# A Short Illustrated Guide to 3D Printing

*By Benjamin Maclaren*

# Introduction

## This Book

This guide was written for anyone with an interest in 3D Printing,it is intended to be a well rounded easy to understand guide with no prior knowledge necessary for the reader.  Catering teenages, adults any english literate species.

I hope you enjoy the pages to come as much as I enjoyed making them.

## About the Author

My name is Ben Maclaren and I wrote and illustrated this book.

I was first introduced to 3D Printing through a variety of forums and technology movements back in 2010, since then I spent years researching and watching the 3D Printing movement start to bloom into the widely spread and innovative presence that exists today.

In the late 2015 I started a 3D Printing business called 3DForge that mainly offered 3D Printing and design services to the Canberra Region in Australia.

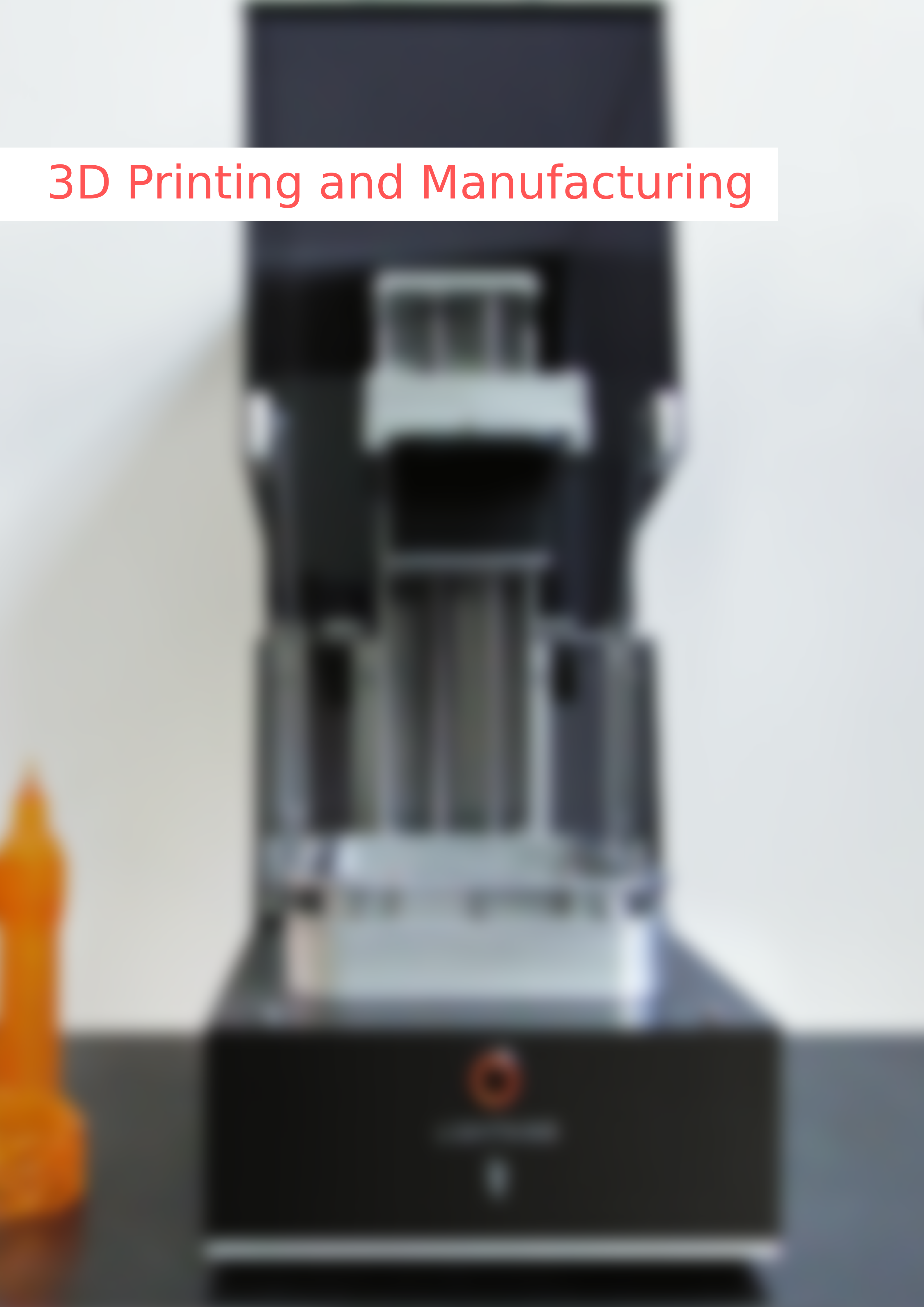
My business mainly involves digitial design and prototyping as well as engaging in side projects including designs of new 3D Printing  Machines, Software Development, Teaching and Technology Consultancy work.

If by chance you need to contact me whether for questions or jobs you can email me at hello@3dforge.design or through my blog at curiosityplace.wordpress.com

Without further ado, let's begin.

# Table of Contents

# 3D Printing and Manufacturing



# Traditional Manufacturing

Traditional Manufacturing in this book refers to the  processes that are expected to be rendered obsolete by additive manufacturing.

These processes took us from the stone age to our current modern era and typically required a vast amount of manual skill and experience.

As time and technology progress, a lot of these processes are being replaced by automated robotics, additive manufacturing and similiar processes.

## Manufacturing Processes

### Casting

Liquid material (Often molten metal) is poured into a shaped mold, the liquid solidifies into a solid object.

### Coating

A image is coated onto a material, common examples include printing on paper and painting.

### Forming

Forming is simply changing the shape of a material, think bending a spoon or a blacksmith hammering metal.

### Joining

Joining does as its name implies, joins materials together in some way shape or form. Nailing wood together, welding metal, glueing and soldering are all examples of joining manufacturing.

# Subtractive Manufacturing

Once known as Machining and now called Subtractive Manufacturing (SM) SM means any process where a piece of raw material is cut into a shape and size by a controlled material removal process.

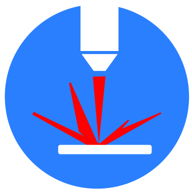
An easy example of subtractive manufacturing is the art of whittling; using a knife you remove shaves of wood from a block or stick in order to carve a shape or item.

## Advanced Machining

With the rise in robotics, traditional styles of manufacturing are automated resulting in computer controlled machines like CNC Mills, Laser, Plasma and Waterjet cutters.

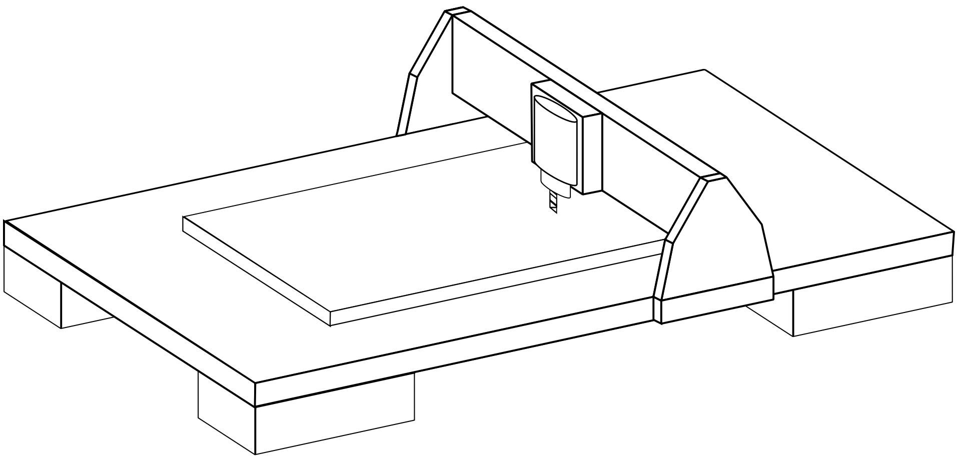
CNC Milling

Turning
& Lathing



Laser Cutting

Replacing humans with robots drastically increased safety, accuracy and production capacity as it enabled working with dangerous chemicals,pressures and methods that previously would have been to harmful for humans to use.



The CNC Mill, one of the main and most versatile Subtractive Manufacturing machine,s

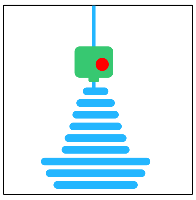
# Additive Manufacturing (AM)

- AM more commonly known as 3D Printing is the process of building an object by the addition of material to space, without

- The topics in this book are about mainly FDM, SLA and SLS. FDM is the main common desktop 3D Printer and the one you are most likely to encounter.

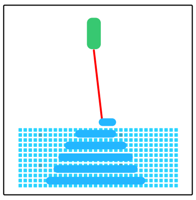
## 3D Printing Types

### Fused Deposition Modelling (FDM)



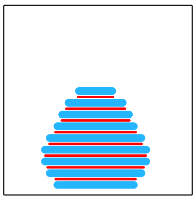
Long strands of filament are melted and extruded out of a nozzle, similiar to how a hot glue gun works.

### Selective Laser Sintering (SLS)



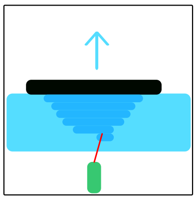
A bed of powder material like nylon or titanium is formed for each layer as a laser melts and fuses the parts of the powder together into the shape of a solid.

### Laminated Object Manufacturing (LOM)

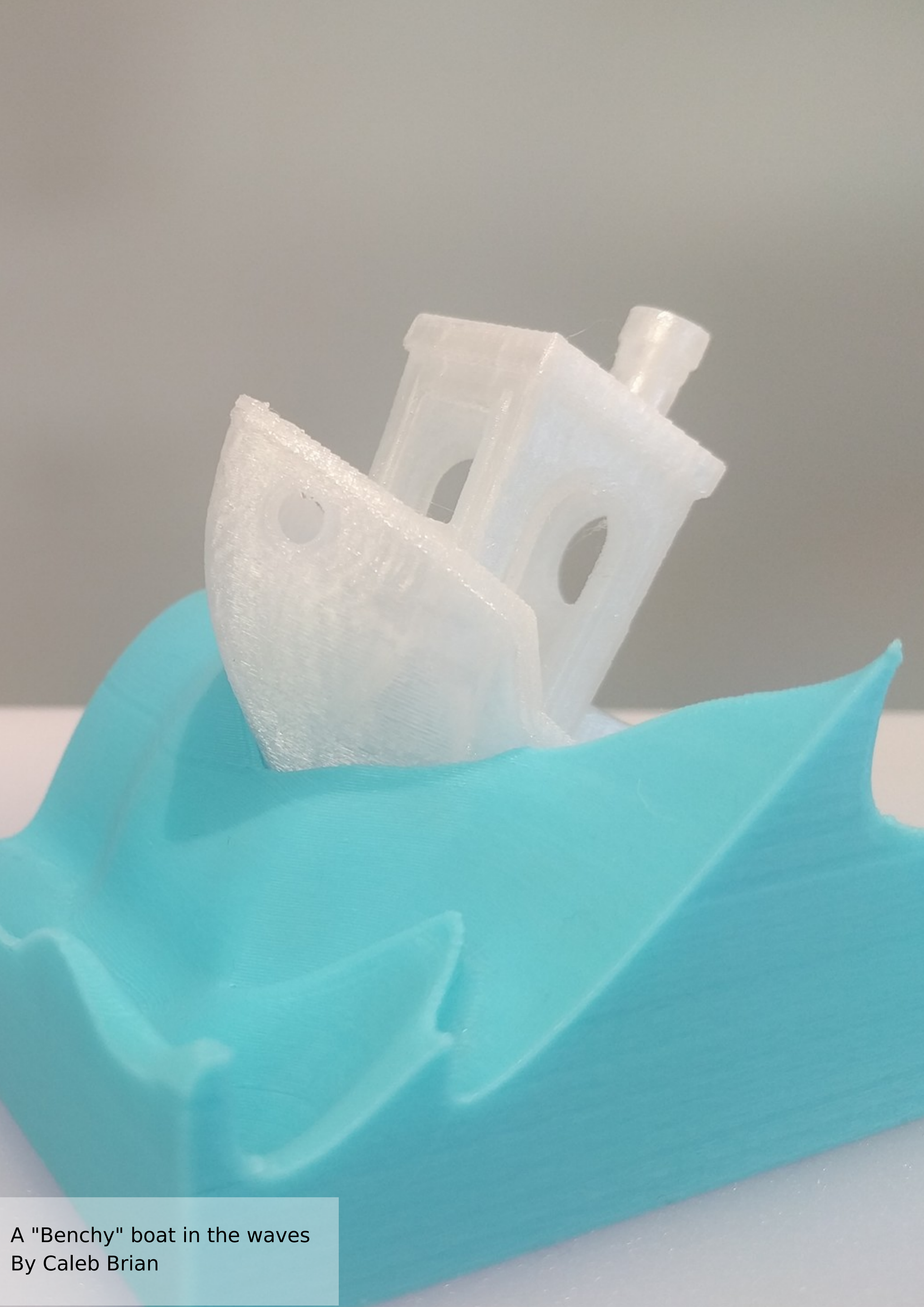


Individual Layers are cut out of a film or sheet of material and bonded together with a form of joining.

### Stereolithography (SLA)

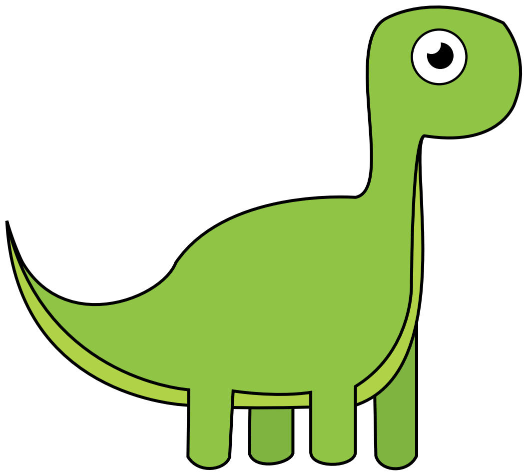


A laser shines on select areas against a platform in a bath of photsensitive resin, the liquid reacts with the laser hardening into a solid, this is repeated layer by layer.

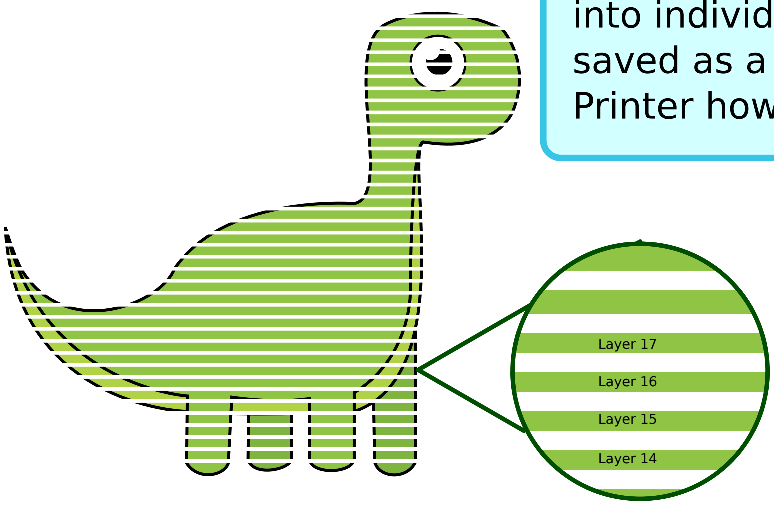


A "Benchy" boat in the waves
By Caleb Brian

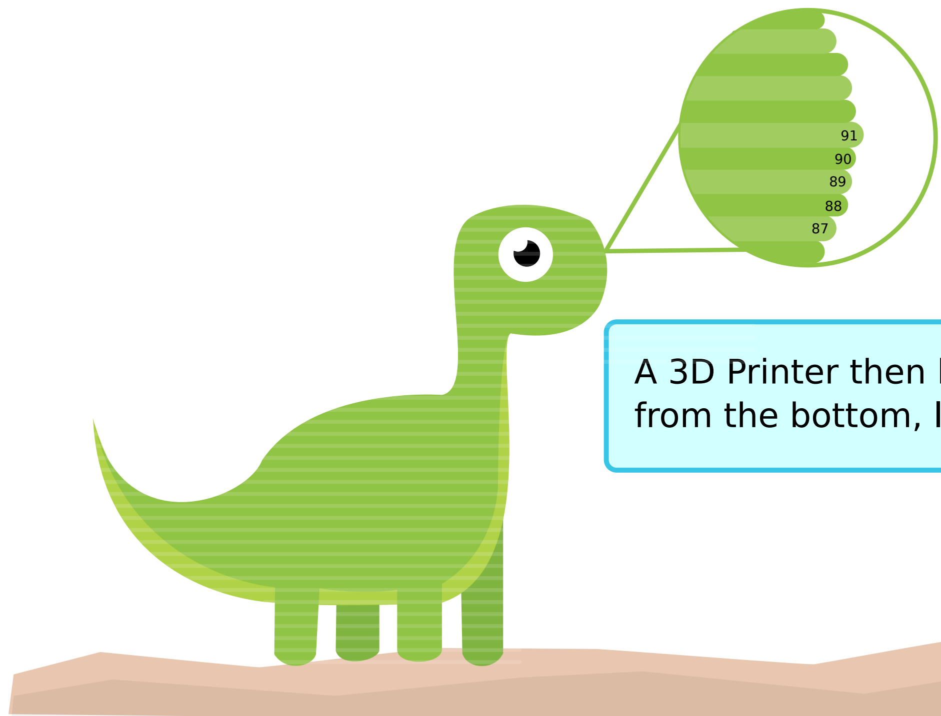
# How 3D Printing Works



A virtual representation of the shape of an object is made using a 3D modelling program. The result is a 3D Model.



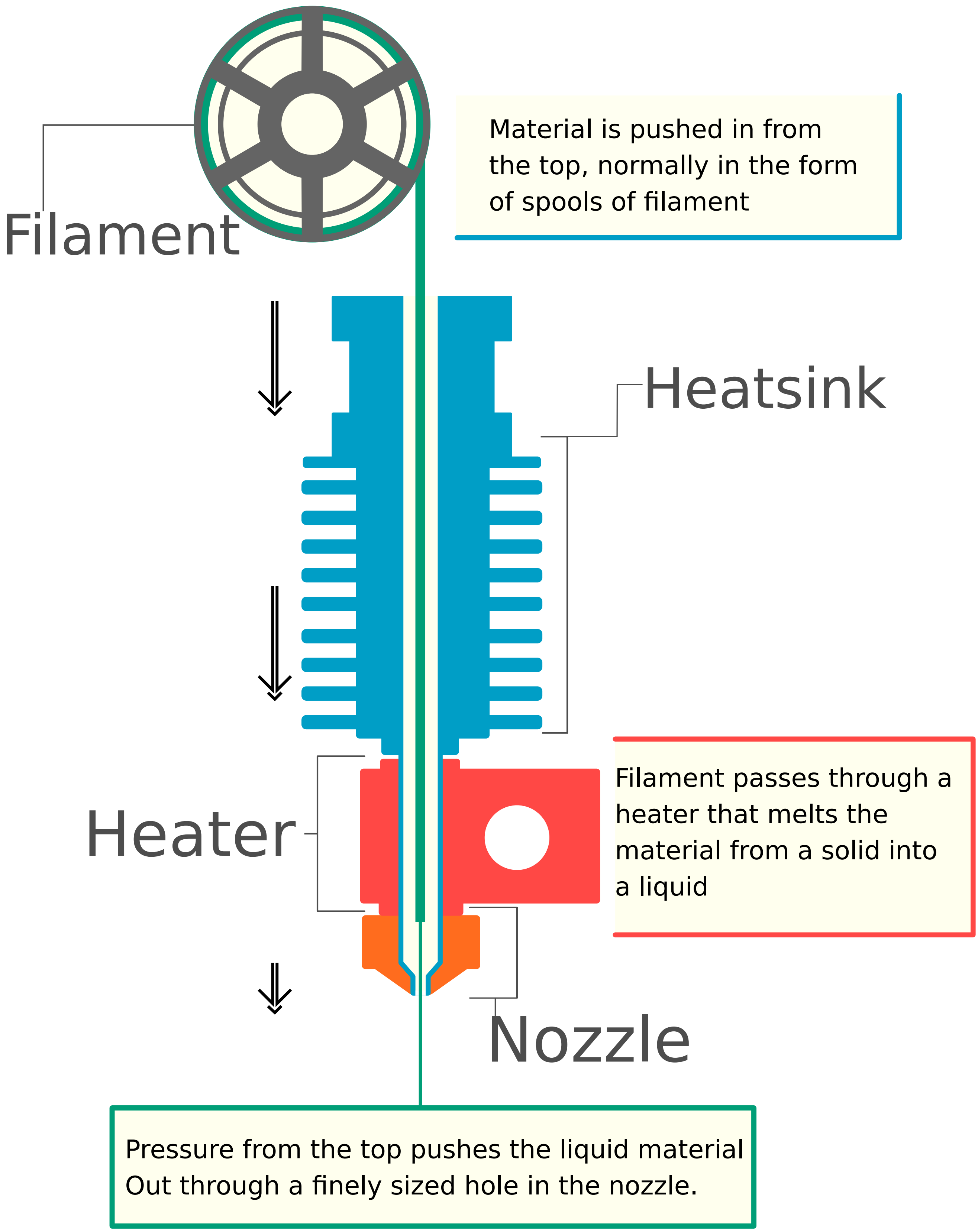

A program called a slicer cuts the 3D model into individual layers or "slices", this is then saved as a "G-Code" file. This file tells the 3D Printer how to build the model.




A 3D Printer then builds the object starting from the bottom, layer by layer

# The Extruder

The heart of a modern 3D Printer is the extruder,it is responsible for controlling the heat, cooling and flow of the plastic as we build up a object.

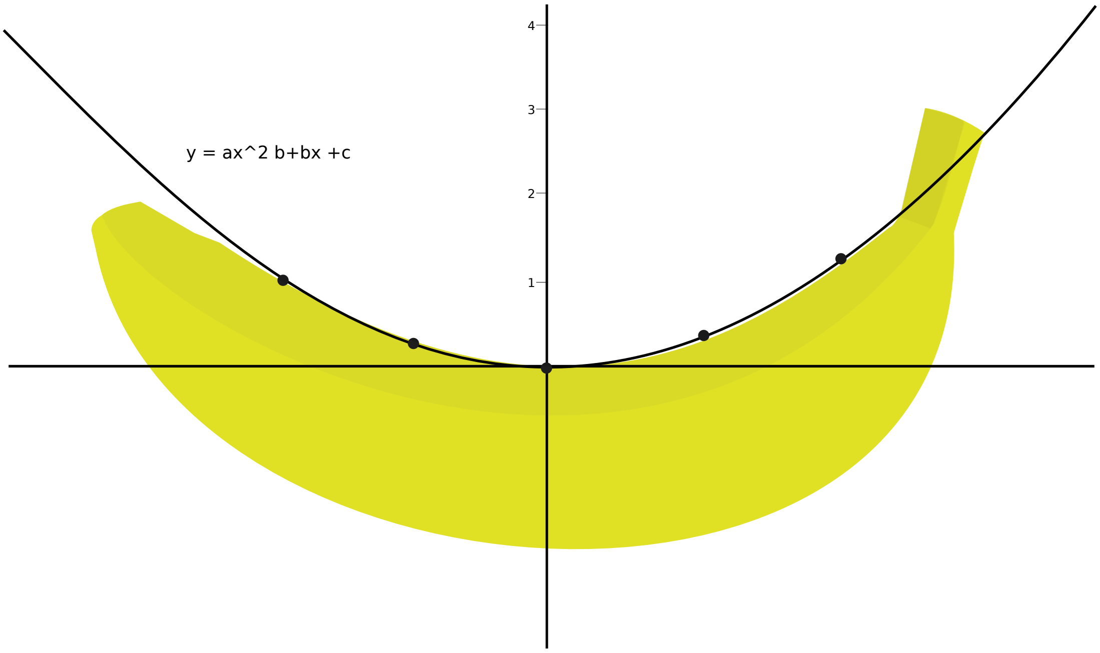


# 3D Modelling

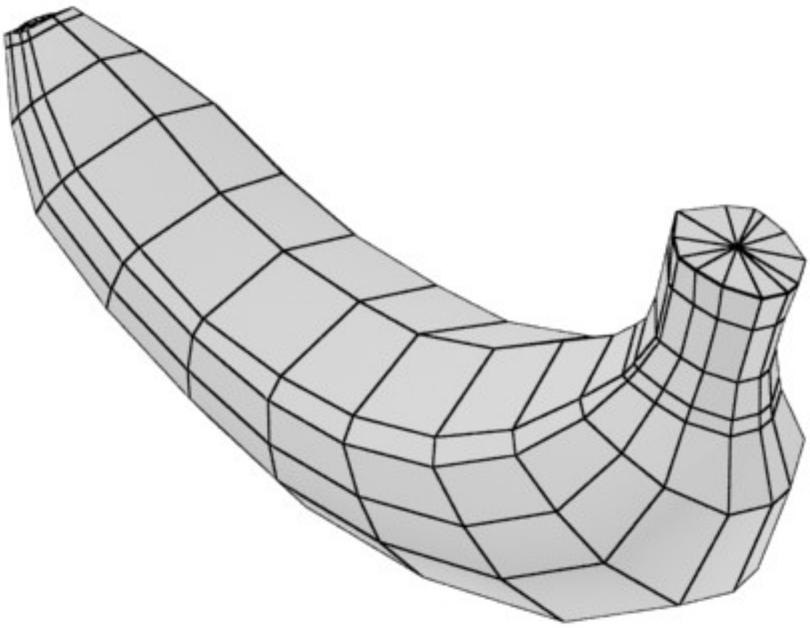
We can represent lines, dots and curves using maths, from these we can make shapes.

When you combine enough shapes together you can describe the shape of an object in 2D or 3D.

## Math Formula for a Banana




To create a real object, we first need a blueprint to tell us what the object looks like. A 3D Model is a digital file that mathematically describes an object's shape.



# 3D Modelling Design Principles

When creating a model for 3D Printing , we are building a blueprint for a real world object so there are a number of things to consider to ensure that our 3D Model accurately represents how a real object is build and shaped.

## Non-Manifold

Manifold means a closed surface, in our case with 3D Modelling a non manifold object means it has a surface that cannot physically exist.

The most common examples are a a models walls not having any thickness. In life every object has some measure of thickness to it whether it be 1 atom thick or millions.

**Rule/Points:**

All surfaces in a 3D Model must have a realistic thickness just like real world objects.
A common rule of thumb is a minimium wall thickness of 0.4mm.

## Bridging

Bridging is how well a 3D Printer is able to print across open gaps without support structures or defects.

A printers capability for bridging is mainly effected by cooling, layer heights and print speed.

**Rule/Points:**

Always check with your printer admin on a 3D Printers bridging capabilities.

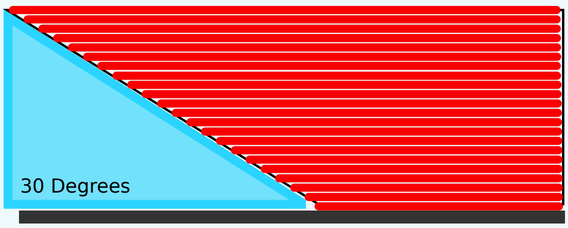
Printers with "active cooling" (a cooling fan around the nozzle of a printer), improves bridging capability as it cools down the plastic faster resulting in less time in a liquid like form.

# Supports

Plastic extruded from a nozzle is still hot and behaves like a liquid, because of this we need some kind of structure to support the molten plastic as it cools and transitions from a liquid to a solid so that it doesn't sag or deform under gravity.

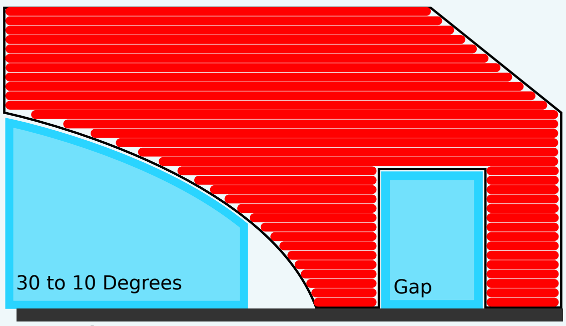

Doesnt Needs Support

When printing an objects the layer below of the printers build plate supports the plastic as it prints.




Needs Support

At a section on a model, angles smaller than 45 degrees the layers are too steep for the plastic to be able to support itself.




Needs Support

To fix this and ensure a good quality print we use support structures to provide a surface for parts of a model that need supporting.

**Rule/Points:**

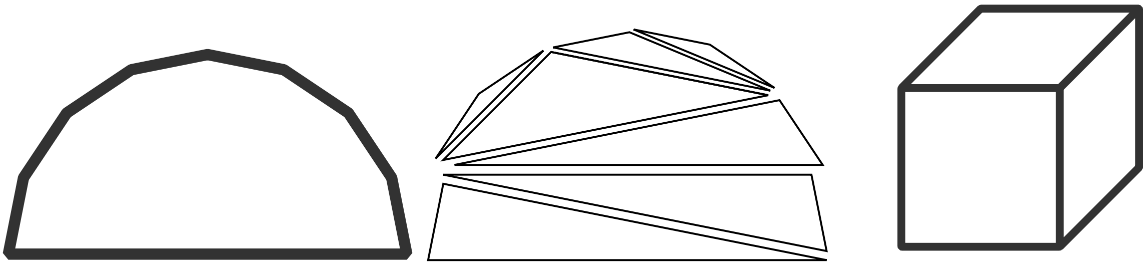
If a section of a model has a angle smaller than 45 degrees from the build plate it will need a support structure.

Best practice is to design a model that doesn't need supports.

Most slicing programs automatically detect overhangs and generate supports for you.

# Slicers

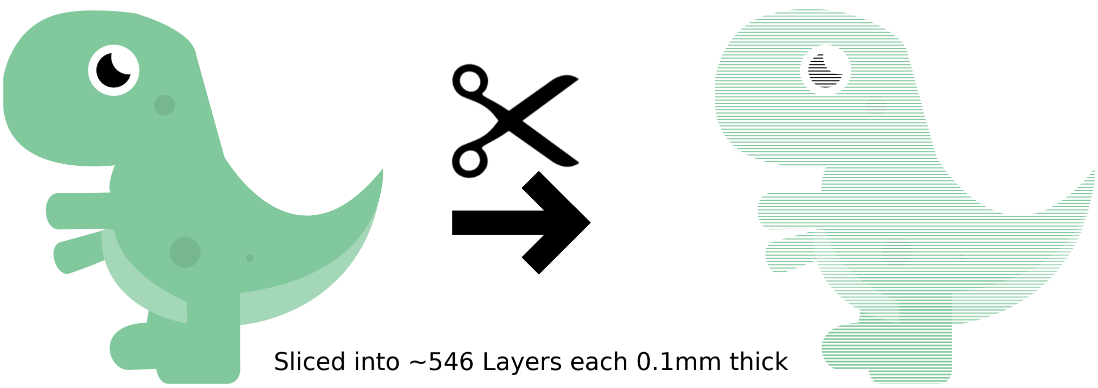
In our 3D Models, the shape of an obect is defined as a mass of mathematically described triangles and polygons all interconnected to form smooth 3D Shapes.



These shapes however don't represent the way 3D objects are built physically, namely layer by layer. They describe the shape of an object not how it is built on a 3D Printer.

In order to print a 3D Model we need to convert it into a format that a 3D Printer can understand.

We do this by using Slicers, as the name implies this takes a 3D Model and slices it into layers and converts it into G-Code. This tells the printer how to build our object.



Sliced into ~546 Layers each 0.1mm thick

# G-Code

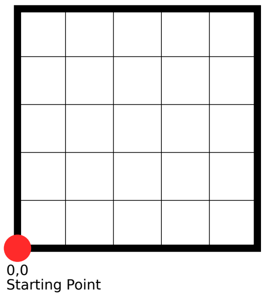
Layers are represented in a "G-Code" File. GCode is the language of CNC machines, it describes the movements and features like left, right, up, turn on heater and others.

G-Code Example

`G1` G1 is GCode for "Linear Move", it takes X, Y and Z as inputs (As well as a few other things)

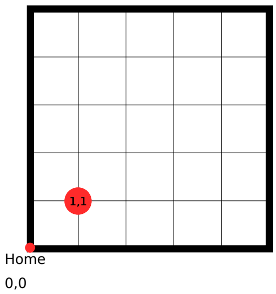
`G1 X2 Y1 Z1` ← A Command like this would mean:
Move 2mm on the X Axis, 1mm on the Y axis and 1mm on the Z Axis

If we simplify this to just 2D Movements we can draw 2D images.



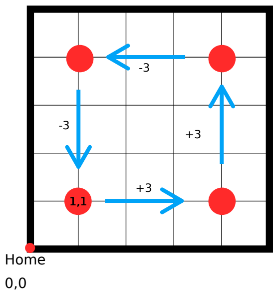

Say we want to draw a square 3 squares in length and width. First we set our "home" this is our starting point, for our grid this is point 0,0.

`G28` G28 is the command for home



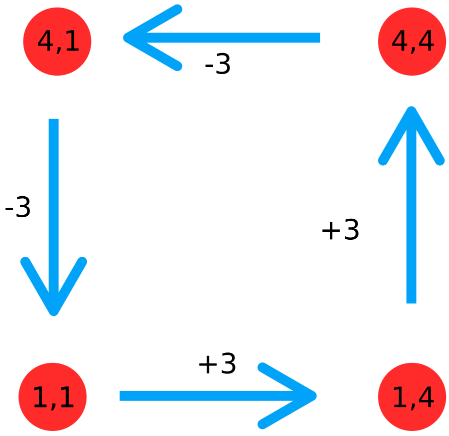

Now we move to point 1,1 this helps center our square so that our shape is evenly distributed on our grid.

`G1 X1 Y1`




To draw a 3 by 3 square we want our drawing point to go right by 3, up by 3, left by 3 and down by 3, at which point we would return to the same position we started in.

Continued




We can look at drawing our square mathematically and draw it with 4 points.

Our first point is point 1,1, we want to move along the X axis by 3 so we add 3 to the X Axis giving us point 1,4.

Likewise we then increase the Y Axis moving upwards giving 4,4, then moving to the left we decrease by 3, giving 4,1 and lastly back down returning to 1,1.

Our Points are:
(1,1) (1,4) (4,4) (4,1) (1,1)

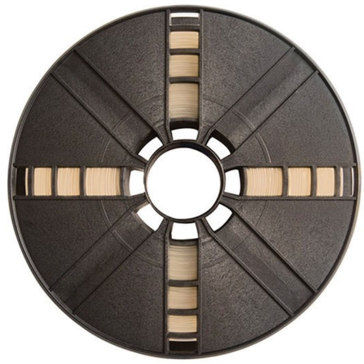
| | | Current Location |
|---|---|---|
| Move to point 1,1 | G1 X1 Y1 | (1,1) |
| Move along the X Asis by 3 | G1 X3 | (1,4) |
| Move along the Y Asis by 3 | G1 Y3 | (4,4) |
| Move along the X Asis by -3 | G1 X-3 | (4,1) |
| Move along the Y Asis by -3 | G1 Y-3 | (1,1) |

```
;Start
G1 X1 Y1
G1 X3
G1 Y3
G1 X-3
G1 Y-3
;Finish
```

A gcode file to draw the square above would look like this, executing this on a printer will move the extruder in a square shape.

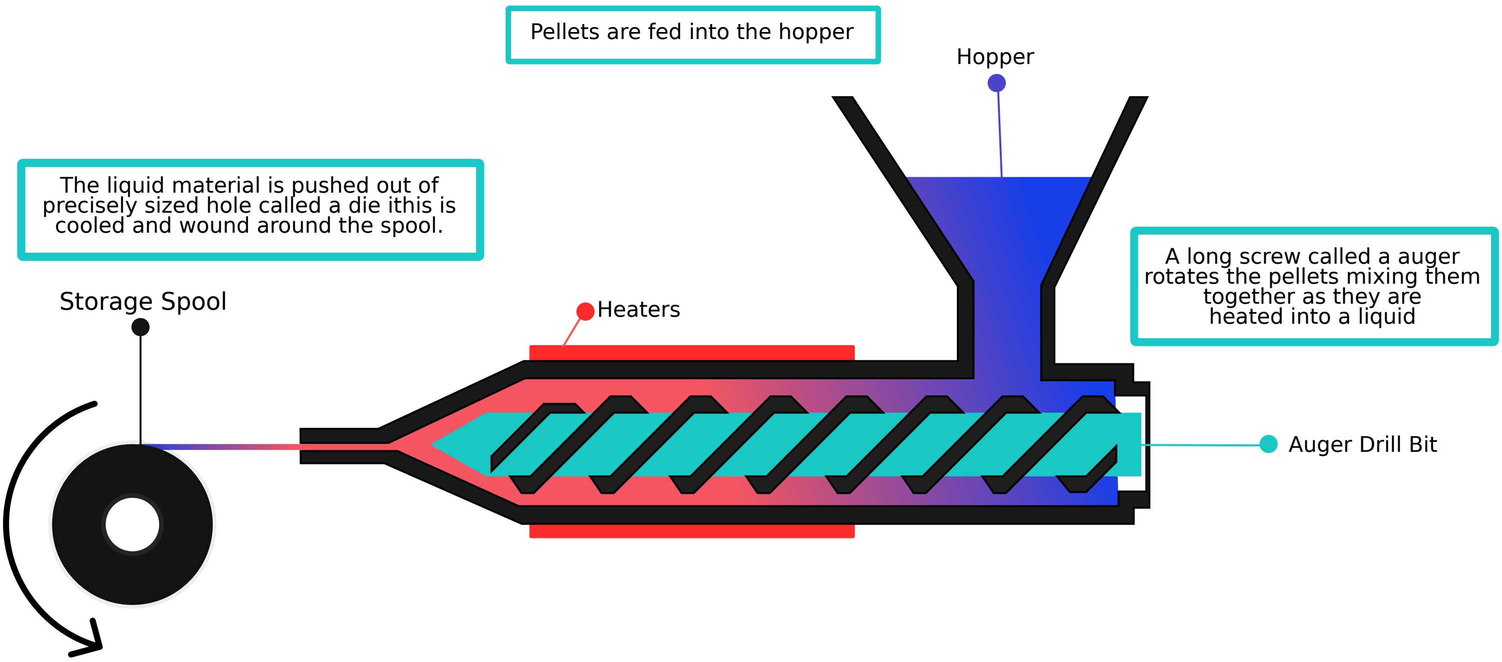
Human Skull
Provided by Leanne Rolton

# Filament

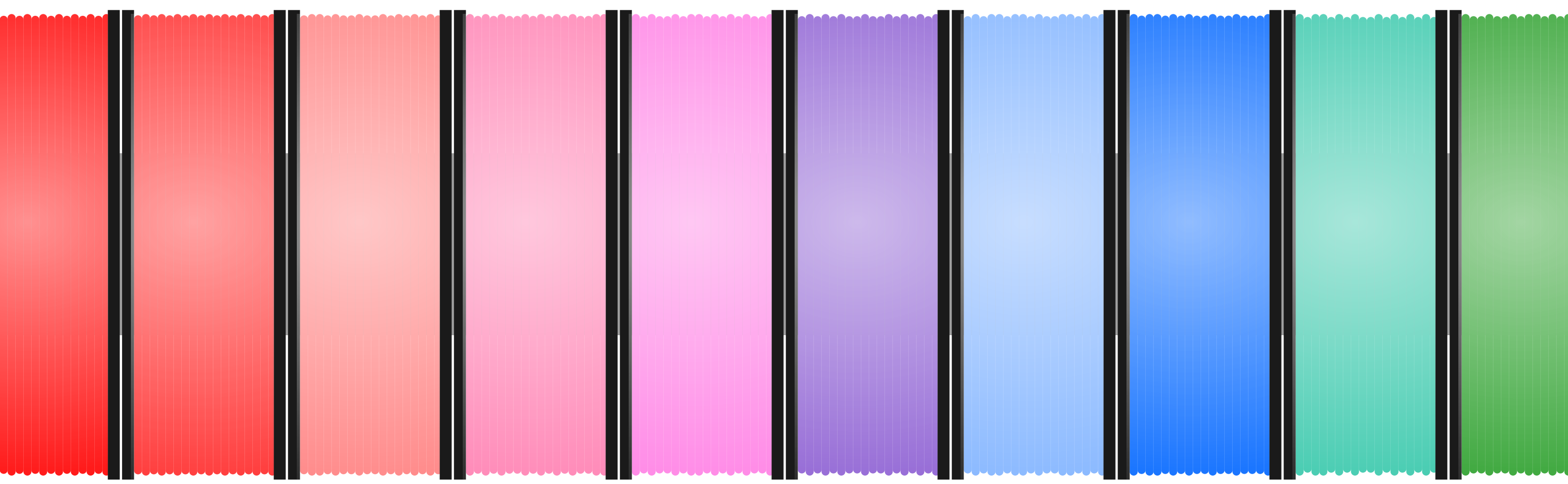


Filament is the proverbial ink for FDM 3D Printing.

It is made by melting plastic pellets and extruding a long continous strand of plastic which is wrapped around a spool

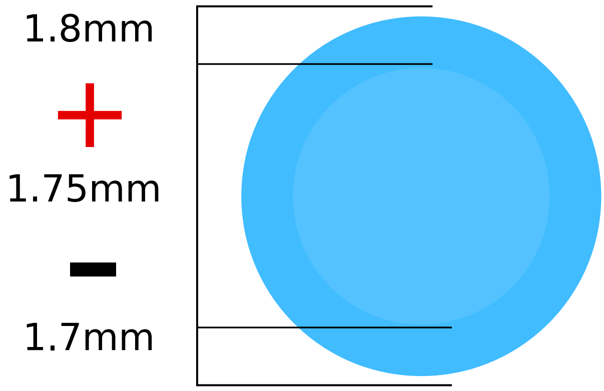



The wrapped spool is then slowly unwound and fed into the 3D Printers extruder.



Continued

Filament comes in a few different sizes, the most common being 1.75mm and 3mm filament.




In choosing a filament, an important property to look at is the "tolerance" or "Diameter Error" of filament.

The smaller the tolerance the sharper and smoother details and lines will be on a print. Most Filament has a tolerance of 0.05+/- with many starting to have tolerances of 0.02+/-.

When storing filament it is important to keep it away from moisture with moisture absorbing packets, this is because most filament is hydroscopic meaning it can absorb moisture which turns it brittle.

# Choosing A Material

There are hundreds of materials in all kinds of sizes and colours to choose from. This begs the question: "how do we choose a material for a project?".

The material we choose will be based upon the needs of our model. We need to figure out what our objects requirements are and match them to a material.

E.g. Do we need it to be used outdoors? Will it be used as a part?, subject to force? Is detail more important than strength?.

**Environment**

Materials vary in how well they resist breaking down in sunlight or how they handle weather. An inside environment will affect a print differently than outside.

**Lifespan**

Will your object be used for a day, a month, years? Depending on these you may need a sturdier or wear resistant material.

**Use**

The use of your print is one of the major factors in what material to choose. Some materials are stronger, others bend easier or are flexible like rubber, a few are easier to sand or paint.

**Printer Capabilities**

Not all materials can work in all printers, different materials may require higher temperatures, setups or hardware that your printers might not be able to use or might not be available.

Below we are going to take a look at some of the most common materials and when/where to use them. PLA and ABS are two of the most popular materials.

A variety of filaments have "mixed" versions, where materials like metal powder, wood or carbon fiber have been added for extra features like conductivity, strength or just a different colour or texture.

## PLA(Polylactic Acid)

PLA is the most common 3D Printing material and is made from  plant fibres making PLA biodegradable. PLA is easy to print, cheap and a well rounded material.

You can use PLA for most projects as well as for prototyping parts before you print in other materials.

| Hotend Temp | Bed Temp | Ease of Printing |
|---|---|---|
| 210 | 60 | ★★★ |

**Features**
Biodegradable
Easy to print

## ABS (Acrylonitrile Butadiene Styrene)

ABS is a less brittle plastic in comparison to PLA, it is mpre resistant to heat and is able to be chemically smoothed with acetone.

ABS is often used in mechanical parts and is common in the automotice industry, however it is falling out of favour in 3D printing due to the acrid fumes that are produced during printing.

| Hotend Temp | Bed Temp | Ease of Printing |
|---|---|---|
| 240 | 90 | ★☆☆ |

**Features**
Heat resistance
Good Strength
Weather Resistant

## PC (PolyCarbonate)

Polycarbonate is very strong and very impact resistance as well as has a high temperature resistance.

PC is best used for parts with a high impact risk like drone parts.

| Hotend Temp | Bed Temp | Ease of Printing |
| --- | --- | --- |
| 290 | 100 | ★★☆ |

**Features**
Very high impact resisstance and durability
Very resistant to temperature

## PETG (Polyethylene Terephthalate )

PETG is one of the most common plastics in use today and takes the form of many water bottles and food packaging.

PETG Is durable, flexible, impact and heat resistant and easy to print.

PETG absorbs moisture from the environment easily which turns it brittle.

| Hotend Temp | Bed Temp | Ease of Printing |
| --- | --- | --- |
| 245 | 60 | ★★☆ |

**Features**
Heat Resistant, flexible, durable.

## Nylon

Nylon is a incredibly strong, durable and versatile plastic that is flexible when thin.

Nylon is best used for functional parts that need strength and durabiliy like hinges and geats.

| Hotend Temp | Bed Temp | Ease of Printing |
| --- | --- | --- |
| 250 | 80 | ★★☆ |

**Features**
High Strength and Durability

## TPE (Thermoplastic elastomers)

TPE is a flexible material rubber like materials and is commonly used for bending or flexible items like belts, springs and phone cases.

TPE needs to be printed slower than most materials to prevent stretching and binding during printing.

| Hotend Temp | Bed Temp | Ease of Printing |
|---|---|---|
| 220 | 40 | ★★☆ |

**Features**
Super Flexibility

## TPU (Thermoplastic Polyurethane)

TPU is a elastic, oil/grease resistant and abrasion resistant material.

The less infill the more flexible your print will be.
TPU is used in power tools, medical devices, footwear, panels and more.

| Hotend Temp | Bed Temp | Ease of Printing |
|---|---|---|
| 250 | 50 | ★★☆ |

**Features**
Flexibility
Oil and Abrasion Resistant

## ASA (Acrylonitrile Styrene Acrylate)

ASA was developed as a alternative to ABS and boasts better weather resistance and bettter printability.

ASA is best used in outdoor items and mechanical parts.

| Hotend Temp | Bed Temp | Ease of Printing |
|---|---|---|
| 250 | 90 | ★★☆ |

**Features**
UV and Weather Resistance

A Brief History of

# 3D Printing through the ages

**1981**

Hideo Kodama from the Nagoya Municipal Industrial Research Insitute publishes first accounts of a 3D Printer (SLA).

**1984**

In 1984, Chuck Hill of 3D Systems created the STL File format, the main 3D Model file type used in 3D Printing today.

**1988**

1988 the main type of 3D Printing known as FDM or Fused deposition modelling was developed by Stratasys.

**2000s**

Late 2000s, as patents expire 3D Printing technologies become openly available which causes a boom in the development of 3D Printers, this results in lower costs making them more accessible.

**2010+**

2010 and onwards, 3D Printing is shaking up industries, it is expected that desktop sized metal printing will eventually emerge and as 3D Printing methods become more developed mainstream traditional manufacturing will fade.

3D Printing becomes the main manufacturing method in all industries, eventually a 3D Printer will be capabale of creating any object from any materials.

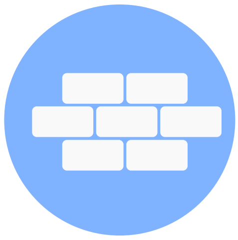
Magnified working 3D printed nut and .53mm threads
Image provided by Greg Evers

Bobble Dolls for Charity
Provided by Leanne Rolton

# Making Money with 3D Printing

Design products

Sell 3D Models



Sell physical
3D Prints

There area few different ways many people have made a living by selling 3D printing related things; designing or making jewlery, props, architectural models and toys are a few ways.

You can sell 3D Modells online through a variety of sites such as: Turbosquid, Plan Marketplace, CG Trader.

If you selling models specific for 3D Printing then you can setup a free shop on shapeways for people to order from.

# Getting Help and Resources

# Social Media and Wikis

## Facebook and Social Platforms

Many people have made social groups to create communities of people with interests in 3D Printers and 3D Printing.

These groups often are specific to local areas, countries or types of printers and are a valuable source of help. They can be found on forums, facebook, google+ and pretty much any social media platform or blog.

## YouTube

There exists a variety of youtube channels that are dedicated to or discuss 3D Printing. Channels like Tom Sanladerer, Makers Muse and 3D Printing Nerd are made by amazing people who create great content and are an invaluable source of infomation.

## Sites and Blogs

**ALL3DP.com** **3D Printing.com** **3ders.org**

ALL3DP, 3ders.og and 3D Printing.com are all sites that post on a varietiey of 3D Printing topics from how to guides to news on the latest 3D Printing Tech and Businesses

### Reprap Wiki

The Reprap wiki is a great resource that despite being a little old has been used by hundreds of people and contains pages on all aspects of 3D Printers as well as many Opensource designs that can be downloaded for free and made.
**http://reprap.org/**

### Instructables

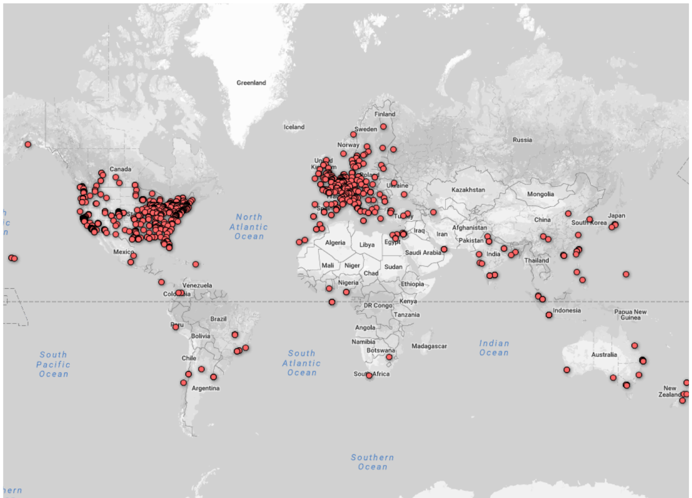
Instructables is a website dedicated to how-to style guides on almost anything imaginable. People create and share a "Instructable" freely, there is often contests on an equally diverse variety of topics, problems and discriplines including creating 3D Printable things for fun and to solve problems.

**https://www.instructables.com/**

# Makerspaces, Fablabs and Communal Spaces

Communal Technology Spaces provide technology, expertise and space to enable people to prototype and create.

Fablabs, Makerspaces, Openlabs, Men's Sheds and Techshops are all examples of branded community spaces.



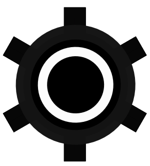

Map of maker resources like makerspaces, fabricaters and more
From themakermap.com

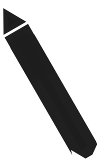
FAB LAB

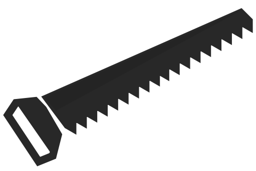
These spaces emphasise a sense of community and collaboration.

You can find a local techspace often by googling for a local makerspace or visiting themakermap.com

A typical space will often have 3D printers, CNC mills, laser cutters, welders, electronics equipment and many other kinds available for people to use.







# Finding 3D Models

3D Model Repositories are online websites that offer hundreds of 3D Models available for download both free and for a cost depending on the website.

thingiverse.com

Thingiverse

Thingiverse is one of the most popular and widely used model repositories.

Created by MakerBot, Thingiverse allows users to share 3D Models they have created.

In 2012, 25,000 designs were uploaded to Thingiverse, as of 2017 there are over 887,030 3D Models available.

GrabCAD

grabcad.com

GrabCAD is a large library of technical and engineering drawings and 3D Models.

TurboSquid

turbosquid.com

TS is a source of extremeley high quality 3D Models often used for professional work.

yeggi

yeggi.com

yeggi is a search engine for 3D Models currently containing over 1 million models worldwide.

Spiral Style Plant Vase
By Caleb Brian

# 3D Printing Services

shapeways

Shapeways is a 3D Printing service offering premium quality printing services and a wide range of materials as well as featuring a digitial marketplace where designers can create shops and sell 3D modelling services.

### Materials

- Gold
- Platinium
- Sterling Silver
- Castable Wax
- Brass
- Aluminium
- Bronze
- ElastoPlastic
- Coloured Sandstone
- Steel
- Frosted Plastic
- Porcelain

3D HUBS

3D Hubs connects people to local 3D Printers. people with 3D Printers can sign up and offer printing and design services, 3D Hubs also offers in house Printing and CNC services.

### Materials

- Industrial Metals
- Prototyping Plastics
- High Detail Resin
- Nylon

# 3D Modelling Software

## TinkerCAD

tinkercad.com

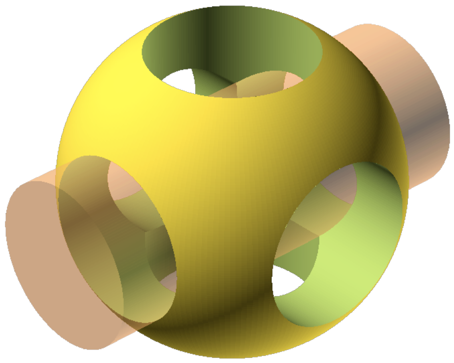
Learning Curve ★☆☆

TinkerCAD by Autodesk is a great program for both beginners and children. With great documentation and a easy interface, if you have never 3D Modelled before this is a great starting point.

## OpenSCAD

www.openscad.org/

Learning Curve ★★☆



OpenSCAD is what is known as a scripting modeller, it is a simplified programming language that you can use to create 3D Models, it is very popular and allows you to create easily customisable models.

## SketchUp

sketchup.com

Learning Curve ★★☆

Sketchup was originally mainly a architectural 3D Modeller but due to its ease of use became well known for 3D Printing, it is recommended if you find TinkerCAD too simple or easy or are just looking to try something new.

# 3D Modelling Software

## Blender

blender.org

Learning Curve

Blender is a full commercial level opensource interactive modelling software, with a built in game engine, sculpting, texturing, physics simulation and a whole lot more.
Blender has a high learning curve to match its high capabilities. It is also free.

## FreeCAD

freecadweb.org

Learning Curve

FreeCAD is a popular  opensource free CAD Package, its primary use is for creating real-life objects of any size, and is suitable for hobbyists and profesionals.

## Sculptris

pixologic.com/sculptris/

Learning Curve

Sculptris is a sculpting program, this is a digitial version of sculpting clay. sculpting is particuliarily useful for creating organic shapes. Think faces, animals, bodies ect.

AUTODESK

# Software Suite

Autodesk has long been an industry standard name for a variety of professional software.

Their Software suite includes programs for Animation, Product Design, Machine Design, Sculpting, Simulation, Game Development and more.

## Autodesk Software

Fusion 360 is the main popular tool among 3D Printing designers and is Autodesk's Cloud Based solution for merging most of it's tools together.

3D Studio Max offers 3D Modelling, animation and rendering tools.

Inventor is a design, visualisation and simulation software for accurately creating and testing products virtually.

AutoCAD has been the leading CAD drafting software for years and is mainly used for engineering and part designs.

# Slicer Software

## Cura

Free

Learning Curve

ultimaker.com/en/products/cura-software

Cura is a popular and easy to use slicing software created by Ultimaker, the creators of the Ultimaker Printer.

## Slic3r

Free

Learning Curve

http://slic3r.org/

Slic3r is one of the earliest slicers made and contains a huge variety of unique and useful settings as well as being responsible for creating a lot of useful features that are common in other software nowadays.

## Simplify 3D

Paid

Learning Curve

https://www.simplify3d.com/

Simplify3D contains preset setting profiles for hundreds of 3D Printers, it includes high quality support generation. If your after good, solid software this is it.

## NetFabb

Free & Paid

Learning Curve

tinkercad.com

NetFabb by Autodesk is an industrial strength advanced Additive Manufacturing Software that offers features beyond standard slicing programs. It can slice models, create advanced supports and optimise topology.

# Printer Host Software

Most printers are able to be controlled using the buttons or touchscreens attached to them, note however host software allows you to control a printer on a computer or remotely through a internet browser or mobile device.

## Repetier Host

repetier.com

Learning Curve

Repetier Host is part of a full suite of host, server and firmware software. It is one of the oldest and most popular printer controller softwares.
With a wide range of quality features like a intergrated slicer, elegant interface and multi extruder support.

## OctoPrint

octoprint.org

Learning Curve

Octoprint is a web interface for your printer. Connect your printer to a device with octopi installed and you can access your printer from any device anywhere. Did we mention it is opensource?

Whilst a simple interface installing octoprint does require a bit of tech knowledge

## AstroPrint

astroprint.com

Learning Curve

Astroprints tagline is 3D Printing made simple. It has a easy to use, straightfoward interface that is poweful yet intuitive.
If paired with the AstroBox Rpi Kit, plug it into your printer and your good to go.
No complex setup required.

## PrintRun

pronterface.com

Learning Curve

Printrun is a free opensource host software it offers features such as slic3r intergration Command Line Printing, Macros and Custom Buttons.

## CraftWare

craftunique.com

Learning Curve

Craftware is a free slicer with machine control that is offered by craft unique, creators of the CraftBot Printers.

## MatterControl

http://www.mattercontrol.com/

Learning Curve

Matter Control is a free, OpenSource printer controller with features like a print que, SMS and email notifications and preconfigured print profiles.

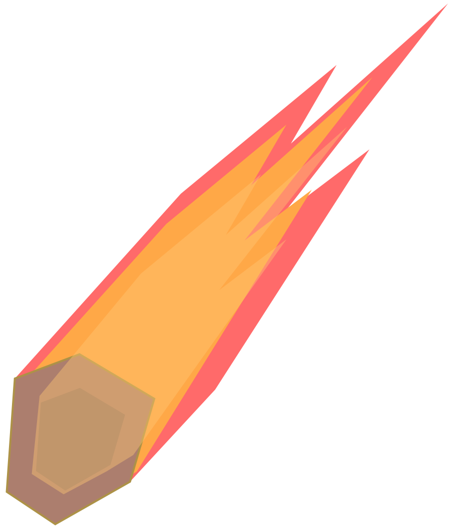
## 3D PrinterOS

3dprinteros.com

Learning Curve

3D Printer OS is a complete cloud based Management App, you can manage multiple printers, queue printing jobs, repair files and grant printing permisions.

# End



Thanks for reading,

I hope you enjoyed these pages and that it in some way it has helped and inspired you to get involved in 3D Printing.

This guide was a fascinating experience to write, I would like to thank the Australia 3D Printing Facebook community for helping provide the 3D Print images  scattered throughout these pages as well as my partner for her constant support and feedback whom without this book may have never been finished...

Sincerely

Benjamin J.D Maclaren