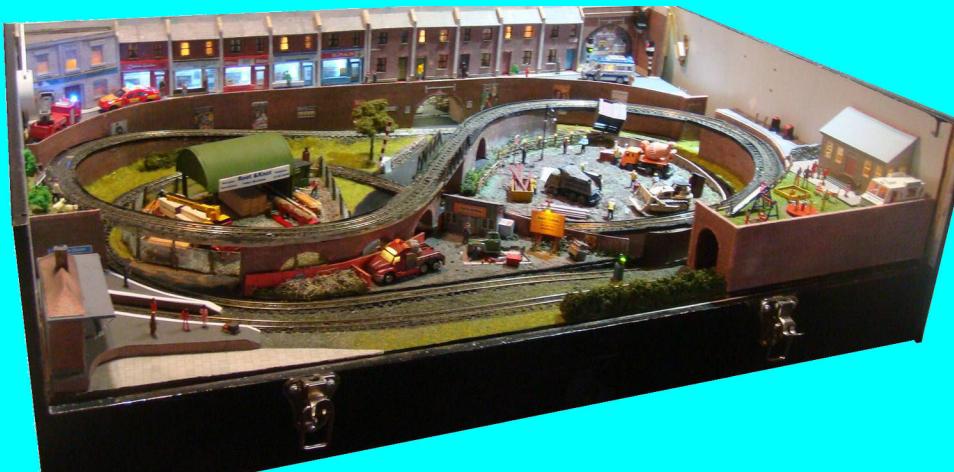


Electronics for Model Railways



Chapter 22

3D printing

By Davy Dick

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In memory of Margaret



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3D printing

3D printing offers a lot to electronics hobbyists and railway modellers.

This is the Oxford Dictionary definition:

The action or process of making a physical object from a three-dimensional digital model, typically by laying down many thin layers of a material in succession:

For the most common hobby printer, this means that a nozzle with a heated element moves around, gradually melting a roll of thin plastic filament on to a flat bed so the layers merge to eventually make a solid object.



Different printers can print with different materials, including metals or even chocolate but for modellers the most common materials are plastic or resin.

Why

Commercial companies produce lots of items that are useful for electronic or model railway use, so why go to the bother of using a 3D printer?

There are a number of reasons:

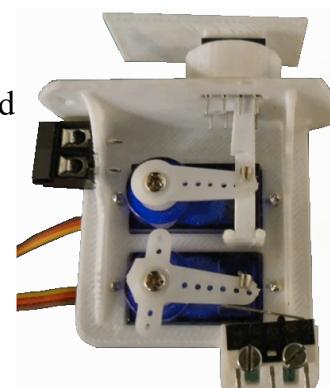
- Commercial companies only make things that sell in quantity, or return a profit. Less common, or unprofitable, items are ignored. 3D printers fill that gap.
- You can create your own products, such as mounts for servos that have unusual dimensions, longer servo horns such as that shown in the image (handy for animations, etc.), brackets for switches and power connectors – and much more.
- You can download plans from the Internet and print them out. Look at this interesting servo mount (opening/closing double door?).
- You can share design files with other users, or amend or improve on existing designs
- It can print shapes that are impossible with other methods.
- It can be used to repair items where a part is unavailable (that handle, cover or cam that snapped).



MERG already produces a range of 3D printed mounts for use with points, signals (single, double and quad arms) and level crossing gates.



The image on the left shows the point servo mount in use, while the image on the right shows an assembled dual semaphore arm mount.



What

There are two methods of 3D printing that are used by modellers.

- FDM – Fused Deposition Modeling
- SLA – Stereo Lithographic Additive

This chapter looks at both.

There are many other printing technologies and you can find a comparison of them at:

<https://penandplastic.com/3d-printer-types/>

The basic shopping list is:

- A 3D Printer (sold in kit form or as assembled units).
- Filament (sold in reels or coils of different material, thickness and colour) or a bottle of resin.
- File of the model to print (download from the Internet or create your own using free or commercial 3D modelling software).
- Software to prepare files for printing and send them to the printer.

FDM printers

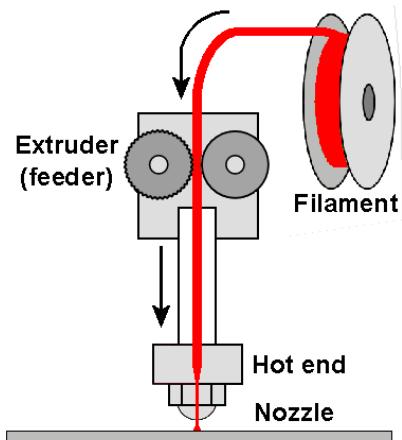
These are the most commonly used type of printer among hobbyists and they vary in print size, resolution, speed, price, etc.

The two types used by hobbyists are called the '*Cartesian*' and '*Delta*' printers. They have different methods of movement but both use the same printing technique shown in the diagram.

The plastic filament is gripped by motor-controlled feeder rollers known as the '*extruder*'. As the motor turns, the filament is fed down to the '*effector*' – the part that is moved up and down. A heating element (the '*hot end*') is attached to the effector and this liquefies the plastic before it is squeezed through a small nozzle on to the surface below (the '*print bed*').

Confusingly, some texts refer to the hot end or to the whole moving effector/hot end/nozzle assembly as the extruder.

Although the extrusion method is similar in both printers types, they move the effector around using different techniques.

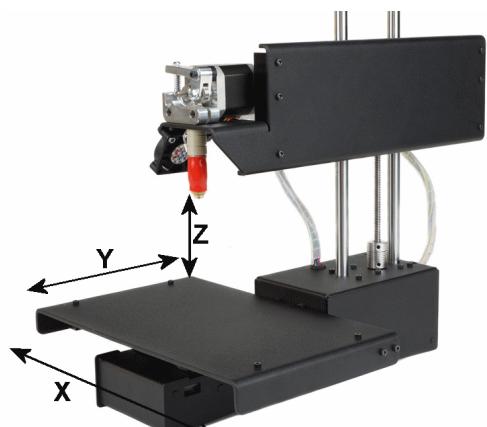


Cartesian printers

These printers are the most common and they use stepper motors to move the effector on the Z axis (up and down) and move the print bed on its X axis (left and right) and Y axis (forward and backward).

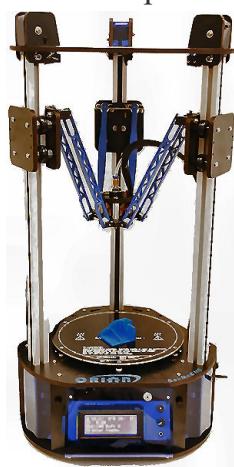
This means that the hot end can cover a square or a rectangular area.

The effector can be moved on any one axis without having to change the position of any other axis.



Delta printers

The delta printer has three vertical rails and the effector is attached to them with three arms (hence the description '*Delta*').



These arms can be moved up and down the rails independent of each other, usually by belts driven by stepper motors. However, the arms are moved in unison to cover the entire print area.

The print bed does not move, only the effector moves.

The effector still moves in the X, Y and Z planes but it always stays parallel to the print bed.

Their design results in less weight and reduced friction compared to Cartesian printers. This, combined with their ability to move diagonally directly between two points, means that they are often faster than Cartesian printers.

They usually have a circular print bed and have tall side rails, so the maximum print job is cylindrical in shape. They are usually capable of taller print jobs and occupy less desk space.

Filament

The raw material used for the extrusion process is known as the filament and a range of materials are used. The large commercial printers can work with steel, brass, bronze, gold, silver, platinum, ceramic, etc. The printers at the hobby end of the market usually work with thermoplastic filaments, the most common being ABS (Acrylonitrile butadiene styrene) and PLA (Polylactic acid or polylactide).



They mostly come in reels, although some are in coils or in special cartridges, depending on the printer. The plastic can be clear (windows?), or in a range of colours,

The most common filament is 1.75mm thick or 3mm thick (mostly actually 2.85mm). Although they sound quite thick, if you look at the illustration on the previous page you will see that after the filament is melted it is forced through a nozzle with a much smaller diameter (anywhere from 1.2mm down 0.2mm, most being around 0.4mm).

ABS or PLA?

Each has its own strengths, weaknesses, and special printing requirements and these are compared next.

Composition

ABS is a petroleum based plastic. It is not biodegradable but it is easier to recycle and there are even gadgets to produce new filament from waste filament, discarded projects, etc. (Google Recyclebot or FilaStruder). When extruded, it gives off an unpleasant 'hot plastic' odour and printers should use vented enclosures and extractors to minimise this effect. There is also a debate as to whether ABS should be used to make products that will come into contact with food.

PLA is plant based, being made from renewable resources such as starch from corn,

wheat, sugar cane and beets. As such, it is biodegradable and is regarded as the 'greener' of the two types. It produces less fumes and gives off a more pleasant smell when extruded (like a sweetish cooking oil).

Temperature and quality

Printers without a heated bed (see later) can only print using PLA filament, while heated bed models can print using both PLA and ABS. ABS and PLA have different temperature characteristics and this affects how they are processed and used.

ABS extrudes at around 225°C and re-melts at a higher temperature than PLA. This makes ABS a good choice for products that may be used in a hot environment.

Print failures can result from the extruded filament cooling too quickly or too slowly. If ABS filament cools too quickly, it can result in shrinking, cracking, delamination or warping. This is more likely when printing large parts.

To prevent this, the job is made to cool slowly after extrusion – hence the use of a heated print bed.

PLA has a lower melting point and prints at a lower temperature than ABS. It extrudes at around 180-200°C but can be operated at up to 230°C. There is a danger that the heat from the hot end travels up the effector and melts the filament prematurely, causing jamming. To prevent this, a fan can keep the filament from softening prematurely.

Since PLA retains heat, the fan can be used to cool the PLA as it extrudes and this minimises curling at corners and at overhangs and so the prints are less prone to warping than ABS.

The lower melting point makes it unsuitable for prints that will be used in a hot environment as it may result in drooping.

Rigidity

Both ABS and PLA have approximately the same degree of strength.

ABS has greater flexibility and this helps when making parts that will be interlocked. Some larger jobs are built up from several individual prints which are slotted or plugged together (think Lego). The slight give of ABS is an advantage here (ABS bends before it breaks). ABS is also more resistant to damage through impact. The disadvantage of ABS prints is that they wear more quickly when subjected to friction (gears, sliding mechanisms, etc.).

PLA is the best choice where rigidity is important (e.g. frames) but it is more brittle than ABS. Its lower melting point has to be considered when a printed job may be subjected to excessive heat. On the other hand, the lower melting point means that PLA parts can be softened in boiling water and then re-shaped.

Finish

The finish of the final print depends on a number of factors such as the nozzle width (how fine is the extruded plastic), the height of each layer and the quality of the filament used.

The layer resolution is usually measured in microns (millionths of a metre).

Most printers offer a range of quality options and they are a trade-off between quality and speed. Higher resolutions mean more layers which mean longer print times.

The speed of the mechanism and the extrude rate of the filament also influences the final print time.

Printers may offer '*Fine*', '*Medium*' and '*Fast*' print options, or perhaps a '*Draft*'

option. The MakerBot Replicator offers layer resolutions of 100 microns, 200 microns and 300 microns, while the Ultimaker 2 can print as low as 20 microns (0.02mm). Thicker layers have a faster print time but it is easier to notice the ridges of the individual layers of the object.

ABS has a slightly smoother finish than PLA. It can be sawn, drilled and sanded and ABS parts can be glued together with ABS glue, SuperGlue, acetone or MEK. You can even weld parts together with your own home-brewed ABS glue, made by dissolving ABS leftovers into acetone. When applied, the acetone dissolves and the ABS hardens and produces a strong bond.

An ABS part can be exposed to acetone vapour, either hot or cold, and this will smooth out the part's surface (being careful not to lose detail).

PLA has a glossier look than ABS and can also be sanded and glued with adhesives such as Super Glue and 2-Pack Epoxy.

Spraying the part with 'high build' primer spray paint also improves the surface. Both types can be painted with acrylics.

Other filament options

PLA and ABS are available in a range of colours.

PLA that is mixed with other materials is also available. They still come on filament reels but provide a new look to the finished object.

- Wood effect PLA (a mix of PLA and recycled wood fibres)
- Stone Effect PLA (a mix using ground chalk)
- Metal effect PLA (a mix with metallic powders such as brass, bronze, copper, etc.)

The finished objects have the appearance of wood, sandstone or metal.

Other mixes provide different properties

- Magnetic PLA (a mix with powdered iron)
- Conductive PLA (a mix with conductive carbon)
- Glow-in-the-dark PLA (a mix with phosphorescent material)
- Carbon fibre PLA

Filaments are also available that use different materials from PLA or ABS

Nylon

This filament is stronger, more flexible and more durable than ABS and PLA, although more expensive.

PETG

This filament is more flexible and durable than PLA and easier to print than ABS.

A comprehensive look at the options can be found at:

<https://3dinsider.com/3d-printing-materials/>

<https://all3dp.com/1/3d-printer-filament-types-3d-printing-3d-filament/>

Note

Some of these filaments contain additives that are abrasive and can quickly wear out nozzles, specially those made from brass. As the nozzle gets progressively worn, its diameter increases and changes the properties of the final object.

Print beds

The print bed is the plate on to which the plastic is extruded and on which the final object is built. The bed is manufactured in a number of materials including Plexiglass (acrylic), aluminium and glass.

The surface of the bed has to be as flat as possible. When working with layers that are only microns thick, even small variations across the surface of the bed can ruin a print. To minimise this problem, a process of '*levelling*' takes place. This may be automatic or manual, or a combination of both. Software is used to probe the height of the bed surface compared to the tip of the nozzle at different points and then adjust the print job to compensate for any unevenness. This setup routine also determines the height of the tiny gap needed between the print nozzle and the bed surface.

The initial layers of the filament have to stick to the print bed during the print process to prevent the job from being ruined. After the job is complete, it has to be easily removed from the bed.

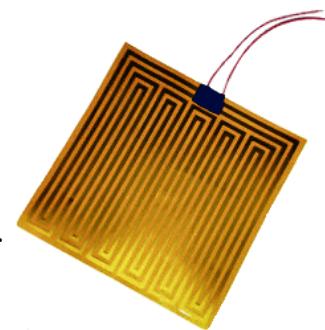
There are two approaches and these can both be used together.

- Heat the bed to prevent the outer edges of plastic from cooling quicker than the inner section, minimising warping at the edges.
- Coat the bed surface to help the initial layers to adhere to the bed.

Heated beds

3D printers may have a heated bed. This is usually a glass sheet over a heating element with the temperature set for best results with the filament being used. Since ABS shrinks more than PLA during cooling, a heated bed is a requirement for printing in ABS.

For ABS, this is between 100-100°C and 50-60°C if used with PLA. PLA does not strictly require a heated bed but can benefit from one for larger prints as it minimises 'warping' and 'curling' of the edges as the print cools.



Bed coatings

To keep the print job from moving during printing, a variety of techniques has evolved. A heated bed helps make the initial layers of filament adhere to the plate but this is usually enhanced with a coating on the bed. Blue painter's tape can be laid in adjoining strips on

the bed surface, taking care to avoid gaps between strips or strips overlapping. It is similar to normal masking tape and its slightly textured surface (see the image) helps improve adhesion.



Others use Kapton (polyimide) tape (see image) which is very heat resistant, or a sheet of Ultem PEI Polyetherimide, or BuildTak. MakerWare uses 'helper discs' which are removed after printing.



Other aids to adhesion include spraying the bed with hair spray or applying a coating from a craft glue stick such as UHU or Pritt Stick. All these methods have their adherents and some techniques can be combined.

Resin printing

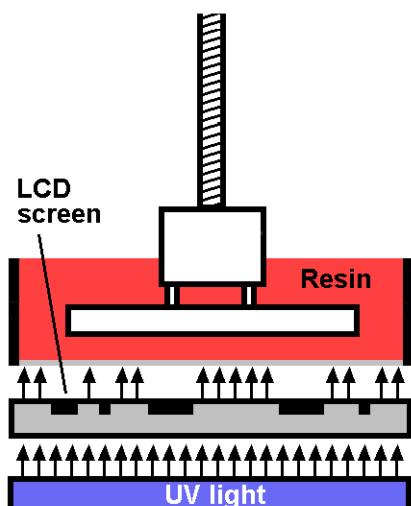
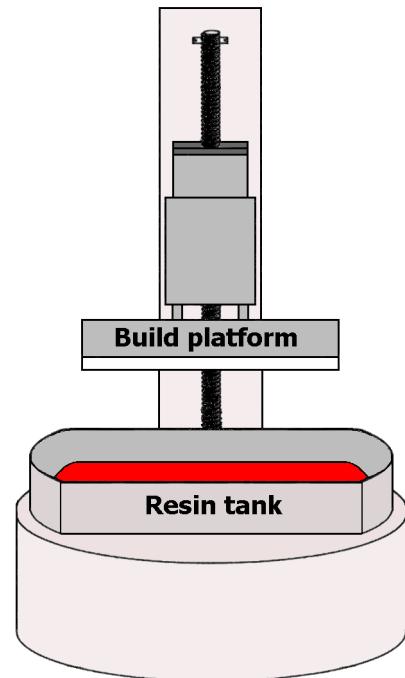
FDM printed an object one layer at a time by moving its nozzle over every spot on the layer that required filament to be deposited. The printer only moved on to the next layer when the layer total nozzle movement for a complete layer was completed.

Resin printers also print one layer at a time. However, there is no nozzle to move. Its construction is much simpler yet it prints a complete layer at a time, in a process known as SLA (stereolithography apparatus).

The illustration shows a typical budget resin printer (from SparkMaker). This printer is only 275mm x 170mm but can print an object that is 98mm x 55mm x 125mm.

A tank stores a quantity of liquid photosensitive resin. A single stepper motor moves a build platform vertically in and out of the resin.

The resin tank has a clear base consisting of a membrane of FEP (Fluorinated ethylene propylene).



Under the membrane is an LCD screen and below that is a source of UV light. The light passes through the LCD screen and the FEP screen and hits the liquid photosensitive resin. On the areas where the LCD passes UV light, the resin is hardened, while the dark areas of the screen block the UV and have no effect on the resin above it.

In FDM, an object to be printed is broken down into a list of movements of the stepper motors and of the filament extruder.

In SLA, an object is broken down into a series of black and white images, each image being a separate slice of the final object.

To print with an SLA printer the process is;

- Lower the build platform into the resin, leaving only the clearance of a single layer. The resin between the platform and the tank membrane provides the material for the first layer.
- Illuminate the LCD for the first layer, displaying all the layer image at the same time. The resin is cured in the illuminated areas, forming a solid layer.
- After a short period, raise the platform out of the resin.
- After a short period, lower the platform again until it is two layers clear from the bottom of the tank. The resin flows between the first solid layer and the membrane.
- Illuminate the LCD for the second layer.
- And so on until the last layer.

The leftover resin left untouched in the tank can be reused.

This type of printer is known as a '*bottom up*' model since the light source points upwards. The other type is the '*top-down*' model as the light source is above the platform and resin tank.

The quality of the final print depends on the resolution of the LCD screen.

The one described is available with resolutions of 854 x 480 pixels or 1920×1080 pixels and a minimum 0.02mm Z layer thickness.

Post-Processing

With FDM, .the printed object may be usable as soon as it is printed. Other objects may need to have their support structures removed, while some users may go on to smooth surfaces.

With SLA, you still have to remove any support structure but there are extra steps to be taken.

When the print is finished, the build platform rises out of the resin. At this point, the object can be removed from the platform. The object may still have uncured resin around it and this is washed off in a container of IPA (isopropyl alcohol) before being rinsed in water. The resin takes some time to fully cure. It can be left to cure slowly (in a sunlit window preferably) or it can be placed in UV curing station.

How - the software

Various software programs are used to create a 3D print.

The stages are:

- Fetch or create the design you want to print.
- Turn the design into a file that describes the layers that will make up the final object.
- Send the processed file to the 3D printer.
- Wait while the printer uses the code in the file to control the printer's operations.

Download a design

Before going to the trouble of learning a design package, you might want to download a design that has been created by someone else. Downloading is a good way to get started with 3D printing, as it allows you to get familiar with the printer and its software before having to grapple with design software. There are a growing number of websites that offer designs of all sorts, including those for model railways. Some designs are free to download while others can be purchased.

Popular sites include:

www.thingiverse.com
www.youmagine.com
<https://3dwarehouse.sketchup.com/?hl=en>

Look at this website for links to sixty websites that offer free 3D model files.

www.hongkiat.com/blog/60-excellent-free-3d-model-websites/

Creating your own

Although a range of designs can be downloaded, you will probably find the need for items that are not already available. To work with designs you will need a 3D design application. You have the option to create a design from scratch or to alter an existing design. Tweaking an existing design might be a good way to start, while you get to grips with the design software options.

3D software is available in two varieties.

- Those that you download from the Internet and install on your computer. Such packages include SketchUp, Blender, Design Spark Mechanical and 3DCrafter.
- Those that are '*browser-based*' – they work directly in your browser, while you are connected to the Internet. They do not require to be installed on your computer. Examples include Tinkercad, openSCAD, 3DTin, Onshape and Shapesmith.

Most are free to install/use, including Shapesmith, Onshape, OpenSCAD, Tinkercad, Autodesk 123Design, Blender and Design Spark Mechanical. 3DTin is free to use but you must agree to share your finished creation.

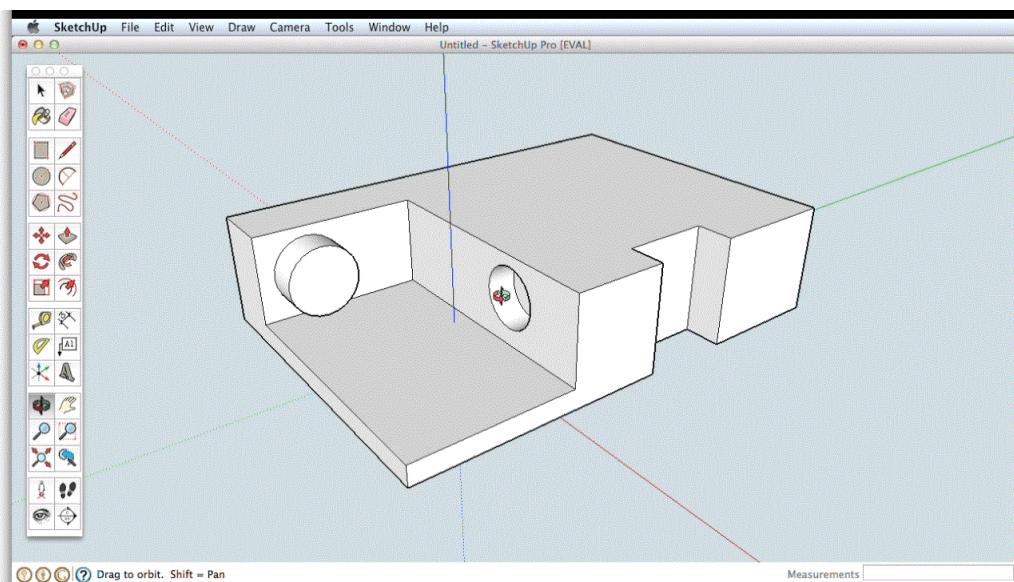
The basic 3DCrafter is free to use but does not allow you to save in a file type that 3D printers use. It is fine to practice with but you have to purchase the Pro version if you want to save in standard 3D printer file formats.

When considering which package to use, it is best to consider the size of the user base, how much documentation and tutorials are available, whether there is a support group, etc. SketchUp seems to be a favourite with hobbyists.

Design techniques

There are two approaches to 3D design. The most commonly used software packages use the '*visual*' method. The user draws on the computer screen with a mouse, maybe using drag-and-drop to pull some pre-designed objects on to the screen.

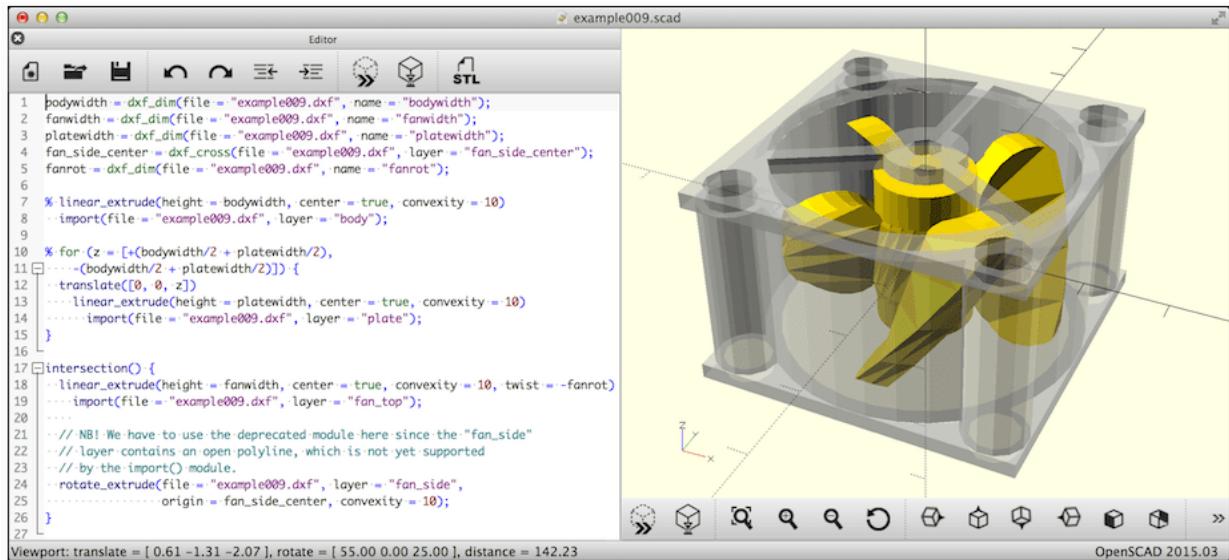
The illustration shows a SketchUp screen.



After the initial learning curve, they look and feel like many other drawing packages and are

relatively easy to use. While useful for most designs, they are difficult to accurately line up with exact spacing for very complex and intricate designs such as gears or fine interlocks.

The other approach is designed to minimise discrepancies with fine and intricate designs. It is called the '*parametric*' approach and this illustration shows it being used by the OpenSCAD program.



In the left panel, the user numerically describes the shapes to be used, similar to a programming language. The right panel then shows the visual representation of the entered script; the right hand panel cannot be edited using a mouse.

The Shapesmith application uses a blend of visual and parametric techniques.

Scan an object

If you don't fancy learning a 3D design package, or you want an object that is too intricate to design (e.g. your own face), you could consider using scanning an object to create a design file. The image shows the Fuel 3D Scanify which is marketed as a

"high-speed, high resolution, handheld 3D scanner that allows you to quickly and easily capture 3D models of everyday objects for 3D printing or on-screen applications."

It can output to industry standard STL or OBJ files (see below).

An alternative is to use Autodesk 123D Catch, which is software that converts a series of photos taken with a camera into a 3D object.



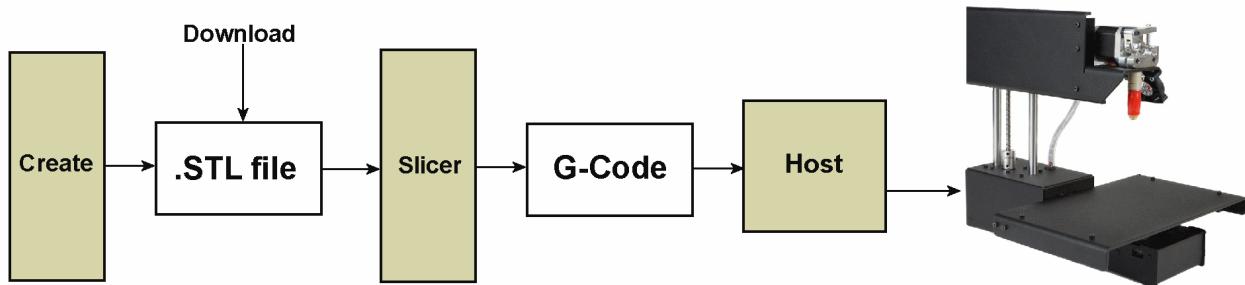
The design file

When you have finished designing the object, the file is saved for further processing. Most 3D printers can process a range of different file types. The most common file type is the STL (Standard Tessellation Language, sometimes also called STereoLithography) which defines the object as triangulated surfaces and vertices. So, a file called servomount.stl might be such a file. The .stl format has become the standard that all design packages can export and all 3D printers can use.

Another common file type is the .obj and others include .3ds, .dae, .iges, .obj, .max, .ztl, .ply

Design Stages

This diagram shows the steps.



The .stl file is shown as being either downloaded or created in your design software. The file stores the details of the overall design shape but the printer prints one layer at a time and needs to know what to do in each individual layer (e.g. where to move the print head). Therefore the design has to be converted into a set of instructions for each layer to be printed. This process is known as '*slicing*' as it slices the model into a set of layers. Each layer is translated into '*G-Code*' which is specific to the 3D printer being used.

An example line of g-code might be:

`G1 X0.0 Y0.0 Z0.0`

Apart from moving the hot end, the code could contain instructions about the head temperature, the feed rate, etc.

The slicer software packages Cura and Repetier Host are free and Slic3r is donationware.

The computer then sends the g-code instructions to the printer and the software that does this is called the '*host*' or '*client*' software. It acts as the interface between the g-code and the printer and allows tweaking of the printer settings such as the axes positions and temperature of the heated bed or the hot end.

ProntoInterface is free while Simplify3D is commercial. Simplify3D and Afinia combine the functions of slicer and host.

The final chunk of program is embedded inside the printer. This controller software receives the g-code from the computer and controls the printer's physical activities. The code is stored as '*firmware*' which means that it can be updated if and when necessary.

Printer settings

If you buy a 3D printer as a kit, you have a lot of adjustments to make prior to using it for the first time. If you buy a ready-built printer it should work out of the box but will still benefit from adjustments. These are:

The printer's physical adjustments

This includes important settings such as the clearance between the hot end and the print bed. Since printing is measured in microns, small adjustments can make a big difference, with even changes in temperature and moving the printer from place to place producing unwanted alterations.

Tweaking the host and slicer software

This is required to get the best quality print with the least amount of filament.

Although many settings are pre-programmed, changing the defaults lets you fine tune the particular printer in use.

The main settings for a print job include:

Infill – Some objects will be made from solid plastic to ensure rigidity (e.g. brackets) requiring a 100% infill, while others can have their inner made from a honeycomb

structure to save plastic.

Rafts and supports – The printer lays initial layers on to the print bed and builds up from there. Although it can build a layer slightly outwards or inwards from the previous layer, it is not able to print in thin air. The software can decide if it should include a supporting web that temporarily supports any protrusions that would otherwise sag; the web is removed after the job is printed.

Object scaling – If an object shrinks a little while cooling down, you will lose the required dimension set out in the design. To compensate, you can scale the object up (e.g. to 103%) before starting the print.

Conclusions

3D printers have a lot to offer. Their performance is continually improving and prices are dropping. Like all technology, you can wait for even more progress or decide to put a toe in the water.

3D printing is not without its problems. Be prepared for failed prints, regularly changing the print bed surface with Blue Painters tape or Kapton, filament jamming, hot end cleaning or unblocking, and maintaining bed levelling.

However, with a bit of perseverance with the hardware and the software, you can make your own items that are not commercially available. The only limit is your imagination – and the depth of your pocket.

Finally, if you like the idea of 3D printing but can't afford a printer, you can buy ready made items from Shapeways.

If you decide to design your own objects you can still avoid the cost and fuss of a 3D printer by sending the design away to be printed (e.g. Shapeways or 3DPrintUK). Or you may use a cheap 3D printer to check on your progress as you refine your design, before sending the design off for printing on a professional printer.

Have a look at the 3D Wiki on the MERG web site.

It contains many tips, tutorial videos and a large selection of files for printing electronic and railway parts.