UNIT 3

VAT POLYMERIZATION AND DIRECTED ENERGY DEPOSITION

3.2 DIGITAL LIGHT PROCESSING (DLP)

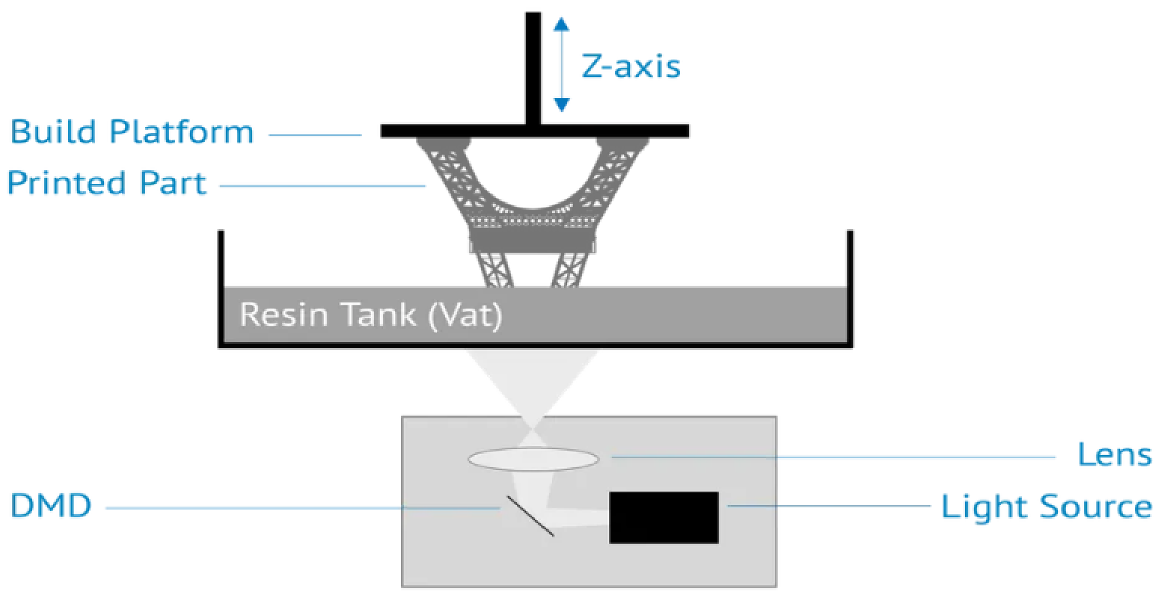
3.2.1 Introduction

As you're probably aware, there are multiple 3D printing technologies available. Some use solid filaments, some use metal powders and some use resins. The ones which utilize a photopolymer resin which cures under a light source are the so-called “vat polymerization “3D printing technologies.

All vat polymerization technologies build parts curing the resin into a solid layer by layer with a certain light source, therefore creating a three-dimensional structure. There are two main vat polymerization technologies, SLA (stereolithography) and DLP (Digital Light Processing). It's interesting that both of these technologies are similar, but at the same time different. Follow us along to the following paragraphs where we'll explain how DLP works and point out the differences with SLA.

3.2.2 What a DLP 3D Printer Looks Like

The best way to understand how a machine works is to understand its anatomy, don't you agree? Well, for this exact reason we'll first explain what components make up a DLP 3D printer before describing how the printing process works. The main components of a DLP 3D printer are the following: digital light projector screen, DMD, vat (resin tank), the build plate and the elevator for the build plate.



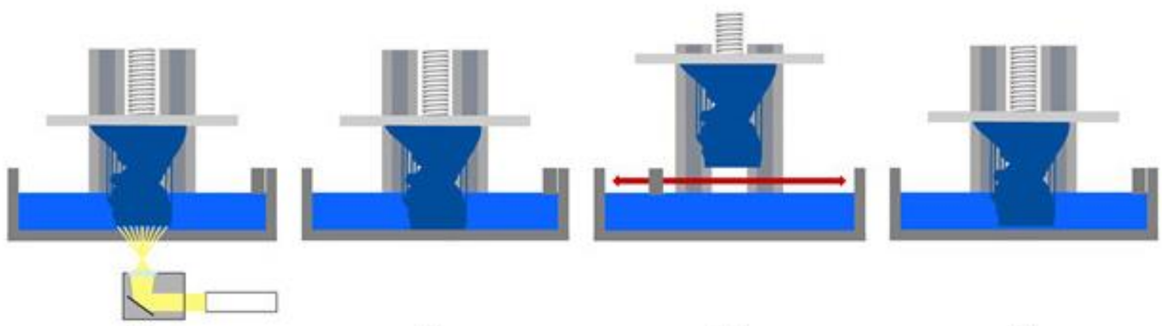
The digital light projector is the light source of a DLP 3D printer. The DMD (Digital Micro mirror Device) is a component which is made of thousands of micro mirrors used for navigating the light beam projected by the digital light projector.

Next up the line is the vat, which is basically a tank for the resin. However, the vat needs to have a transparent bottom so that the light projected by the digital light projector reaches the resin and cures it.

The build platform is simply the surface the printed objects stick to during printing. The z-axis is also a self-explanatory component, used for slowly lifting the build platform during the printing process.

3.2.3 The Printing Process

Now that you're hopefully more familiar with the main components of a DLP 3D printer, it's time to take a closer look at the printing process itself.



3D Models & Slicing

Naturally, everything starts with a 3D model. To make sure that the 3D models are well prepared for 3D printing, the user makes use of a so-called 'slicer software' which is either provided by a third party (there are open source versions available) or the printer's manufacturer. The main purpose of slicer software is to give the user the ability to set all the parameters for the printing job, and then prepare a file that can tell the printer what to print. For example, the users define the print speed, layer height and support material positioning in the slicer. After that, the slicer quite literally virtually slices the 3D model into hundreds of layers.

After the slicing is done, we are left with a PNG stack of images that is flipped through like a picture book, one layer at a time until you reach the last layer of the model, our default layer thickness is 100um. If a part is 100mm tall, there is 100mm/100um = png number, each image is displayed on the UV projector which cures the UV photopolymer 100um's at a time.

Note that this is different from a technique like FDM: With 3D printing techniques that use machines with multiple motors on gantry's, like FDM printing, you need a different kind of file in a format called g-code. Think of g-code as the language for some 3D printing techniques, but also

CNC machining for example. The g-code file contains all the important print parameters as well as the locations of the individual layers.

3D Printing the File

As for any 3D printer, the first step of the printing process is uploading a 3D model to the printer. When that's done, the resin needs to be poured into the vat. That's then followed by the build platform lowering into the resin tank and the resin. The build platform lowers into the resin to the point when only a tiny bit of space is left between the vat's bottom and the build plate.

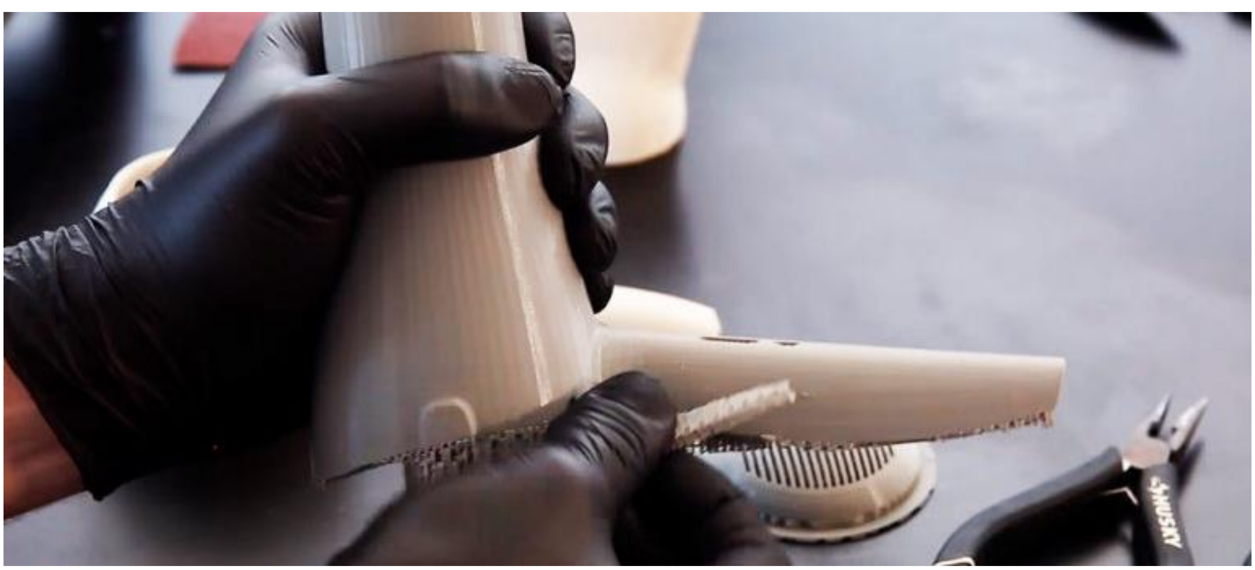
Interestingly enough, the tiny bit of space left between the vat's bottom and the build plate is specified by the layer height of the future part. If the desired layer height for the part is 50 microns, then the space left between the two is set to 50 microns.

When that's all set and done, the digital light projector starts its work. It flashes an image of the individual layer. The projected light making the image of the layer is then guided to the transparent bottom of the vat in the pattern of the layer by the DMD.

When the image of the layer reaches the vat's bottom, the resin is cured into a solid forming the first layer. In order to create the space in the vat for the next layer to be cured, the build platform moves up one layer in height. Well, to be more precise: the platform usually needs to move up more than 1 layer thickness to allow for resin to flow black under the build head. This is especially true for higher viscosity resins. Then, once again, the digital light projector flashes an image of the layer to the vat's bottom causing yet another layer to cure into a solid. That process is repeated until the entire part is finished.

Post Processing 3D Printed Parts

Believe it or not, the parts are still not yet completely ready to use after printing. Parts made from the photopolymer resin require UV light treatment after printing. The parts exposed to the UV light for a certain amount of time, usually dictated by the resin's manufacturer. Exposure of the parts to the UV light ensures the parts are cured correctly and ready to use.



3.2.4 The Pros and Cons of DLP

Naturally, DLP comes with its own pros and cons. Since DLP is a technology which shares a bit or two with SLA, most of its pros and cons are made in direct comparison with the capabilities of SLA.

For that reason alone, let's just remind ourselves what makes SLA and DLP different before jumping into the discussion about DLP's pros and cons: The core difference between SLA and DLP is the light source used for the solidification of the resin. DLP uses a digital light projector screen which flashes the image of the layer and therefore cures the resin in the form of the layer.

However, despite SLA and DLP being the technologies of similar nature, SLA 3D printers cure resin in a much different way. Instead of the digital projector screen, SLA 3D printers use a laser. The way the laser cures the resin into layers is by "drawing" the layer's pattern on the bottom of the resin tank while curing the resin.

Speed

This all leads us to the first benefit of DLP when compared to SLA. Because the digital light projector of a DLP 3D printer flashes the entire image of a layer at once and therefore cures the layer, layers are made fast. On the other hand, the laser in the SLA printer has to go "point by point" to cure a single layer. SLA 3D printers don't cure layers slowly, but DLP does it quicker with the single flash of the layer's image.

You could say that the digital light projector screen is the two-sided sword for DLP 3D printers. As much as the fast layer curing is a great benefit, the same digital light projector which makes it all possible is also the reason that causes one of the DLP's biggest limitations.

Precision

Because the digital light projector used as the light source in a DLP 3D printer is a digital screen, it's made of pixels. These very pixels which make the image of the layer used for curing the resin are later translated into three-dimensions. So, the layers of a part printed on a DLP 3D printer are made of many “3D pixels” called voxels. The best way to think of voxels is to imagine tiny bricks which all together form the part's layers. Remember that the voxels are indeed very tiny, meaning that it's almost impossible to see them.

The limitation of DLP in comparison with SLA caused by voxels is the possible lack of details on a complex curved structure and the rougher curved surfaces. Because voxels are like tiny bricks, it's tough to produce a very smooth curved surface.

For the sake of understanding this in the best possible way, think of LEGO bricks. No matter how many LEGO bricks form a curved surface, it's not going to be 100% smooth, right? The same is for DLP. Despite all this, DLP still produces very nice detailed parts. The precision of the machine is of course projector dependent. As you know, projectors have advanced from 1080p to 2k and now 4k and soon to be 8k. Some of the latest DLP machines get sub 50um accuracy.

Another limitation of DLP when compared to SLA is about printing large detailed parts. Because the resin is cured into layers with a digital image of the very layer, the image size dictates the resolution. As the layer's image size increases, the resolution decreases. This doesn't mean that big parts printed with DLP have bad quality, not at all. Instead, the general rule suggests that the same part when printed in larger scale might suffer a bit in the detailed parts of the model.

3.2.5 What about the strength of the printed parts?

Well, parts printed DLP can be surprisingly strong considering the material they're made of - photopolymer resin - plastic. Traditionally DLP and therefore SLA usually weren't used for the manufacturing of parts which are under load, but more for the parts which prioritize the aesthetics and dimensional accuracy. Ideal for making visual prototypes. Recently there have been significant developments in this area. The strength of the parts is dependent upon the specific polymer that is chosen and some DLP resins from BASF, or Henkel are equal to or greater in strength than traditional injection molded parts.

Accuracy

Let's end the discussion of DLP's pros & cons with a positive note by highlighting one of DLP's biggest advantages in the world of 3D printing in general. Alongside SLA, DLP is considered to be one of the most accurate 3D printing technologies. The details it can produce on a part are truly something to behold.

3.2.6 Materials for DLP

As you already know, DLP 3D printers use liquid photopolymers in the form of a resin. There are various different resins out there and so are the price ranges. However, there's always the good old general approximation. The standard resin which is also the cheapest resin usually costs from about $45 to $55 per liter.

The prices go up significantly when we step into the territory of resins used for industrial purposes. These resins, which are castable and very high detailed can cost several hundreds of dollars per liter. In general, you're looking at around $350 and upwards per liter of such resin. As you can tell by the prices, the resin is quite more expensive than filament used for FDM 3D printing. Resins are also more tricky to handle, but their shelf life is also limited. Most of the time, resins have a shelf life of about 1 year. Up until recently the resins for DLP didn't exist in many colors (usually neutral color like black, white and grey), but new developments make that resins can have CMYK colored pigments added to them commercially, thus matching the wide range of colors you can get FDM filaments in.

3.2.7 Applications of DLP

Great dimensional accuracy and the fast print speed make DLP a rather desirable choice when it comes to the manufacturing of parts. It's important to keep in mind the fact that DLP is unable to produce parts with great strength, it's much more suited for making accurate and beautiful parts which are not intended to deal with the load. These days, the most common applications of DLP include the dental, medical and jewelry industry.

Dental Industry

The dental industry is all about precision, right? Dentists work with tiny complex parts every day, making sure each patient is satisfied. Well, since DLP is able to produce parts with such great dimensional accuracy, it's an ideal technology for the industry. DLP 3D printers are usually used for the making of models of patient's mouth. Thanks to the other great benefit of DLP which is the print speed, these mouth models are created in a matter of hours instead of a few days.

Medical & Healthcare Industry

The medical industry was one of the earliest adopters of DLP technology. There are hundreds of different applications of DLP in the medical industry, but the most impressive one refers to the production of hearing aids. Because hearing aids need to be individually suited for each customer since everyone has a different ear shell, the process of making the hearing aids is exhausting and long-lasting.

Vat polymerization technologies, which include both SLA and DLP have revolutionized the way hearing aids are made with a goal to make them both cheaper and better-fitting. The process of making hearing aids is now much faster and efficient. The 3D scan of the patient's ear shell is made and turned into a 3D model, which is then 3D printed on a DLP 3D printer.

Thanks to 3D printing, more patients are able to get their hands on hearing aids at a cheaper price, with a better fit. Studies have also shown that 3D printers reduced the returns of hearing aids caused by bad fittings.

Jewelry Industry

The jewelry industry is also one of those industries which require ultimate precision and great details, which makes a DLP 3D printer a perfect tool to help in the production. DLP 3D printers are often used for the production of jewelry with very fine details via the investment casting manufacturing process. DLP 3D printing sometimes even enables the production of ultimate details which otherwise won't be possible.

Midsole manufacturing

A promising application of DLP is the manufacturing of midsoles. This type of application is still in its development. Adidas is one of the brands which utilized a DLP 3D printer in the production of a sneaker named Future craft 4D. Adidas decided to manufacture the revolutionizing midsole with 3D printing is due to its complexity. The innovative midsole of the Adidas Future craft 4D sneaker seeks to provide extreme comfort and great performance for runners. The midsole features such a complex design that it wouldn't be possible to produce it without 3D printing.

For the means of producing around 100.000 pairs, Adidas partnered with a company named Carbon. Carbon is a young company which invented 'Digital Light Synthesis,' a 3D printing technology similar to DLP, but improved. DLS is special for continuous printing thanks to the continuous motion of the build plate elevator. Standard DLP machines pause at a certain height until the layer is finished, but Carbon's 3D printers continuously raise the build plate.

Apart from that, Carbon's 3D printers are also special for creating a tiny zone of uncured resin which constantly flows between the part and the bottom of the vat. This ensures that the parts never stick to the build plate, excluding the need for the elevator to stop, but instead making it possible for the elevator to constantly move upwards. Another new additive manufacturing company is Origin, which focuses on creating a 3D printer that can be developed upon by material companies. Origin has partnered with large chemical companies such as BASF, Henkel, and DSM to create unique photo polymers at a low cost that can be used to mass manufacture products. The Origin One uses a process called 'Programmable Photo Polymerization' which allows the user end-to-end control of the photo polymerization process to create unique material properties for each application.

3.2.8 Selection Criteria of DLP Printers

DLP printers are readily available to the public, giving buyers many options when choosing one for their next 3D printing project. To help narrow the search for the best fit DLP printer, this article will outline some of the key selection criteria for DLP printers. Note that this list does not contain every specification but should clarify how to choose one based on quantifiable metrics.

Personal vs. Industrial Use

There are many types of DLP printers, some with more functionality than others. Determining why and how you will use your 3D printer is the first decision when sourcing one, as you want to make sure it can handle the task at hand. If primarily interested in 3D printing as a hobby, or making small parts for prototypes, consider an entry-level desktop printer. On the other hand, if you need a printer that can handle large parts and will run for many hours on end, consider a larger industrial DLP printer. The price of a printer does not directly correlate to its effectiveness; choose a printer based on application and find a printer that can provide the right parts within the timeframe you need them.

Resin Type & Print Speed

There are many choices when considering a resin for your new DLP printer, but not all printers can handle all resins. By specifying your desired material(s) and mechanical properties, you can outline the resin you need and eliminate printers that are incompatible with those resins. Also, some specialized materials such as metal resins will require specialized printers, so be sure to factor this in when finding a DLP printer. If unsure of what materials you will use, find a printer that is compatible with many different types to provide a large material selection for your project.

The type of resin used will also directly impact the speed with which the print finishes. Due to viscosity, hardening time, and other features of the resin, the time to finish a part will invariably change. If looking to increase the pace of printing, find a thinner resin with a fast cure time, or find a printer that uses unique advancements to cut down on printing times.

Dimensional Accuracy, Minimum Layer Thickness, & Minimal Printable Feature Sizes

How accurate and precise does your print need to be? Most printers on the market should have defined minimum wall/layer thicknesses, minimum detail sizes (also known as minimal printable feature sizes), maximum dimensions, and standard accuracy specifications. These values will determine how loyal your part will be to its original 3D model, as well as how much post-processing must be done to it. Typical accuracy of DLP printers is within 0.2% of true value, but also know that this changes with exposure to direct sunlight/UV source. Define your necessary tolerances before looking for a machine.

Physical Dimensions, Weight, & Onboard Electronics

Determine the desired footprint of a DLP printer. These machines can be quite large and heavy, and their weights can easily exceed 300 lbs if buying a larger printer. Ensure that you find a printer that will fit your workspace.

Also, determine the maximum effective build volume you will need for your 3D prints. All DLP printers will specify their effective build volumes, which bound the maximum part size they can make. If interested in small, relatively flat parts, then you can stick to DLP printers with small build platforms and low volume vats. If looking to print large, dense parts, then a larger vat volume, build platform, and elevator will be needed to accommodate for the increased size.

Finally, determine what electronics will be needed in your DLP printer. Many come with build-in controller displays and connectivity options such as Wi-Fi chips, ethernet ports, SD & USB slots, and other features that will make usage more streamlined. Some may even have built-in storage to save 3D models and easy-to-use software for non-technical individuals.

3.2.9 Advantages & Limitations of DLP

DLP printers are a fantastic option for 3D printing, and in some situations even beat out their tried-and-true SLA counterparts. DLP still has its limitations, however, so this section will show the pros and cons of choosing DLP over other 3D printers.

Starting with the advantages:

- DLP printers are highly accurate and have great surface finishes when compared to other types of printers. Their surfaces can be taken to a high polish and are aesthetically pleasing.
- Though sometimes comparable, DLP prints generally take less time than SLA prints thanks to their uniform projection of layers.
- Specialty materials such as transparent and castable resins set this 3D printing technology apart from most other machines.
- Desktop (bottom-up) DLP printers are very affordable and are plug-and-play in nature.
- DLP parts are isotropic – they are equally strong in all X, Y, or Z planes, which is not the case with FDM parts. Also, DLP parts are 100% watertight and generally unreactive with anything besides light.
- Specialized DLP printers can make sintered metal parts, eliminating many of its material downsides (for an increased cost).

Now for DLP printing’s disadvantages:

- DLP prints are less useful for functional prototypes and are best suited towards visual prototypes due to their brittle nature.
- Sunlight damages the appearance and mechanical properties of resin parts, meaning that DLP printed parts are not reliable in outdoor applications.
- In general, DLP printers have fewer material choices than other 3D printing technologies (though this is rapidly changing)

- While still much more accurate than FDM printers, DLP printers produce voxelated parts that must be sanded down and smoothed to reach the same surface quality as SLA parts right out of print.

3.2.10 Conclusion

As you've seen DLP 3D printing is an interesting and complex technology that currently undergoes rapid developments. Because of its speed, precision, and material versatility it holds the promise of enabling mass production. That leads to expect you'll encounter the DLP printing technology and DLP printed parts more and more, and that it will show up in many new applications.