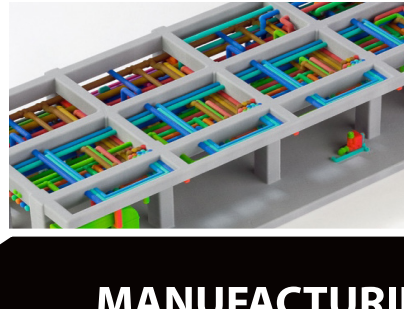
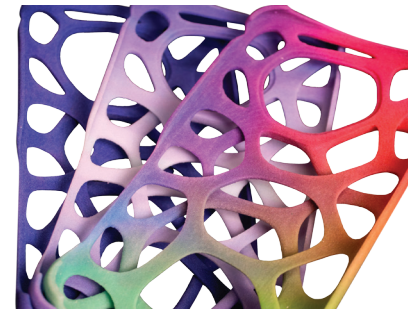




3DSYSTEMS®

# 3D Printing with Color

The Applications and Technologies of Color 3D Printing



MANUFACTURING THE FUTURE

# 3D Printing with Color

## Introduction

Color is something nearly every person on earth is familiar with. We take color for granted when it comes to the world around us, but few people actually understand what color is, and how it affects us every day.

Companies around the world spend billions of dollars on marketing each year. Marketing collaterals which are illuminated with the colors of the rainbow and designed to grab your attention and sell you—the consumer.

Designers who are creating new products use color to appropriately portray their new design. Artists express themselves with color through whichever medium they so choose. You and your family take photos and videos, probably full of color, to capture special moments of your life. Even ancient civilizations used colors to document the world around them.

Think about it—what would the world be like without color?

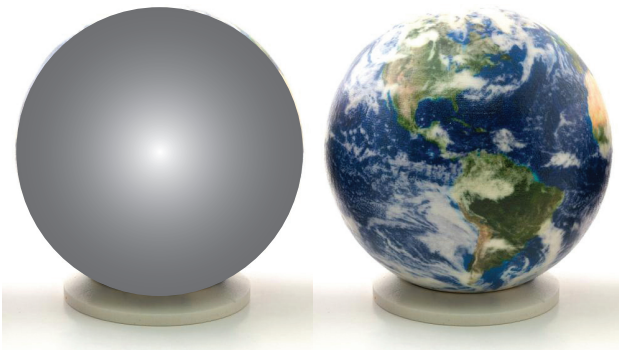


Figure 1: Globe without color (left), with color (ProJet® 660Pro) right

Technologies and advances in color printing, painting and lamination allow the designers, the companies, the artists, and you to reproduce the colors of nature and the man-made objects you see every day. Color enhances the world around us and triggers the senses of human beings.

What would you do if you only had one, two, or three colors in your family vacation photo?



Figure 2: RGB-Color (left); 3-Color (right)

Would this be the memory you want or described to others?

When it comes to 3D printing, color is equally as important as in 2D for exactly the same reasons. With the number of 3D printing companies growing by the month, it may be hard to keep track of the buzz words surrounding these machines and to determine which are best for your application—particularly in regard to color capability.

There are quite a few 3D printing companies on the market today that state their product is “color”, “multi-color”, “simultaneous color”, or “full color”—to name a few. These adjectives lead to the question:

*What are the possible applications of such a printer?*

## 3D Color Printing Applications

3D models are used for everything from conceptual modeling to end-use parts. Depending on the application of your model, color may or may not be important to you.

Designers typically use color on 3D models (as they would a photo or rendering) to convey the concept of the final product. These conceptual models are critical in every design process. When it comes to color, they want to be able to portray their designs as the final product would look in real life, not just geometrically. For example, Amcor uses ColorJet Printing (CJP) technology to create packaging concepts for food products. With a simple clear coat on the finished print, the bottles look like the real thing, labels and all.

# 3D Printing with Color



Figure 3: Amcor concept models

When Laika created its full-length, stop-motion picture, *ParaNorman*, the team printed 40,000 faces for the characters in the movie using ColorJet Printing.



Figure 4: The Faces of ParaNorman

Artists such as n.e.r.v.o.u.s. system in Massachusetts use ColorJet Printing as a new canvas to bring its digital designs to the real world.

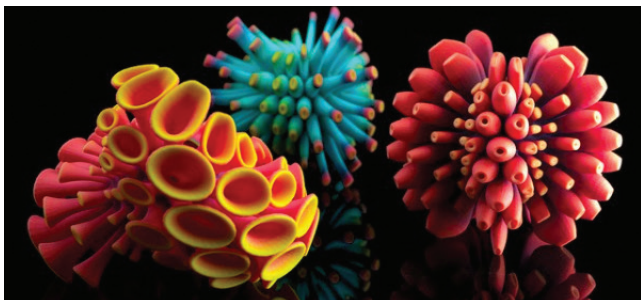


Figure 5: n.e.r.v.o.u.s. system's artwork

Architects are another group of design-oriented people who commonly use models to win bids and show progress/design changes.



Figure 6: Architectural model printed in full-color

Depending on your applications, color may or may not be important to you. If so, you'll require a higher or lower level of color quality from a 3D printer. If you are printing conceptual models, architectural models, figurines, medical models, or artistic pieces, then clearly color is important to your models and their application. While it may only be necessary to label a certain area of the model one color, many designers want to be able to present their designs as the final product would look in real life, not just geometrically. Such a model is critical to their design process and is used to convey the concept of the final part.

So, how is this possible?

## Colors of the World – The Basics

The color of an object depends on the composition of the light shining on the object, as well as the reflective properties of the surface of that object. In general, the light hitting an object is either reflected or absorbed due to the properties of that object—as is the case of 3D printed parts.

# 3D Printing with Color

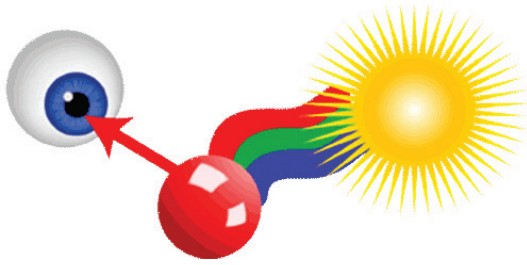


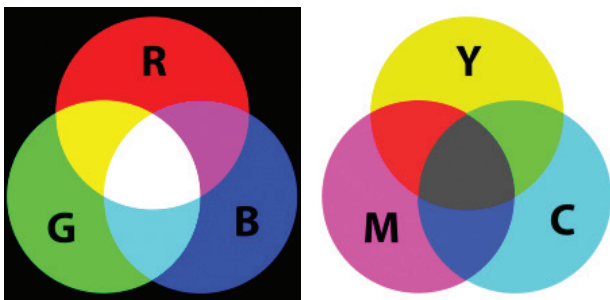
Figure 7: Reflected light

The color perceived by the eye and brain is determined by the wavelengths of light that are reflected off an object (while the wavelengths of light that are not reflected are absorbed). Opaque objects that appear black are absorbing all wavelengths, while objects that appear white are reflecting all wavelengths.

## Color Reproduction

In order to produce color, there are two methods—additive and subtractive. Additive coloring is created by mixing together light of two or more different colors. Red, green, and blue are the additive primary colors. Projectors and computer monitors use additive coloring.

Figure 8: Additive (left) vs subtractive (right) coloring



In contrast, 3D printed objects, and other objects which do not emit light use subtractive coloring, similar to 2D printing. This technique relies on a very white base material from which to “subtract” the color. The ink that is printed absorbs certain light wavelengths and gives the appearance of a certain color to the human eye. Cyan, Magenta and Yellow (CMY) are the subtractive primary colors in most printing processes. A fourth color, Black (K), is also typically used to improve image sharpness.

## Color 3D Printing Today

There are three basic categories of color 3D printers:

- **Color-choice printers** that print one to three colors at a time, depending on the loaded material
- **Basic-color printers** that can print a few dozen colors together in one part
- **Full-spectrum color printers** that can print 500,000 to 6 million colors in a single part

In addition to the number and range of colors that a given printer can create, technologies differ in how finely they can print distinct colors. Some can print color pixel by pixel, while others must print color in large blocks or shells.

## Color-Choice 3D Printers

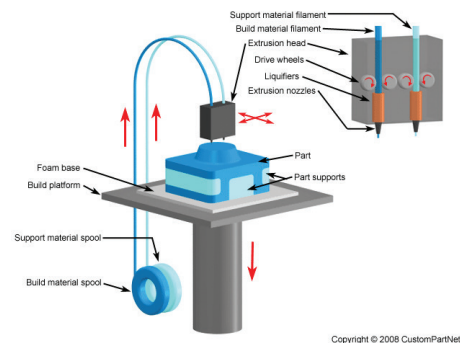


Figure 9: Fused Deposition Modeling

Color-choice printers depend on the color of the material which is loaded into the printer. Most people who hear about 3D printing relate to FDM technology. This is a common technology among consumer/prosumer users and is considered color-choice, though is frequently advertised as “multi-color”. Basically this technology works like a computerized hot-glue gun which is able to “draw” lines of molten plastic to create a part.

# 3D Printing with Color

By adding colorants to the plastic filament which is fed into the hot nozzle (extruder) color can be added to the part. To reproduce multiple colors, you either need multiple nozzles to extrude different colored plastics in different regions of a model, or you need to be able to mix those colored filaments together in a single nozzle. While gradients and block colors are possible in different regions of the model, a photo-realistic part is not possible because of the nature of the FDM technology.



Figure 10: Typical "multi-color" parts from FDM

All of the other color 3D printing technologies rely on "drop-on-demand" inkjet printing and can be split into basic-and full-spectrum color capabilities.

## Color InkJet 3D Printing

Just as in the 2D world, with basic- and full-spectrum color 3D printers, the quality of the color print is determined by three main factors: the resolution of the printer, the number of primary colors and the processing capability per channel, and the printer's capability of dithering (or halftoning).

In 2D printing, an inkjet printhead selectively "jets" drops of ink onto a substrate (typically paper). By using multiple printheads (or multiple channels in a single printhead) multiple colors can be selectively jetted at the same time. As described above, using subtractive primary colors and combining those drops in a single pixel, an image is created on the substrate.

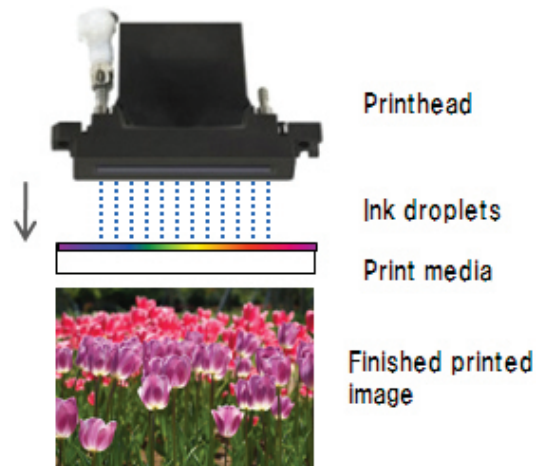


Figure 11: Inkjet printhead (image courtesy of Konica-Minolta)

In 3D printing, there are generally two types of inkjet processes. One which uses the inkjet printhead to print the entire amount of material used to make a model ("drop-on-drop"). The other is where the printer uses the inkjet printhead to deposit a "binder" onto thin layers of a second, solid material. In both cases, the part is built up layer by layer to get to a full 3D model.

## Resolution

A printer with higher resolution can print more dots per inch (DPI). This is typically determined by the printhead and the capability of the printer to precisely move that printhead. A printer capable of a higher resolution will be able to print crisper colors and more accurate features. Resolution is typically given per axis of motion. For 3D printing, the resolution of the printer is given in X, Y, and Z, as the mechanical movements of the printer vary in each of these dimensions.

# 3D Printing with Color

## Processing Capability

A “bit” is the smallest unit of data. At the simplest level, it can be either on or off, 1 or 0, black or white, ink or no ink. As the number of bits used to encode the inking of each voxel (the “bit depth”), the number of printable tones increases exponentially. Typical digital images contain 8 bits per channel,  $2^8$ , or 256 discrete tones. When more than one color is involved, the total number of printable colors is the product of the number of printable tone of each color. This is referred to as “bits per pixel,” or BPP, in 2D printing. In the 3D world, a volumetric element, or “voxel” is typically used. So for 3D printed color, we will use the term “bits per voxel,” or BPV.

$$BPV = (\# \text{ bits} \times \# \text{ channels})$$

The number of colors available per voxel is therefore:

$$\text{Possible Colors per Voxel} = 2^{BPV}$$

This does not mean the model uses all of these colors – only that it is possible to specify colors with that level of precision in each voxel.

The following table illustrates how the BPV relates to number of colors:

Bits per voxel	# of Possible Colors
1	2
2	4
4	16
6	64
8	256
10	1024
12	4096
16	65536
20	1,048,576
24	16,777,216
32	4,294,967,296
40	$1.1 \times 10^{12}$

Table 1: Bits per pixel and theoretical possible colors

## Dithering (halftoning)

Finally, a printer with the ability to dither, or halftone, that color information will allow for gradients and more discernable colors. Essentially, this is the ability to print patterns of color such that the different color drops appear to be a single combined color when viewed from a sufficient distance. When it comes to selecting a 3D printer for color, halftoning is particularly important since this is the feature that provides the ability to create photorealistic models by precisely dropping patterns of color. This feature distinguishes a printer from being a basic-color 3D printer or a full-spectrum color 3D printer.

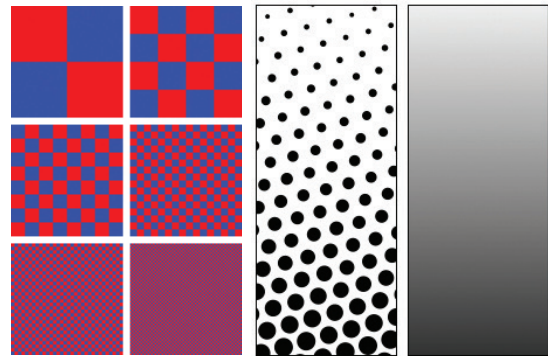


Figure 12: Dithering, or halftone printing produces the illusion of continuous tone at a sufficient viewing distance

As seen in Figure 12, gradients are formed by changing the size and pattern of ink drop on the paper. In addition, using halftoning allows the printer to produce images as seen in Figure 13.

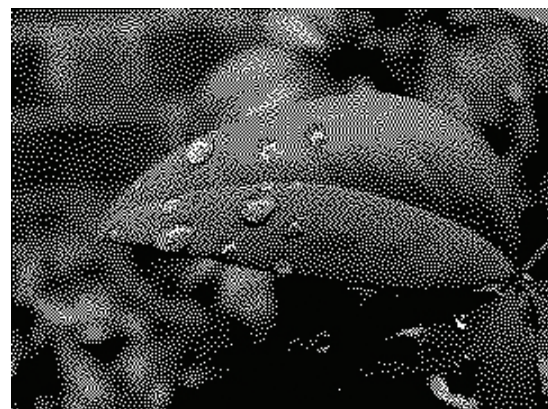


Figure 13: Dithering allows a 1-BPV printer to produce an image

# 3D Printing with Color

In conclusion, a higher resolution printer can print more dots per inch (DPI). A printer that can process more bits per voxel will be able to print more possible colors. A printer which has the ability to dither or halftone, as well as variably drop different amounts of colors into each voxel will allow for photo-realistic quality parts.

When it comes to selecting a 3D printer for color, all of the factors described above are important—particularly halftoning since this is the technique which provides the ability to create photo-realistic models. Without halftoning, you have a basic-color printer.



*Figure 14: With the ability to halftone, or dither, the colors, 3D models can be made to look just like the real thing (ProJet 660Pro)*

## Applying Color to a 3D Model

As you can imagine, a full-color 3D model contains a significant amount of data. In addition, some 3D printers now also contain material information as well, as there are multi-material/composite printers on the market.

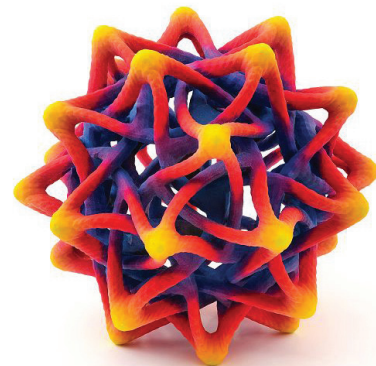
Depending on the format, color can be applied to a basic 3D model in a variety of ways: A picture can be wrapped or projected onto the surface, it can be colored by region, or even painted digitally. The method by which you do this is generally up to the user.

More advanced 3D printers are capable of halftone printing. The software for these printers is able to decipher many different file formats which contain color data as well as the geometric data. The software then splits the models into slices

which it sends to the printer. Any texture maps, pictures, which are wrapped on a surface can then be printed accurately. Printers without halftone capability can only color by “shell” or region of the part. While the shells can be colored separately according to a color palette, actually printing a true, photo-realistic color part is not possible because the printer and its software cannot process this data appropriately.

## ColorJet Printing (CJP)

The most advanced 3D color printers on the market today are, without a doubt, 3D Systems’ ColorJet printers. These 3D printers are the only ones in the world which have the ability to print photo-realistic 3D models with use of halftoning and variable drop per voxel technology. This is possible by using Cyan, Magenta, Yellow, and in some printers, Black binders to print onto a white powder. By using at least 3, and sometimes 4 channels of color, CJP does not limit the colors which can be created to one section of the rainbow. Colors can be placed anywhere on the model and can be matched to the desired color.



*Figure 15: Artistic model making use of halftone printing. Printed on the ProJet 660Pro.*

Ranging from 6 BPV to 40 BVP, ColorJet Printers from 3D Systems have the ability to print more than 6 million discrete colors the human eye can see.

CJP allows for figurines with faces, patterns on architectural models, company logos, and labels on bottles to be printed creating photo-realistic models which reflect the colors in the world around you.



## How is this possible?

Similar to printing an image on a piece of paper, CJP prints on a white background essentially using the principles of the well-developed inkjet technology.

With years of materials science work under its belt, 3D Systems uses the very best ingredients in the world, processed in proprietary ways, which allow for highly accurate color printing and reproduction on everything from mineral composites, acrylic composites, ceramic composites, and even edibles.

The process is as follows:

1. Using a CAD program like Geomagic® Design, for example, a 3D model can be designed.
2. Once designed, color is added to the part—similar to painting, only digitally. Geomagic Sculpt offered by 3D Systems allows you to airbrush the model or wrap a picture (or texture map) around the model.
3. Once colored, the model can be saved into a ZPR, WRL, VRML, OBJ, or PLY format for printing.
4. Loading the part into 3DPrint™ software allows you to position your part in three dimensions, stack and nest parts through the print volume, and rotate/scale your part as you see fit.
5. By pressing “Print”, 3DPrint will then take the model(s), go through its slicing algorithms, and send those slices to the ProJet x60 series, or ProJet 4500 3D printer.
6. As the slices are received, the printer then proceeds to print those slices using powder and binding liquid.

7. The powder is spread using a roller in a thin layer over the printer platform.
8. The inkjet printhead then prints that slice using Cyan, Magenta, Yellow, Clear, (and Black in select models) inks onto that thin layer of powder. Every pixel is printed with the desired color, reproducing the model you created exactly.
9. That build platform is moved down just a hair, and another layer of fresh powder is spread over the top.
10. The printheads then print the next layer, and the process repeats.
11. At the end, all the powder which was not printed on can be reused, and the part can be cleaned by simply blowing with compressed air, or brushing with a paintbrush.

## Conclusion

Your application will make the color quality decision for you. If you're printing conceptual models, architectural models, figurines, medical models, or artistic pieces—clearly color is important to your models and what you do with them. But to get true, life-like color, there is no alternative to the ColorJet Printing technology from 3D Systems.

If you have any questions regarding color and 3D printing, please contact 3D Systems. We are delighted to answer any questions and tell you about our wide range of capabilities to help meet your needs.

