IOT
Chapter 6
PROTOTYPING THE PHYSICAL DESIGN

PREPARATION

- To best prepare for design work involves **developing an interest in design and having examples of design ideas you like**.
- All you need to do is **develop an interest in the world around you and start paying attention to the wealth of objects and experiences that you encounter.**
- This first step **will help you work out what you like and what you don't like.**
- Over time, **you'll start to work out which qualities you particularly appreciate.**
- As you go, **collect details about the items that inspire you.**
- **Take photos, jot down things in your notebook, or sketch them out.**
- Paste them into an old-school scrapbook.
- Over time you'll **build up an archive of good design that will help you spark your creativity when designing things of your own.**
- The other side to a (very) basic design education is **an understanding and appreciation of the tools available** and the ***materiality*** **of the processes involved in making things in the physical.(rather than the digital)**
- **Items crafted in** the **digital** world can focus exclusively on appearances and **take on any form they like**; in the **real world,** those annoying laws of **physics** and the **limitations of the tools for fabrication** come into play.
- As with most things, **the more experience you gain with different materials and tools, the better your understanding will be when you come to design something.**
- **Start playing around with the tools you've got to hand.**
- Get involved in local (or not so local) hackdays(event in which computer programmers and others involved in software development, including graphic designers, interface designers, project managers, and others, often including subject-matter-experts, collaborate intensively on software projects).
- **Make things to give as gifts** (or just to see what happens).

SKETCH, ITERATE, AND EXPLORE

- In the early stages of a design, you can never do too much iterating through ideas and trying out different approaches to solving the problem.
- However, **your first idea is unlikely to be the best, so you should be optimising for speed of iteration rather than quality of prototype.**
- You could **iterate through designs** with a 3D printer, but doing so **with a pen and paper is much quicker.**
- **Use whatever tools make most sense to help with the idea generation and exploration.**
- You might **use** a mood board—**a whiteboard where you jot down thoughts and sketches over a few days**—or a notebook that you doodle sketches in while sitting on a park bench watching the world pass by.
- **The sketches aren't for an art gallery; they're to help you work through your thinking.**
- They only need to **capture and convey your ideas**.
- **The more sketching you do, the better they will get.**

- **Don't be afraid to take your sketching into three dimensions.**
- **Try out different sizes** and see how the changes in dimensions affect the feel or the look of the design.
- **Then give it or show it to some of the people who might use the finished item to find out how they interact with it.**
- The **key lesson** is to **use these techniques to experiment with different possibilities** and learn which features of which designs are best.
- Consider, for example, the **evolution of the design for the Good Night Lamp.**
- The **original design** was a **more traditional lamp shape**, but in a design workshop, the team batted around a range of ideas with the help of a purely functional prototype.
- They realised that a design echoing the **shape of a house better conveyed the core concept of connecting loved ones in their homes.**

The evolving design for the Good Night Lamp (from left to right): original design; functional mockup; redesign mockup; redesign functional prototypes (orange and wood/acrylic); revised size mockup; revised size functional prototype.

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NONDIGITAL METHODS

- Many of **traditional craft techniques** are just as valid for use when prototyping the physical form of your device.
- One of the **key advantages** that these techniques have over the newer digital fabrication methods is their **immediacy.**
- **Three-dimensional printing times are often measured in hours**, and although laser cutting is much faster, performing a cut still takes minutes.
- And all this is without including the **time taken to revise the design on the computer first.**
- Let's look at some of the more common options here:
- ▪ **Modelling clay:**
- The most well-known brands are Play-Doh and Plasticine, but you can find a wealth of different versions with slightly different qualities.
- Some, like **Play-Doh**, have a **tendency to dry out and crack if left exposed to the air.**
- **Modelling clay is best used for short-term explorations of form, rather than longer-term functional prototypes.**

- ▪ **Epoxy putty:**

- **It is adhesive to most materials, tough and durable, and self hardening.**
- Product as the brand Milliput; it is similar to modelling clay although usually available in fewer colours.
- **It comes in two parts, one of which is a hardener.**
- **You mix equal parts together to activate the epoxy.**
- **You then mould it to the desired shape, and in about an hour, it sets solid.**
- If you like, you can then sand it or **paint it for a better finish**, so this product works well for more durable items.

- ▪ **Sugru:**

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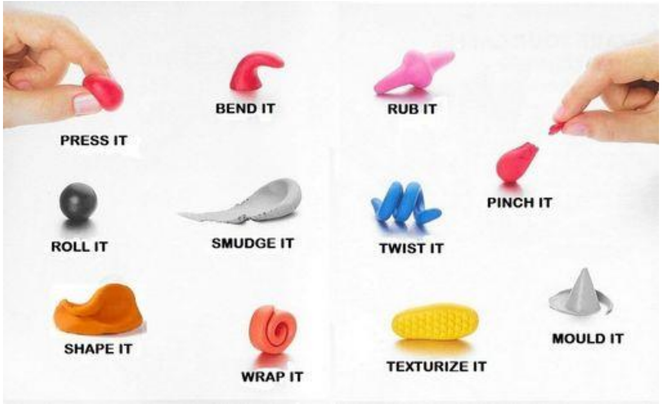
- 

- **Sugru is a mouldable silicone rubber.**
- Like epoxy putty, **it can be worked for only a short time before it sets** (about 30 minutes, and then about a day to fully cure); but unlike epoxy, once cured, it remains flexible.
- **It is also good at sticking to most other substances** and **gives a soft-touch grippy surface**, which makes it a great addition to the designer's (and hacker's) toolkit.

- ▪ **Toy construction sets:**
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- The other interesting feature of these sets is the **availability of gears, hinges, and other pieces to let you add some movement to your model.**
- You can purchase systems to control LEGO sets from a computer.
- **Many hackers combine an Arduino for sensing and control with LEGO for form.**

- ▪ **Cardboard:**
- Cardboard **is cheap and easy to shape with a craft knife or scissors**, and available in all manner of colours and thicknesses.
- It provides a reasonable amount of structural integrity and **works well for sketching out shapes** that you'll later cut out of thin plywood or sheets of acrylic in a laser cutter.

- ▪ **Foamcore or foamboard:**

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- This sheet material is **made up of a layer of foam sandwiched by two sheets of card.**
- It's readily available at art supplies shops and comes in 3mm or 5mm thicknesses in a range of sizes.
- **Like cardboard, it is easily cut with a craft knife.**

- ▪ **Extruded polystyrene:**

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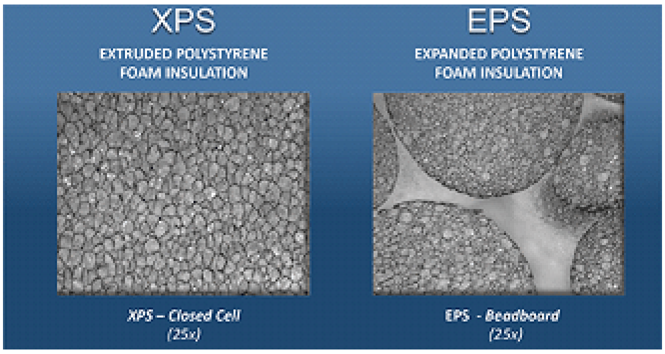

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- **Extruded polystyrene** boards are used as an insulation.
- This product is similar to the *expanded* polystyrene that is used for packaging but is **a much denser foam that is better suited to modelling purposes.**
- It is often referred to as "blue foam", although it's the density rather than the colour which is important.
- **Light yet durable, it can be easily worked: you can cut it with a craft knife, saw it, sand it, or, for the greatest ease in shaping it, buy a hot-wire cutter.**
- Sheets of extruded polystyrene are much **thicker than foamboard**, usually between 25mm and 165mm.
- As a result, it is great for mocking up solid three-dimensional shapes.

- If you need something thicker than the sheet itself, you can easily glue a few layers together.
- **The dust from sanding it and the fumes given off when cutting it with a hot-wire cutter aren’t too nice, so make sure you wear a dust mask and keep the area ventilated when working with it.**

LASER CUTTING

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- **Three-dimensional printers can produce more complicated parts**, but the simpler design process **greater range of materials which can be cut, and faster speed make the laser cutter a versatile piece of kit.**
- **Laser cutters range from desktop models to industrial units which can take a full 8' by 4' sheet in one pass.**
- Most commonly, though, **they are floorstanding and about the same size as a large photocopier.**
- Most of the laser cutter is given over to the **bed**; this **is a flat area that holds the material to be cut.**
- The bed **contains a two-axis mechanism with mirrors and a lens to direct the laser beam to the correct location** and focus it onto the material being cut.
- It is similar to a flatbed plotter but one that burns things rather than drawing on them.
- **The computer controls the two-axis positioning mechanism and the power of the laser beam.**
- At a sufficiently **low power**, this feature **enables you to etch additional detail into the surface of the piece.**
- You can also **etch things at different power levels to achieve different depths of etching.**
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- CHOOSING A LASER CUTTER
- When choosing a laser cutter, you should **consider two main features:**
- ▪ **The size of the bed:**

- This is the place where the sheet of material sits while it's being cut, so **a larger bed can cut larger items.**
- A larger bed allows you to buy material in bigger sheets (which is more cost effective), and **if you move to small-scale production, it would let you cut multiple units in one pass.**
- ▪ **The power of the laser:**
- **More powerful lasers can cut through thicker material.**
- Depending on what you're trying to create, you can cut all sorts of different materials in a laser cutter.
- **You are able to get laser cutters which can cut metal**, they tend to be the more powerful and industrial units.
- **The lower-powered models don't cut through the metal**; and worse, as the shiny surface of many metals does an excellent job of reflecting the laser beam, you run a real risk of damaging the machine.
- If you don't have a laser cutter of your own, there is a good chance that your local makerspace or hackspace will have one that you could use.

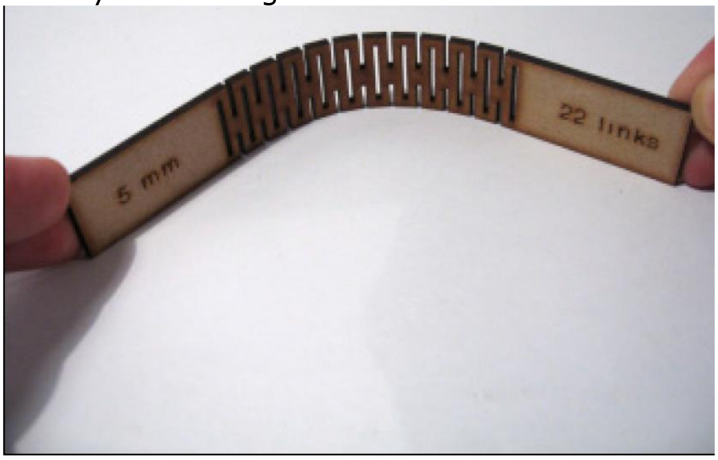
SOFTWARE

- The file formats or software which you need to use to provide your design vary across machines and providers.
- Although some laser-cutting software will let you define an engraving pattern with a bitmap, typically you **use some type of vector graphics format.**
- Vector formats **capture the drawing as a series of lines and curves, which translate much better into instructions for moving the laser cutter than the grid-like representation of a bitmap.**
- **With a bitmap**, as you might have seen if you've ever tried blowing up one small part of a digital photo, **the details become jagged as you zoom in closely**, whereas the **vector format knows** that **it's still a single line and can redraw it with more detail.**
- **CorelDRAW is a common choice for driving the laser cutters themselves, and you can use it to generate the designs too.**
- Other popular options are **Adobe Illustrator**, as many designers already have a copy installed and are familiar with driving it.
- The ***best*** **choice** is the **one you're most comfortable working with**, **or** failing that, **either the one your laser cutter uses or the one you can afford.**
- **When creating your design, you use the stroke (or outline) of the shapes and lines rather than the filled area to define where the laser will cut and etch.**
- The ***kerf*****, the width of the cut made by the laser**, is about 0.2mm but isn't something you need to include in the design.
- **A thinner stroke width is better,** as it will stop the laser cutter from misinterpreting it as two cuts when you need only one.
- **Different types of operation—cut versus etch or even different levels of etching—can usually be included in the same design file just by marking them in different colours.**
- **Whoever is doing your cutting may have a set convention of colour scheme for different settings, so you should make sure that you follow this convention if that is the case.**

HINGES AND JOINTS

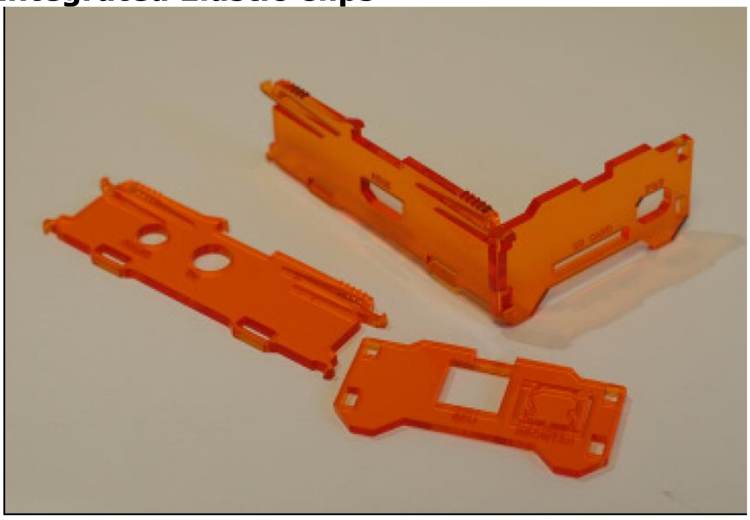
Lattice (or Living) Hinges

- To introduce some curves into your design.
- A series of closely laid-out cuts, perpendicular to the direction of the curve, allows the material to be bent after it has been cut.
- Varying the number of cuts and their separation affects the resulting flexibility of the hinge.

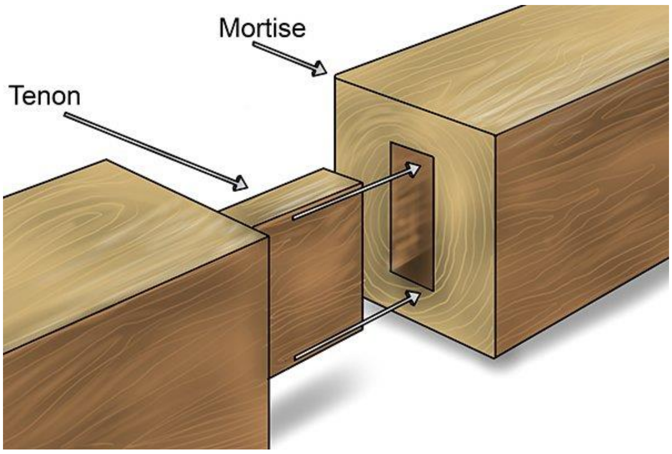


- The lattice (or living) hinge.

- **Integrated Elastic Clips**



- Integrated elastic clips.



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- This jointing technique is used in situations similar to a through mortise-and-tenon joint, when joining two sheets of material at 90 degrees.
- The tenon is replaced with two hooks for holding the mortise sheet tight to the tenon sheet without any need for glue or additional fixings.
- To provide the required flexibility in the tenon to fit it through the mortise during assembly, additional, deeper cuts are made into the tenon side.

- **Bolted Tenon (or T-Slot) Joints**
- It is a modified version of the standard mortise-and-tenon joint which adds a T- or crossshaped slot to the tenon sheet, with the crossbar of the T or cross being just big enough to hold a nut.
- You can then thread a bolt through a hole in the mortise sheet, down the slot and through the nut.
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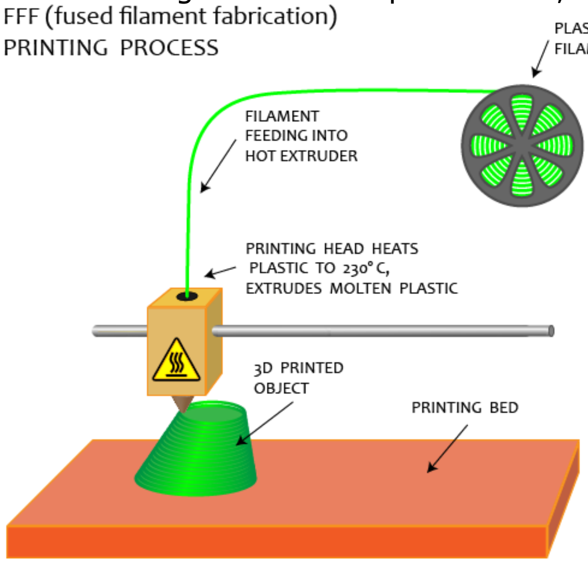
3D PRINTING

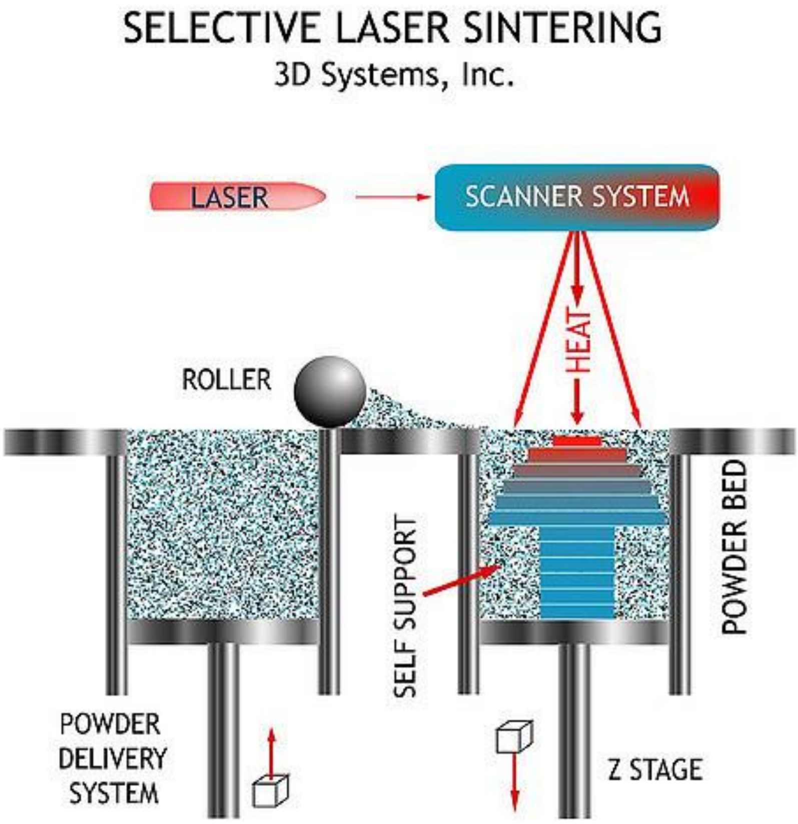
- The term *additive manufacturing* is used because all the various processes which can be used to produce the output start with nothing and *add* material to build up the resulting model.
- This is in contrast to *subtractive manufacturing* techniques such as laser cutting , where you start with more material and cut away the parts you don’t need.
- We have three-dimensional computer model as the input.
- The software slices the computer model into many layers, each a fraction of a millimetre thick, and the physical version is built up layer by layer.
- It can produce items which wouldn’t be possible with traditional techniques.
- For example, because you can print interlocking rings without any joins, you are able to use the metal 3D printers to print entire sheets of chain-mail which come out of the printer already connected together.
- Another common trick with 3D printing is to print pieces which include moving parts: it is possible to print all the parts at the same time and print them ready-assembled.
- Other processes, such as the extruded plastic techniques, require you to print a second material, which takes the supporting role.
- When the print is finished, this support material is either broken off or washed away.
- (The support material is specifically chosen to dissolve in water or another solution which doesn’t affect the main printing material.)

TYPES OF 3D PRINTING

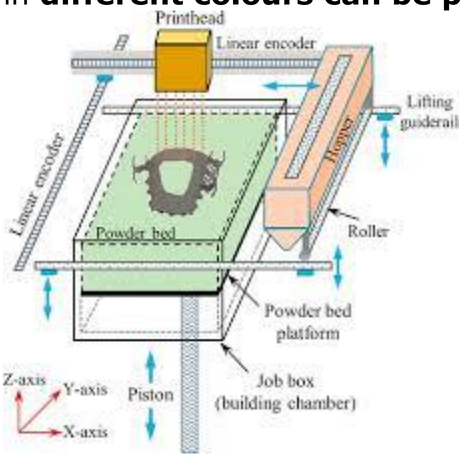
- ▪ **Fused filament fabrication (FFF):** Also known as fused deposition modeling (FDM).
- It works by extruding (**Plastics extrusion** is a high-volume manufacturing process in which **raw plastic is melted and formed into a continuous profile.**) a fine filament of material (usually plastic) from a heated nozzle.
- The nozzle can be moved horizontally and vertically by the controlling computer, as can the flow of filament through the nozzle.
- The resulting models are quite robust, as they're made from standard plastic.



- **Laser sintering:**
- This process is sometimes called selective laser sintering (SLS), electron beam melting (EBM), or direct metal laser sintering (DMLS).
- It is used in more industrial machines but **can print any material which comes in powdered form and which can be melted by a laser.**
- It **provides a finer finish than FDM**, but the models are just as robust, and they're even stronger when the printing medium is metal.
- This technique is **used to print aluminium** or titanium, although it can just as easily print nylon.

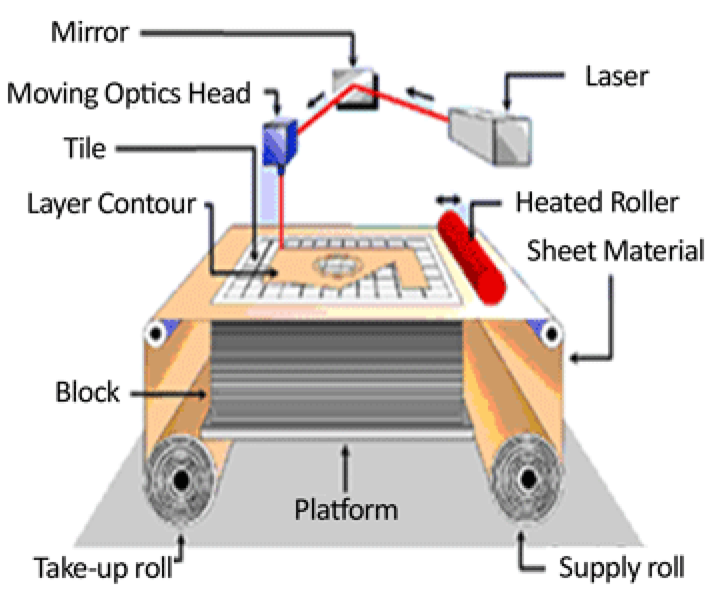


- **Powder bed:**
- Like laser sintering, the powder-bed printers **start with a raw material in a powder form, but rather than fusing it together with a laser, the binder is more like a glue which is dispensed by a print head similar to one in an inkjet printer.**
- After the printing process, the **models are** quite brittle(**delicate and easily broken**) and so **need postprocessing where they are sprayed with a hardening solution.**
- The great advantage of these printers is that **when the binder is being applied, it can be mixed with some pigment**; therefore, full-colour prints in **different colours can be produced in one pass**.

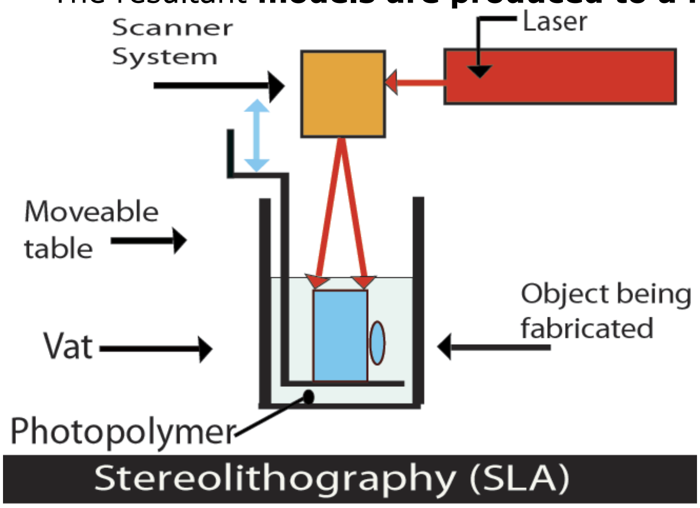


- ▪ **Laminated object manufacturing (LOM):**
- This is another method which can produce full-colour prints.
- LOM **uses traditional paper printing** as part of the process.
- Because it **builds up the model by laminating many individual sheets of paper together, it can print whatever colours are required onto each layer** before cutting them to shape and gluing them into place.

Laminated object Manufacturing (LOM)



- **Stereolithography and digital light processing:**
- Both approaches **build their models from a vat (tank) of liquid polymer resin (adhesive)** which is **cured** (refers to the toughening **or hardening** of a polymer material by cross-linking of polymer chains, brought about by electron beams, heat, or **chemical** additives.) **by exposure to ultraviolet light.**
- **Stereolithography uses a UV laser to trace the pattern for each layer,** whereas **digital light processing uses a DLP projector to cure an entire layer at a time.**
- The resultant **models are produced to a fine resolution**.



SOFTWARE

- If you are already familiar with one 3D design program, see whether it can export files in the correct format for the machine you'll use to print.
- If you are using a printing service, it will advise on which program it prefers you to use or what formats it accepts.
- Or failing that, choose one to suit your budget.
- Working out how to design items in three dimensions through a two dimensional display isn't trivial, so it's more important than usual to work through the tutorials for the software you choose.
- Tinkercad (http://tinkercad.com) and Autodesk's 123D Design Online (http://www.123dapp.com/design) are two options which just run in your web browser.
- So they let you start designing without having to install any additional software.
- Autodesk also has a range of 123D apps available to download and install.
- You can find a desktop version of 123D Design and also of 123D Catch, a clever application which takes an array of photos of an object and automatically converts them into a 3D model.
- SolidWorks (http://www.solidworks.com) and Rhino (http://www.rhino3d.com) are the industry-standard commercial offerings.
- In the open source camp, the main contenders are OpenSCAD (http://www.openscad.org) and FreeCAD (http://free-cad.sourceforge.net).
- When you have your design ready, you need a further piece of software to convert it into a set of instructions which will be fed to the printer.
- This is usually known as the *slicing algorithm* because its most important function is to carve the model into a series of layers and work out how to instruct the printer to build up each layer.
- Skeinforge was the first slicing software used by the open source printers, but it has been largely overtaken by the newer and more user-friendly Slic3r.
- Both will let you change parameters to fine-tune your 3D prints, specifying options like the temperature to which the plastic should be heated, how densely to fill the solid objects, the speed at which the extruder head should move, etc

CNC MILLING

- Computer Numerically Controlled (CNC) milling is similar to 3D printing but is a *subtractive* manufacturing process rather than *additive*.
- A computer controls the movement of the milling head,much like it does the extruder in an FDM 3D printer.
- However, rather than building up the desired model layer by layer from nothing, it starts with a block of material larger than the finished piece.
- It cuts away the parts which aren't needed—much like a sculptor chips away at a block of stone to reveal the statue, except that milling uses a rotating cutting bit (similar to an electric drill)
- Because cutting away material is easier, CNC mills can work with a much greater range of materials than 3D printers can.
- CNC mills can also be used for more specialised (but useful when prototyping electronic devices) tasks, such as creating custom printed circuit boards.
- the CNC mills away lines from the metal surface on the board, leaving the conductive paths.

- An advantage of milling over etching the board is that you can have the mill drill any holes for components or mounting at the same time, saving you from having to do it manually afterwards with your drill press.
- A wide range of CNC mills is available, depending on the features you need and your budget.
- Sizes range from small mills which will fit onto your desktop through to much larger machines with a bed size measured in metres.
- The challenges of accurately moving the carriage around increase with their size.
- Beyond size and accuracy, the other main attribute that varies among CNC mills is the number of axes of movement they have:
- ▪ **2.5 axis:** This type has three axes of movement—X, Y, and Z—it can move only any two at one time.
- ▪ **3 axis:** Like the 2.5-axis machine, this machine has a bed which can move in the X and Y axes, and a milling head that can move in the Z.
- However, it can move all three at the same time
- ▪ **4 axis:** This machine adds a rotary axis to the 3-axis mill to allow the piece being milled to be rotated around an extra axis, usually the X (this is known as the *A axis*).
- ▪ **5 axis:** This machine adds a second rotary axis—normally around the Y—which is known as the *B axis*.
- ▪ **6 axis:** A third rotary axis—known as the *C axis* if it rotates around Z—completes the range of movement in this machine.
- As with 3D printing, the software you use for CNC milling is split into two types:
- ▪ **CAD** (Computer-Aided Design) software lets you design the model.
- ▪ **CAM** (Computer-Aided Manufacture) software turns that into a suitable toolpath—a list of co-ordinates for the CNC machine to follow which will result in the model being revealed from the block of material.

REPURPOSING/RECYCLING

- As with the other elements of building your connected device, a complete continuum exists from buying-in the item or design through to doing-it yourself.
- So, just as you wouldn't think about making your own nuts and bolts from some iron ore, sometimes you should consider reusing more complex mechanisms or components.
- One reason to reuse mechanisms or components would be to piggyback onto someone else's economies of scale.
- If sections or entire subassemblies that you need are available in an existing product, buying those items can often be cheaper than making them in-house.
- If the final design requires processes with massive up-front costs or the skills of a designer that you don't have the funds to hire right now, maybe a product already exists that is near enough to work as a proxy.
- That lets you get on with taking the project forwards, ending up at a point.
- And, of course, it doesn't have to be a finished item that you reuse.
- The website Thingiverse (http://www.thingiverse.com) is a repository of all manner of designs, most of which are targeted at 3D printing or laser cutting.
- All available under creative commons licenses which allow you to use the design as is or often allow you extend it to better suit your own needs.

<u>Case Study: The Ackers Bell</u>

- The Ackers Bell is an Internet-connected bell, which was commissioned by the big-data startup ScraperWiki (http://scraperwiki.com).
- It is connected to the company's online billing system and rings the bell whenever a new payment hits its bank account, giving the sales team further incentive to make more sales and everyone else a chance to celebrate every success.
- Casting a bell from scratch was always going to be a stretch, so the first step was to investigate what bells could be sourced elsewhere and reused.
- An initial discussion with a campanologist friend quickly found some very nice tuned bells, but sadly they were outside the available budget.
- The customer on the choice led to their settling on a traditional brass ship's bell.
- the next step was to work out how to mount it.
- They just needed to devise a way to assemble the two parts: electronics and bell.
- The following photo shows some of the initial sketches made in Adrian's notebook,

- Early design ideas for the Ackers Bell.
- They thought wood made the best choice of material to complement the brass of the bell but also wanted a darker wood.
- In addition, the potential joint design would require wood a fair bit thicker than the 3mm ply, so they finally chose an 8mm thick oak from the range of hardwoods at the local timber merchant.

- Unfortunately, some test cuts—or more accurately, test burns—showed that the oak was too hard for either of the readily available laser cutters to manage.
- Further experimentation was required.
- For the choice of wood, they tried a variety of different veneers.
- In the end, a dark beeswax (used in polishes) on the birch ply (**Birch** wood **is** a light wood with a very fine grain.) gave a good colour with the added benefit of some protection and treatment for the wood.
- student from Liverpool University who was spending some time at the company on an internship. He came up with the idea of housing the bell inside a lattice framework of stock 3mm ply, shaped to echo the lines of the bell itself.
- That design meant that although the final form was a fairly complex three-dimensional design, it could be constructed from flat sheets of wood cut on the laser cutter.
- In addition to providing a support to hang the bell, the laser-cut design included a platform to hold the Arduino board and a mounting point for the solenoid— cleverly hidden inside the bell to keep the external profile clean.
- Eventually, they fashioned a shim which adjusted the angle at which the solenoid struck the bell, to make it perpendicular to the bell's surface at the point of impact.

The Ackers Bell, ready for delivery to the customer.