



What Does Resolution Mean in 3D Printing?

What do 3D printer manufacturers mean when they talk about the resolution of a printer? And, more importantly, how do these numbers affect the final printed parts? Read on to find out.

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Demystifying 3D Printer Specifications

When the 3D printing industry exploded in 2014, a myriad of new companies rushed in, claiming to be the next revolution in 3D printing. Every week, a new professional 3D printing company would crop up—each of them touting a product with a new feature or a unique specification.

Naturally, all of this novelty caught the attention of consumers and business buyers. With each product launch, more and more people became interested in applications for 3D printing, particularly for industrial engineering and design prototyping. However, as that interest grew, so did the use of confusing marketing jargon in professional 3D printer specification charts.

To illustrate that trend, here's a common specification comparison chart:

Technology	DLP-SLA	Laser-SLA	LCD-SLA	DLP-SLA	DLP-SLA	Laser-SLA	FDM
XY Resolution	25~ 80µm (adjustable)	140µm	75µm	100µm	37~ 100µm	250µm	> 100µm
Layer Resolution	10µm (Customized)	25µm	10µm (Customized)	20µm	5µm	5µm	100µm
Max Speed	3.8 in/hr (Z 100µm) (very fast)	1.2 in/hr (Z 100µm)	1000cc/hr (=1.7in /hr) (Z 100µm)	1.0in / hr	2.7 in/hr (Z 100µm)	-	Slow
Surface	Good	Good	Good	Good	Good	Good	Good (Lower speed)
Max Print Volume (inch)	6.1 x 3.7 x 7.1 (L x W x H)	5.7x5.7x 6.9 (L x W x H)	7.5x4.8x 7.8 (L x W x H)	5.0x3.2x 9 (L x W x H)	7.5x4.25x 9.4 (L x W x H)	7x7x8 (L x W x H)	11.2x6.0x6.1 (L x W x H)
Material	Resin	Resin	Resin	Resin	Resin	Resin	PLA
XY Resolution Control	YES	NO	NO	NO	YES	NO	NO
Price	\$1,699+	\$3,999	\$1,399	\$3,499	\$2,999	\$2,999	\$1,999

What do you notice about it? What stands out is all of the capital letters, numbers, and parentheses. One might look at this information and assume that they needed the highlighted printer. After all, it has the best specs and the most impressive (albeit confusing) set of numbers.

The problem? That chart doesn't actually say much of anything.

If you were buying a professional 3D printer, this chart wouldn't help you understand what really matters: how the part will come out. That approach doesn't help customers choose the right 3D printer for their needs and, in the long run, it doesn't help the professional 3D printing industry grow.

This isn't meant to be a super technical breakdown of every 3D printer specification out there. Instead, the goal is to shed light on what some commonly discussed 3D printer specifications really mean and help businesses understand what they should actually be looking for.

Let's start by diving into some of the individual specs listed in the chart above.

XY Resolution

XY resolution is the most talked about specification for stereolithography (SLA) 3D printers. In many circumstances, it also happens to be the most misunderstood.

Typically, XY resolution is used to describe the details or features of a part. In the chart above, the XY resolution listed for this digital light processing (DLP)-SLA printer (25-80 microns) is amazing, but what does that number actually describe?

In all likelihood, it's the resolution of the actual projector, which is why it's a variable range. That number doesn't tell the whole story. Ultimately, there are a plethora of variables that can affect a printer's output. By looking only at XY resolution, we're led to believe that there's a 1:1 ratio between the size of a pixel on the projector and the cured resin of the part.

Here's why that's a faulty calculation: It doesn't take into account the material itself, the print process, the software used, or numerous other variables. As a result, this spec doesn't tell us anything about what you could actually produce with this machine.



These two rooks were printed with the same XY resolution. The rook on the left looks smoother because it is made with our new matte black material.

Layer Thickness

Layer thickness is typically used to describe the surface finish of a part. While the thickness of a layer is often better at lower layer heights, the issue is that the roughness of a surface is not standard in relation to the layer height.



Black Resin (25 microns layer height).



Castable Resin (50 microns layer height).

To illustrate this, consider these images of two parts, both printed on the Form 2 to show that the relationship between layer thickness and surface finish is not what one might expect. In the pictures above, you'll see two rings—one printed in Castable Resin and the other in Black Resin. The Castable Resin has a slightly smoother surface finish and the micro pavé is a bit crisper.

Here's the catch: the ring printed in Castable Resin was actually printed at 50 microns, whereas the ring printed in Black Resin was printed at 25 microns.

The reason the ring printed in Castable Resin looks better at 50 microns is because this resin was designed to produce the best results at 50 microns. Also, the Formlabs team dialed in the print/material settings on the Form 2 to make sure it produced the best results for casting.

Some companies list Z-axis resolution instead of layer height, which has the same usefulness as XY resolution because it speaks to the distance the [Z-axis motor](#) can mechanically move/step.

The bottom line: just because a printer manufacturer claims "X" layer height, doesn't mean that printer will have a better surface finish.

Maximum Speed

Maximum speed is a hard metric to quantify, particularly across different printers. Again, there's not enough information for us to really understand how these printers will perform when producing parts. Not only do the standard variables impact print time, so too do factors like geometry and orientation of the part.

For instance, a taller part will take more time than one oriented closer to the build plate because there are more layers to print. Also, the way that an object is oriented and supported will change the time it takes to print the part.

A common benchmark is how fast a printer can produce a one-inch cube. The problem with that example is that it's very specific. Unless you're a dice manufacturer, one-inch cubes aren't a great way to estimate how long your part will take to print.

Surface Finish

Decisions in life would be so much easier if "good" and "bad" were the only ways of quantifying specifications. Surface finish was discussed earlier in relation to layer thickness, but one thing to keep in mind: there is no real specification for surface finish. Surface finish can differ depending on the geometry (curved vs. straight surfaces) and orientation. The only way to compare surface finish between printers is if every 3D printing company published results from an industry standard part and profilometer. Unfortunately, this is probably not going to happen anytime soon.

Accuracy

Accuracy isn't included in the chart in the introduction, but it is something that a few 3D printer companies have been publishing recently. The mistake that a lot of 3D printer buyers make is assuming that XY resolution or layer thickness will determine the accuracy of the final part.

The truth is that global accuracy is hard to determine, largely because it can be impacted by length, geometry, and orientation. Here's an example of an accuracy statement for a large industrial machine:

Accuracy (typical)	0.001-0.002 inch per inch (0.025-0.05 mm per 25.4 mm) of part dimension. Accuracy may vary depending on build parameters, part geometry and size, part orientation, and post-processing.
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Accuracy for a large industrial printer (priced around \$100,000).

At first it seems all parts will be within 25-50 microns but the footnote references just about every aspect of producing a part.

A Better Way to Evaluate Professional 3D Printers

It's not that everyone in our industry is trying to mislead you. The truth is, the 3D printing industry as a whole lacks a set of standard specifications that adequately describes what you can expect from a 3D printer. Even with established technology, specifications don't tell the whole story.

Output is truly dependent on hardware, operating system, application, and several other factors.

With that said, all hope is not lost. Here are four tips that will help you effectively evaluate different 3D printers:

Talk to your vendor. You're investing in something to help you iterate faster and build better products. The best way to better understand a company's technology and how its products work is to talk to its team.

Request a sample part. We've established that 3D printer specifications aren't a great way to evaluate what a printer can actually produce. To see if a specific printer will meet your needs, ask your vendor to send you a sample part. Once you receive the sample, ask the company to provide more information. For example:

How long did it take to print?

How much material was used?

What's the layer thickness?

If you do this a few times with a few different printers, you'll see that surface finish from different printers can vary, even at the same layer height.

Ask for custom sample parts. Not all companies will do this, but it doesn't hurt to ask. Seeing your design printed will help you to understand what you can expect when you begin running the machine. If most of your parts are protected IP, try designing a part with similar features to avoid worrying about confidentiality agreements.

When sending a design for a custom sample, make sure the design is representative of your business or use case. For most prototyping applications, we typically recommend sending a design that represents roughly 80 percent of your business. Sending a complicated part that is a small percentage of what you'll be printing can lead to purchasing a solution that doesn't really make sense for your work.

Look for design guides. Most 3D printing manufacturers have published design guides that help customers understand how to better use and design models for their printers. Guides like the [Formlabs design guide](#) provide specifications for different types of features.

Resolution vs. Minimum Feature Size

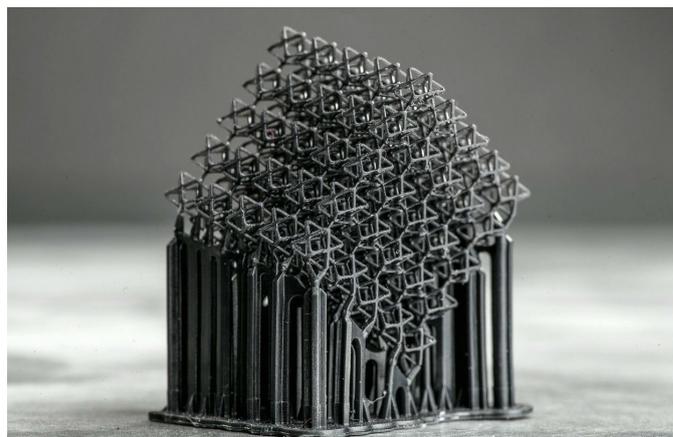
Technology has been in a resolution war for decades. Televisions recently quadrupled pixel counts from HD to 4K and are poised to do it again soon to 8K. Cell phones, tablets, and anything with a screen will have its resolution as the lead on the spec sheet, provided that it's something to boast about. But this is nothing new. Resolution wars have been waged since digital technology became popular, and the printing industry was one of the first battlegrounds.

If you were around in the 80's and 90's, you remember Canon, Brother, HP, Epson, and Lexmark (among others) battling it out for print speed and resolution. What started at 100x100 dots per inch (DPI) quickly escalated to 300x300, then 600x600, and finally the current industry standard of 1200x1200 DPI. Back then, the meaning of these values was clearly understandable; even the units made perfect sense. Unfortunately, things get more complicated when you add another dimension to printing.

Resolution in Three Dimensions

In 3D printing there are three dimensions to consider: the two planar 2D dimensions (X and Y) and the Z dimension that makes it 3D printing. Since the planar and Z dimensions are generally controlled via very different mechanisms, their resolutions are going to be different and need to be treated separately. As a result, there is a lot of confusion about what the term "resolution" means in 3D printing and what level of print quality to expect.

The Z-axis resolution of a 3D printer is easily determined and therefore widely reported even though it is less related to print quality. The more important XY resolution (minimum feature size) is measured via microscopic imaging and is therefore not always found in spec sheets. Practically, it means that you should pick a printer that performs well in both categories like the [Form 2](#) does.



Level of detail is impacted by the resolution in all three dimensions.

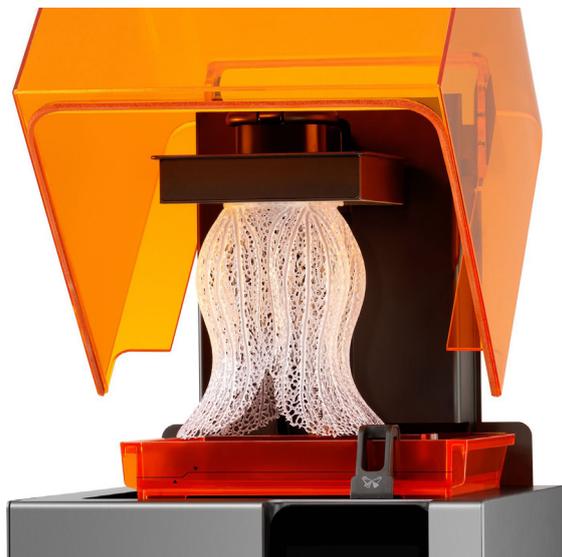
SLA vs. FDM

A lot has changed since the first desktop 3D printers became available to the public. Now stereolithography (SLA) 3D printers, like the Form 2, are competing for the same desktop spots as FDM printers. One of the main advantages that SLA printers hold over their plastic-melting cousins is print quality: SLA printers produce significantly smoother and more detailed prints. While SLA printers can usually also achieve significantly smaller layer heights, the reason for the improved print quality lies in their much higher XY-resolution.

Unlike FDM printers, minimum feature size in the XY plane on SLA printers is not limited by melted plastic flow dynamics but rather optics and radical polymerization kinetics. While the math is complicated (and outside the scope of this post), it shakes out to this: features on SLA prints can be approximately as small as the diameter of their laser spots. And laser spots can be really small, especially compared to extruder nozzles.

Laser vs. DLP

Within SLA, there are two main types of imaging systems, laser-based and DLP. Unlike DLP printers, which have a fixed matrix of pixels relative to the build area, laser-based devices can focus the laser beam on any XY coordinate. This means that laser-based machines, given high-quality optics, can more accurately reproduce the surface of a part even when the laser spot size is larger than the DLP pixel size. Whichever printer you choose, it should be able to capture the finest details of your creations, from stress test models to photorealistic busts of famous leaders. The right high-resolution 3D printer will bring your designs to life.

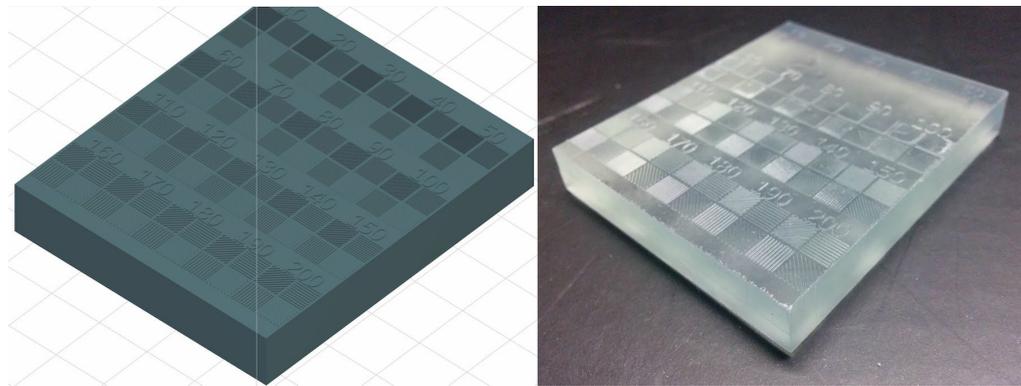


The Form 2 SLA 3D printer has a high Z-axis resolution and a low minimum feature size on the XY plane, allowing it to produce fine details.

Understanding XY Resolution

In the world of 3D printing, no factor influences print quality more than XY resolution. Often discussed but seldom understood, XY resolution (also called horizontal resolution) is the smallest movement that a printer's laser or extruder can make within a single layer. The lower the number, the better the details. Yet this number is not always included in spec sheets, and when it is, the published value is not always accurate. To truly know a printer's XY resolution, it's important to understand the science behind the number.

Practically, how does XY resolution affect your 3D prints? In order to find out, we decided to test the Form 2 SLA 3D printer. The [Form 2](#) has a laser spot size of 140 microns (FWHM), which should allow it to print fine details on the XY plane. We put it to the test to see if this ideal resolution holds true.



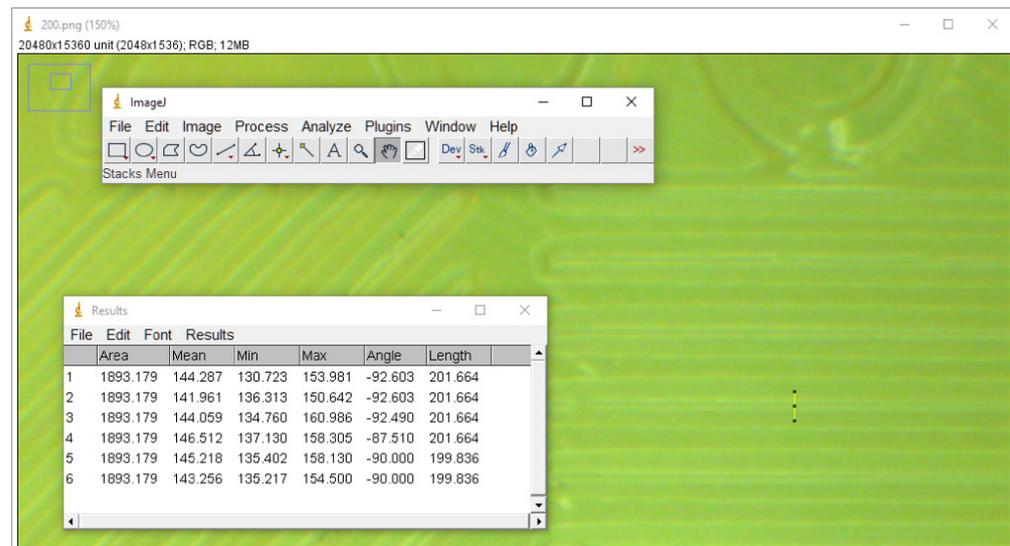
To test the Form 2's minimum feature size on the XY plane, we designed a model (left) with lines ranging from 10 to 200 microns and printed it in Clear Resin (right).

Designing a Test Model

First, we designed and printed a model to test the minimum feature size on the XY plane. The model is a rectangular block with lines of varying widths in horizontal, vertical, and diagonal directions to avoid directional bias. The line widths range from 10 to 200 microns in 10 micron steps and are 200 microns tall, which equates to two layers when printed at 100-micron Z resolution. The model was printed in Clear Resin, washed twice in an IPA bath, and [post-cured](#) for 30 minutes.

Analyzing the Model

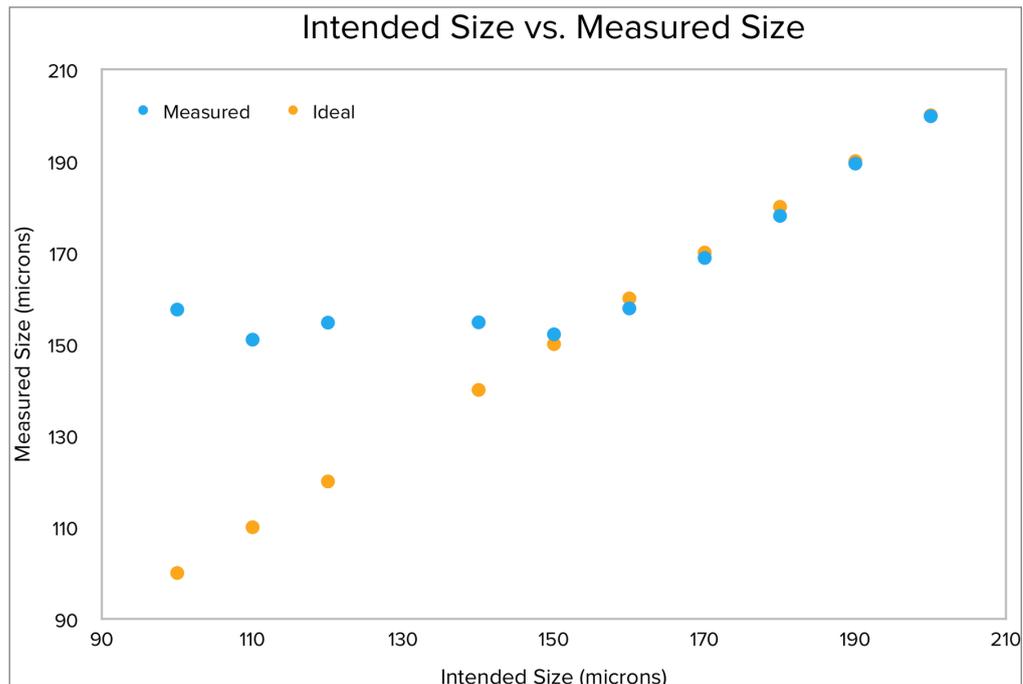
After post-curing, we put the model under a microscope and took high-resolution photos for analysis. Using [ImageJ](#), the NIH's free image analysis software, we first scaled the pixels of the images and then measured the actual widths of the lines printed. We collected over 50 data points per line width to eliminate measuring errors and variability. In total, we printed and analyzed three models on two different printers.



The model was photographed and tinted green to improve visibility. On the right side of the window, the vertical yellow line with black points measures the width of a photographed line.

Understanding the Results

As the print's line width decreases from 200 to 150 microns, the ideal values are within the 95% confidence interval of the measured value. As the intended line widths get smaller than 150 microns, the measured interval starts to deviate significantly from the ideal. This means that the printer can reliably produce XY features as small as 150 microns, about the size of a human hair.



The results indicate that the Form 2 has the same ideal and actual XY resolution for features that are 150 microns and larger.

Based on our measurements, the Form 2's minimum feature size on the XY plane is about 150 microns, which is only 10 microns larger than its 140-micron laser. The minimum feature size can never be smaller than the laser spot size, and there are many factors that affect this value: laser refraction, microscopic contaminants, resin chemistry, and much more. Considering the printer's entire ecosystem, a 10-micron difference is nominal. Not every 3D printer's published resolution holds true, so it's a good idea to do plenty of research before choosing the one that's right for your project. If your work calls for prints with intricate details, look for a printer with an XY resolution that's backed by measurable data, not just a number.

Understanding Z Resolution

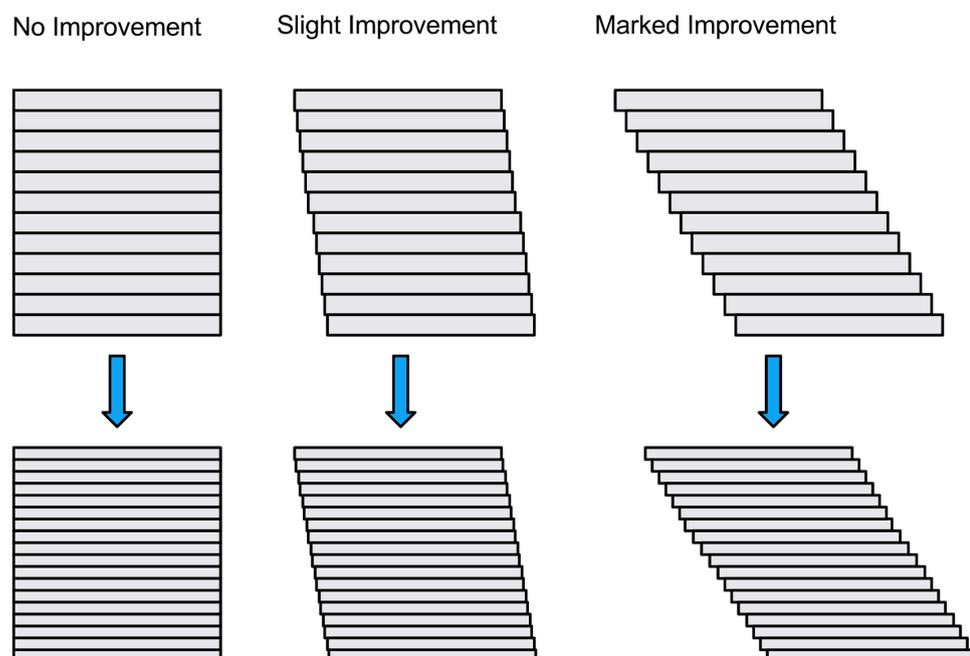
When you read 3D printer spec sheets, you'll see one value show up more than any else: Z resolution. Also known as layer height, Z resolution was the first major numerical differentiation between early 3D printers. Early machines struggled to break the 1 mm barrier, but now layer heights on FDM printers can be sub-0.1 mm thin, while SLA machines are even more precise.

Currently, the [Form 2](#) SLA 3D printer supports layer heights of 100 and 50 microns in [all resins](#). Clear, White, and Castable Resins can achieve Z resolutions as high as 25 microns. This selection of layer heights gives you the ideal balance of speed and resolution. The main question is: what is the best layer height for your print?

Are Smaller Layer Heights Always Better?

High resolution comes with a tradeoff. Thinner layers mean more repetitions, which in turn means longer times: printing at 25 microns vs. 100 usually increases the print time four-fold. More repetitions also mean more opportunities for something to go wrong. For example, even at a 99.99% success rate per layer, quadrupling the resolution lowers the chance of print success from 90% to 67% if one assumes that a failed layer causes total print failure.

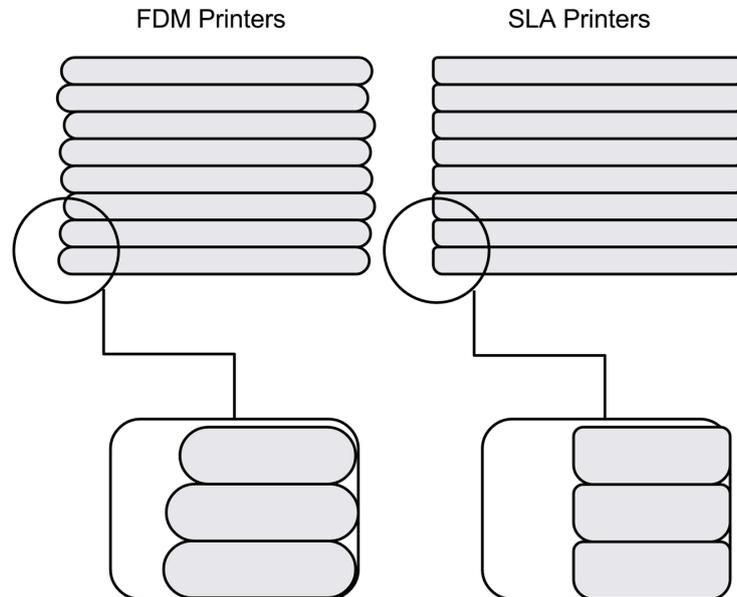
Do thinner layers result in better prints? Not always — it depends on the model to be printed and the printer's XY resolution. In general, thinner layers equals more time, artifacts, and errors. In some cases, printing models at lower resolutions (i.e. thicker layer heights) can actually result in higher-quality prints.



When Thinner Layers Don't Help

Thinner layers are typically associated with smoother transitions on diagonals, which leads many users to generalize and push Z resolution to the limits. But what if the model consists mostly of vertical and horizontal edges, with 90-degree angles and few diagonals? In those cases, additional layers don't improve the quality of the model.

The issue is compounded if the XY resolution of the printer in question is not perfect and “colors outside the lines” when drawing the outside edges. More layers means more mismatched ridges on the surface. While the Z resolution is higher, the model will look like it is significantly lower quality in this case.



When to Choose Higher Z Resolution

That being said, there are times when you want higher resolution. Given a printer with good XY resolution and a model with intricate features and many diagonal edges, dialing down the height of the layers will yield a much better model. In addition, if that model is short (200 or fewer layers) upping the Z-axis resolution can really improve the quality.

Certain designs benefit from a higher Z resolution: organic forms, rounded arches, small embossings, and intricate engravings. As a general guideline, err on the side of thicker layers and only bump up the Z resolution when completely necessary. With the right printer and a certain type of model, higher Z resolution will capture the intricate details of your design.