continued on next page.)

OTHER PUBLICATIONS

H. Kodama, "Automatic Method for Fabricating a Three-Dimensional Plastic Model With Photo-Hardening Polymer," *Review of Scientific Instruments*, vol. 52, No. 11, Nov. 1981, pp. 1770-1773.
 A. J. Herbert, "Solid Object Generation," *Journal of Applied Photographic Engineering*, 8 (4), Aug. 1982, pp. 183-188.
 H. Kodama, "A Scheme for Three-Dimensional Display by Automatic Fabrication of Three-Dimensional Models," *JEECE*, vol. 36-4, No. 4, Apr. 1981, pp. 237-241. (Translation).
 Request for Reexamination of U.S. Pat. No. 4,575,330 filed Sep. 27, 1989 by E.I. Du Pont de Nemours & Co.
 Abstract of Japanese Reference (Kokai) 58-211413 Published Dec. 1983.
 Primary Examiner—Luis B. Tumbati
 Attorney, Agent, or Firm—Dennis R. Stalley, Anna M. Vandenbergh

ABSTRACT

A system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed at a selected surface of a fluid medium capable of altering its physical state in response to appropriate optoelectronic stimulation by impinging radiation, particle bombardment or chemical reaction, successive adjacent laminae, representing corresponding successive adjacent cross-sections of the object, being automatically formed and integrated together to provide a step-wise laminar buildup of the desired object, whereby a three-dimensional object is formed and drawn from a substantially planar surface of the fluid medium during the forming process.

U.S. PATENT DOCUMENTS

3,361,236 8/0485 Symons 4/00294
 2,525,510 10/0980 Deppendorf 4/00419
 2,708,617 5/0700 Magt et al. 2/04298 X

8 Claims, 4 Drawing Sheets

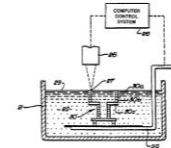


Figure 3: Patent for Apparatus for Production of Three-Dimensional Object by Stereolithography (Hull, 1996)

CAD Software

CAD software stands for computer-aided design. It has also been used interchangeably with computer-aided drafting. This software creates the models that will be constructed with a 3D printer and allows the user to easily create the object that they are customizing. The objects designed using CAD are used in many industries. Such as engineering, architecture, people in car manufacturing, aerospace, or electronics. Another type of CAD software called the Design File Format, enabling people who are not familiar with CAD to construct models for printing.

CAD Software

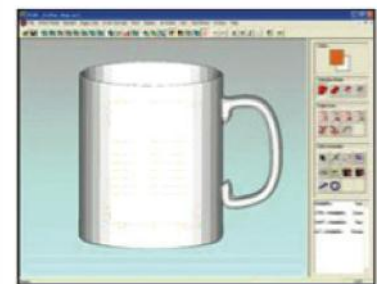


Figure 4: Mug mad using CAD Software (ZCorperation, 2009)

The 3D printing process

Regardless of the object to be printed, the 3D process is basically the same. An object must be created using the CAD software before going to the printer. The CAD software is specifically designed to be compatible with the 3D printer, it is similar to the software Google SketchUp. Once the model is created, it needs to be converted to the STL format (Standard Tessellation Language), developed in 1987. At this point in the process, the object is sliced into many layers in preparation for printing. The next step is to transfer the file to the computer that controls the 3D printer. The printer's computer receives the file as if it were an e-mail. Then the user has the ability to manipulate the size, orientation, and proportions once the STL file is uploaded to the computer. After setting up the 3D printer, it starts to build the object. The procedure begins as multiple layers of designated materials, such as plastic, metal, wax, or gold, adhere together to form the desired object. Once it has been successfully created, the user must take safety precautions when coming into contact with toxins and other harmful chemicals. They use gloves and tongs to hold the object. Post printing, the creator must brush remaining powder from the object then put it to use.



Figure 5: Mug made using CAD Software (ZCorperation, 2009)

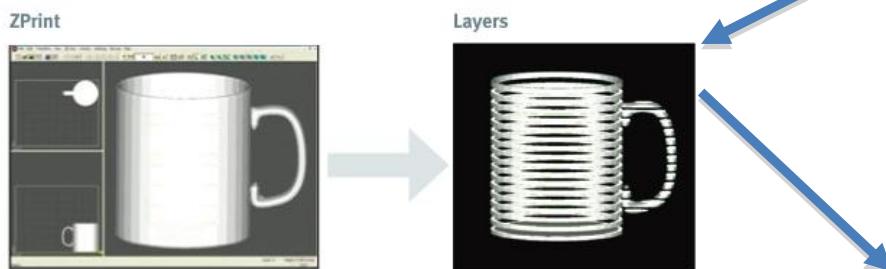


Figure 6: STL format, slicing the mug into printable layers (ZCorperation, 2009)



Figure 7: Mug in the process of being printed (ZCorperation, 2009)

Inkjet Printing

Inkjet Printing was introduced during the 1980's. It is the printing method that uses small dots of mixed colors to display an image. There are two main categories of inkjet printers,



Figure 8: Inkjet Printer
(GoogleCloudPrint, 2011)

Impact and Non-Impact. An Impact Printer uses a mechanism that touches the ink to the paper to create an image. Impact technologies include the Dot Matrix and the Character. Non-Impact systems are printers that do not use a mechanism to touch ink to the paper to create an image. Non-Impact technologies include Laser, Solid Ink, and Dye-Sublimation.

Direct and Binder 3D Printing

Direct 3D printing uses inkjet components that are also available for 2D printers. In the 3D printing process nozzles in the printers move back and forth to create the different layers of the desired object using various materials such as plastics, metals, waxes, etc. Binder 3D Printing is a process that uses inkjet nozzles to apply the material used to make the layers to the base platform. This method uses two nozzles to create the multiple layers of the object being printed. Of the two nozzles, one dispenses a powder, a type of starch or plaster, and the other is a liquid/glue to bind them together. To print, a layer of powder is spread along the base of the printing platform, and the nozzles place the binder in the shape of the desired object. The glue holds the shape and the process will repeat until the item is finished printing. Advantages of this technology are the rapid pace of the printing process due to less materials being transported

through the nozzles allowing a object about 2cm by 2cm to be printed in 5 to 20 minutes. Other benefits are the variety of materials that can be used, and the capability of printing in color.

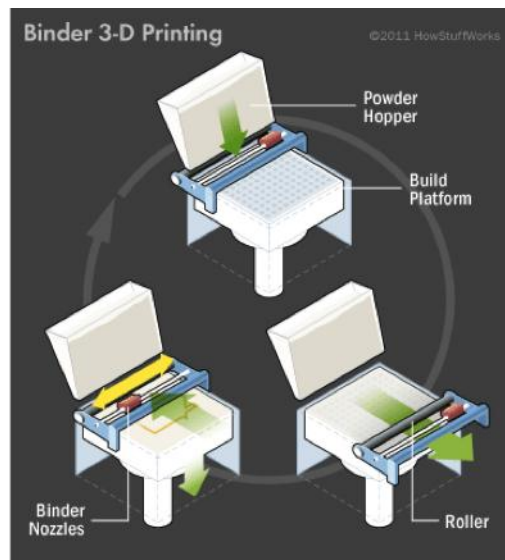


Figure 9: Binder Printing Process (HowStuffWorks, 2011)

Photopolymerization

Photopolymerization consists of using drops of liquid plastic that are exposed to a laser beam of ultraviolet light. The UV light changes the liquid plastic into a solid that will be used to create the layers that make up the desired model. An object made using Photopolymerization is an action figure.

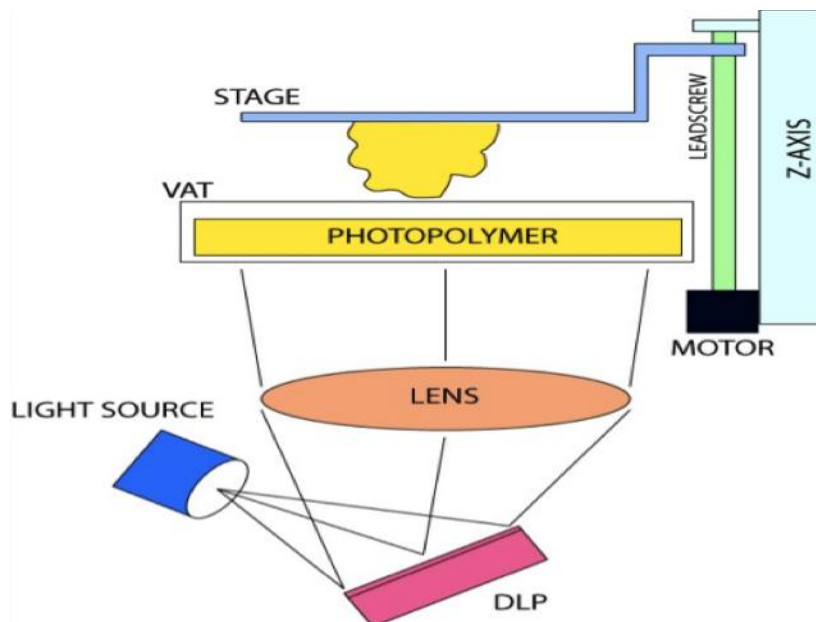
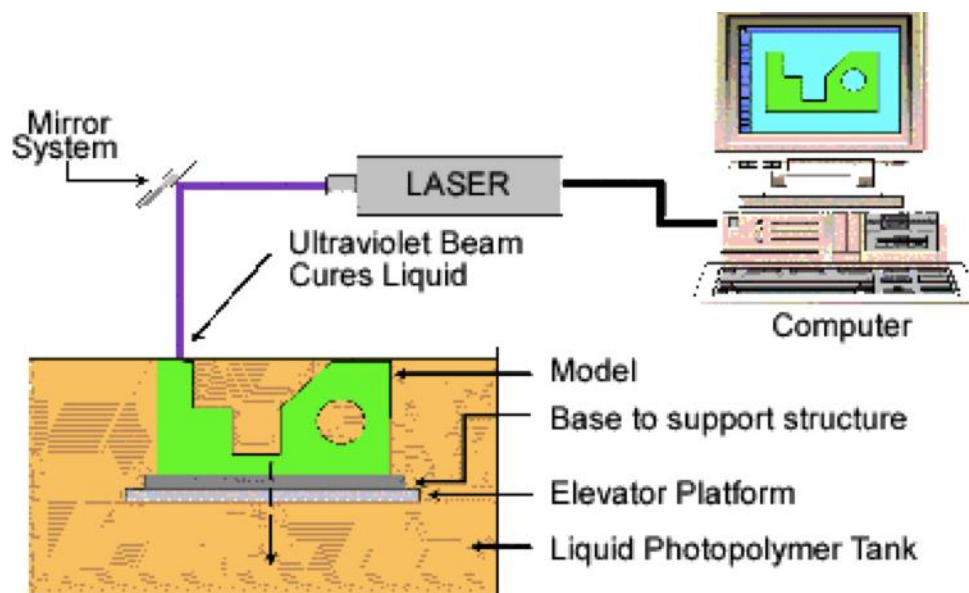


Figure 10: Photopolymerization Printing Process (Lemoncurry, 2012)

Stereolithography

Stereolithography uses an Ultraviolet laser, a build platform, and a liquid polymer to create the 2D cross sections of a model. The UV laser draws the shape of the layer on the base of the support structure. The support structure is lowered and a coating of liquid polymer is applied to the layer that was just drawn to harden it. This process repeats until the desired model is finished printing. Some items made using this process are an engine manifold or game pieces such as those on a chessboard. Stereolithography is accurate, provides detail, and has a smooth surface when finished.



**Figure 11: Stereolithography Printing Process
(Center for BioMolecular Modeling, 1998-2008)**

Fused Deposition Modeling

Fused Deposition Modeling (FDM) uses thermoplastic material to build the models it prints. Thermoplastic material is a polymer that is moldable when heated and quickly hardens when cooled. The CAD software converts the model into several thin layers. The desired material used to make the model is heated then applied onto the platform to be molded into one of the 2D cross sections. Within minutes the layer solidifies. The platform lowers and the next cross section is applied to the existing layers. The process repeats until the model is complete. Gears or models of various objects, such as a jaw, are made using this process. Fused Deposition Modeling is mainly used for conceptual models, functioning prototypes, or manufacturing tools. This accurate process uses strong materials, and has the ability to produce models with color.

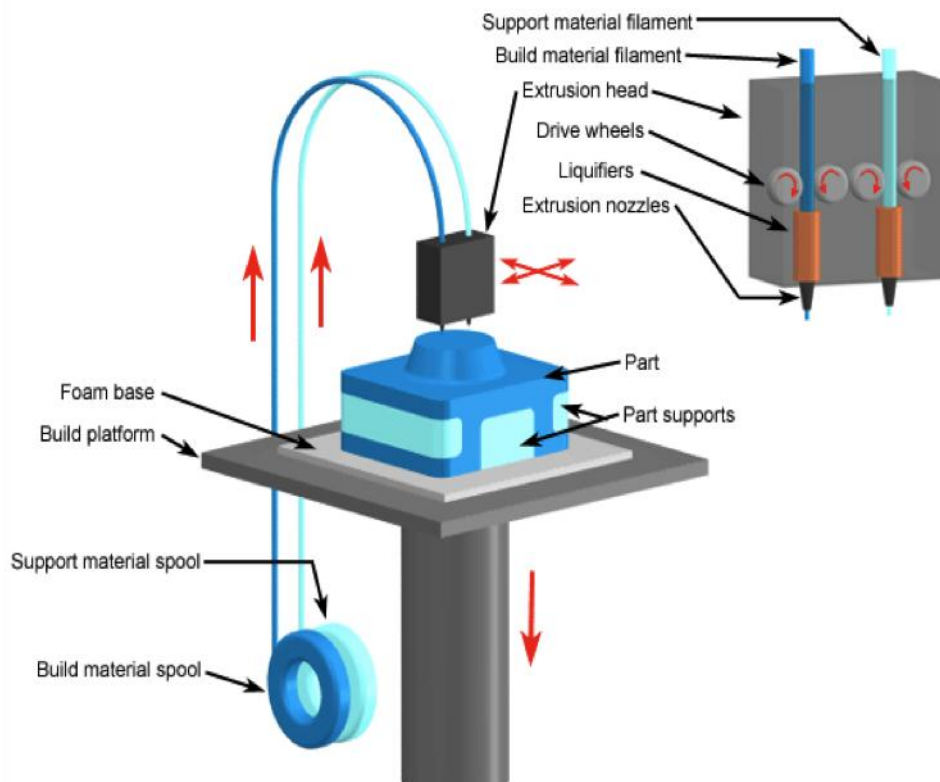


Figure 12: Fused Deposition Modeling Printing
(ProcessPartNet, 2008)

Selective Laser Sintering

Selective Laser Sintering (SLS) builds objects using a Carbon Dioxide laser, powders, and composites. A layer of powder is first laid down onto the base platform. The laser selectively adheres the powder when the UV light is over it to create the cross section that was sent to the computer. The base platform is lowered (according to the thickness of the layer) when the layer is completed, then a new cross section of powder is placed on top of it. The laser melds the new powder to the other finished layers combining them together. This is done until the object is finished. The model is then removed from the printer and all excess powder is brushed away. Synthetic bone is made using this method printing. A characteristic of using this type of printing process is that it uses strong materials. However, this technology is less accurate, leaves a rough finished surface, and models cannot be created with color.

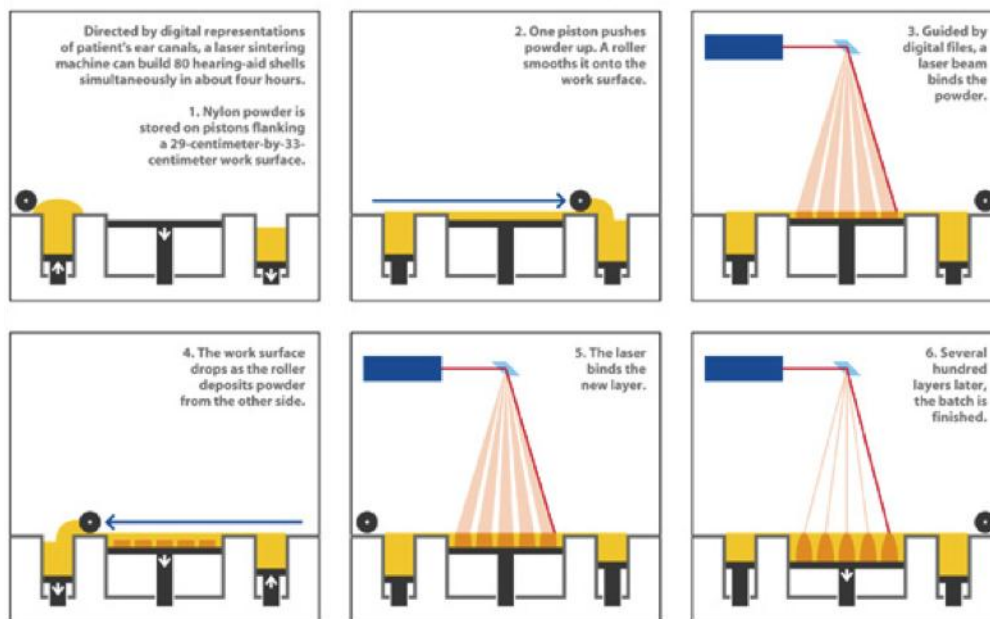


Figure 13: Selective Laser Sintering Printing Process (Kikuchi)

MultiJet Modeling

MultiJet Modeling (MJM) is a process that uses molten plastic to create the thin cross sections of an object. The machine uses nozzles to dispense the material onto the base platform, which holds the model, as well as the support structures that are automatically generated. When the material layer is successfully printed onto the platform, it is instantly cooled and hardened by Ultraviolet light. The base then lowers itself in order for the next cross section to be printed. An item made using this process is a mechanical heat melter. This fast process, allows several projects to be completed around the same time

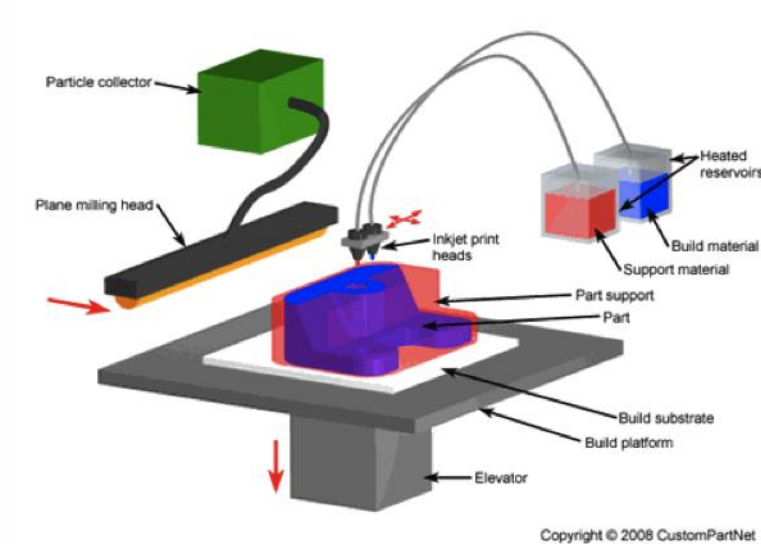
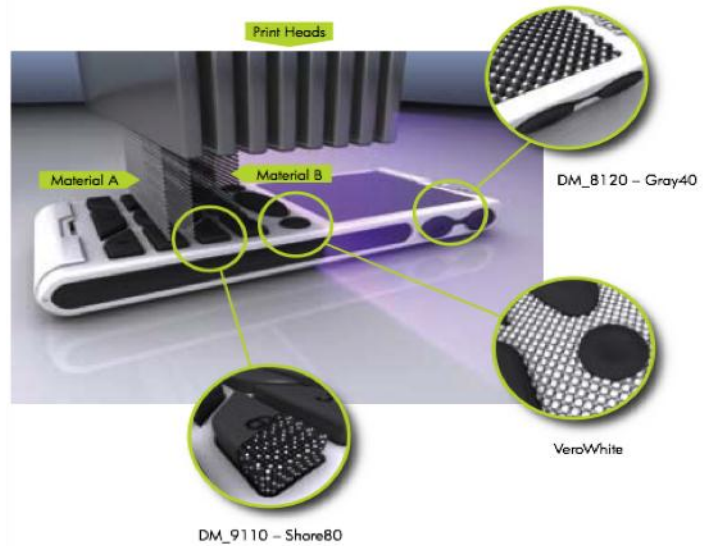


Figure 14: MultiJet Modeling Printing Process (CustomPartNet, 2008)

Polyjet Matrix

The Polyjet Matrix is a system that has the ability to use two different materials simultaneously. The print heads place the materials in the position of the layer it is trying to create, and then use Ultra Violet light to harden the layer instantly. This is a unique process because its uses many materials at one time, has the ability to print with a variety of colors, is

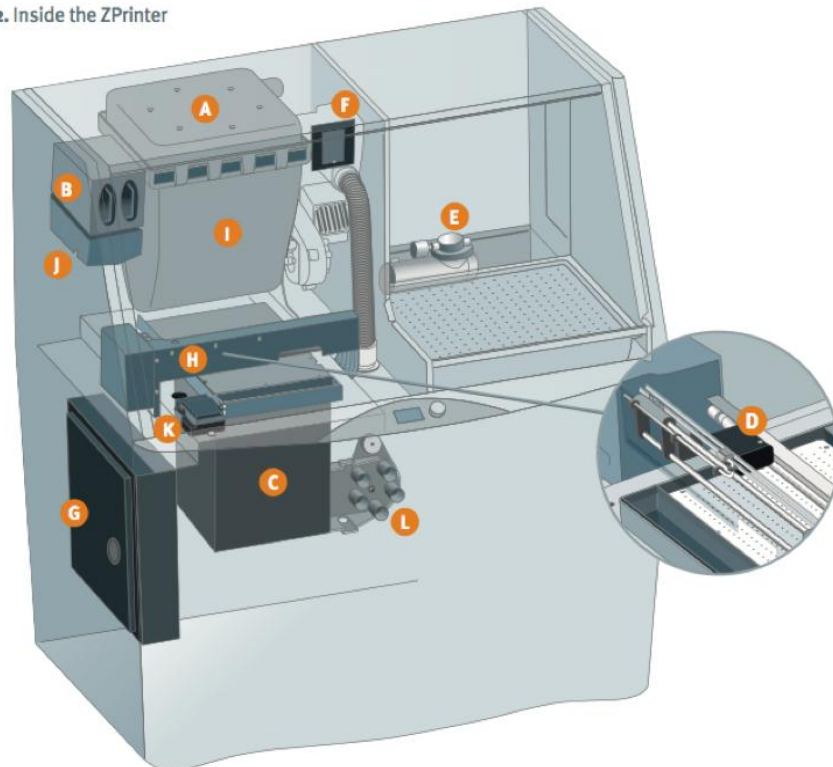
precise, and very durable. Some items made using this method are shaving razors and blades or a GPS mold.



**Figure 15: Polyjet Matrix Printing Process
(Object Geometries, 2009)**

Breaking Down the Parts of a Printer

Figure 2. Inside the ZPrinter



**Figure 16: Standard 3D Printer made by
ZCorperation (ZCorperation. 2009)**

Table 1: Breaking Down the Parts of a Standard 3D Printer made by ZCorperation

a. Automatic Air Filter	makes sure all the powder stays within the printer only allowing clean air to be emitted into the outer area
b. Binder Cartridge	holds the adhesive that solidifies the powder
c. Build Chamber	the area where the model is built
d. Carriage	slides along the gantry to position the print heads
e. Compressor	generates compressed air to rid finished parts of unwanted powder
f. Debris Filter	prevents any solid material from entering the hopper after the building process, it ensures the next build to be clean
g. Electronics Box	the computer controlling the printer
h. Ganty	horizontal bar that travels back and forth to build each layer
i. Hopper	contains that powder that is used to create models
j. Reservoir	collects binder from the cartridges and supplies binder to the gantry
k. Service Station	automatically cleans the print heads (as necessary)
l. Vacuum Valve	vacuums excess powder from the building chamber or if there is an overflow of powder

The Cost of Printing

In the past 3D printing has been expensive. The cost of the printing would exceed \$250,000, including the expenses printer and materials. Now the prices of machines are lower. For example, in February of 2011 3D Systems' ProJet CPX 3000 sold for \$79,999. This printer is able to produce models with high quality details with dimensions up to 11.75 inches by 7.3 inches by 8.0 inches. Another printer called the Dimension Elite by Stratasys, which can build plastic models up to 8.0 inches by 8.0 inches by 12.0 inches starts at \$29,900. Smaller printers, like those found in a dental office, can cost anywhere from \$30,000 to \$60,000 and can produce molds for crowns, bridges, and dentures faster and with greater accuracy resulting in greater consumer satisfaction. There are also now small 3D printers that are available for home use. An example is the V-Flash Personal 3D Printer made by 3D Systems. This system weighs less than 150 pounds, builds objects of 9.0 inches by 6.75 inches by 8.0 inches, and is small enough to fit

on a standard home office table. The V-Flash is selling for \$9,900 and the material cartridge is selling for \$850 each. Another personal printer is called the RepRap that sells for approximately \$1,000.

Another approach to printing at home without purchasing a printer, is by ordering through an online company such as shapeways.com. The data of the model will be sent to the printing company and the finished product will be sent back to the consumer.



Figure 17: Image Taken From shapeways.com

Going Green

3D printing is a green and sustainable process. The ability to send data wirelessly, across the country or to other continents, eliminates wasted time and the shipping process. The amounts of fossil fuels, emitted by trucks or airplanes, are lowered and in turn it lowers the overall carbon footprint allowing the earth to be cleaner and healthier.

The Future

The Future of 3D Printing looks to be very promising. There has been much interest by NASA, the US Army, and throughout the medical industry. NASA is considering the use of this technology to make parts for aircrafts that will be sent deep into space. The US Army wants to use the technology to print parts of tanks and other vehicle components while on the battlefield, and the medical industry is using this technology to create artificial organs replacements of the human body. The uses of 3D printing are limitless and the possibilities are endless.

Glossary

Additive Fabrication – the process of joining materials to make objects from 3D model data
(interchangeable with additive manufacturing)

Additive Manufacturing – the process of joining materials to make objects from 3D model data
(interchangeable with additive fabrication)

Auto CAD - AutoCAD is a CAD (Computer Aided Design or Computer Aided Drafting)
software application for 2D and 3D design and drafting

CAD Software - Computer-aided design (CAD), also known as computer-aided drafting and
design (CADD) it is the software used to build model that are going to be printed

Carbon Dioxide Lasers – a laser beam of infrared light that binds layers of material together

Carbon Footprint – the amount of carbon dioxide emitted due to the use of fossil fuels

Design File Format – software created for non-CAD users

Dimension – an extension in a given direction

Fabrication – the act of process of manufacturing

Fossil Fuels – a natural fuel (coal or gas) formed from the remains of living things

Manufacturing – the making or producing of anything

Photopolymer - A substance that has a molecular structure built up completely from a large
number of substances bonded together

Prototype – the original model of a new product

Standard Tessellation Language Format – the software that the 3D printer recognizes and uses to break a model into layers before the printing process

Ultra Violet Light – wavelengths shorter than light but longer than X rays

Varian Product – an alteration of a product (changing the size, shape, orientation, etc)

Violate Organic Compounds - bonds of carbon hydrogen and oxygen that evaporate at room temperature

Works Cited

(n.d.). In Google. Retrieved December 5, 2012, from

<http://www.google.com/search?q=polymer+definiotn+&sourceid=ie7&rls=com.microsoft:en-us:IESearchBox&ie=&oe=&surl=1&safe=active#hl=en&safe=active&tbo=d&rls=com.microsoft:en-us:IE-SearchBox&spell=1&q=po>

(n.d.). In Google Images. Retrieved November 26, 2012, from [http://www.msoe.edu/acad](http://www.msoe.edu/academics/research_centers/graphics/sla_process.gif)

[emics/research_centers/graphics/sla_process.gif](http://www.msoe.edu/academics/research_centers/graphics/sla_process.gif)

(n.d.). Retrieved November 25, 2012, from [http://elblogdelplastico.blogs.upv.es/2012/10/](http://elblogdelplastico.blogs.upv.es/2012/10/19/prototipos-avanzados-graduado-en-diseno/)

[19/prototipos-avanzados-graduado-en-diseno/](http://elblogdelplastico.blogs.upv.es/2012/10/19/prototipos-avanzados-graduado-en-diseno/)

(n.d.). Retrieved November 30, 2012, from <http://www.printer-printer.com/wp-content/u>

[ploads/2011/06/1308330931-80.jpg](http://www.printer-printer.com/wp-content/uploads/2011/06/1308330931-80.jpg)

3D Printing. (2012). In PCMAG. Retrieved December 1, 2012, from <http://www.pcmag.c>

om/encyclopedia_term/0,1237,t=3D+printing&i=37077,00.asp

3D Printing. (n.d.). In Explaining the Future. Retrieved December 4, 2012, from [http://w](http://www.explainingthefuture.com/3dprinting.html)

www.explainingthefuture.com/3dprinting.html

3D Printing. (n.d.). In Wikipedia. Retrieved December 3, 2012, from [http://en.wikipedia.](http://en.wikipedia.org/wiki/Additive_manufacturing)

[org/wiki/Additive_manufacturing](http://en.wikipedia.org/wiki/Additive_manufacturing)

3D Systems. (2008, March 4). 3D Systems - Selective Laser Sintering. In YouTube. Retri

ved November 4, 2012, from <http://www.youtube.com/watch?v=gLxve3ZOmvc>

3D Systems. (n.d.). Selective Laser Sintering. In 3D Systems. Retrieved November 15,

2012, from <http://production3dprinters.com/sls/selective-laser-sintering>

AutoCAD. (n.d.). In Wikipedia. Retrieved December 2, 2012, from [http://en.wikipedia.o](http://en.wikipedia.org/wiki/Auto_CAD)

[rg/wiki/Auto_CAD](http://en.wikipedia.org/wiki/Auto_CAD)

CAD Primer. (n.d.). In Introduction to Engineering. Retrieved November 28, 2012, from

<http://www.sphsengineering.com/index.php/cad-primer>

CAD Software Combined. (2012). In Autodesk. Retrieved December 3, 2012, from [http://](http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=17690382)

usa.autodesk.com/adsk/servlet/item?siteID=123112&id=17690382

Carbon Dioxide Laser. (n.d.). In Wikipedia. Retrieved December 5, 2012, from [http://en](http://en.wikipedia.org/wiki/Carbon_dioxide_laser)

[.wikipedia.org/wiki/Carbon_dioxide_laser](http://en.wikipedia.org/wiki/Carbon_dioxide_laser)

Computer-Aided Design. (n.d.). In Wikipedia. Retrieved December 5, 2012, from http://en.wikipedia.org/wiki/CAD_software

Crawford, S. (n.d.). How 3D Printing Works. In How Stuff Works. Retrieved October 29, 2012, from <http://computer.howstuffworks.com/3-d-printing2.htm>

DLP-Drucker. (2012, April 11). In Hobbytheke. Retrieved November 25, 2012, from <http://blog.krieft.de/2012/04/11/dlp-drucker/>

Fabrication. (n.d.). In Dictionary Reference. Retrieved December 5, 2012

Fused Deposition Modeling (FDM). (n.d.). In CustomPart. Retrieved November 3, 2012, from <http://www.custompartnet.com/wu/fused-deposition-modeling>

Manufacturing. (n.d.). In Dictionary Reference. Retrieved December 5, 2012

Objet Geometries Inc. (2009). PolyJet Matrix Technology. Retrieved November 26, 2012, from <http://www.dmsf.ust.hk/manuauto/PolyJet%20Matrix.pdf>

Prototype. (n.d.). In Dictionary Reference. Retrieved December 5, 2012

QuickParts. (n.d.). Fused Deposition Modeling. In QuickParts. Retrieved October 28, 2012, from <http://www.quickparts.com/LowVolumePrototypes/FDM.aspx>

S. Scott Crump. (n.d.). In Wikipedia. Retrieved November 24, 2012, from <http://en.wikip>

edia.org/wiki/S._Scott_Crump

Stratasys. (n.d.). Get a sample part produced on an FDM machine. In Stratasys. Retrieved

November 18, 2012, from [http://www.stratasys.com/Flex-Items/Home/Items/Sam](http://www.stratasys.com/Flex-Items/Home/Items/Sample-Part-Request.aspx?gclid=CPCC5feY67MCFcuZ4AodICMAvg)

ple-Part-Request.aspx?gclid=CPCC5feY67MCFcuZ4AodICMAvg

Thermoplastic. (n.d.). In Wikipedia. Retrieved December 3, 2012, from [http://en.wikip](http://en.wikipedia)

edia.org/wiki/Thermoplastic

Tyson, J. (n.d.). How Inkjet Printers Work. In How Stuff Works. Retrieved November

13, 2012, from <http://computer.howstuffworks.com/inkjet-printer.htm/printable>

ultraviolet light. (n.d.). In Princeton WordNet Search. Retrieved December 1, 2012, from

<http://wordnetweb.princeton.edu/perl/webwn?s=ultraviolet+light&sub=Search+W>

ordNet&o2=&o0=1&o8=1&o1=1&o7=&o5=&o9=&o6=&o3=&o4=&h=

US EPA. (2012, July 9). An Introduction to Indoor Air Quality. In United States Enviorn

mental Protection Agency. Retrieved November 5, 2012, from <http://www.epa.go>

v/iaq/voc.html#content

ZCorperation. (2009). How 3D Printing Works. In ZCorperation. Retrieved November

18, 2012, from http://itg.beckman.illinois.edu/visualization_laboratory/equipm

ent/3Dprinting/files/791_8914-3DPrintingWhitePaper.pdf