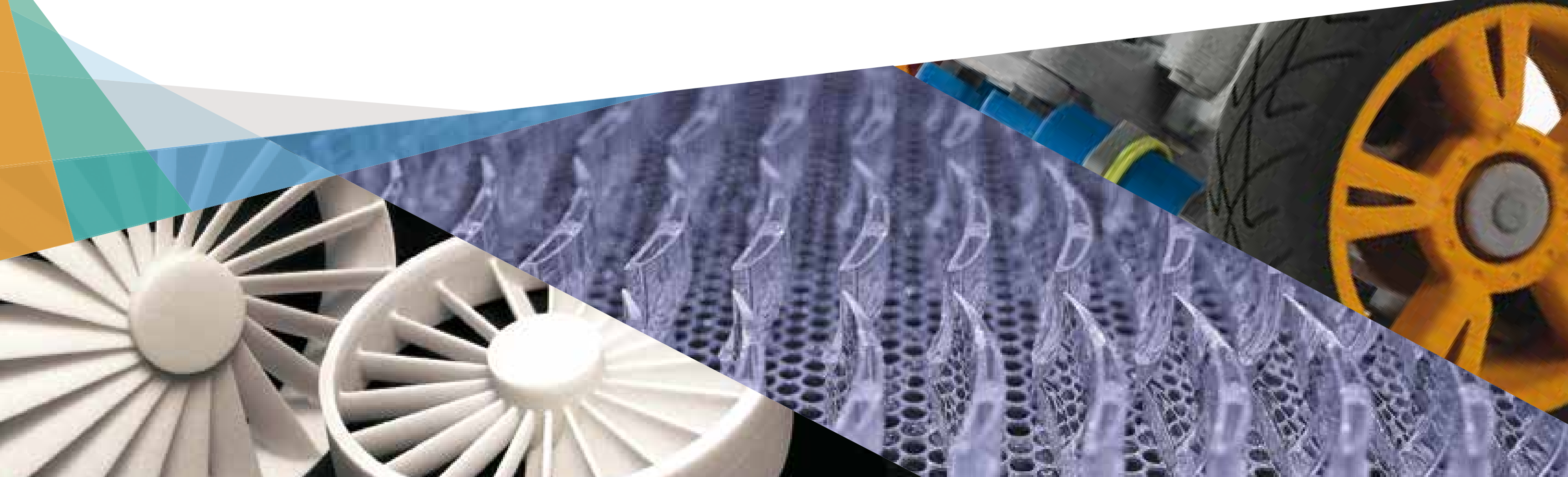
3D SYSTEMS

3D Printer Buyer’s Guide

For Professional and Production Applications



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1 Introduction

3D Printing Has Come Of Age

3D Printing is more than just prototyping. Today, 3D Printing offers transformative advantages at every phase of creation, from initial concept design to production of final products and all steps in between. Today's competitive environment makes choosing the right 3D printers for every phase of creation more important than ever.

Just a few years ago in-house 3D printing was enjoyed by only a few professional design engineers and was often limited to printing concept models and some prototypes. Once considered a novel luxury, 3D printing has proven to yield long-term strategic value by enhancing design-to-manufacturing capabilities and speeding time to market. Today, 3D printing technologies have allowed an ever-growing number of creators, designers, engineers, physicians, researchers, academics and manufacturers to unleash and multiply the benefits of rapid in-house 3D printing across the entire creation process.

Leading companies are now using 3D printing to evaluate more concepts in less time to improve decisions early in product development. As the design process moves forward, technical decisions are iteratively tested at every step to guide decisions big and small, to achieve improved performance, lower manufacturing costs, delivering higher quality and more successful product introductions. In pre-production, 3D printing is enabling faster first article production to support marketing and sales functions, and early adopter customers. And in final production processes, 3D printing is enabling higher productivity, increased flexibility, reduced warehouse and other logistics costs, economical customization, improved quality, reduced product weight, and greater efficiency in a growing number of industries.

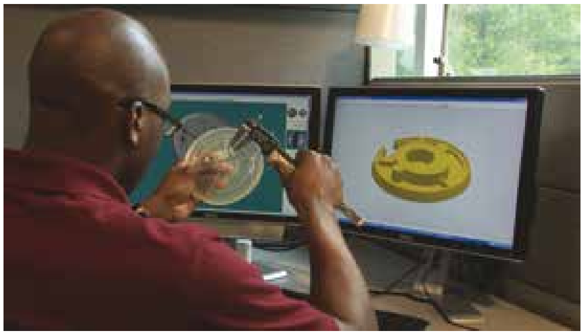
2 What is the right 3D printer technology for your application?

Choosing the right 3D printer among the various alternatives may at first seem like a daunting task. There are significant differences in how each printing technology turns digital data into a solid object. Today's 3D printers can use a variety of materials with vast differences in mechanical properties, feature definition, surface finish, environmental resistance, visual appearance, accuracy and precision, useful life, thermal properties and more. It is important to first define the primary applications where 3D printing will be used in order to guide the selection of the right technologies that will provide the greatest positive impact for your business. This article will highlight some of the common 3D printing applications and outline some key attributes to consider when selecting a 3D printer.

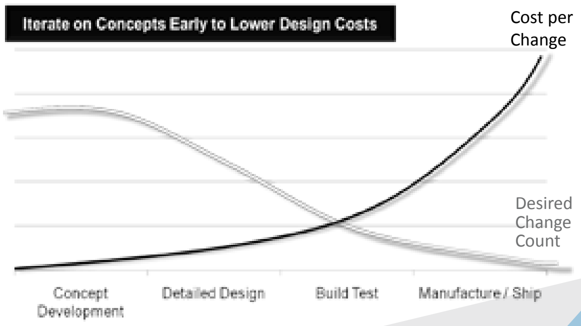
Concept Models

Concept models improve the early design decisions that impact every subsequent design and engineering activity. Selecting the right design path reduces costly changes later in the development process and shortens the entire development cycle, so you get to market sooner. Whether designing new vehicle components, power tools, electronics, architectural designs, footwear or toys, 3D printing is the ideal way to evaluate alternative design concepts and enable cross-functional input from all stakeholders so they can make better choices.

For most concept modeling applications the key performance attributes to look for in a 3D printer are print speed, part cost, ease of use, and life-like print output.



Holding and measuring a printed part offers a better understanding than viewing a rendering on screen.



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Printed concept models let sales and marketing show a product before it goes into production.

During this early phase of product development, it is desirable to quickly and affordably evaluate numerous design alternatives with models that look and feel like the real thing but do not typically need to be fully functional. Stakeholders can better visualize design intent, and they can make faster, more effective decisions, when they can see and touch alternative concepts side by side.

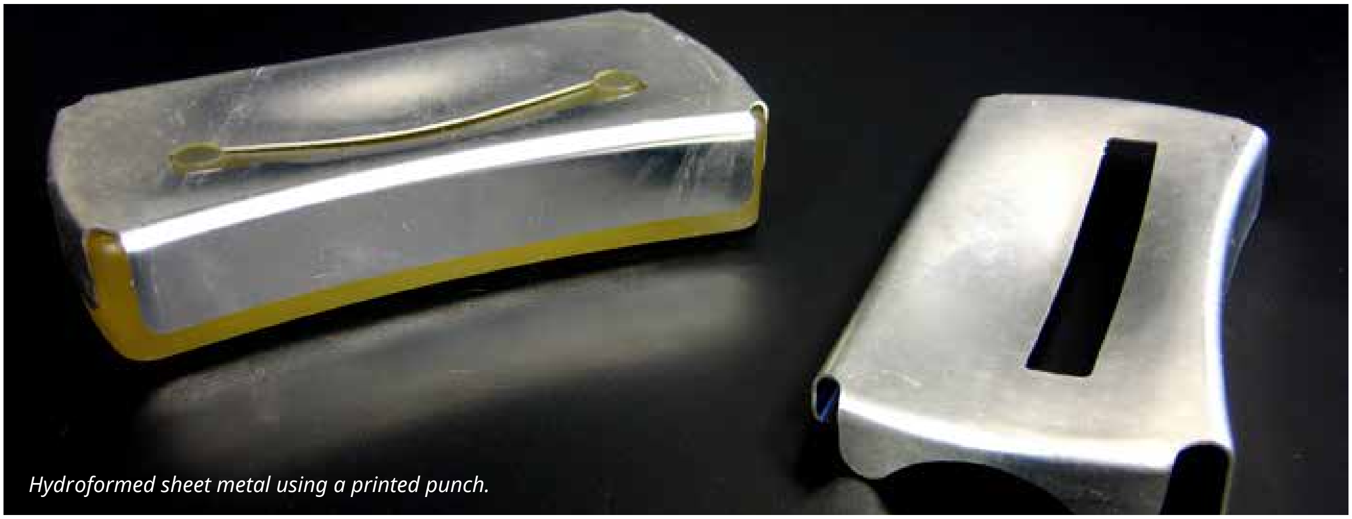

Some 3D printed prototypes so closely match the mechanical properties of production parts that they can be used for crash testing and other functional testing.

Functional Prototypes

As product designs begin to take shape, designers need to verify and test design elements to ensure the new product will function as intended. 3D printing allows design verification to be an iterative process where designers identify and address design challenges to spur new inventions or quickly identify the need for design revisions.

Applications may include form and fit, functional performance, assembly verification and aerodynamic testing, to name a few. Verification prototypes provide real, hands-on feedback to quickly prove design theories through practical application.

For verification applications, the parts should provide a true representation of design performance. Material characteristics, model accuracy, feature detail resolution and build volume are key attributes to consider in choosing a 3D printer for functional verification.


Hydroformed sheet metal using a printed punch.

Pre-Production Applications

As product development converges on the final design, attention rapidly turns to manufacturing start-up. This stage often involves significant investment in the tooling, jigs and fixtures necessary to manufacture the new product. At this stage the supply chain expands with purchase commitments for the raw material and other required components. Lead time for these required items can stretch out time to market, and 3D printing can, in a variety of ways, reduce the investment risk and shorten the time cycle for product launch.

Pre-production 3D printing applications include rapid short-run tools, jigs and fixtures, which enable early production and assembly of final products, as well as end-use parts and first article functional products for testing and early customer placements.


Vacuum forming can be done with 3D printed molds for pre-production or short run production.

At this stage the functional performance of the print materials is critical. Accuracy, precision and repeatability are also of paramount importance to ensure final product quality is achieved and manufacturing tooling will not require expensive and time-consuming rework.

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3D printing is revolutionizing dentistry. Above, a printed wax-up (prosthesis pattern) on a printed dental model, cast in metal and assembled into partial denture.

Digital Manufacturing

Some 3D printing technologies can print virtually unlimited geometry without the restrictions inherent in traditional manufacturing methods, thus providing designers greater design freedom to achieve new levels of product functionality. Manufacturing costs are reduced by eliminating time and labor-intensive production steps, and reducing raw material waste typical with traditional subtractive manufacturing techniques.

3D printed components may be end-use parts or sacrificial production enablers, such as casting patterns, that streamline production flow. Leading companies in industries as diverse as jewelry, dental, medical instruments, automotive, electronics and aerospace have adopted 3D printing to produce end-use parts, casting patterns or molds. Doing so reduces manufacturing costs, increases flexibility, reduces warehouse costs and logistics, enables greater customization, improves product quality and performance, reduces product weight, and shortens production cycle times.

Aircraft air ducting geometry is no longer limited by the means of production so it can be printed lighter and stronger.

For some medical and dental applications, materials may need to meet specific biocompatibility requirements. As well, some aerospace components need to be compliant with UL 94 V-0 for flame retardancy.

For manufacturing applications, the key 3D printer attributes are high accuracy, precision and repeatability, material properties, specialized print materials specifically engineered for application requirements, part cost, and production capacity.

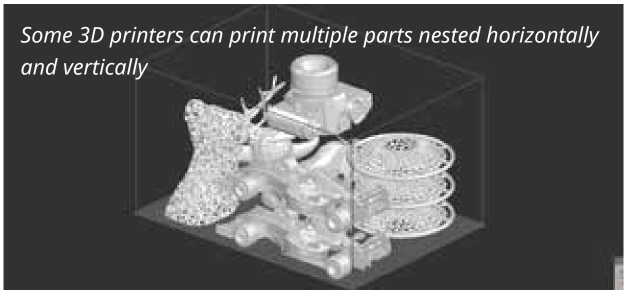
3 3D Printer Performance Attributes

Selection of the right 3D printer is driven by application requirements and matching the key performance criteria that will provide the best all-around value. Here are specific 3D printer performance attributes to consider when comparing various 3D printers.

File-to-Finished-Part Speed

Depending on the vendor and the specific 3D printing technology, file-to-finished-part speed may mean different things, including build preparation, print speed, required post-processing and optional finishing time. The ease-of-use notion is also a factor with a significant impact on the perceived and actual speed to obtain finished parts, with different levels of automation, involving a lower or higher level of manual labor skills and time.

In most cases, the build preparation can be done from any workstation on the network. Software used by desktop and office environment printers allow a fully automated and fast print job setup and submission, with automated part placement within the build area and automatic support generation when required. Recent remote control and monitoring applications from tablets and smart phones further increase productivity and limit down times, with the same controls as onboard (start and stop, job queue management, materials monitoring and diagnostic tools).



Some 3D printers can print multiple parts nested horizontally and vertically

Production printing technologies offer automated build preparation tools but also include more editing tools for the operator to optimize part placement and orientation, support generation, layer thickness, material-specific build parameters, build time, and statistical process control, which is especially important for manufacturing applications.

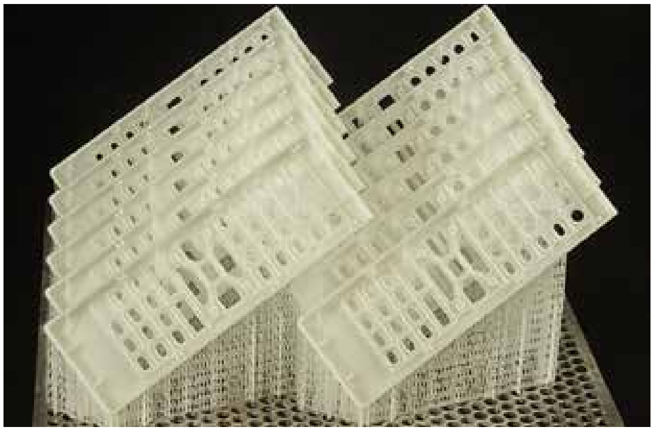
Print speed may be defined as time required for printing a finite distance in the Z-direction (i.e., inches or mm per hour in the Z-direction) on a single print job.

This method is usually preferred for 3D printers that have stable vertical build speeds independent from the geometry of the parts being printed and/or independent from the number of parts being printed in a single print job. 3D Printers with higher vertical build speeds and little-or-no speed loss due to part geometry or number of parts in the print job are ideal for concept modeling, pre-production and digital manufacturing as they enable the rapid production of numerous parts in the shortest time period.

Another method to describe print speed is as time required to print a specific part or to print a specific part volume. This method is often used for technologies that quickly print a single, geometrically simple part, yet they slow down when additional parts are added to a print job or when the complexity and/or size of the geometries increase. The resulting degraded build speed can slow down the decision-making process and defeat the purpose of having an in-house 3D printer for concept modeling or production.

Each 3D printing technology requires a different level of post-processing once the parts are built. These post-processing steps can be more or less automated. Powder-based technologies are usually the ones requiring the least post-processing as they only need to be depowdered and no supports are needed. Some plastic 3D printed parts will require rinsing, UV post curing and manual support removal, while others can be post-processed with automated tools, minimizing labor requirements.

Optional finishing time also needs to be taken into consideration to fully match application-specific requirements. It may include infiltration, polishing, dying and painting to name a few.



High throughput production of remote control covers.

For file-to-finished-part speed, look at:

- ***Build preparation time***
- ***Print speed***
- ***Required post-processing***
- ***Optional finishing time***
- ***Level of automation through all steps***

Part Cost

Part cost is typically expressed in cost per volume, such as cost per cubic inch or cost per cubic centimeter. Costs for individual parts can vary widely even on the same 3D printer depending on specific part geometry, so be sure to understand if the part cost provided by a vendor is for a specific part or a "typical" part that is an average across a group of different parts. It is often helpful to calculate part cost based on your own suite of STL files representing your typical parts to determine your expected part costs.

In order to properly compare claims made by various vendors, it is also important to understand what has, and has not, been included to arrive at the part cost estimate. While typically excluded from the part cost calculation, printer amortization, manual labor cost resulting from amount of time and different levels of skills required, and facility requirements should be considered. Some 3D printer vendors will only include the cost of a specific volume of the print material that equals the measured finished part volume. This method does not adequately present the true cost of the printed parts as it excludes the support material used, any waste generated by the print technology, and other consumables used in the printing process. There are significant differences in the material efficiency of various 3D printers, and understanding the true material consumption is another key factor in accurately comparing print costs.

Part cost is driven by how much total material a 3D printer consumes to print a given set of parts and the price of the materials consumed. The lowest part costs are typically found with powder-based 3D printing technologies. Inexpensive gypsum powder can be used as the base model material that forms the bulk of the part. Unused powder is continually recycled in the printer and reused, resulting in part costs that may be one third to half the price of parts from other 3D printing technologies. With powder-based technologies using polyamide, another decisive factor is the recycling/blending with fresh powder rate that the material allows for without compromising mechanical properties, feature resolution and surface detail. The higher the rate of used powder being blended back in, the lower the resulting part cost.

Powder-based printing technologies recycle unused material, resulting in less waste.

Some plastic part technologies use one consumable material for printing both the part and the supports needed during the printing process. These technologies typically produce sparse support structures that are easily removed, and use less material. Most single material 3D printers do not generate significant in-process waste, making them extremely material efficient and cost effective.

Other plastic technologies may use a separate, less expensive support material that is removed after printing by melting, dissolving or blasting with high-pressure water. These technologies typically use greater amounts of material to print the supports. Dissolvable supports may require the use of caustic chemicals that mandate special handling and disposal precautions. Water-blasting methods require a water source and drain that can add to your site preparation cost. This method is labor intensive and can result in damage to fine part features, as force is applied to remove supports.

Also, supports located in hard-to-access cavities may be stranded and impossible to blast away. The fastest and most efficient support removal is available with 3D printers using melt-away wax support material. Melt-away supports can be quickly removed in batches with a specialized finishing oven that minimizes labor and eliminates the surface force that can damage fragile fine features. Also, supports can be removed from otherwise inaccessible internal cavities, providing the greatest flexibility to successfully print complex geometries. Removal of the wax supports does not require the use of chemicals and the support wax can be disposed as regular trash, eliminating the need for special handling.

Be aware that some popular 3D printers blend build material into the support material during the printing process to create the supports, thereby increasing the total cost of materials consumed during the print. These printers also typically generate greater amounts of in-process material waste, using more total material to print the same set of parts.

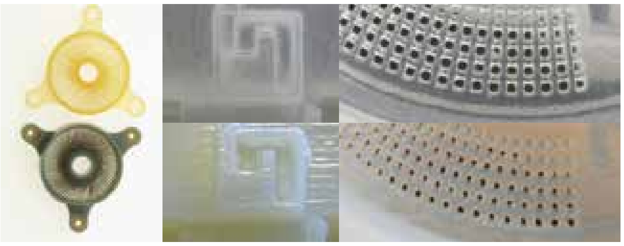
Test more concepts, produce without tooling costs.

To define the part cost, look at:

- ***Vendor's estimate based on your typical parts***
- ***Material cost should include consumption of build and support materials, waste and other consumables depending on the technology***
- ***Printer amortization, manual labor cost and facility requirements need to be considered***
- ***Recycling rate for powder based technologies***

Feature Detail Resolution

One of the most confusing metrics provided on 3D printers is resolution, and it should be interpreted carefully. Resolution may be stated in dots per inch (DPI), Z-layer thickness, pixel size, beam spot size, bead diameter, etc. While these measurements may be helpful in comparing resolution within a single 3D printer type, they are typically not valid comparison metrics across the spectrum of 3D printing technologies.



Compare razor sharp edges and corners definition, round circles, minimum feature size, sidewall quality and surface smoothness.

The best comparisons are provided by visual inspection of parts produced on different technologies. Look for razor sharp edge and corner definition, round circles, minimum feature size, sidewall quality and surface smoothness. A digital microscope may be helpful when examining parts, as these inexpensive devices can magnify and photograph small features for comparison. When 3D printers are used for functional testing, it is critical that the printed parts accurately reflect the design.

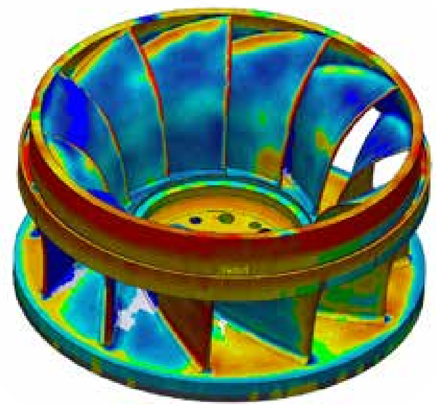
To evaluate feature detail resolution, look at:

- ***Resolution measurements***
- ***Edges, corners, circles, minimum feature size, sidewall quality and surface smoothness (visual inspection)***

Accuracy

3D printing produces parts additively, layer by layer, using materials that are processed from one form to another to create the printed part. This processing may introduce variables, such as material shrinkage, that must be compensated for during the print process to ensure final part accuracy. Powder-based 3D printers using binders typically have the least shrink distortion attributable to the print process and are generally highly accurate. Plastic 3D printing technologies typically use heat and/or UV light as energy sources to process the print materials, adding additional variables that can impact accuracy.

3D scanners can be used to check printed part accuracy, which varies among print technologies and materials



Other factors impacting 3D print accuracy include part size and geometry. Some 3D printers provide varying levels of print preparation tools for fine tuning accuracy for specific geometries. Accuracy claims by manufacturers are usually for specific measurement test parts and actual results will vary depending on part geometry, so it is important to define your application accuracy requirements and test the 3D printer under consideration using your specific application geometry.

For pre-production and digital manufacturing applications, precision and repeatability are critical complementary factors to consider in order to match the final product quality requirements. The capability to hit the right accuracy at the first print is especially important when production batches involve various geometries, sizes and types of parts.

To match your accuracy requirements, look at:

- ***Material shrinkage and compensation/ accuracy optimization tools***
- ***Part size and geometry impact on accuracy***
- ***Precision and repeatability for production applications***

Material Properties

Understanding the intended applications and the needed material characteristics is important in selecting a 3D printer. Each technology has strengths and weaknesses that need to be factored in. Claims about number of available materials should be viewed with caution as that does not guarantee the available materials will provide the real functional performance needed. It is vital that printed parts are tested in the intended application prior to making a purchase decision. Stability of parts over time and across various use environments are not discernible from standard published specifications, and they may lead to limitations in actual usefulness if not fully considered and tested.

For concept modeling applications, the actual physical properties may be less important than part cost and model appearance. Concept models are primarily used for visual communication and may be discarded shortly after being used. Verification prototypes need to simulate final products and have functional characteristics that closely resemble final production materials. Materials used for direct digital manufacturing need to deliver the mechanical, thermal and aesthetic requirements of the product. End-use parts will typically need to remain stable over longer time periods. For indirect manufacturing via casting or tooling, materials may need to be castable or may need to provide high temperature resistance to perform in application.

Each 3D printing technology is limited to specific material types. Materials are typically grouped as plastic, composite, wax, metal, ceramic, and other non-plastic. Your selection of a 3D printer should be based on which material categories provide the best combination of value and application range. Combining multiple technologies can provide additional flexibility and expand your addressable applications beyond what can be achieved with a single 3D printer. In some cases, the combination of two less expensive 3D printers may provide more value than one more expensive system and allow for greater application range and print capacity, while staying within a similar investment budget.

Plastic materials range from flexible to rigid and some provide higher temperature resistance. Clear plastic materials, biocompatible plastics, castable plastics and bioplastics are also available. The performance of plastic parts produced on different technologies varies widely and may not be apparent from published specifications.

Some 3D printers produce parts that will continue to change properties and dimensions over time or in varying environmental conditions. For example, one commonly reported specification used to indicate heat resistance of a plastic is Heat Distortion Temperature (HDT). While HDT is one indicator, it does not predict material usefulness in applications that exceed the HDT. Some materials may have rapidly deteriorating functional properties at temperatures slightly above the stated HDT while another material may have slow degradation of properties, thus expanding the temperature range in which the plastic is useful. Another example is the effect of moisture on the part. Some 3D printed plastics are watertight while others are porous, allowing the part to absorb moisture potentially causing the part to swell and change dimensions. Porous parts are typically not suitable for high-moisture applications or pressurized applications and may require further labor-intensive post-processing to be useable under those conditions.

Some desktop printers can print with three different plastic materials within one part. Multi-material composite 3D printers go much further, mixing various materials to achieve hundreds or thousands of unique materials in a single part. These systems print a precise variety of engineered plastic or rubber needed within one part, and at one time, without assembly. The hundreds of materials variations that are available in a single build allow engineers to print parts with a varying degree of flexibility, transparency and colors for overmolded parts, multi-materials assemblies, rubber-like components, living hinges and high temperature testing, for instance.

Stereolithography printers offer an expanded range of plastic materials that truly offer the functional performance of ABS, polypropylene and polycarbonate plastics, as well as castable and high-temperature materials, in a single 3D printer. They offer easy, fast and affordable material changeovers allowing one 3D printer to provide a wide range of addressable plastic applications. When looking at technologies that claim numerous materials, pay particular attention to material waste that is generated during material changeover. Some of these 3D printers have multiple print heads that must be fully purged, thus wasting expensive print materials in the process.

Plastic powder-based technologies generate true thermoplastic parts in a range of engineered production plastics like polyamide, glass filled and heat resistant material, some of them in both black and white color. With their excellent mechanical properties and stability over time, laser sintered parts are widely used for functional testing as well as direct manufacturing of low to medium runs.

Multi-material composite parts, built in one part/one time.

Parts can be printed in a variety of ferrous and non-ferrous metals, and ceramics.

When looking at metal 3D printing materials that can typically be used only on specific direct metal printers, it is important to carefully look at the particle size of the material as it directly influences the part denseness as well as the accuracy, surface quality and feature resolution. The smaller the material particle size, the better the quality of the final part. Direct metal 3D printers typically offer a choice of standard metal alloys and ceramics, including steel, CrCo, Inconel, Al and Ti alloys.

Other non-plastic materials include gypsum powder used with a printed binder, resulting in dense, rigid parts that can be infiltrated to become very strong. These parts make excellent conceptual models and provide some limited functional testing opportunities where flexural properties are not required. The bright white base material combined with exclusive full-color printing capabilities can produce life-like visual models that do not need additional painting or finishing.

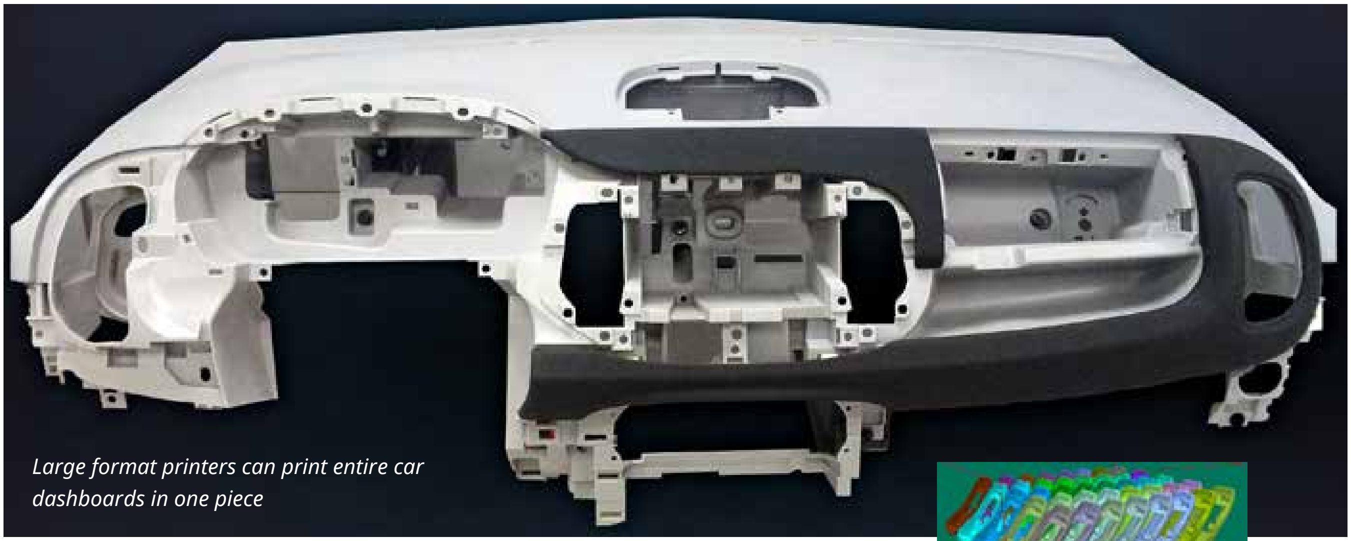
Print Capacity

From the functional prototyping stage, it is critical to print full-size parts to test product functions in real conditions, so the build volume is key for real-size parts. Printing several iterations of the same part at once can also be beneficial to speed the product development cycle and improve product quality by testing more design options. The largest build volume is available with Stereolithography technology, with a printing length of up to 1500 mm, allowing engineers and designers to print complete dashboards, for instance.

In functional testing, it is specifically important to build

For 3D printing material properties, look at:

- ***Your material properties and materials variety specific application(s) requirements***
- ***Your part stability requirements over time and in use environment***
- ***Combination opportunities of multiple technologies/material types for added flexibility and addressable applications***



Large format printers can print entire car dashboards in one piece

With nesting, hundreds of parts can be printed in a single build, and each one can be unique

parts in one piece. If your part size exceeds your build volume, there still is the option to join parts. Be aware however that joining affects part functionality. Mechanical testing on a joined part will not accurately reflect the performance of a part that will later be produced in one piece.

For production, the required print capacity will be defined by the part size, the production run volume, and the printer's ability to make the breadth of parts you need to create. Those criteria will allow one to select between large build capacity for highest throughput or several lower build capacity printers for increased flexibility.

The capability of stacking and nesting parts within the printer's build envelop significantly increase the print capacity to produce more parts at once with longer unattended operation.

To fulfill your print capacity requirements, look at:

- ***Part size and/or number of parts/iterations to print at once***
- ***Large build capacity for highest throughput***
- ***Several lower capacity printers for flexibility***

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.

There are three basic categories of color 3D printer:

- **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

A printer with higher resolution can print finer details and crisper images.

By using Cyan, Magenta, Yellow, and Black, millions of colors are possible with a full-spectrum color 3D printer.

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 and basic-color printers can represent different materials or regions in different colors. Full-spectrum color printers can additionally apply photos, graphics, logos, textures, text labels, etc., and can produce models that are difficult to distinguish from the real product.

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).

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.

3D printed objects, and other objects that 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. The number of colors that can be printed is determined by the number of primary colors, the processing capability of the printer, and the whiteness of the base material.

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.

Color-choice and basic-color printers typically print parts in various plastic materials. Full-spectrum color printers available today can print in plastic or gypsum powder, or with paper as a base material.

With the ability to halftone, or dither, the colors, 3D models can be made to look just like the real thing.

For your color needs, look at:

- ***Resolution of the printer for crisp details***
- ***Amount of colors printed in one part and in one build***
- ***The capability of halftoning for photo-realistic results***

4 Conclusion

3D printing can offer benefits across the entire creation process from initial concept design to final manufacturing and all steps in between. Different applications have unique needs and understanding those application requirements is critical when choosing a 3D printer. Multiple systems may offer broader use opportunities than a single system. Thus, identifying your unique requirements within your entire design-to-manufacture process will help you select the ideal 3D printing technology and help you optimize the benefits of 3D printing: shorter time-to-market, improved product performance, streamlined and cost-reduced manufacturing, and improved product quality and customer satisfaction.

Learn more about 3D Systems at www.3dsystems.com.

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