White paper

Full-color 3D printing, poised to change the game for businesses everywhere

Companies experience benefits throughout their product's lifecycles and in support of their business processes

While full-color 3D printing has been around for many years, it is now gaining meaningful traction. In part this is because next-generation technologies are entering the market, offering capabilities that improve quality and performance, while at the same time helping to reduce cost. Soon affordable, high-quality color 3D printing will benefit organizations in many different industries by allowing them to innovate more quickly, improve the performance of their current products, and generate new revenue while simultaneously decreasing their manufacturing and supply chain costs.

The importance of color

Humans are designed to see in color. In fact, experts estimate that the average person can distinguish between as many as 7 million different colors.[1]

There are some exceptions of course. It's also estimated that 4.5% of the population (8% of men and .5% of women) have some deficiency in color perception.[2]

Color occurs in nature and is manufactured by people through a variety of methods. Whether its used online, in print, or to decorate a physical object, base colors are typically mixed to arrive at a specific hue.

There are two principle ways to achieve a specific color. Red-Green-Blue (RGB) uses an additive method of adding light to achieve a specific color. This system is primarily used to represent things digitally, on a screen.

In the physical world, Cyan-Magenta-Yellow-Key (CMYK) are used to create color. Key is just another way of saying black and it's called that because in the old days of analog print, the other three color plates were "keyed" or aligned with the black plate. It served as the base.

The CMYK system is subtractive. As more ink is applied, less light is visible. When blended together, CMYK can theoretically allow for millions of color combinations. Individual colors are often referred to as "spot colors."

With print, colors can also be affected by the surface on which they are applied. Glossy and matte paper stock, for example display colors very differently. As a result, the same color formula can look different depending on where it is applied. There can be significant variance between coated and uncoated papers for example, not to mention other surfaces including textiles and plastics.

In print, and with product manufacturing, understanding the difference between spot and full color is critical. Spot color allows a user to select a color and apply it to a specific area. In 3D printing for example, fused deposition modeling (FDM) filaments can be switched to change color from layer-to-layer. In this example, it's important to note that there are only a finite number of choices and the number depends on the number of filament colors available. Verbatim, for instance, offers 9 different colors for its PLA filament.

As mentioned above, full color allows for a much wider gamut. With 4-color (process) printing, each dot on the page can be addressed separately, allowing for photos, text, and other graphic elements. With digital imaging technologies, the color mix of each pixel or dot can change from one page to the next, allowing for prints that are customized or even personalized.

Full-color 3D printing offers a similar capability, however instead of two-dimensional pixels, color can be assigned to three-dimensional boxes, or voxels. 3D printing at the voxel level enables full-color printing both on the surface and inside a part. With physical products, this enables both the decorative and functional uses of color.

Uses of color

Scientists have found cave drawings that are estimated to be 40,000 years old. Since that time, man has used pigment and other agents to produce color. For prehistoric man, it probably served foremost as a communication tool, but was also decorative. In the modern world, color has evolved to serve many purposes.

Color helps us identify, organize, group, and understand objects in context. Consider a traffic light for example. Green means go, yellow means caution, and red means stop. It's just one example of how color is used to protect our safety. Color also serves other utilitarian purposes, from assisting with product installation and use, to cleaning, maintenance, and repair.

Color also gets attention and retention and helps sell things. It's an important marketing tool that is frequently used in branding and packaging. It can even be used to influence how products are perceived. It can create the illusion of scale, making products look bigger or smaller, and inviting or unfriendly. Color can even serve as camouflage, helping things better blend into their surroundings.

Color in 3D printing's past

In 1993, a new 3D printing technology based on binder jetting was developed at the Massachusetts Institute of Technology.

As with other additive manufacturing processes, it enabled parts to be produced digitally, layer-by-layer. It used a traditional inkjet printhead, that moved across a bed of powder, applying a binding agent to form each layer. Simultaneously, the inkjet printheads could disperse ink in CMYK format. This enabled a new kind of 3D printer capable of printing gradients of color, which at the time was something no other machine could do.

Early on, the process was primarily focused on full-color models for the architectural and medical markets. More recently, with improvements in 3D scanning, the technology has been used to make personalized figurines or 3D selfies. Further, with the growth of video games, it has enabled the printing of avatars and other virtual objects.

While the technology became an early market leader in full-color 3D printing, there were limitations. In addition to being slow and expensive, the quality of finished parts was significantly lacking. But perhaps a bigger challenge had to do with materials. Sandstone or gypsum powders are typically used with binder jetting and they're very brittle.

Other companies were also working on technology that enabled color 3D printing. Based on stereolithography (SLA), a process called material jetting was developed that deposited layers of curable liquid photopolymer onto a build tray. The liquid photopolymer was then directly cured by UV rays to obtain a solid, colored layer.

By 2014, 3D printers based on material jetting had advanced to the point where they were capable of using multiple colors, allowing them to print a portion of the color gamut. They were also able to print different material properties (soft and hard surfaces, for example) and could even print transparent materials.

Like binder jetting, material jetting did have its share of limitations. As mentioned above, the system only allowed for simultaneous printing of certain color spectrums. Changing colors was laborious and time consuming. Further, the system used expensive, proprietary resin. Also, since the system used UV light to cure the resin, parts were susceptible to exposure from sunlight, causing them to discolor, and even melt.

Color in the present

More recently, material jetting has improved to the point where machines based on that technology can now provide true full-color (CMY and K) and offer better economics, however those devices are still based on UV-curable resin, which still limits them primarily for prototyping applications.

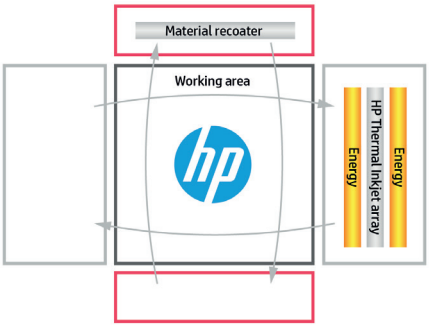
Why hasn't color been adopted?

As mentioned above, earlier technologies that enabled full-color printing had some challenges.

The speed, quality, and economics of those technologies limited their ability to support higher volume production. Further, while the materials they used were adequate for prototyping, they weren't practical for production of final parts. The sandstone and gypsum used in binder jetting was brittle, and the resins used in material jetting would discolor when exposed to sunlight.

But in traditional manufacturing, color is widely used. Some products are manufactured in multiple colors. Others are decorated post-production using many different techniques including labels and wraps, dyes, paints, and other methods.

For 3D printing to go beyond prototyping



and tap into the much bigger opportunities with end-use parts, brands must be able to digitally manufacture parts that are as good or better than those that are mass produced.

HP's technology changes the game

HP's Multi Jet Fusion 3D printing technology was big news when it officially launched at RAPID 2016. The announcement actually included two new printers; the HP Jet Fusion 4200 and 3200 Printing Solutions, as well as the separate HP Jet Fusion 3D Processing Station. The solution is unique in its ability to address over 340 million voxels per second, versus the voxel-by-voxel approach taken by others.

HP's Multi Jet Fusion technology starts with a bed of material powder. Then, a printhead applies fusing and detailing agents to the powder, and a heating lamp passes over the print area. When the heat's energy is applied to the powder, areas with the fusing agent fuse together, forming a part, while areas with the detailing agent are left unfused. This process is repeated layer-by-layer until the part is completely finished.

Since the launch of HP Multi Jet Fusion technology, HP has fulfilled orders for hundreds of its initial HP Jet Fusion 3D printing solutions. Feedback from the field has been overwhelmingly positive. HP Multi Jet Fusion technology is providing customers with the quality, speed, reliability, and economics that were previously lacking.

Out of the gate, HP Jet Fusion 3D printing solutions were capable of printing one color (black) in thermoplastics like nylon. But even during the initial release, HP hinted that new materials and applications were on the horizon.

The inkjet printheads used with HP Multi Jet Fusion technology are similar to those used in HP's large-format commercial inkjet printers. In addition to detailing, their proven design also enables other types of agents, including color. In fact, HP has been producing color parts in its lab for some time.

At a Securities Analyst Meeting in late 2017, HP, Inc. CEO Dion Weisler said that HP planned to "double down" on 3D printing, including moves into metal and full color.

At SolidWorks 2018, HP delivered on a portion of Mr. Weisler's statement, expanding its portfolio with the introduction of its new HP Jet Fusion 580/380 Color and 540/340 3D Printers. The new devices offer the industry 3D printing technology that enables manufacturers to produce engineering-grade, functional parts in full color, black or white—with voxel control—in a fraction of the time[3] of other solutions.

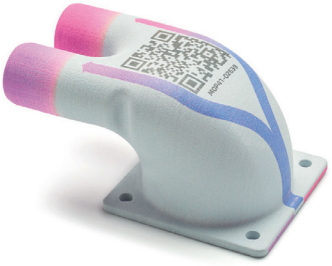
At the time of the announcement, Stephen Nigro, President of 3D Printing at HP Inc., described the kind of impact HP's full-color devices could have for a wide variety of organizations. He said that, "No matter your industry, no matter your design complexity, no matter what colors fit your business needs—black, white, or the full color spectrum—the new HP Jet Fusion 580/380 Color and 540/340 3D Printers gives you the freedom to create brilliant new parts liberated from the constraints of traditional production methods."

Applications where color adds value

As discussed above, color is more than an aesthetic. It helps people communicate and take action. It also helps companies sell and support their products.

Prototyping

3D printing has played a prominent role in prototyping for years, but as manufacturing becomes digitized and democratized, it will also fuel a boon in product development. As the huge upfront costs associated with mass manufacturing wither away, more new products will make it to market.



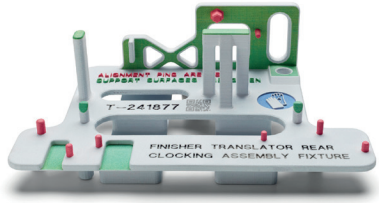
This air duct model has a QR code to scan for more information

Prototyping in color gives designers the ability to more clearly visualize their creations and accelerate their design cycles. Furthermore, When the final iteration of the product is decided upon, the same color choices can be used to produce accurate, colorful display models. As the speed, quality, and economics of full-color 3D printing continue to improve, the lines between prototype and product may blur to the point where they are produced exactly the same way, spurring even more constant innovation.

But even in the present, with the ability to prototype more often and more quickly come a new set of challenges. In instances were multiple versions of a model are created, it can be difficult to discern between them. With the ability to color-code or embed labels in different prototype iterations, designers can help eliminate uncertainty around similar models that may be in the same print job, or even just lying around their office.

Tooling

Even as manufacturing moves to an era of highly automated, digital workflows, considerable effort will be made to retrofit and blend older technologies with new.



HP originally created this fixture for its inkjet manufacturing line. With color, HP was able to add specific information for the operator.

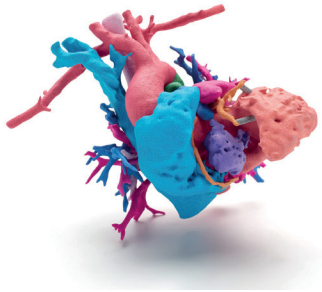
Traditional manufacturing methods require the use of jigs, fixtures, templates, and other tooling to operate productively. These tools are used throughout the production process to align, clamp, hold, assemble, calibrate, and test parts and sub-assemblies. While they may not be visibly obvious when production is running optimally, they must be highly visible and easy to troubleshoot when problems arise. In those instances, when new tooling is required, it needs to be quickly designed and deployed.

While 3D printing is already being used for jigs and fixtures, full color could help manufacturers operate even more productively. Color can be used to improve visibility, while also communicating information about use and safety.

It's also worth noting that tooling like this isn't only used in manufacturing. The medical, dental, and veterinary markets, for example, also use positioning and alignment guides to simplify procedures and provide proper fit. Color could provide them with many of the same benefits as other tooling.

Models

As mentioned above, full-color 3D printing has been used for some time to produce models for the architectural and medical markets. In fact, 3D printed medical models are becoming more mainstream. Several hospital systems are already utilizing 3D printing to print surgical models.



At Phoenix Children's Hospital, doctors scan and print 3D models of their patients' hearts to practice surgeries.

One of the key challenges however, is managing cost versus benefit. New 3D printing technology featuring higher quality and better economics will help expand what until recently was a fairly limited market.

Decoration

As mentioned earlier, color has been serving a decorative purpose for thousands of years. Many artistic products, from fine art, to more common decor items are offered in color. In fact, products in nearly every category, from hardware and sporting goods, to fashion and tech accessories utilize color to decorate their products.

Artists reinvented a traditional chess set with a new mesh design.

Consider fine art for a moment. With 3D printing, artists have full creative freedom to create shapes that have never been seen

before. With the addition of color in 3D printing, they can give their creations more depth and fidelity.

Customization and personalization

Henry Ford once quipped that you could have his Model T car "in any color, as long as it was black." In his view, offering different colors created additional manufacturing complexity. But as the automotive industry grew, it began to understand that customers wanted choice. They wanted to customize and personalize their vehicles.

Cell phone cases designed with a map of Barcelona.

Today, car buyers have many choices when it comes to color. In 2017, 23% of buyers selected silver, 15% ordered white, and 12% ordered black. 50% ordered something else. Today, color is a critical feature when selecting a car. One study found that 39% of consumers said they were even likely to change brands if they couldn't get the color they wanted.[4]

While there are certainly times when a single color makes sense, full-color 3D printing can offer benefits beyond decoration. For example, full color also makes it easier to customize and personalize mainstream products. Consider smartphone and other device accessories for a moment. Instead of a generic offering, some people elect to purchase cases and other items that match their personal style. In the present, most of this is accomplished through offline finishing, which is both limiting and expensive.

Tech accessories aren't alone. Many product categories can benefit from customization.

Branding

Color gets attention and it helps sell. With products, branding is one of the most important uses of color. Think about DeWalt for a minute. The distinctive yellow they use in their products not only make them stand out on the shelf, it also makes them more visible in the field, where they're used every day.

Product design and support

Beyond the decorative and marketing opportunities, color can also help make products more functional. From installation, to cleaning, maintenance, and repair, color can help make products safer and easier to use.

Think about an office copier for a moment. Key areas that require attention for jam clearance and other maintenance are typically color-coded for easy recall. As 3D printing becomes more prevalent, more of the parts inside commercial and industrial devices are likely to be 3D printed. In part, this is because 3D printing allows for lighter weight and more efficient geometries, which can lower the overall weight of a machine and allow engineers to use space more effectively.

But color can play an even more functional role. Today, parts are either replaced preventively based on a duty cycle, or when they break. With full-color capabilities and voxel-level control, companies can design wear indicators into a part, so for example, when a gear or fitting reaches a certain wear point, it visibly indicates the need for change. Instead of prematurely replacing a part, or suffering catastrophic downtime, the machine's parts can be replaced by the end user only when they're needed.

Which industries will benefit?

Consumer goods and industrial machines aren't the only things that will benefit from the availability of affordable, full-color 3D printing. We've already looked at use cases with consumer products, fine art, and in manufacturing and healthcare,

but opportunities abound for nearly any organization.

- **Automotive**—while much of the plastic used in automobiles today is under the hood, a considerable amount is also used for interior surfaces. Consumers are increasingly interested in customizing their vehicles. Color could play a vital role in helping manufacturers differentiate their products, both at the point-of-sale and in the aftermarket.
- **Education**—3D printing is gaining acceptance as an important tool in Science, Technology, Engineering, and Math (STEM) programs. Access to 3D printing not only enables students to become "makers," but also gives teachers new ways to produce learning aids. Color gets attention, assists with retention, and helps people learn.
- **Architecture**—firms in this industry have been using full-color 3D printing for some time to help sell their designs—both at the front end of the process, before a building is constructed, and as it is being finished to assist with the leasing of space.
- **Medical devices**—beyond surgical models and guides, 3D printing is also being used in the development and construction of new medical devices. Color can be used for scale, to make devices look bigger or smaller, and even to impact our perception of the friendliness of the device.
- **Promotional products**—as mentioned above, full-color 3D printing can create branding opportunities. In the U.S. alone, the ad specialties (promo products) market is a $22 billion industry where nearly every product is branded.[5]

In fact, it's hard to think of an industry that can't benefit from the wider availability of full-color 3D printing. New technologies like HP's Multi Jet Fusion technology are already helping companies rethink how they design, produce, and deliver their products. Color adds value through branding, decoration, and customization. It also fosters communication and improves performance. When used correctly, color can provide companies with a unique competitive advantage. Like other digital technologies, color 3D printing levels the playing field, making the benefits of color more accessible.

From the user's perspective, it's also a game changer. Accessibility spurs innovation. With full-color 3D printing, products are easier to design and manufacture. They perform better and are also easier to install, operate, and maintain. But perhaps most importantly, 3D printing allows users to fully personalize a product's look, in addition to its form and function.

Connect with an HP 3D Printing expert or sign up for the latest news about HP Jet Fusion Color 3D Printing at

hp.com/go/Color3DPrint

Learn more about HP Multi Jet Fusion technology at

hp.com/go/3DPrint

1. RELIAWIRE, “How are Brains Evolved to See 7 Million Different Colors,” Florian Rosado, December 21, 2014.
2. Colblindor, “Color Blindness—learn all about it,” 2016.
3. Based on internal and third-party testing for HP Jet Fusion 580 and 540 3D Printers, printing and cooling time is a fraction of the time of the printing times of comparable plastic fused deposition modeling (FDM), stereolithography (SLA), and material jetting solutions from $20,000 USD to $120,000 USD on market as of June, 2017. Testing variables for the HP Jet Fusion 580 3D Printer: Part quantity: 1 full build chamber of parts from HP Jet Fusion 3D at 10% of packing density versus same number of parts on above-mentioned competitive devices; Part size: 30 cm^3; Layer thickness: .08 mm/0.003 inches. Competitor testing variables are comparable.
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