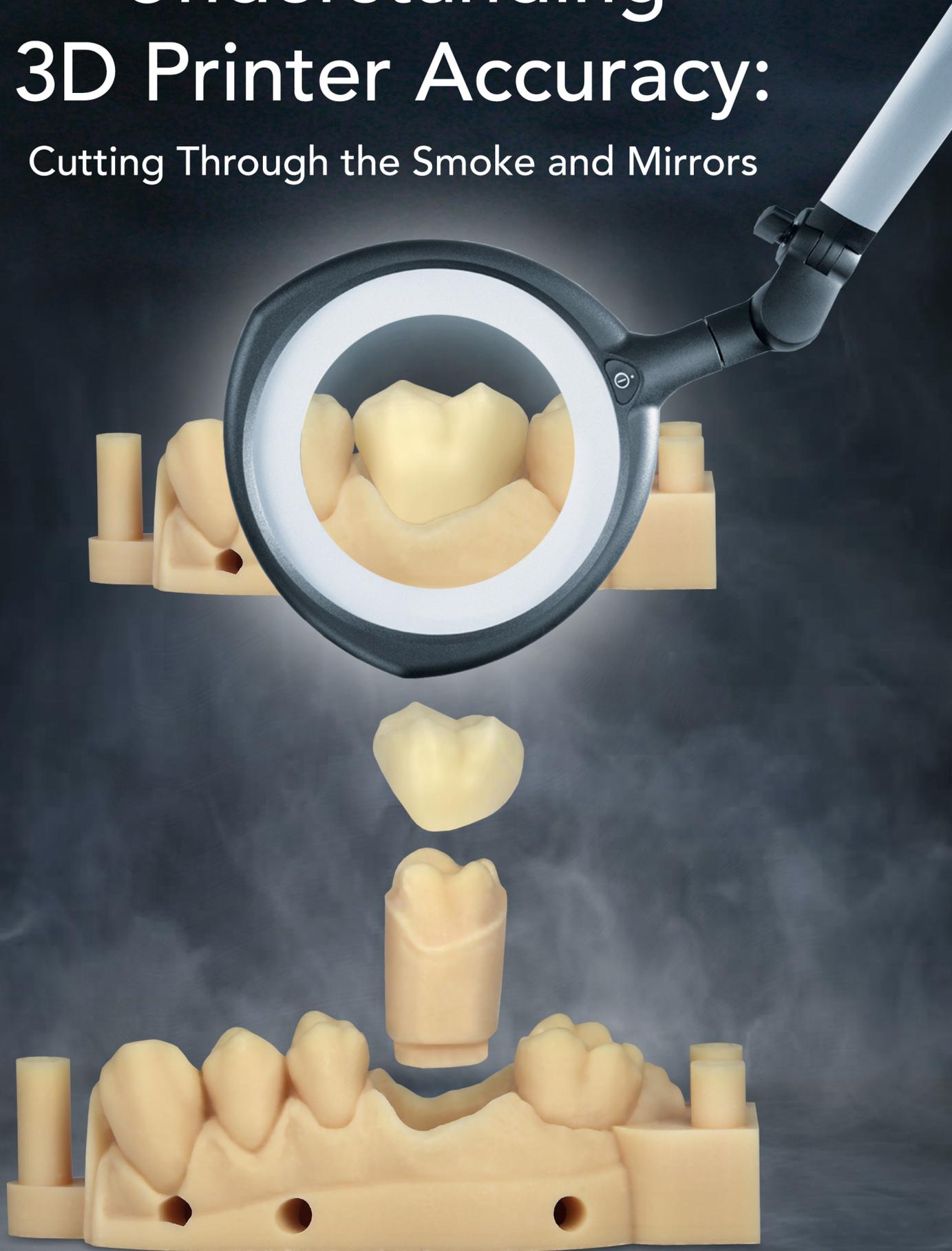


Understanding 3D Printer Accuracy:

Cutting Through the Smoke and Mirrors



Understanding 3D Printer Accuracy: *Cutting Through the Smoke and Mirrors*

Who sells the most accurate 3D printers? Are accuracy and resolution the same thing? What does resolution mean in 3D printing? Is there a relationship between accuracy and resolution? Where does tolerance fit in? When considering final dimensional part accuracy, what matters most: X, Y or Z?

Yes, there is certainly a lot of confusion about accuracy in 3D printing and, unfortunately, a lot of potential customers are deliberately spun in circles on the issue.

As a 3D printer manufacturer since 2002 — known for delivering best-in-class accuracy and surface finish, especially when it comes to tight-fitting crowns — EnvisionTEC believes in giving customers the facts so they can make informed decisions. That is especially true when it comes to critical parts that go in the body or a critical product, such as a car or airplane.

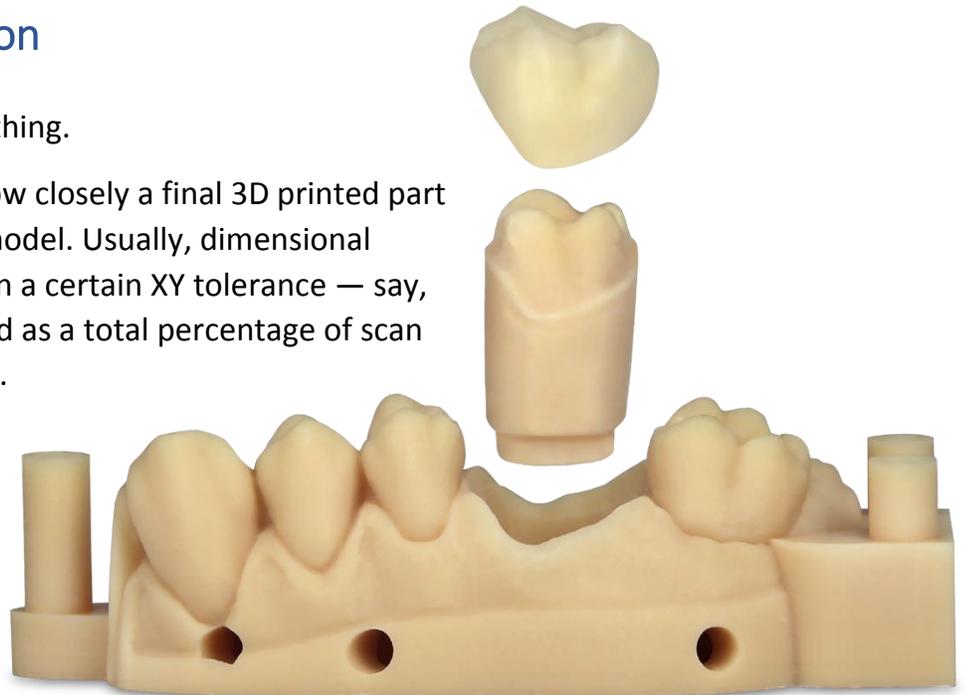
So, let's un-spin the issue:

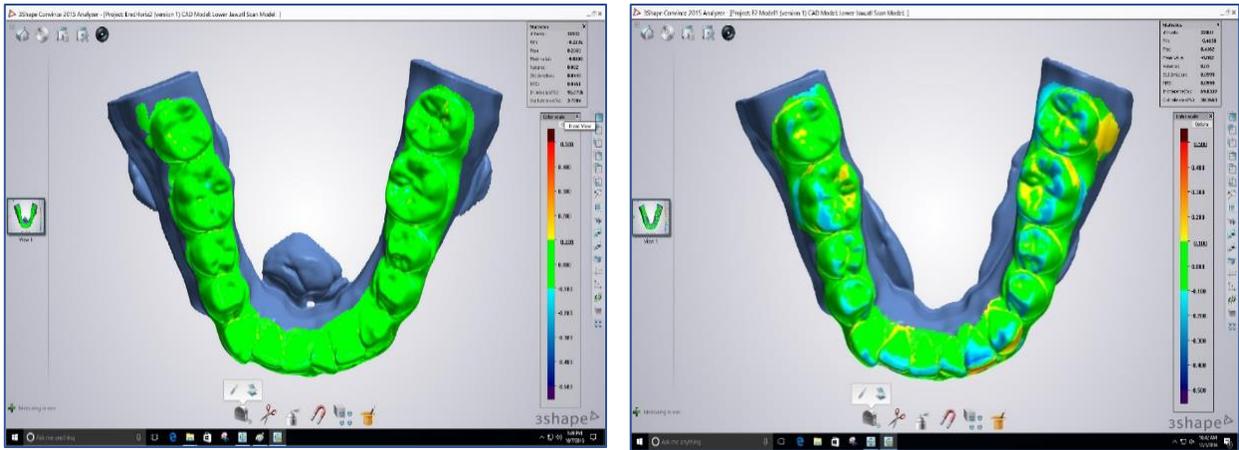
Accuracy v. Resolution

No, they are not the same thing.

Accuracy is, very simply, how closely a final 3D printed part measures up to its digital model. Usually, dimensional accuracy is measured within a certain XY tolerance — say, +/- 42 μm — or it's reported as a total percentage of scan accuracy against the model.

The only way to determine the accuracy that a *particular 3D printer* delivers for a *certain 3D printed part* is





This dental model shown left was 3D printed horizontally on the EnvisionTEC Vida 3D printer and has scan accuracy against the original digital model of 96.3% at 100 µm layer thickness. This dental model at right was printed on a low-priced SLA printer and has scan accuracy against the original model of 69.8%; that means the model is out of tolerance by 30+%.

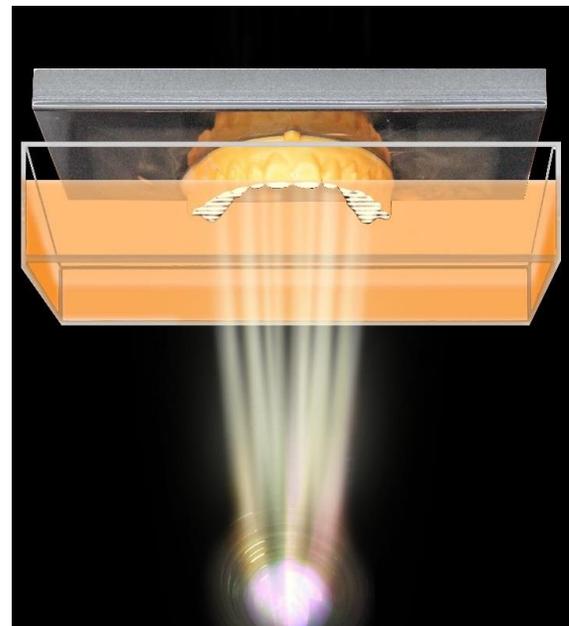
to print the part, scan it and compare the scan to the original digital model.

In fact, it's *very difficult* to say with absolute certainty that *any* given 3D printer model delivers a certain final accuracy, because, as you will learn in this paper, accuracy can be affected by so many factors, including user decisions such as print orientation of the part, the color of the print materials and more.

Resolution, meanwhile, is the fixed number of pixels displayed by a projector when 3D printing using Digital Light Processing (DLP).

For example, EnvisionTEC currently offers the highest definition projector used in DLP printing today, a 1920 x 1200 resolution projector offered in our Perfactory 4 Standard XL LED.

This projector delivers a total of 2.304 million pixels (which is determined by multiplying the number of pixels in X and Y) within the industry's largest DLP build envelope of 7.6 x 4.7 x 9.06 in (192 x 120 x 230 mm).



In DLP printing, a projector exposes light up through a clear tray filled with light-sensitive resin to cure and build an object one exposure layer at a time.

Each pixel in this configuration has a native or actual size in XY of 0.0039" (100 μm). This is determined by dividing the X or Y value of the build area by the corresponding number of pixels delivered X or Y. So, the native pixel size for X in this instance is determined by dividing 192 mm by 1920 pixels.

It's also important to note here: while the number of pixels is fixed, their size and shape is not. For example, if the same projector size is used with a smaller build area, the native pixel size becomes smaller — just as a flashlight beam aimed a wall becomes more tightly focused the closer it gets to the wall.

Consider: the Perfactory 4 Standard also uses a 1920 x 1200 resolution projector but with a smaller build area of 6.3 x 3.9 x 9.06 in (160 x 100 x 230 mm). This results in a finer native XY pixel size of 0.0033" (83 μm).

What's more, not all pixels are square. Some projectors used in 3D printing actually deliver diamond-shaped pixels, which means they have a different size in X and Y.

While it seems like more pixels, and finer pixels, would deliver better accuracy, that's not *always* the case, as you will learn below.

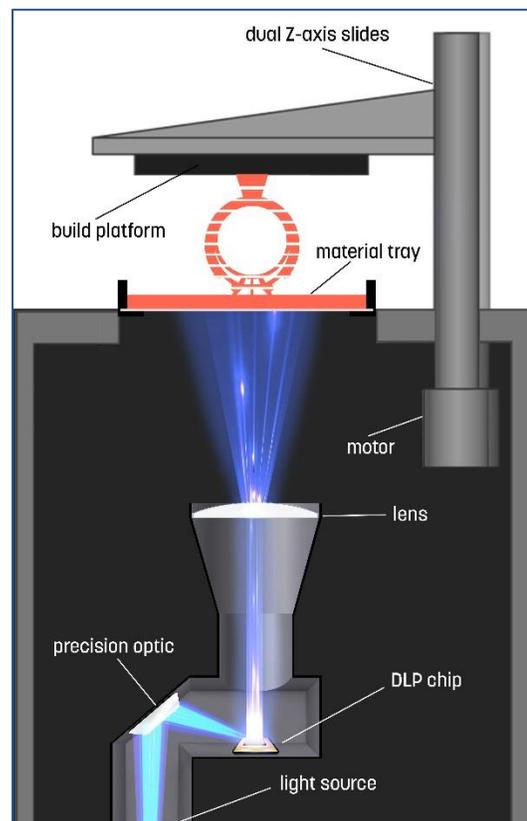
Relationship Status: It's Complicated.

When it comes to the relationship between accuracy and resolution, it's more complicated than the numbers would suggest.

For starters, not all projectors deliver the same high-quality image, even when they deliver the exact same number and size of pixels.

Take a swing through any electronics store to examine TVs or monitors, and you will see that that quality can vary greatly even when the projector resolution and display size is the same.

The quality of the projector used in a 3D printer is a critical starting point for determining how accurately the machine will print, but it's also just one part of the story.



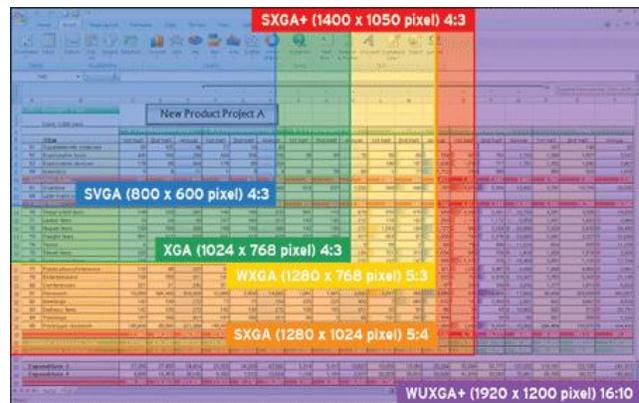


One way to see the quality of the resolution on a 3D printer is to actually look at it, if you can, just as you would when shopping for a TV.

In the case of a 3D printer, lay down a black sheet of paper in the build area to see how crisply the projector delivers an image in white and grays. Look at how the projected image looks across the entire build area, too, because some projectors deliver great resolution in the centermost portion of the build area but not along the far edges.

For the best quality and accuracy, you're looking for a very crisp edge across the entire build area.

But, again, the quality of the projector isn't the only factor to consider when on the hunt for an accurate 3D printer. Beyond the projector itself, other mechanical design and components of a system can also have a profound impact.



*This chart shows some of the projector sizes offered in the commercial market today, and quality can vary greatly based on manufacturer and the quality of the optics used with the projector. **EnvisionTEC primarily uses custom-designed and manufactured optics.***



Mechanical Components Matter

Consider just one moving part: the build plate.

Every time a layer of material is exposed with the projector, the build plate moves up to advance the job and repositions itself in the material tray again for the next exposure layer. If the motion control system isn't highly accurate, then the part being built won't be accurate either.

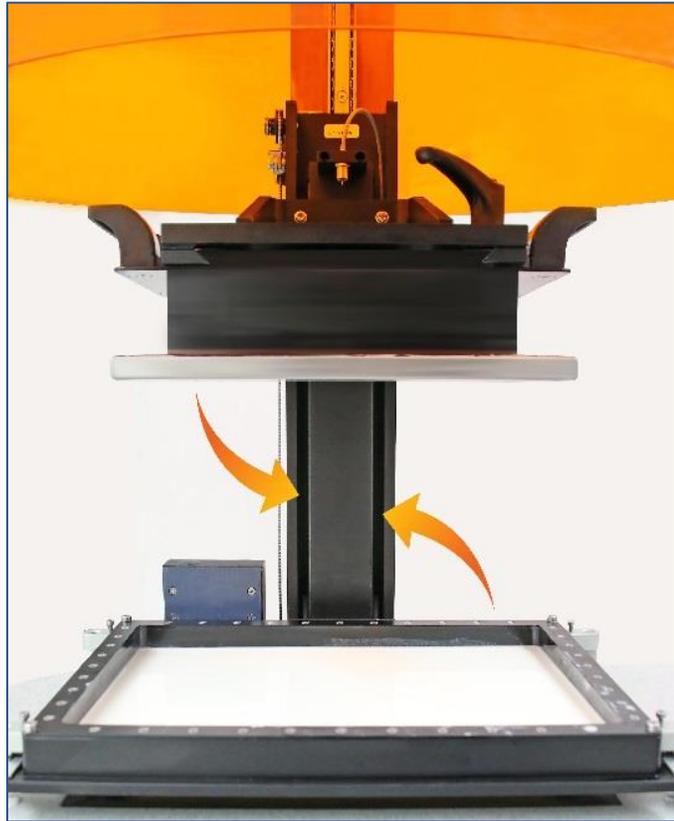
What's more, if the build tray doesn't remain completely parallel to the material tray during this movement — if it tilts to the left or right — you can end up with a lopsided, inaccurate part.

This is why EnvisionTEC uses a dual rail system, as shown here, to move its build plate up and down in the Z direction with high-quality German-engineered motion-control components.

This mechanical design helps to ensure an even and accurate exposure layer in the Z direction.

Many low-cost 3D printers use a single rail system, and it's a decision that can compromise quality.

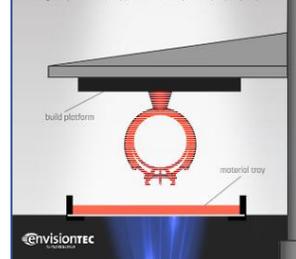
In fact, every moving part of the 3D printer can compromise final part accuracy. This is also why EnvisionTEC provides professional installation for most of its 3D printers, along with a professional calibration, to ensure the highest performance possible after a printer has been shipped and mechanical parts may have shifted during transport.



LEARN EVEN MORE

3D Printing 101: Stay Flat and Parallel

For an accurate 3D print job, it's crucial that the material tray and build platform remain flat and parallel to each other in order to print precise layers. Yet, some budget 3D printers use cheap plastic material trays that impact print quality.



[EnvisionTEC.com/101](https://www.envisiontec.com/101)

Software (and Firmware) is Vital

Because 3D printing is digital production, software and *firmware* — the software that controls the actual machine hardware — is critical.

EnvisionTEC uses many proprietary software techniques to control the projector and mechanical components of the machine so they deliver a higher quality print.

Our software, for example, controls the volumetric depth of each pixel, or voxel, being cured and offers specific exposure strategies for certain applications and geometric shapes, such as dental models.

One of our key patented software techniques is called grayscaleing, an anti-aliasing technique that projects 255 shades of white and gray to black into the resin to feather a smooth surface finish.

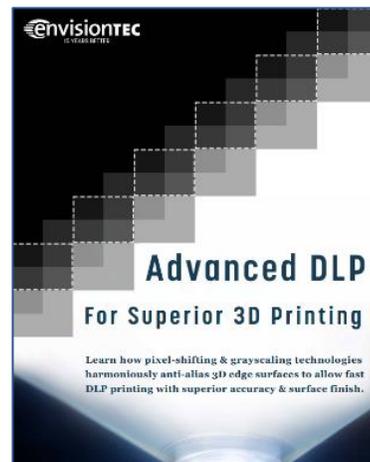
The software works harmoniously with an electromechanical component called an Enhanced Resolution Module (ERM) to deliver a final resolution that is twice as good as any competitor using the exact same projector.

Using grayscaleing and the ERM, EnvisionTEC machines make sure that every Z slice of a part is actually exposed twice, with the second exposure moving a half pixel in X and Y, delivering a superior super-smooth final result.



This is photograph of the EnvisionTEC Enhanced Resolution Module. The projector shines through the center of the ERM, which moves the projector a half pixel in X and Y, to shift the second exposure in a sophisticated 3D anti-aliasing technique.

LEARN EVEN MORE



EnvisionTEC.com/better3D

Multiple Choice: X, Y or Z?

People love to walk up to our team at trade shows and ask, “How thin are your print layers?”

That question belies a pretty hazy truth in 3D printing: Z layer thickness has very little relationship to final dimensional accuracy once you go below 100 μm .

Z layer thickness is actually *a better indicator of surface finish*, because nobody likes seeing those stairstep lines on their parts that they have to post-process. Still, while the smoothest surface finish looks good in the hand, and makes for more comfortable dental pieces in the mouth, it’s not the best indicator of final dimensional accuracy.



While EnvisionTEC is known for delivering best-in-class surface finish — a result of its hardware, software and material processing knowledge — outstanding surface finish does not necessarily mean outstanding dimensional accuracy.

In fact, as independent research has shown, sometimes there is even an inverse relationship between super-thin Z layers and dimensional accuracy.

[Ortho Cosmos](#), an orthodontics blog with whom EnvisionTEC has no financial relationship, did a cross-test of several 3D printers and found:

“Another interesting finding was that the most accurate prints were attained with 100 micron layer thickness (Z res) and when a finer Z resolution was used on

the same machine (50 microns on the Form2 instead of 100 microns) **the accuracy of the print did not improve.”**

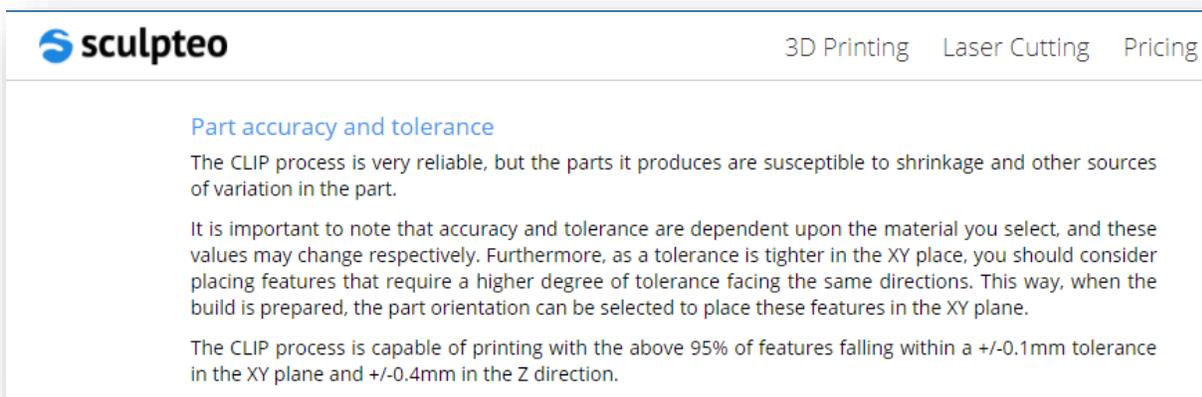
<https://tinyurl.com/orthocosmos>

In fact, their study showed that the average dimensional accuracy in this example declined to 73 μm at a 50 μm Z-resolution setting from 67 μm at 100 μm layer thickness.

Why would part accuracy decline when using a finer Z resolution setting? While there are several potential reasons, it could be that finer exposure layers means *more* exposure layers, twice as many in this example. That, in turn, requires more repositioning of the build plate in the Z axis during the build process and more opportunities for motion control and repositioning errors.

So, when considering what axes matter most when contemplating machine accuracy, the correct answer is usually X and Y — especially if you’re doing curved organic shapes, as with dentistry or hearing aids, that require a tight fit.

But the absolute truth is that it depends on what you’re building, the part’s final purpose and the overall quality of the machine.



The screenshot shows the Sculpteo website header with the logo on the left and navigation links for "3D Printing", "Laser Cutting", and "Pricing" on the right. Below the header is a section titled "Part accuracy and tolerance" with the following text: "The CLIP process is very reliable, but the parts it produces are susceptible to shrinkage and other sources of variation in the part." "It is important to note that accuracy and tolerance are dependent upon the material you select, and these values may change respectively. Furthermore, as a tolerance is tighter in the XY plane, you should consider placing features that require a higher degree of tolerance facing the same directions. This way, when the build is prepared, the part orientation can be selected to place these features in the XY plane." "The CLIP process is capable of printing with the above 95% of features falling within a +/-0.1mm tolerance in the XY plane and +/-0.4mm in the Z direction."

The French service bureau Sculpteo reports tolerance levels from Carbon’s CLIP process on its website, as shown above. An XY tolerance of 0.1 mm equates to 100 μm . For a good dental crown fit, a tolerance of 50 μm is required.

Meanwhile, Sculpteo reports that the CLIP process results in a tolerance of +/- 0.4 mm (400 μm) in the Z direction, a level at which Z layer thickness could compromise final XY part accuracy and bite registrations.

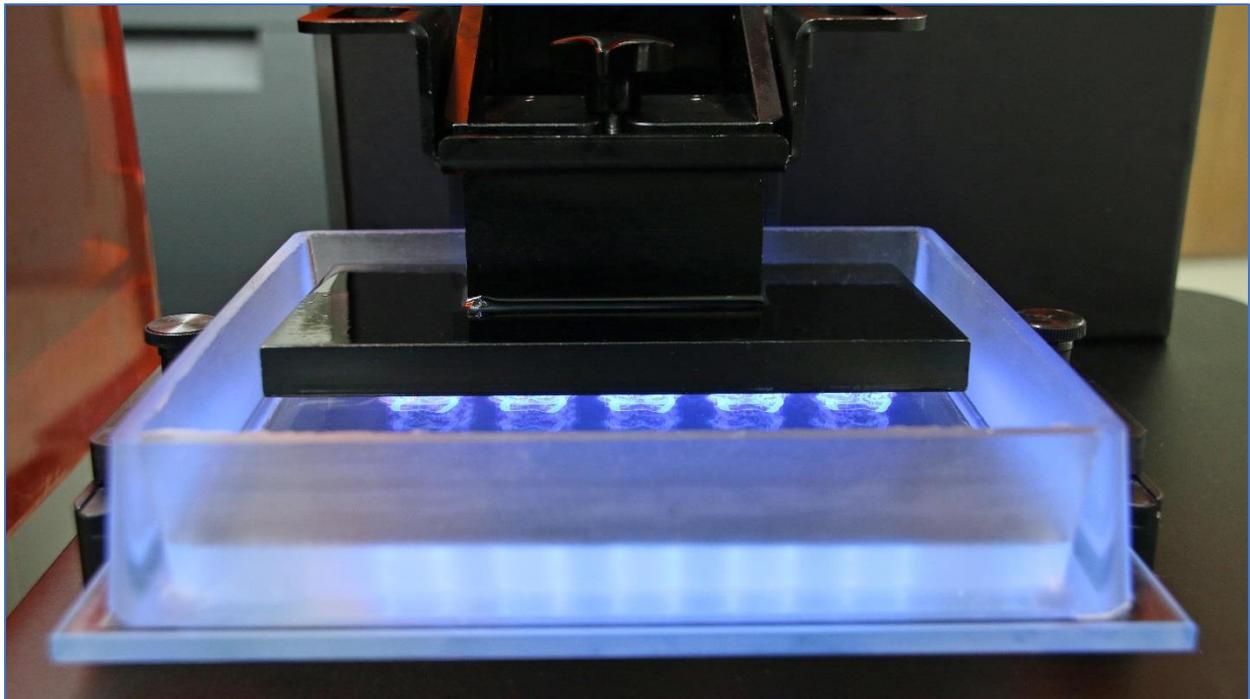
Print Orientation Matters, Too.

EnvisionTEC has done many studies over the years on how part orientation affects 3D print quality during a build. It is undeniable that some geometric shapes print more accurately when printed horizontally and some print better vertically. This is true regardless of projector resolution.

What's more, some parts may actually print better on a slant, somewhere between the flat XY plane and Z, depending on the technology and materials being used. The reasons why accuracy is affected by part orientation are related to the way light travels around certain geometric shapes divided in Z slices and the color of the photopolymer material being used.



These bite guards were printed in EnvisionTEC's clear E-Guard material nested together on a slight slant as a strategy to more accurately print this clear material.



For example, when a part is printed in a clear or transparent material, there may be overexposure of some layers as the build develops, simply because the light can transfer through the solidified part during the build. This challenge may not occur when building a part in a material that is yellow, blue or green, colors that absorb light better.

The geometry of the part being built and the chosen print orientation can cause a similar distortion as light transfers through the resin tray.

So, there should be some strategy in deciding print orientation to minimize potential overexposure when using certain materials and printing certain types of geometries.

With some 3D printers, it's not even just the print orientation that matters, but the part's placement on the build platform.

For example, with some low-cost SLA printers, accuracy can diminish as the part moves farther from the centermost point of the build area. This has to do with the way the laser beam elongates to reach the farthest edge of the build area.



EnvisionTEC resins come with an RFID material tag that conveys specific information to the 3D printer about the "Build Styles" to be used to optimally print a specific material. For example, not all materials should be printed at the same Z layer thickness.

The Final Print isn't the Final Story

Did you know that accuracy of the final 3D printed part can actually change over time?

If you've been 3D printing for a while, then you likely know something about parts that curl, warp, shrink and even expand or turn gooey if the material is exposed to high humidity or water.

This is where material quality and final curing processes come into play. Some materials simply deliver a more accurate part, with more stability, over time.

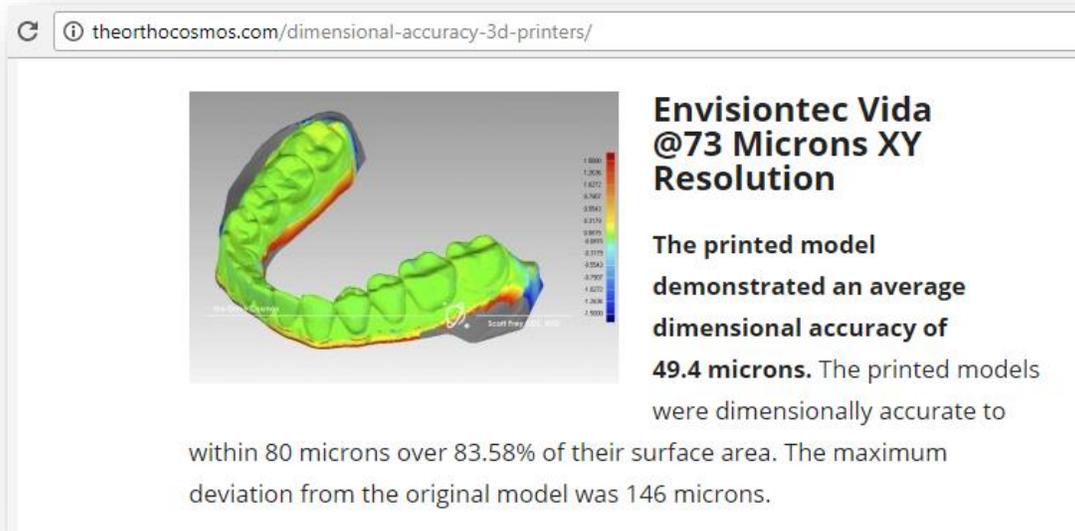
When shopping for a 3D printer, this is another great reason to ask for a benchmark of a real 3D printed part that can be compared against a digital model, and then compared again later with the passage of a little time.

Over its 15 years in business, EnvisionTEC has developed specific "Build Styles" for its materials. These Build Styles convey specific software settings to the 3D printer to ensure the highest quality result from a specific printer processing a specific material.

That means we've already optimized the machine and material settings to work together to deliver the best possible result, taking post-processing changes, such as shrinkage during post-curing, into account. We also provide very specific instructions and tools for post-processing to ensure an accurate and stable part.



To ensure that parts remain as stable as possible after 3D printing, EnvisionTEC provides specific post-curing instructions with its materials, along with specific post-curing technology, such as this OtoFlash. The lamps in this unit produce a very intensive light radiation in a spectrum from 300 to 700 nm. Because of this intensive light radiation, a better hardening of the materials is possible.



The Bottom Line

Determining dimensional accuracy of 3D printers isn't as easy as many people would like it to be. What's more, there are no industry standards for reporting 3D printer accuracy.

This is why EnvisionTEC reports only fixed, undisputable figures such as resolution and native voxel size. Because the truth is that many factors, including mechanical components, build orientation and material choices, can play a role in final part accuracy.

The best way to determine if a 3D printer meets your accuracy requirements is to have a part printed for a comparison test — a benchmark.

There are also some organizations that have started to do independent testing for specific kinds of parts. As previously mentioned, [Ortho Cosmos](#) in early 2017 reported on its accuracy tests of four popular dental 3D printers:

“Of the printers tested, the EnvisionTEC Vida showed the highest print accuracy; the Stratasys Objet Eden 260vs at the high-speed print settings (30 micron layers) demonstrated the lowest print accuracy of the printers tested.

“The overall accuracy results underscore that fact that **high resolution does not mean high accuracy. ... Manufacturers' stated printer resolutions are no guarantee of accuracy. When evaluating any new printer for purchase, the dimensional accuracy of the prints must be validated and contrasted with existing purchasing options.”**

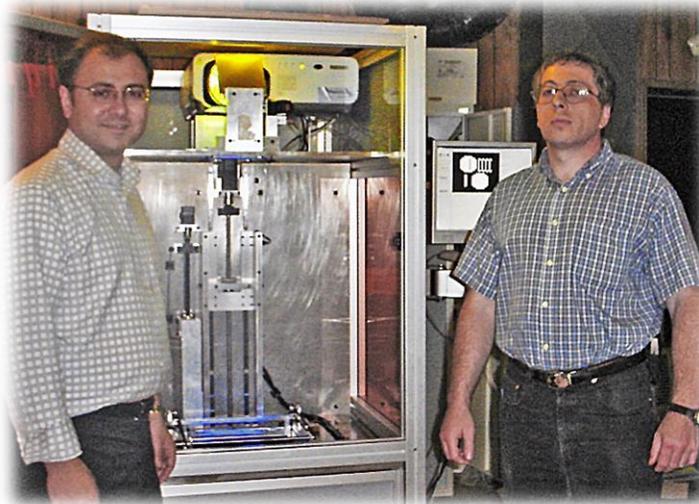
Of the EnvisionTEC Vida desktop 3D printer, which delivers a native XY pixel resolution of 73 μm , Ortho Cosmos reported: “The printed model demonstrated an average dimensional accuracy of 49.4 microns. The printed models were dimensionally accurate to within 80 microns over 83.58% of their surface area.”

Ultimately, 3D printer accuracy is a complex combination of many factors and the best way to determine if a 3D printer meets your accuracy needs is to have your part benchmarked, or printed on a certain machine in the desired material. Then, have the part 3D scanned and compared to the digital model.

“The overall accuracy on the Vida is better,” said Matt Shafer of Bay View Dental, which owns several brands of 3D printers.

For more information about having a benchmark made for your business, visit EnvisionTEC.com/printmypart.

Experience Matters



At EnvisionTEC, we aren't new to this 3D printing thing. Our 3D printers are backed by more than 15 years of development and exclusive patent-protected processes. That means the objects that come off our machine are better, too, with superior accuracy and resolution. That means less post-processing. And did we mention we're known for speed, too?

Dental Desktops

All EnvisionTEC dental 3D printers are easy to use and deliver high accuracy, surface finish and speed. However, build area, throughput, resolution and material processing capabilities vary based on specific application needs of dental labs, dentists and orthodontists.

Micro



- Entry level affordability
- Reliable, easy-to-use machine design
- Efficient build area
- Accurate, smooth finish

Starter Advantage Model

Build Area
65 x 40 x 100 mm
2.36 x 1.77 x 3.94 in

Resolution
XY: 60 µm (0.0024 in)

Upgrade: Micro Plus Hi-Res for high precision restorations and Micro Plus XL for a larger build envelope

Vida



- Best-selling model
- Accurate, smooth finish
- Versatile 3D printing, prints more than 9 materials
- Balance between price and performance

Build Area:
140 x 79 x 100 mm
5.5 x 3.1 x 3.95 in

Resolution:
XY: 73 µm (0.0029 in)

Upgrade: Vida Hi-Res with resolution suitable for crown and bridge applications

DDDP



- The Original Desktop Digital Dental Printer
 - Premium DLP technology
 - Accurate, smooth finish
 - Reliable, easy-to-use machine since

Build Area:
100 x 75 x 80 mm
3.94 x 2.95 x 3.15 in

Resolution:
XY: 71 µm (0.003 in.)

Micro cDLM



- High-speed continuous 3D printing
- Accurate, smooth finish
- Delicate features, such as partial framework clasps
- Ideal for castables, crowns, models

Build Area:
45 x 28 x 75 mm
1.8 x 1.1 x 2.95 in

Resolution:
X: 39.8 µm (0.002 in.)
Y: 31.25 µm (0.001 in.)

Upgrade: Vida cDLM with larger build area and XY resolution of 50 µm (0.002 in.)

Production Printers

EnvisionTEC's high-throughput printers are widely used in both lab settings and orthodontic practices. Consistent quality and excellent surface finish with little to no post-processing makes these workhorses essential tools for a variety of digital applications.

3Dent 3SP



- Fast, production 3SP technology
- Balance between volume and price
- Meets accuracy requirements for dental applications
- Built-in touchscreen
- Crisp anatomical features

Build Area:
266 x 175 x 76 mm
10.5 x 6.9 x 3 in

Resolution:
XY: 50 µm (0.002 in.)

Vector 3SP



- Even larger build area than 3Dent
- Accurate, smooth finish
- Low cost of operation

Build Area:
300 x 200 x 275 mm
11.8 x 7.9 x 10.8 in

Resolution:
XY: 100 µm (0.004 in.)

Upgrades: HD version of the Vector 3SP with XY accuracy to 50 microns. Ortho version ideal for orthodontic applications. Even larger build areas with the Xtreme 3SP and Xede 3SP

ULTRA 3SP Ortho



- About half the price of the 3Dent with the same build area
- High production 3SP-style 3D printing
- Balance between volume and price
- Meets accuracy requirements for orthodontic applications

Build Area:
266 x 175 x 76.2 mm
10.5 x 6.9 x 3 in

Resolution:
XY: 100 µm (0.004 in.)

P4 DDP



- The ultimate in accuracy, surface finish and speed

- Premium DLP technology
- Versatile 3D printing, prints more than 9 materials

Build Area:
115 x 72 x 180 or 230 mm
4.5 x 2.8 x 8.66 or 9.06 in

Resolution:
XY: 30 µm (0.0024 in.)
with ERM

Upgrades: Medium (M) and Large (XL) version of the P4 DDP accommodate higher levels of production

Learn more: [EnvisionTEC.com/Learn3SP](https://www.ENVISIONTEC.com/Learn3SP)