A SunCam online continuing education course

3D Printing for Engineers

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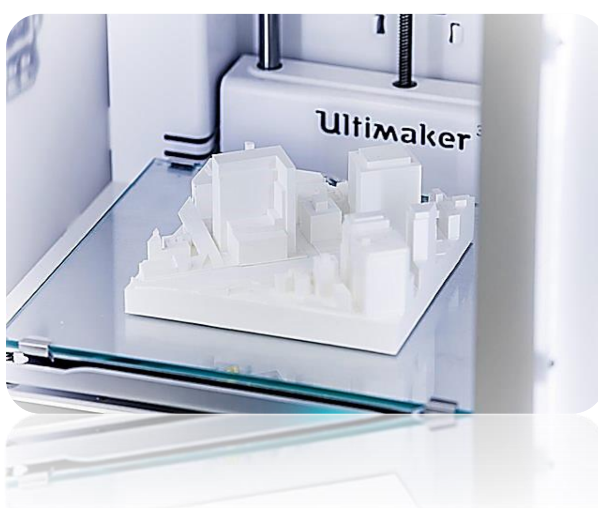


Introduction: What is 3D Printing?

3D printing is an umbrella term for an assortment of processes and technologies used in production of parts. The commonality of all 3D printing aspects is the manner of production; that is, layer by layer in an additive process (i.e. additive manufacturing). Contrast this with subtractive manufacturing, where a billet or block of material is machined to reveal the final part, and formative manufacturing, where material is formed over a mold. The expense of tooling, fixturing, material waste, and assembly can impose unacceptable constraints on traditional manufacturing methods which can be largely avoided by 3D printing. Also, extremely complex geometry can be printed at *no extra cost*. When properly integrated, 3D printing can save businesses hundreds of thousands of dollars and months of time, increasing their competitive advantage and allowing them to get better products to market faster.

Common applications for 3D printing include proof-of-concepts, small production runs, working prototypes, tooling and molds, and replacement parts. New applications of 3D printing are rapidly emerging. The true potential may only just have begun. The technology has developed beyond prototyping and is now available to do-it-yourselfers at home. The adoption rate is exponential.

This course addresses the basics of 3D printing and the uses that can be integrated into engineering. By no means is this a comprehensive document; there is much left untouched. However, this course can be used as a jumping-off point for those to whom 3D printing is new, or a refresher for accomplished users.

History of 3D Printing

1977 Wyn Swainson files a patent for using a laser to create covalent cross-linking at the surface of a liquid monomer.

1981 Innovators further develop concepts for using lasers with photopolymeric solutions in liquid polymers.

1986 Charles Hull is granted a patent for stereolithography apparatus (SLA) and also develops the STL file format. He went on to cofound one of the largest and most prolific organizations operating in the 3D printing sector today.

1987 Carl Deckard, who was working at the University of Texas, patents selective laser sintering (SLS) which fuses plastic, metal, ceramic, or glass powders into solid 3D forms via laser. This patent was issued in 1989.

1989 Scott Crump filed a patent for Fused Deposition Modeling (FDM). As of 2015, FDM has become the most popular 3D printing technology for entry level machines.

1991 Helisys creates laminated object manufacturing (LOM) by using paper that is unrolled and glued layer by layer.

1991 Cubital Ltd. introduces solid ground curing (SGC) which flashes layers of material with ultraviolet light to harden polymers on a plate.

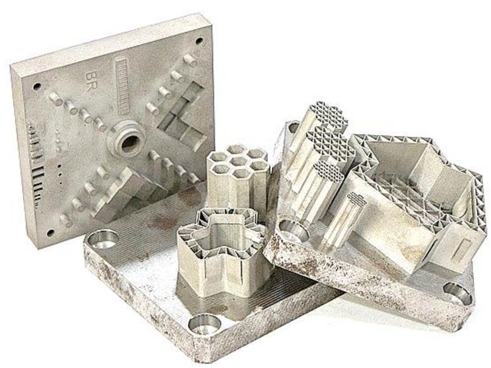
1993 The first computer sculpture exhibition is introduced at the Ecole Polytechnique in Paris.

1997 Materialise NextDay, a 24-hour service, allows customers to order 3D-printed parts online.

AeroMat produces the first 3D printed metal using Laser Additive Manufacturing (LAM) which fused powdered titanium allows with high powered lasers.

1999 Scientists create the first 3D printed lab-grown organ, a bladder, made from a patient's own cells. This organ was non-working and was not implanted.

2003 The first working 3D printed organ, a kidney, is made in China.



2005 At-home 3D printers emerge by the RepRap project at the University of Bath.

2006 Cobalt chrome and stainless steel are printed via laser sintering.

2008 RepRap project releases the first open-sourced 3D printer hardware which initiates an enormous 3D printing global make community.

First usable prosthetics are printed in one piece, without assembly required.

2009 ASTM Committee F42 is established for Additive Manufacturing Technologies, leading to the first standard reference publication.

2010 The Centre for Fine Print Research 3D prints porcelain for the first time.

2011 The Advanced Manufacturing Process Partnership (AMP) is announced by President Obama to bring together industry, education, and government to increase U.S. competitiveness in manufacturing.

The first 3D printed dress is named by TIME Magazine as one of the 50 Best Inventions of the year.

First 3D printed aircraft is developed in just seven days at the University of Southampton.

First 3D printed vehicles, including a nylon bicycle, emerge.

2012 LayerWise builds the first 3D printed jaw implant for an 83-year-old patient in the Netherlands.

3D printed affordable housing appears on the horizon with potential to build an entire housing unit in one day for 25% of the cost of traditional methods.

First 3D printed handgun is made by Cody Wilson, a Texas law student. Wilson is subsequently labeled as one of the “15 Most Dangerous People in the World” by Wired Magazine.

Gold is 3D printed for the first time.

A 3D chocolate printer is made commercially available.
Fully articulated custom-molded “magic arms” are 3D printed which give a two-year-old child the use of her limbs.

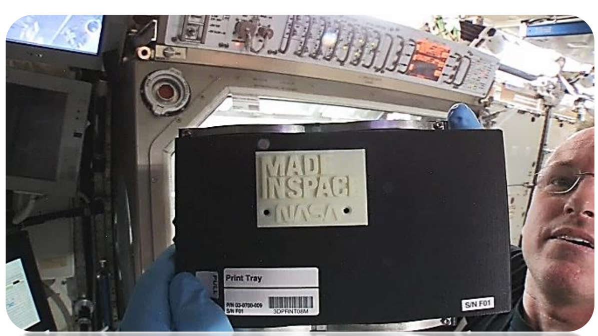
2013 3D printed lunar habitations are planned as future moon housing.

A baby’s life is saved with a groundbreaking 3D-printed splint created at the University of Michigan. The splint, made of biological material, opened up the child’s lungs and allowed him to breathe freely.

NASA announces a plan to explore 3D printing food and tools in space for astronauts. NASA also successfully tests the first 3D printed rocket fuel injector.

3D printing is mentioned in the State of the Union speech.

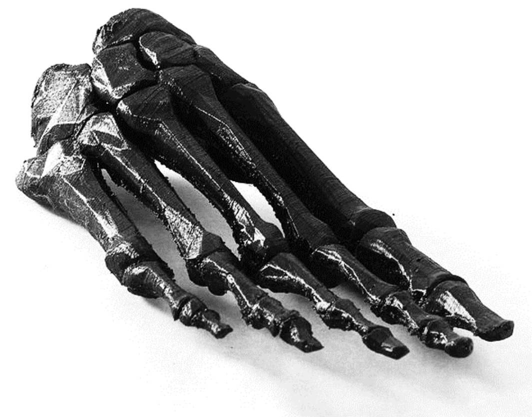
2014 The first object is 3D printed in space by NASA astronauts, aboard the ISS.



2015 Carbon 3D introduces their ultra-fast CLIP 3D printing machine.

Bio-ink is designed as a method of printing tissue cartilage, leading to the release of INKREDIBLE 3D printer for bioprinting.

The world's tallest 3D printed building, a 5-story apartment, is built.



2016 Daniel Kelly's lab announces the ability to 3D print bone.

2018 The first family moves into a 3D printed house.

2019 There are over 170 3D printer system manufacturers around the world.

The world's largest 3D printed building is created.

Naval Group and Centrale Nantes engineering school 3D printed the first hollow propellor blade.

2020 KFC announces 3D bioprinting technology to create the "meat of the future" in the form of fried chicken.

3D printed COVID-19 products such as masks, face shields, and PPE flood the market.

Globe Newswire projects the 3D printing market to grow from $11.5B to $47.5B by 2028.

2021 A British patient received the world's first fully 3D printed prosthetic eye for Moorfields Eye Hospital in London.

University of Alberta develops a method of 3D bioprinting customized nasal cartilage for disfigured cancer patients.

3D printed parts are integrated into a ConcoPhillips polar oil tanker.

2022 A team from Imperial College London designed autonomous drones that print in flight, just like a swarm of bees.

Researchers from Tohoku University Graduate School of Dentistry in Japan reveal that 3D printing dental crowns is superior to existing methods.

Israeli company Steakholder Foods Ltd. unveils their new product, Omakase Beef Morsels which are bioprinted cultured meat.

The world's first 3D printed church is to be built in California.

Lufthansa and Premium AEROTEC print an EASA flight-approved load-bearing metal part for use on an aircraft. The part is a component within the A320 engine's anti-icing system.

Azure Printed Homes has reportedly become the first construction 3D printing company to repurpose plastic wastes as a primary home building material.

E-mobility tech company JAMADE unveils its new 3D printed underwater scooter in Germany.

2023 A Chinese medical firm launched a new 3D printed spinal implant.

Relativity Space semi-succe3sfully launched the world's first 3D printed rocket, the Terran 1.

Wilson Sporting Goods creates an airless 3D printed basketball.

2024 23-piece 3D printed surfboards ride the waves in California.

A Chinese company prints the first titanium alloy bicycle frame in Asia.

3D Printing Terminology

3D Printer	An additive fabrication machine that is designed to join materials to make objects from 3D model data through depositing of material usually layer upon layer also known as 3D printing.
3D Printing	A process of fabricating objects from 3D model data through depositing of material usually layer upon layer.
ABS	Acrylonitrile Butadiene Styrene
Additive Fabrication	An automated method to build models, prototypes, tools and manufactured parts directly from CAD data, that constructs these parts by depositing and bonding materials on a layer-by-layer basis.
Base Layer	Sacrificial initial layers used to stabilize the part on the build tray to create a strong foundation and ensure a level build plane.
BASS	Break-Away Support Structure.
Bead	The data used to describe extruder tip position and extrusion properties when building a part on an FDM™ printer. It also describes the thin strip of extruded thermoplastic deposited by the 3D printer.

Boundary Curves	A closed curve used to define a region in the XY plane. Two different types of boundary curves are present in the system: part boundary curves and support boundary curves.
CAM	Computer Aided Manufacturing.
Direct Digital Manufacturing (DDM)	The process of going directly from a digital representation of a part to the final product (finished goods) via additive fabrication technologies.
Digital Material	Engineered materials manufactured from two or more different constituent materials, according to a digitally encoded three dimensional phase structure design (the DM code), and produced by an additive manufacturing process.
DMLS	Direct Metal Laser Sintering

Envelope	The modeling envelope is the space where the part is built. The part must be small enough to fit inside the modeling envelope.
Extruder	The extruder draws the filament from the spool, melts it, and pushes it through a nozzle onto the build plate.
FDM	Fused Deposition Modeling. The Stratasys-patented additive manufacturing process that extrudes a filament of semi-molten thermoplastic to build parts.
Fill	Density of the material inside the 3D printed model. Fill influences the model's weight and strength.
Filament	The thermoplastic material that is used to build parts in FDM technology. The filament comes on a spool and is loaded into the 3D printer.
Gantry	The apparatus that allows the extruder assembly to move around.
Head	Liquefies the thermoplastic modeling material and extrudes it into precise layers that fuse to form the complete model.
Home	A head and platen position for the FDM hardware. It is the mechanical X = 0, Y = 0, Z = 0 position.
Hygroscopic	A tendency to absorb moisture.
Layer	A 2D, horizontal cross-section used to additively construct a part. The thickness of each layer is equal to the slice height.
Layer Thickness	The height of the slices used to manufacture an FDM part. Thicknesses can be 0.005 in. (0.127 mm), 0.007 in. (0.178 mm), 0.010 in. (0.254 mm) and 0.013 in. (0.33 mm). Shorthand for these thicknesses are 5 slice, 7 slice, 10 slice and 13 slice, respectively.
Material Jetting	Material jetting machines utilize inkjet print heads to jet melted materials, which then cool and solidify. By adding layer on layer, the part is built. Wax materials are used with this technology. Material jetting requires support structures for overhangs, which are usually built in a different material.
Material	The substance used by the modeler to build or support the part. This is generally a type of polymer plastic.

Mesh — Collection of stitched surface patches to represent 3D data model. A way to represent solid objects through polygon division.

Modeling Envelope — The space within the modeler where the part is built. The part must fit inside the modeling envelope.

Mold — A tool with a pocket or cavity for giving a particular shape to something in a molten or plastic state.

Nesting — Positioning of parts on the tray for optimal build efficiency. Orientation, printing time and material use are common parameters to consider.

Open Curve — A gap between part boundary contours on a particular layer of a sliced STL file.

Path — The data used to describe extruder tip position and extrusion properties when building a part on an FDM printer.

PLA — Polylactic Acid

Platen — The Z-stage table on which the modeler builds parts. The table moves down in the direction so that the extrusion head can build successive Z layers.

PolyJet — Photopolymer jetting machines utilize inkjet print heads to jet a liquid photopolymer which is immediately cured by a UV lamp. By adding layer on layer, the part is built. Several materials can be jetted at the same time. Photopolymer jetting requires support structures for overhangs, which is usually built in a different material. The support material is generally a UV curable gel-like material which enables easy removal and leaves a well-defined and smooth object surface.

Print Time — How long it will take to 3D print a part.

Raster — A zig-zag pattern of material extruded from a die, usually used to fill in the area within a contour. This pattern can be adjusted so that there is negative air gap or positive air gap between each toolpath section to create different desired densities for a part.

Road — The data used to describe extruder tip position and extrusion properties when building a part on a 3D printer.

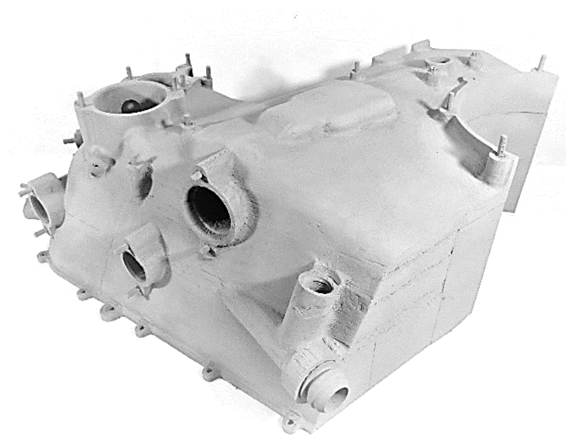
Self-Supporting Angle — The minimum slope that allows an overhanging feature to be built without a base structure below it. The recommended default value is generally around 45 degrees but depends upon material, slice modeler and build mode.

SLA — Stereolithography Apparatus

Slice — A horizontal cross-section of user-defined thickness that describes the geometry of an additive fabrication part (i.e. layer).

Slice Curve — The horizontal outline of a part to be produced. Slice curves will be stacked vertically at intervals consistent with the layer thickness.

Slicing — The process of taking a 3D data model and dividing it into horizontal 2D thin slices so tool paths can be generated, allowing the printer to print the slices layer upon layer.



SLM — Selective Laser Melting

Stepping — Small, abrupt transitions in the horizontal build plane that are evident on all surfaces not parallel to the X, Y or Z planes. Stepping results from the layer-based procedures of additive fabrication.

Stereolithograph Apparatus (SLA™) — Stereolithography machines build parts out of liquid photopolymer through polymerization activated by a UV laser. Parts are built on a build platform inside a vat filled with the liquid photopolymer. The laser scans the surface of the vat to solidify the material. The build platform is lowered into the vat and the part is built layer by layer. Stereolithography requires support structures for overhangs, which are built in the same material.

.STL File — A file format commonly used as input for additive fabrication systems. This file describes only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. The file describes a raw, unstructured, triangulated surface by the unit normal and vertices of the triangles using a three-dimensional Cartesian coordinate system.

Supports	Scaffold of sacrificial material upon which overhanging geometry is built. Also used to rigidly attach the part to the build platform.
Surface Finish	A measure of the texture or roughness of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth.
Tip	The nozzle through which the extrusion head extrudes the semi-liquid material for building the part. Tip size determines the layer thickness and road width for an FDM part.
Toolpath Width	Horizontal measure of a road. Toolpath widths are determined by the tip size.
Warp	Deformation of vertical walls (generally from too much heat).
Watertight	A watertight mesh is one with no holes, cracks or missing features.
WaterWorks™	A soluble support removal system used for FDM parts.

3D Print Processes

The starting point for any 3D print is a digital 3D model. This model can be created using a 3D design software or by 3D scanning. Today, there are many open-source data bases that offer 3D models for users, saving time and effort by allowing rapid downloads.

Once the model is created, the next step is slicing. This involves slicing the model into layers which are converted into a readable file for the 3D printer. 3D printer manufactures offer slicing software that is compatible with the printer. Once slicing is complete, the file is exported to the printer.

Depending on the shape of the part, support material may be required, usually determined by the slicing software. There are two options here: breakaway and soluble. Breakaway material is the same as the part material and is intended to be broken off after the print is complete. This can be accomplished with a single head extruder. However, if the part is complex, soluble material can be printed along with the part material, and dissolved after printing. This requires a dual-head printer.

The 3D printer begins to print the file layer by layer using a specified material. The different types of 3D printers employ various technologies, as is demonstrated here:

STEROLITHOGRAPHY APPARATUS (SLA)

The first 3D printing process; SL is a laser-based system that works with photopolymer resins that react with the laser and cure in a precise way that produces very accurate parts.

The photopolymer resin is held in a vat with a movable platform inside. A laser beam is directed in the X-Y axes across the surface of the resin according to the 3D data supplied to the machine (the .stl file), whereby the resin hardens precisely where the laser hits the surface. Once the layer is completed, the platform within the vat drops down by a fraction (in the Z axis) and the subsequent layer is traced out by the laser. This continues until the entire object is completed and the platform can be raised out of the vat for removal. Many objects 3D printed using SL need to be cleaned and cured. Curing involves subjecting the part to intense light in an oven-like machine to fully harden the resin.

Stereolithography is generally accepted as being one of the most accurate 3D printing processes with excellent surface finish. However, limiting factors include the post-processing steps required and the stability of the materials over time, which can become more brittle.

A similar alternative to SLA is MSLA, which stands for masked stereolithography apparatus. The printing concept is the same except resins are cured by exposure to ultraviolet light instead of a laser beam. MSLA printers mask the uncured areas with an LCD screen. This has the advantage of curing the entire layer at once, generally in 3-5 seconds, rather than tracing every detail with a laser. MSLA printers are faster the SLA and can create one part at the same rate as many parts. Print resolution is based on the LCD screen and is commonly measured in microns, which generates very accurate parts.

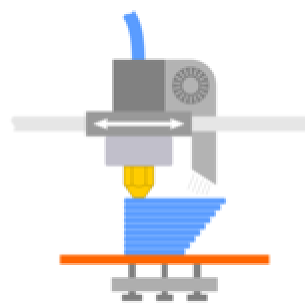
Digital Light Printing (DLP)

DLP is much like stereolithography; however, the main difference is the light source. Instead of a laser, DLP uses conventional lighting such as an arc lamp with lenses or LCD panels. This process is generally faster than SL. DLP produces high quality and accurate parts but also requires post-curing. One advantage is that DLP takes much smaller resin vat than SL, resulting in less cost.

Selective Laser Sintering (SLS)

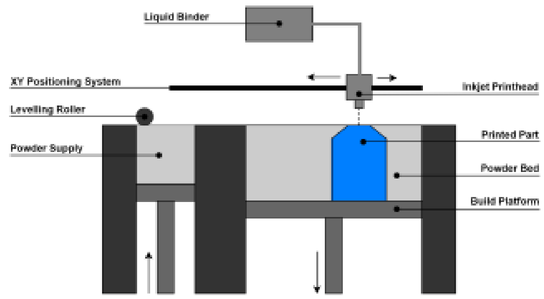
Laser sintering (also laser melting) is a process that 3D prints parts from powdered materials. A powder bed of compacted powder is traced by a laser, thereby sintering, or fusing, the particles to become a solid. Incremental layers are formed and each is covered with powder before fusing. Precise temperature control is critical during the process. Complex shapes are made more easily with laser sintering than other processes. However, high temperatures create longer cooling times. Surface finish and accuracy are reduced, but strength is much higher than SL or DLP parts.

Fused Deposition Modeling (FDM)



FDM is the most common and recognizable 3D printing process. It works by melting plastic filament that is deposited by a heated extruder one layer at a time. The build platform supports the print and each layer hardens as it is deposited and bonds to the previous layer. Support structures are required for overhanging geometry; water soluble or breakaway materials are common options.

BINDER JETTING



Binder jetting is where the material is sprayed into a powder bed via jets to fuse it one layer at a time to create a part. Similar to other powder bed systems, the bed drops in increments after each pass. Supports are not needed and many different material types may be used. Also, it is easy to add a full color palette to the build. Binder jetted parts are not as strong as sintering and require post-processing.

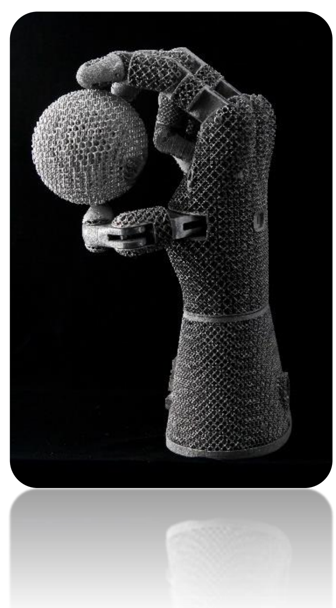
MATERIAL JETTING

Material jetting is another 3D printing process that jets liquid material through multiple jet heads. Instead of fusing, however, this process uses UV light to cure each layer. The material used is commonly liquid photopolymers. Material can be simultaneously deposited of different material type, meaning that a part can have differing local properties and makeup. This process is very accurate and produces smooth parts.

SELECTIVE DEPOSITION LAMINATION (SDL)

SDL, or sheet lamination, is a process whereby parts are made layer by layer using standard copier paper. Yes, you read that correctly. Each new layer is bonded with adhesive to the previous one. The adhesive is selectively deposited by the machine; more in the footprint of the actual part, and less in surrounding areas. Pressure and heat are applied to the stack, completing the bond. Then, a tungsten carbide blade cuts the newest sheet's outline and another paper is added to the stack, restarting the process.

ELECTRON BEAM MELTING



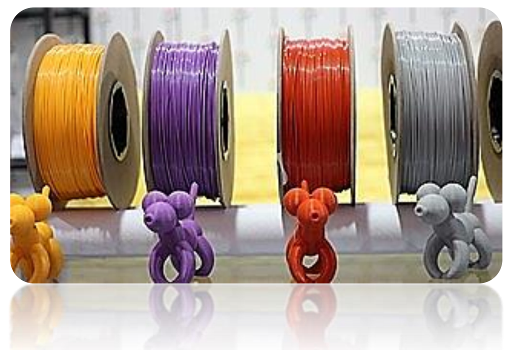
EBM is similar to metal laser sintering with the main difference being the heat source. Instead of a laser, an electron beam is used to fuse the powder to form a part. Printing, therefore, is under vacuum conditions.

3D Print Materials

Plastics Plastics are the original 3D printing material. Strong, flexible, and cheap, plastics are the go-to for 3D printers worldwide. The following is a list of available plastic filaments on the market today. There are many, many others; this list just describes a few of the most common:

PLA/PLA+ PLA (polylactic acid) is the go-to material for basic 3D printing. It's strong in tension and modulus, tough, and easy to use. One downside is its brittleness.

PETG The chemical resistance of PETG (glycol-modified polyethylene terephthalate) makes it a top choice when printing containers or fittings in contact with fluids. PETG has high transparency and is a glossy material.



NYLON The capacity to be durable and withstand high temp environments makes nylon a strong choice. A classic product to print from nylon are gears, which take abuse and abrasion. Other applications include snaps, hinges, impact components, etc.

ABS ABS (acrylonitrile butadiene styrene) is great for products that will be injection molded. It has a clean smooth surface finish, is durable, and holds up well to heat. ABS prototypes perform and look like final products.

PVA When in need of a water-soluble support material, PVA (polyvinyl alcohol) is a logical choice. Using PVA allows you to create complex parts because the water can reach into tiny crevices in the part and reduce damage to the print, as might happen with breakaway supports. It's biodegradable and non-toxic.

PMMA A strong, lightweight filament, PMMA offers impact strength higher than glass and half the density. Transparency and UV properties are comparable to glass. It's naturally translucent.

ABS KEVLAR The combination of ABS and Kevlar offers high strength and durability which are superior to standard ABS. The aramid fibers enhance resistance to abrasion and material toughness.

Metals Metals and metal composites are becoming common in industrial applications. Aluminum, cobalt, stainless steel, Inconel, bronze, gold, silver, and titanium are a handful of the common metals that are printed. Sintering metal powders is the typical process. Biocompatible metals with mechanical strength and corrosion resistant properties are used in medical and transportation applications. High heat environments use printed nickel alloys.

Ceramics Ceramics are relatively new to the 3D printing world, with mixed results. As any other traditional ceramic part, it undergoes post-processing in the form of firing and glazing. The pottery industry is seeing revolutionary shapes being printed that far exceed hand-formed capabilities. Clay prints are safe, very fast (50 mm/sec), and can be worked after printing.

Paper Paper as a 3D printed material produces safe, eco-friendly, and recyclable parts. They also require no post-processing.

BioMaterials Physicians are using 3D printed models to consult with their patients and evaluate how to best proceed with treatment. Patient-matched prosthetics, hearing aids, casts, etc. all meet the exact needs of the patient and can be replaced without having to travel and repeat fitting. Same-day crowns and other dental products are precisely tailored to eliminate custom fits. Bioprinting may one day close the gap between supply and demand for organs and tissues. Although an entirely different material than traditional 3D printing (i.e. living tissue vs. spool of filament), the host of applications goes beyond imagination. Human organs, replacement body parts, skin, implants, teeth, and eyes are just a few worth mentioning.

Wood Nature’s composite material is making a splash in the 3D printing world. Although wood filament is actually mostly polymers with a little wood fiber, it turns out that lignin, the natural glue in wood, works in binder jet systems to create 100% wood printed products. It even can have digital grain patterns and maintain isotropic material properties.

Rubber 3D printed rubber parts can replace molded rubber in most applications. Printed rubber parts require no molds or tooling, reducing cost and time to manufacture. Gaskets, hoses, seals, plugs, tires, grips, and many other products represent options for rubber uses. The most effective rubber-like materials for 3D printing include TPU and TPE, both thermoplastics.

Concrete Concrete can be printed by depositing cement-based materials from a gantry mounted nozzle (much like FDM on a large scale). 3D printing concrete promotes several benefits over using concrete in the traditional way (forming and casting). It is faster, cheaper, safer, and more efficient. It also reduces labor requirements and minimizes material waste. Additionally, as with other 3D printing methods, complex geometry is virtually equivalent in cost as simple geometry.

Food 3D printing food is a novel experiment that has yielded interesting and tantalizing results. Chocolate is the most popular material, but printed meats, pasta, and other foods are becoming common. Other highly viscous food items such as jelly, cheese, and mashed potatoes may be used as extrusion material. Edible sintered powders include sugar, chocolates, and protein powder. Printing food in space has been experimented with by NASA to improve shelf life and minimize need for refrigeration aboard the ISS. One food printing manufacturer predicts that in 10-15 years, 3D food printers will become a “common kitchen appliance.”

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Strangest 3D-Printed Objects

Zach Cabading | September 7, 2019

Let's discuss some of the weird objects that have been 3D printed. Some of these objects are actually quite useful. Others are not. But all of them are wonderfully weird. Here are 10 very bizarre things that have been crafted with 3D printers.

1. Mouse ovaries

Researchers at Northwestern University in Chicago created the first artificial mouse ovaries using a 3D printer. [1] Okay, so mouse ovaries aren't technically useless - they'd be very useful for any infertile mouse. But ovaries aren't the first thing you'd expect to be 3D printed, right?

The mouse ovaries were created by 3D printing layers of gelatin. Then they were surgically implanted in seven infertile mice. Of the seven mice that received implants, three mice successfully gave birth to litters of pups.

There are human implications to this discovery, of course. The researchers hope that someday, they'll be able to print artificial human ovaries for cancer patients and others who are infertile.

2. Food

Speaking of mice: researchers at University College, Cork in Ireland 3D-printed objects using cheese. [2] They filled a 3D printer nozzle with Easy Cheese and printed "cheesy" designs with it, including a small bear. The designs were mostly flat because aerosol cheese isn't the most stable printing substance.

There are other types of foods that have been 3D printed, too, one of the most famous being 3D printed chocolate. If you think that chocolate rabbits are neat, you should see some of the nifty chocolate designs that have been made with 3D printers. Chocolate makes for a great 3D printing substance because it can be layered while it's melted then easily hardened. There are several companies that sell 3D-printed chocolate, including chocolate behemoth Hershey. [3]

They've also 3D-printed pizza. A printer was equipped with three nozzles that dispensed liquid dough, tomato sauce and cheese. In under five minutes, the pizza dough was ready for baking. Researchers said they were able to accurately control the crispiness of the bread thanks to the 3D printer.
Here are some other cool foods that have been 3D-printed:

- Quiches
- Croutons
- Candies
- Cereal

So what's on the horizon for 3D-printed food? For one, restaurants and bakeries will be able to print large quantities of stylized foods and pastries. But the hope is that people will be able to prepare food in their own homes without having to cook. Very futuristic, indeed. "Computer...Tea. Earl Grey. Hot."

3. Skin

Researchers at the University of Toronto created a handheld 3D printer that could apply skin cells on a pig. The pig had its cells harvested, and the cells were grown to a larger quantity. Once researchers had enough cells, they used the cells as the printing substance. The 3D printer was rolled over the pig's wound "like a white-out tape dispenser." Success! The skin cells successfully attached to the open wound area. Scientists think that in the future, this technology could be used to replace skin grafts. It would make it much easier to treat victims with open wounds - especially burn victims. [4]

The science of printing living tissues is known as bioprinting. Researchers have printed:

- Artificial bone
- Artificial blood vessels
- Artificial bladders

Scientists are hoping they'll be able to finally end the long - and sometimes fatal - wait for organ transplants. [5]

4. Fashion

Textiles are notoriously difficult to print, but a company called Continuum Fashion has created a number of cool 3D-printed fashion items. Their standout fashion piece is the 3D-printed bikini. You can hit the beach and go swimming in style and comfort. Continuum printed the bikini using a material called Nylon 12, which is strong, flexible, and waterproof. The bikini has an awesome texture, too. It's composed entirely of interconnected beads, a testament to the intricate kinds of designs that can be printed. The company also produces a line of 3D-printed women's shoes. [6]

5. Mini Power Drill

You've got to see it to believe it. A man in New Zealand created the world's smallest power drill with a 3D printer. The drill measures 17 x 7.5 x 13 mm, and is equipped with a 0.5 mm drill bit. And it works! The drill is powered by a hearing aid battery and utilizes a miniature motor and headphone-cable wiring. [7]
Should we call this the world's smallest drill, or the world's cutest drill?

6. Microscopic race car

There's a bizarre creation courtesy of researchers at the Vienna University of Technology. They created a 3D printer that can create near-microscopic objects. To demonstrate its abilities, the researchers printed a tiny race car that's just about the width of a hair follicle. [8] It's not quite built to tackle the Monaco Grand Prix, but it would make a perfect vehicle for lice.

7. Wall-climbing robot

South Korean scientists used a 3D printer to build a robot that can climb walls. The robot mimics the movement of a gecko and is capable of climbing up vertical walls with the help of adhesion pads. The robot's body was 3D-printed using a material called Polyamide 12. [9]

Another cool robot was 3D-printed at the University of California, San Diego. This robot has three legs and can navigate rough terrain, like sand and rocks. 3D printing was integral in building the robot. In order to crawl over rough terrain, the robot needed to be constructed of softer, more flexible materials than what most robots are made of. The researchers were able to 3D-print the robot's soft and hard surfaces together. [10]

8. Unborn babies

Thanks to 3D printing, expectant parents can hold their baby before it pops out of the womb. A Russia-based company uses ultrasound scans to create a 3D-printed model of the unborn child. Umm… cute?
In actuality, the models aren't made to be baby shower gifts. They help doctors evaluate the health of the developing child. The models are a bit surreal. They're highly detailed and capture the smallest facial features of the unborn baby. [11] Imagine the comedic possibilities of using an unborn baby model at a gender reveal party.

9. Buildings

Buildings aren't strange (unless we're talking about some contemporary architecture). But constructing a building with a 3D printer is strange. How on earth can a 3D printer construct something so gigantic?
Concrete is the main substance that's used by a 3D printer to print a home. A crane lifts the printer nozzle above the ground and maneuvers the nozzle as it places layers of concrete. Some 3D printers can also layer insulation materials.

Most 3D-printed buildings don't adhere to building codes, so they're either built as temporary structures or they're built very small. But construction firms are optimistic that they'll be able to build more advanced structures as the technology progresses. [12]

10. 3D printer

That's right: a 3D printer has printed a 3D printer. [13] This is the most "meta" item on this list. You can't print a 3D printer in its entirety, but people have printed all of its individual parts, and then they've manually assembled them.

Honorable mention: light-created objects

Researchers at the University of California, Berkeley discovered how to 3D print solid objects out of liquid and light. The researchers used a gooey liquid that turns solid when exposed to a certain amount of light. They used light beams to sculpt solid figures within the liquid. The benefit of this technique is that it's easier to print bendable items. Objects printed in this way are also much smoother than those that are 3D-printed by traditional methods. [14]

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