EBOOK

After the basics:
a 3D printing handbook

GRABCAD

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Introduction

Welcome to the first volume of 3D printing for intermediates.
Welcome to all of you who kind of know what you're doing.
You are among friends here.

When it comes to 3D printing, there is a giant gap between learning material for beginners and content meant for the extremely experienced. We're here to help.

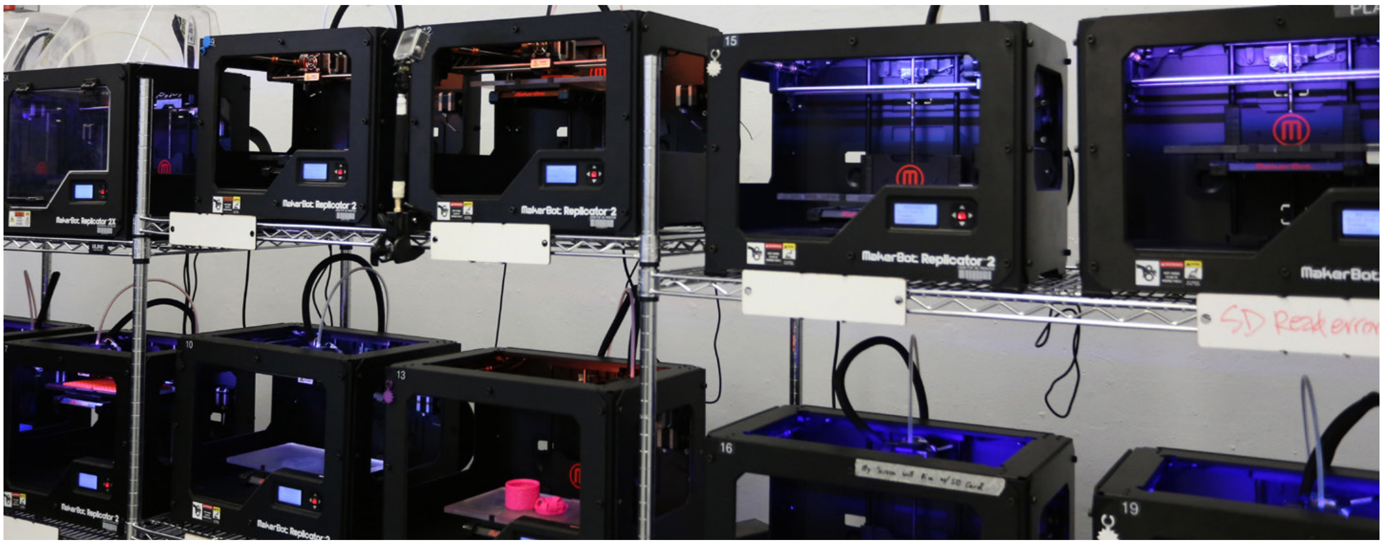
We've set out to save you hours of googling and forum searching to bring you the intermediate 3D printing topics you're craving - like when to use specialty filaments and tips for starting a print lab.

As always, feel free to share your feedback. Are these topics useful? What should we cover in volume two? Let us know.

Dennis Bella is a freelance writer with diverse range of experience in 3D printing, software, and technology. In his former life, he was a 15 year veteran in IT security sales, CAD quality assurance, and technology public relations. While offering his own 3D printed items, Dennis works with clients to create a variety of designs, from dimensioned parts to artistic sculptures. He is a graduate of Northeastern University in Mechanical Engineering Technology and received certification in Technical Communications from University of Massachusetts at Amherst.

When starting a 3D print lab, material choices matter

With additive manufacturing technology reducing in size and simplicity, your home garage could one day be the machine shop of tomorrow. We're talking a micro factory! A 3D print lab where the mad scientist in you now has full spectrum dominance on every level, from design to production, in the comfort of your own home or small office. You'll have total engineering and manufacturing synchronicity at your fingertips.



In the famous words of Rex Kramer from Airplane!:

> **"But it's his ship now, his command. He's in charge, the boss, the head man, top dog, big cheese, a head honcho, number one..."**

Now remember, despite the excitement, chaos, and myriad of life altering choices you'll make at Macho Grande, you need to decide how best to outfit, operate, and strategize your new 3D print lab. From material selection to service offerings, consider me your inflatable co-pilot.

While your new 3D print lab can focus solely on rapid prototyping for clients, low volume manufacturing is attainable, albeit to a smaller degree as you get started. This will change as advancements in 3D print speed, intelligence, and consistency are made.

One of the greatest advantages of low volume manufacturing is the ability to print near-net-shape objects, thereby reducing raw material waste when compared to subtractive manufacturing. For prototyping, you've drastically improved your design and manufacturing cycle by days instead of months with little to no ripple effect on the overall process.

Be sure to embrace both

Look into providing rapid prototyping for clients while exploring the possibility of selling your own products. Since you're the design department, use your CAD skills to come up with a niche. Break traditional barriers and bring your products to life. Even if you find no avenue to sell your widgets online, you already have the design ready for partners who can run with it on your behalf.

However you equip your lab, remember that you still have the option under your belt to utilize online services should the need arise for unique materials like metal. Partner with several companies and utilize their experience and technology as a resource instead of thinking of them as a competitor. As innovation catches up, you can easily shift strategy to offer your own services later.

Material selection vs. what you're trying to achieve

Let's consider that despite advancements in 3D printing, there's no Swiss army knife unit capable of doing everything. Material selection starts with deciding on what you're trying to achieve. The materials used, coupled with the printer's capability, will equip you for a variety of situations.

Plastics

Materials such as ABS, PLA, HDPE, Nylon, and Polycarbonate are the most popular, offering varying degrees of strength, rigidity, flexibility, and function for multi-part assemblies. Plastics are ubiquitous in prototyping and are economically feasible for low volume manufacturing runs.

Plastics fill a large range of needs, from standard prototypes to functional models. Offered in a myriad of colors and characteristics, plastics are the cornerstone for rapid prototyping or low volume manufacturing on 3D printers.

Plastic filaments and powders are available in a broad range of technologies, price ranges, color capabilities, build volumes, and features. In the world of FDM (Fused Deposition Modeling), a $2,500 desktop printer can sometimes provide you with a “close enough” degree of print quality compared to a $50,000 unit, depending on your use case. The models will be functional, offer reasonable dimensional accuracy, and inexpensive to produce.

FDM printers also have a head start on material availability. Recent filaments in the market simulate aluminum, steel, iron, carbon fiber, wood, or rubber. For electronic components, conductive 3D printer filament can dissipate static and provide electromagnetic shielding. FDA approved filaments are appearing, allowing you to focus on 3D printing for the medical and food & beverage industries.

Thermoplastic powders are the next step, requiring lasers to melt or sinter thermoplastic powder by into 3D objects. Technologies such as SLS (Selective Laser Sintering) and SHS (Selective Heat Sintering) provide excellent surface quality and detail when compared to FDM printers. Available for plastic, metal, or ceramics, they are more expensive and not yet consumer friendly. SLS and SHS units yield significant material savings, especially when printing complex objects. It’s also a popular choice for low volume manufacturing runs.

There’s also the steady rise of small-office sized SLA (Strereolithography) and DLP (Digital Light Processing) 3D printers. They use laser or light to cure photosensitive polymer resins into 3D objects. SLA printers excel at fine detail, smooth surfaces, and yield reasonable strength characteristics depending on the object’s geometry.

Latest resins available feature enhanced strength properties, flexibility, and the ability to produce molds for metal casting.

Metals

Metal 3D printing is the holy grail of additive manufacturing. While not yet easily attainable for your garage startup, we're seeing significant advancements on all fronts, from desktop level to professional grade. Several companies are now in the race, setting the stage for your 3D print lab to become the ultimate machine shop. The rise of metal 3D printers will help take near-net-shape manufacturing to the next level.

Metal's most obvious advantage, apart from its strength characteristics, is the ability to 3D print prototypes that are also fully functional for the real world.

Various titanium, aluminum, chrome, and stainless steel alloys are commonly used with SLM (Selective Laser Melting), SLS, and DMLS (Direct Metal Laser Sintering). Each of these technologies use laser melted or sintered metallic powders with various alloy compositions, giving you a wide range of properties to work with. Metallic powder is also available for brass, sterling silver, solid gold, bronze, and alumide.

Alternative Materials

For rapid prototyping or manufacturing, alternative materials provide a viable option for clients with outside-the-box design needs. Sandstone-like surfaces are growing in popularity, allowing for multicolor objects at affordable prices. It's useful for details and color but not for flexibility and strength. Consider this material for clients that design art, novelty, home decor, or sculptures.

Ceramics also offer a great choice for home goods as well, with a variety of surface finishes and colors to choose from.

Whilackluster in strength, flexibility, and detail, 3D printed ceramics can add chemical corrosion resistance or waterproofing to your client's design.

Surely, you can't be serious

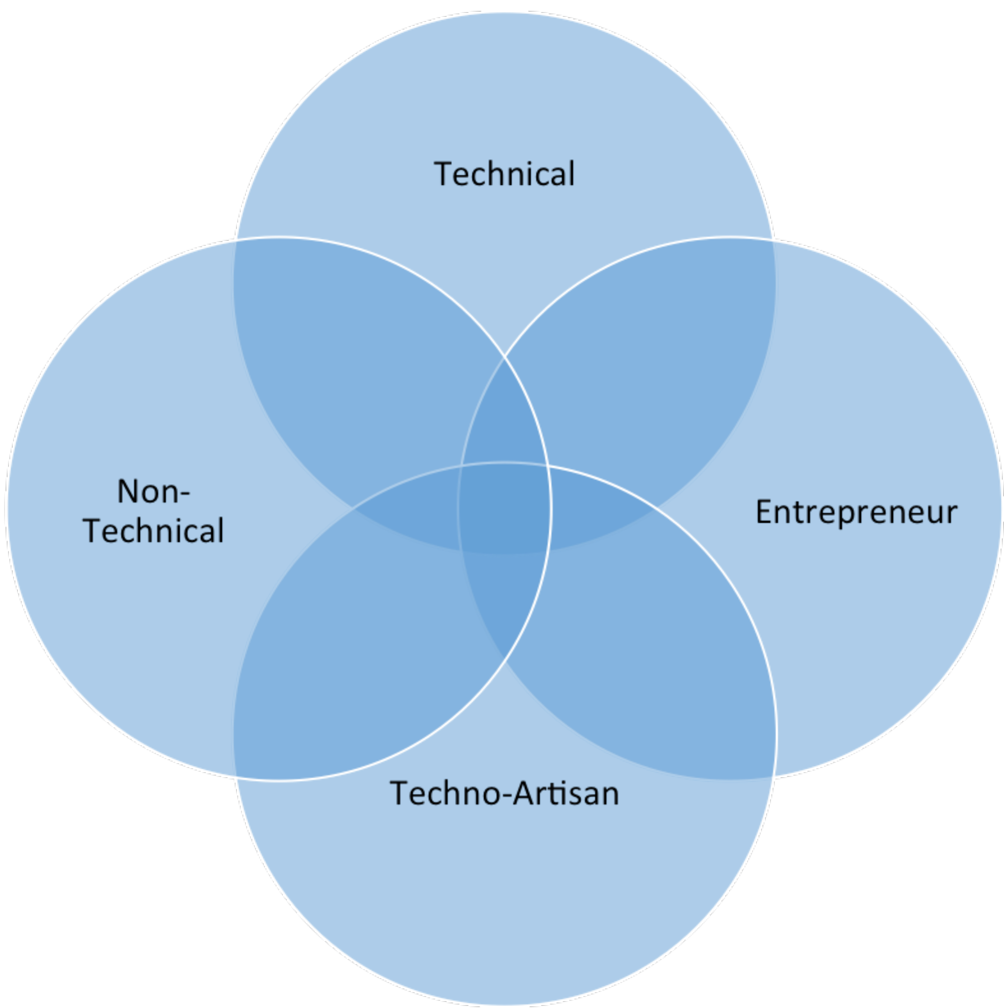
The decision making process for your new 3D print lab may seem daunting. Technology aside, it really starts with the path you choose. Rapid advancements in 3D printing yields an interesting overlap of material choices for the startup micro factory. Don't shy away from using your 3D print lab to practice all three disciplines: prototyping, inventing, and low volume manufacturing. With an array of materials to choose from, you'll be better prepared for the overall client experience while also offering operational flexibility.

The 3D printing career matrix

Navigating the 3D printing career path is combination of desire, experience, and skill choices. Don't panic just yet – you're probably way ahead of the curve already just by having an interest in 3D printing. Since the industry is constantly evolving, so are the choices. Let's sit back and take a snapshot of what's out there and how you can get started.

Who you are and who you can be

Let's divide up our 3D printing careers by the following categories: Technical, Non-Technical, Entrepreneur, and Techno-Artisan. There's plenty of overlap between each of them so don't feel like one is isolated from the other. Since you decided to keep reading, we'll show you how far the rabbit hole will go regardless of which circle you might reside.



Technical

Engineers, technicians, architects, or scientists have the easiest transition into the 3D printing career matrix. You most likely have dealt with SolidWorks, Rhino3D, AutoCAD, or countless other iterations for 3D modeling and design. Chances are you may even have experience with CNC programming for laser cutters, lathes, or mills. As an architect, you may have used programs that include Revit or Sketchup to create models of buildings and houses, if not made them by hand using raw materials. You're not afraid to work with a 3D printer, build one yourself, or prototype an object from scratch. You have plenty of choices in industries that include defense, automotive, materials science, agriculture, medical, aerospace, architecture, and software development. Regardless, new opportunities are organically growing each day.

I want to design stuff

If you just want to design objects for 3D printing, CAD and 3D modeling are the bedrock for any freelance, small business, or company role. Whether it's engineering a new coupling or creating a concept car for industrial design, you've got the technical background to get started. Performing design work culminates all of your technical talent, prototyping experience, and solid modeling skills over a broad range of industries. Whether working for an aerospace company or a boutique design firm, your "CAD-foo" will be in heavy demand.

I just like to print stuff

You just love watching the whirl of a 3D printer in action. We get it - it's exciting (if not hypnotizing). If you love 3D printing services, you can open your own 3D printing store, service your own gear, and work with customers on getting their objects printed according to their design specifications. In this case they would either provide you with a digital file of your model or you would provide the additional service of designing it for them. Whether you're starting a service franchise or working for a worldwide on-demand 3D printing company, you'll have the experience and fundamentals down to pave your own destiny. Keep in mind you'll still need some CAD-Foo skills as well as an understanding of 3D printing software for preparing and analyzing digital files.

Are you a former or current machinist? You'll have the background for both additive manufacturing and subtractive manufacturing under one roof. You'll provide in-house rapid prototyping as well as production level metalworking for clients.

Interested in technical support? As a techie who loves 3D printing and problem solving, there's a growing need to troubleshoot and help customers understand their new toy. On-site support for 3D printers or phone based support service might be your thing.

I'm an R&D geek

You want to get into the nuts and bolts of 3D printing, designing units on behalf of a major company or simply to kick start your own business. Here you have the pleasure of building, experimenting, designing, and engineering your own rig. R&D gets into the science of 3D printing, researching new methods and technologies that improve 3D printer performance.

Don't forget to stay ahead of the latest news in bioprinting; the ability to 3D print an organ, bacteria, cell, or other organic material for medical research or donors. While still a unique role, bioengineers and medical scientists with 3D printing experience will certainly be in high demand.

If you're a programmer, you may want to develop the next best slicing software or CAD modeling tool. You might develop a suite of tools designed to maximize or prepare digital files for 3D printing or perhaps create utilities that streamline the design process for a 3D printed object.

In the industrial engineering realm, the science of assembly line manufacturing using 3D printers will also be required to maximize production speed, efficiency, quality control, and automation. Your research will culminate into the future of mass production. Ready for the future of construction engineering? Checkout this Chinese firm 3D printing 10 houses in less than 24 hours.

Non-Technical

While you don't have a technical background or education, you're curious – and rightfully so. You don't have to be Mr. Wizard to understand 3D printing fundamentals. Just by simply owning a desktop 3D printer helps you learn the basics. One of the best ways to learn is not only to operate a unit, but build one yourself from a kit. Companies such as Ultimaker and Printrbot offer user-friendly procedures for building your own. While there may be some thinking and troubleshooting involved, you'll be grateful for the learning experience down the road. With basic desktop printer prices down to nearly $200, learning 3D printing at home will equate to on-the-job training.

There are an array of non-technical roles to choose from thanks to 3D printing. If you have a legal background then intellectual property, copyrights, and patent law are right up your alley. Sooner or later you'll be busy trying to protect the latest fabricated gadget or 3D printer from being duplicated by users worldwide. Love to sell technology? The transition would be easy for new or former tech salesman to start selling 3D printers to businesses, schools, and other organizations. In the retail segment, sales executives are necessary for in-person store consultations. In addition, your sales skills will easily translate to areas in marketing where branding, promotions, tradeshows, and strategy are required to penetrate new territories, gain mindshare, and deal with the competition. As a marketing or sales executive, getting up to speed with 3D printing won't be difficult after some trial-by-fire.

Artists will also have plenty of opportunity with 3D printing – concept drawings, graphic design, marketing materials, user guide artwork, and packaging design are sure to be required to grab a customer's attention or help an engineer easily understand the diagrams of their newly purchased $350,000 laser sintering system.

For teachers, training users in 3D printing will have benefits for students and employees alike. Teachers who grasp 3D printing are a necessity for training the makers of the future. Whether you're in a high school classroom or corporate training facility, 3D printing trainers will be a breath of fresh air for anyone wants to learn how to prototype or mass produce.

For the wordsmith, writing user guides, books, procedures, marketing material, websites and blogs, legal information, and countless other pieces of 3D printing content will yield an array of freelance or full-time positions. Writers will be key in communicating complex ideas into simple concepts so that any audience, from consumer to potential investor, will understand the world of 3D printing.

Entrepreneur

You want to be a founder, CEO, or captain of industry. We get it! The kingdom is yours for the taking. Do you want to create a hot tablet app for remote 3D printing and control?

Are you the guy who figures out how to make 3D printing materials made of wood, carbon fiber, or simulated brass? Perhaps you've come up with a way to create affordable 3D printed prosthetics with style?

Under the entrepreneurial umbrella, you have limitless directions for starting a company. With a broad range of product and service ideas to choose from, any industry can benefit from the effects of 3D printing. To gauge the scope of possibility, stay on top of the latest industry news.

In software, everything from android apps to 3D scanning software are being developed as you read this. Online services such as collaborative design websites, print-on-demand tools, model databases, and a variety of web-based applications allow users from across the globe to enhance their 3D printing efforts.

In 3D printer hardware, new tools and modifications are being engineered to help increase 3D printing performance and efficiency. From Arduino-based controller boards to new hot-ends for FDM printers, hardware entrepreneurs are paving the way.

For consumer goods, the power of 3D printing for customizable products is vast and intoxicating. Examples include custom 3D printed earphones, role playing games, toys, 3D scanning of pets, jewelry, furniture, and electronics components.

The Techno-Artisan

You are the artist, animator, sculptor, and designer that uses 3D printing for a variety of expressions. Many artists are cross training - blending technique with technology to create styles and designs that transcend traditional methods. In some cases, the act of a 3D printer creating art is just as amazing as the art itself. A blend of art, engineering, and innovation, has resulted in a new patent-pending, anti-gravity, object modeling 3D printer. We present to you the MX3D robot, capable of creating 3D printed structures in mid-air.

For the digital animator and sculptor, creating cartoon characters, monsters, sci-fi ships, and more now entail 3D printing their digital design into a resin or plastic model. Various figures, statues, structures, objects, and parts help creators understand their work or prepare their designs for mass market production. From canvas to computer screen to 3D printed model, digital effects artists and animators turn designs into reality.

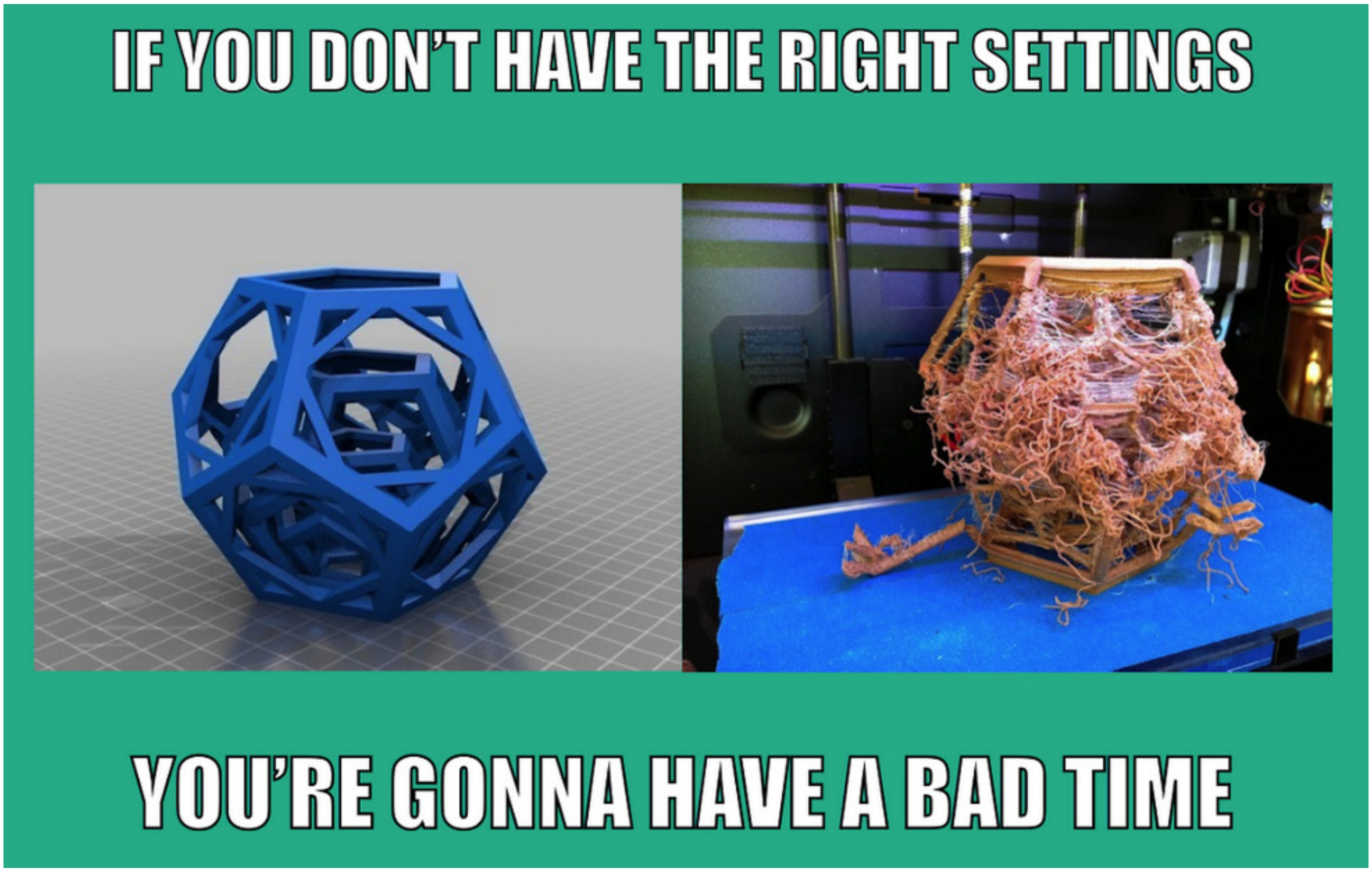
Architects also make use of 3D printing for concept buildings, representations, topology, and landscapes. 3D printing helps reduce the cost of traditional modeling while adding more detail and freedom of expression to their representations than ever before. In addition, an architect may now present clients with 3D printed versions scaled to larger sizes that help highlight physical features in more depth and detail.

Organic career choices

3D printing career paths allow different professionals across the board to embrace technology and promote their interests. Countless products, designs, and engineered devices are becoming a reality, spawned by the imagination of the engineer, scientist, artist, or entrepreneur. The residual growth for opportunities span multiple directions and gives opportunity for those who haven't yet touched a 3D printer. This industry is organically creating new work roles, new visions, and better futures for all.

Making desktop 3D printing more user-friendly

Fused Deposition Modeling still reigns supreme in the desktop fabrication market. While FDM continues to expand in function, flexibility, and filament variety, there's still an adoption gap – a disconnect that needs to be solved if 3D printers are to invade every household.



The first iteration of desktop 3D printing was primarily "hobbyist" level and involved serious time, problem solving, and patience. As maker communities gathered and the RepRap movement rose, an open source design initiative helped spark the desktop 3D printing revolution.

The next iteration began when units such as the Makerbot Replicator 2, Cube, Ultimaker, and PrintrBOT began to take hold. Although these printers (and others) succeeded in wooing early adopters, the broader market remained apprehensive. Word spread about long or failed prints, troubleshooting issues, and accompanying frustration. Some are still hesitant to adopt 3D printers owing to the "problem solving" stigma. Why don't the printers "just work?"

The current iteration is at a crossroads. How can companies make desktop additive manufacturing (using FDM) as easy to operate as a microwave? All things being equal, we know that a moving nozzle spewing hot plastic layer by layer can only be so accurate, so fast, or so dependable. Assuming FDM continues its pace for the home or small office market (considering other technologies such as SLA and SLS are steadily lowering in cost and becoming easier to use) there's still plenty of room for innovation.

I've identified a number of features that I believe will help win over dubious potential buyers. The aim is to move away from the hobbyist mentality and focus on fail-safe features, productivity, and ease of use. You have to prove to households there is a net gain in productivity when using a 3D printer.

Speed

In order to move away from the stigma of 3D printing as merely a "fun project," speed should be top priority. If you want consumers to consider it a household necessity, reduce the print time. Faster print times mean better productivity at home and an appreciation for quickly fabricating objects instead of having to buy them.

Automated build plate leveling

A leveled build plate is the cornerstone for successful 3D prints and a common denominator for print failure. The traditional technique of measuring plate-to-nozzle distance using a sheet of torn paper has to end. While manual leveling may be easier for some, it's tedious or frustrating for others. Swedish manufacturer Zyyx may already have the answer. Their unit includes a probe attached to the nozzle assembly. Before printing begins, the surface-compensating leveling system engages and eliminates the need for manual plate adjustments. The probe positions itself at each corner of the plate, adjusting the print plane automatically.

Scalable build volumes

Once you purchase a 3D printer on the market today, you're bound to an exact build volume. A scalable 3D printer that utilizes multiple volume sizes will help consumers see the utilitarian value in their purchase. It also opens the door for additional revenue from value added products such as expansion kits. From 3D printing small toys to large closet shelving units, marketers can increase the focus on their brand's "at-home" or DIY capabilities.

Multi-function printer systems

Some companies are designing several Cartesian-based manufacturing processes into one platform, combining 3D printing, milling, laser engraving, cutting, or 3D scanning. FABTotum and Piranha FX offer "multi-purpose personal fabrication devices" that may help shoe-in "The Jetsons" age for households.

Smart extrusion technology

For Makerbot's 5th generation series, a new swappable extruder unit was designed for easy maintenance and troubleshooting – especially for less technical audiences or those who aren't interested in the "tinkering" aspects of 3D printing. As a completely enclosed and modular unit, there's no need for part-by-part disassembly. It allows for both quick replacement and easy upgrades in the future. Makerbot and Zyyx printers incorporate filament sensing capabilities that pause the printer in the event of clogs or feeding issues. Zyxx has also added detection features that sense warping, curling, or loose objects during printing.

Predictive slicers and virtual reality

When a digital model is sent to 3D printing software, it's converted into a set of instructions (known as G-code) that a 3D printer will understand and follow. Otherwise known as "slicing software", it's available in either proprietary or open source formats and an array of print settings. Household friendly 3D printing software requires additional simplification and predictive capabilities. While a "fix everything button" would be really cool, we all know it's not that simple.

Visualizing a model in the digital world helps anticipate how the physical object will look once 3D printed. As virtual reality becomes more attainable for the home user, so will the ability to study a 3D model in a digital environment. VR allows modelers and designers to test, live, and experience their design from alternate points of view. Swiss startup theConstruct provides a new perspective in 3D modeling and 3D printing by allowing users to work with their models in a virtual setting before hitting the print button.

Non-proprietary filament cartridges

Filament cartridges with proprietary designs or “smart sensors” are more trouble than they’re worth and drive away the households they’re targeting. Allowing consumers to price shop their filament without being bound to one manufacturer’s proprietary design is vital and economically sound. Proprietary cartridges add complexity where it’s not necessary and potential for additional failure. It also gives budget conscious buyers bad vibes.

Easier general maintenance

If a general degree of maintenance is still required for a 3D printer, especially if a consumer has to work with technical support, easier troubleshooting ergonomics will help keep things calm. From color-coded controller board wiring to easy timing belt calibration, the maintenance process needs to be as simple as setting up your stereo or computer via plug and play. The goal should be to make the repairs or replacements for common issues as easy as building Ikea furniture or replacing your computer’s DVD drive. Tighter support integration between the printer, its ergonomics, and customer service will induce buyer confidence and may even get buyers hooked on DIY upgrades down the road.

Core performance before cool widgets

Focus on the productivity and utility a new consumer wishes to have with their 3D printer. When asked what they want, buyers will most likely say: “I just want it to print when I tell it to.” They’re less likely to say “I want it to print while I watch it happen over the internet via my printer's built in Wi-Fi using a tablet app". If the printer is providing a problematic core experience, getting Wi-Fi to work will be the last problem on their mind. LCD displays and webcams are necessary and useful, but it's not what they bought it for. The finished physical 3D printed model, as well as the seamless experience to create it, is what the home market is searching for.

Moving toward a 3D printed future for households

Whether for engineers or not, friendlier and more proactive design features are essential to capturing the attention of the "not sure if I should wait until the technology gets better" audience. When 3D printing is mentioned, you'll most likely hear "I saw it on the news, it's amazing!" What you should hear is "my neighbor 3D printed me a garden hose attachment at the press of a button, I've got to get myself a Makerbot!" It should be as socially normal to 3D print an object as it would be to recycle one. To win consumer hearts and minds, we'll need to push the boundaries in usability that rivals any home appliance.

3D Printing file format cagematch: AMF vs. 3MF

With 3D printers, applications, and distributed manufacturing speeding ahead, our beloved .STL file may soon be considered an honorable mention. While it will always have a place in our toolbox, it lacks the information package required to keep pace with the evolutionary trajectory of 3D printing.

Who will take the crown as the de facto file standard for additive manufacturing?

The rapidly evolving world of additive manufacturing is approaching a nexus in terms of interoperability. Your design process may involve multiple file formats as the product originates from napkin concept to 3D printed model. While the .STL file has been an industry standard for over 25 years, it only contains surface mesh information – just enough to print in a single material or homogeneous shape. It lacks any data accrued during the design loop such as information on materials, model orientation and position, textures, colors, sub-structures, and multi-material geometries.

During the design-to-print pipeline, the passing of file information through different applications (CAD, slicers, etc.) may also cause a loss of data or incompatible geometries in the model during translation. Intermediate file formats do not support all of the capabilities that each printer may offer. Other popular formats such as .IGES, .STEP, .NURBS, .OBJ, and .VRML provide varying degrees of capability, information, and accuracy.

This has fueled the call for a single, backward compatible, interoperable, and unified file format that would act as the model's complete DNA; containing the entire genetic code of its design, from color to geometry that could operate across multiple platforms and applications. The intended result is to not only streamline manufacturing, but also provide a scalable and easy-to-understand format that could be interpreted by any system. It would need to optimize the ability for 3D printers or other systems to easily interpret the complexities of a model's geometry, arrays, resolution, and internal features with improved accuracy. While .STL reigns king, the .AMF (Additive Manufacturing Format) and .3MF (3D Manufacturing Format) file formats are jockeying for position:

AMF (ISO/ASTM 52915:2013)

In 2009, the American Society for Testing and Materials tasked ASTM Committee F42 on Additive Manufacturing Technologies to address the need for a replacement to the .STL file. At the time it was dubbed "STL 2.0" and a design subcommittee led the development effort. Their goal was to create a file format analogous to a .PDF file for documents, containing as much information possible to describe an object in the same way. This would provide more data prior to conversion into a format for fabrication and would also allow developers to create OEM software that could pick and choose whatever information was necessary for their 3D printing hardware to operate.

The subcommittee developed the .AMF format for technology independence, simplicity, scalability, performance, and both future and backward compatibility. Its first iteration was developed in 2011 and subsequently approved in 2013 in conjunction with the International Standards Organization (ISO).

AMF is an XML-based open format that provides complete information through a hierarchy of five main elements: object, material, texture, constellation, and metadata. This provides the basis for information on a model's shape, composition, color, materials, and geometry. It also introduces the concept of print constellations, allowing information on multiple objects to be positioned and arranged together. This would result in increased packing efficiency or for use with large arrays of identical objects that would be 3D printed on a single build tray. Among .AMF's additional characteristics:

- XML-based for easy reading, writing, and processing with as much information as possible to describe an object, its materials, and other manufacturing features

- Incorporates triangular meshes to describe surfaces, allowing all vertices to be defined as opposed to single vertices in .STL files.

- AMF triangles can describe curved surfaces and/or non-planar edges on 3D surfaces more accurately than .STL files. They are not limited to straight-edged, planar triangles.

- Objects can be defined in CAD programs more easily, allowing 3D printers and other hardware to pick and choose information necessary to perform its operation. For example, if a printer is only capable of working with one color, multi-color information is simply ignored. This capability works for all elements including material, texture, and composition.

- Incorporates extensive metadata including name, author, company, description, volume, tolerances, and more.

- Geometry support for mixed and graded materials, sub-structures, microstructures, porous, and stochastic materials.

- Defines color specification using RGBA values.
- Includes support for graded colors, texture mapping, and transparency backgrounds.
- Supports texture data for 2D and 3D maps.
- Can be stored in plain text for or can be compressed into .ZIP file format.

While starting off slow, acclimation to .AMF has grown since its introduction. CAD vendors originally took a "wait and see" approach to the matter, preferring to integrate .AMF according to customer demand. Development has been ongoing since and eventually gained a foothold with larger application such as SOLIDWORKS and Autodesk's suite of products. Stratasys also signaled its cooperation, foreseeing the potential benefits in .AMF and continue to support it today. 3D printing service providers such as Shapeways and Materialise added .AMF to their lineup of accepted formats while also contributing resources to its development. Due to the myriad of interdependent technology requirements these companies require, .AMF was ready to work with 3D printers on the market today. In addition, conversion and creation tools have been developed to help users migrate older .STL files to .AMF.

3MF

Parallel with application development for Windows 8.1 and subsequent work with the upcoming Windows 10 OS, the .3MF file was developed by Microsoft with the goal of creating a seamless, high quality, 3D printing experience for consumers or manufacturers. After concluding that current formats would be incompatible with their print pipeline, the .3MF format was developed as a standardized framework for Microsoft hardware and software ecosystems, easily passing data from apps to their devices while retaining detailed model information. .3MF would help define a feature set for 3D printers on the market while also supporting subtractive manufacturing devices such as laser cutters and CNC mills.

This year, Microsoft announced the 3MF Consortium, a managed program by big name companies to help develop a “full-fidelity” 3D file that could work on a variety of printers, devices, applications, services, and platforms. Companies such as NetFabb, Shapeways, Materialise, Stratasys, 3D Systems, SIEMENS, HP, Autodesk, and Dassault Systemes soon became members, seeing the benefit of developing a format that would solve classic interoperability issues. The result would help teams across multiple industries focus on innovation rather than the grunge work of 3D model integrity.

3MF is also XML-based and features geometry representation similar to .AMF, but in a more compact and size-friendly format. The file defines all standard, optional, and mandatory parts, with complete model information contained in a single archive. It centers on the concept of a “3D payload”, a collection of interdependent parts and relationships that reside in one standard package. The payload consists of a 3D model(s), core document properties, digital signatures, 3D print settings known as “PrintTicket”, thumbnail images of all models, and 3D texture information.

The goal is for 3D printing in Windows to be the same as any document: select a printer from list, choose options, and print. The application converts the model to .3MF and encapsulates it in an OpenXPS package. It’s then extracted by the print driver, converted into a readable format, and sent to the 3D printer. The .3MF file not only solves Microsoft’s own print pipeline, but also provides the following advantages for everyone across the board:

- Complete model description designed around the principle of extensibility - allowing additional functionality and information updates in the future.

- Seamless interoperability for Windows users and developers, offering a feature set designed with 3D printing capabilities in mind.

- Human readable, XML based-data format with definitions relevant to 3D manufacturing.
- Scalable and usable across multiple platforms.
- Accommodates larger amounts of data in a smaller compressed file size.
- Multi-material and multi-color support.
- Support for custom metadata by third parties.
- Support for various subtractive manufacturing devices.
- Supports transforms, object references, and multiple objects within a single archive.
- Single objects can be referenced or moved without affecting the mesh.
- Support for older .STL files.

The complete specification document for the .3MF file is available through the 3MF Consortium or can be found here.

While still in its infancy, .3MF is gradually becoming acclimated with the 3D printing industry. Support has yet to be confirmed for additional features such as scripting and curved triangles. In addition, concern has also been raised on how .3MF handles hardware resource issues when working with larger meshes. Doubts also arose after its debut. Would 3MF become a proprietary Trojan horse for larger companies to monopolize and grind out competition or would it be released as open source? Would this open the door to DRM issues, resulting in .3MF derivatives that would be subject to lawsuits? Was it simply a matter of benevolently advancing the concept of “plug & play” for 3D printing?

Regardless of the dubious buzz, Microsoft chose wisely, donating code to Github and helping to form a consortium of companies that would help manage the process. You can also request the 3D Printing SDK and .3MF format specifications by contacting ask3dprint@microsoft.com. While doubts remain in terms of patent legalese and source code rights backed by a consortium of conglomerates, the move was seen overall as a positive step for the 3D printing industry.

Let the battle rage on!

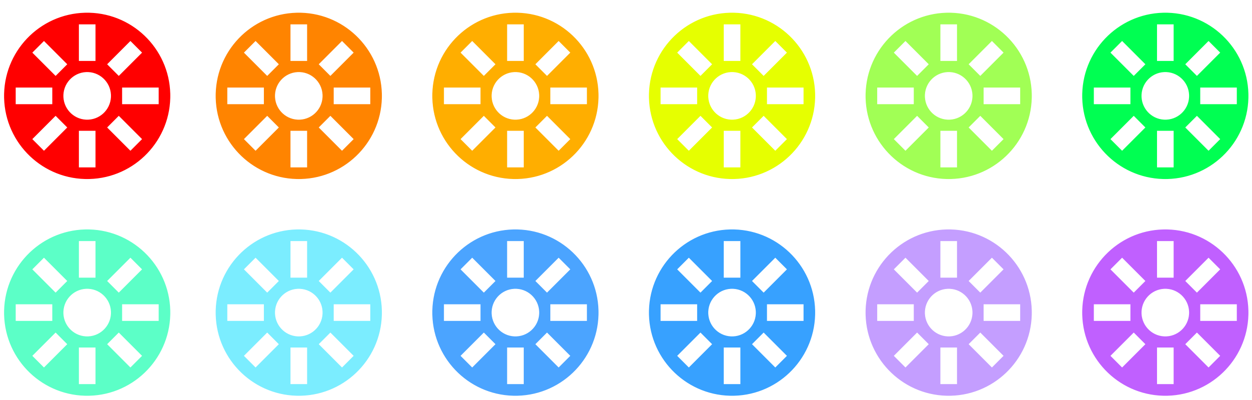
Both formats are creating gradually creating their own path and plenty of development still lies ahead. Some argue that since the development of the .AMF file, there's no need for .3MF. Technical differences aside, both accomplish what they were set out to do. The real difference is the backing and publicity behind .3MF as well as buzz about Microsoft's modus operandi. Customer demand and acceptance for is also a factor that remains to be seen. But from a design and engineering standpoint, a unified file format is a welcome relief in a sea of crisscrossing compatibilities.

Specialty filaments for 3D printing are on the rise

If you own a desktop 3D printer, chances are you've shopped around and tested various plastic filaments from different suppliers. Each offers their own hue of color, tempting buyers with different shades and tones. While printing a household item in neon green or ultra-transparent purple may not go with your current kitchen décor, painting it is always an option. Everyone's striving for more realism in their prints so it's only natural that the market responded with an array of specialty filaments for either practical or aesthetic needs.

Specialty 3D printing filaments aren't just about new colors, they're also about utility. In the realm of fused deposition modeling (FDM), the industry is moving forward with inventing new filaments that solve practical needs. Whether you're trying to 3D print biodegradable products, create a mold for lost wax casting, or reproduce an ancient sculpture in bronze, there's a filament for that.

Below are some of the latest specialty 3D printing filaments on the market today, each offering their own set of characteristics and nuances. Some have evolved, making them quite easy to use for the newbie. Others require a degree of patience, experience, and skill.



Metal 3D printing filaments: the holy grail for desktop FDM

At the moment, the latest metal 3D printing filaments are as close as you can get to the real thing. Several companies have combined micron-sized metal particulate or powder with plastic, creating a class of filaments that closely simulate the look of various metals. Proto-Pasta was one of the first to combine

PLA plastic with 15% chopped carbon fibers. Carbon Fiber PLA is extremely popular, exhibiting increased rigidity beyond standard PLA or ABS. In wake of its popularity, the team also expanded their offerings to include Stainless Steel (PLA plastic with powdered steel) and Magnetic Iron PLA (ground iron powder with PLA).

Over in the Netherlands, ColorFabb continues to innovate with their own lineup of metal-like filaments. The company offers BrassFill, BronzeFill, and CopperFill, all of which are designed to work without the need for a heated build plate.

Each combines plastic with powderized metal, providing users the ability to create parts that almost look laser sintered. There's also tungsten or bismuth metal 3D printing filament known as GMASS. This filament combines ABS and tungsten or bismuth; formulated for desktop 3D printers. It features "metal-like" characteristics that include weight, feel, and density. GMASS has grown in popularity for innovative medical engineering applications. It's perfect for sporting goods, lab equipment, vibration dampening, and x-ray shielding. Developed by Tuner MedTech, these filaments are used for medical grade products. You can also use GMASS to 3D print radiation shielding. You know, just in case you want to print an Iron Man chest plate for use at the dentist's office.

Metal filaments require a bit more TLC than standard PLA or ABS. Most desktop 3D printers are configured and sold with brass nozzles. While they'll work fine, metal filaments dramatically increase their wear and tear. Fine metal particles that are constantly heated, cooled, and pushed through the tip of a brass nozzle will dramatically decrease its performance life. If you plan on doing a lot of printing with metal filaments, stainless steel nozzles are harder than brass and more resistant to internal abrasion.

There are other factors to consider as well. Direct drive 3D printers reportedly handle metal filament better than Bowden designs, making it easier to control filament flow and extrusion rates. Temperature, print speed, and retraction settings should also be experimented with depending on your unit.
Metal 3D printer filament also requires extensive post processing. A final object will have the appearance of cast metal rather than true metal. Extensive sanding, polishing, and buffing will reduce the plastic surface and help bring out the metallic shine. There are a number of finishing techniques that can be used including wire brushing, polishing, rock polishing, and wheel polishing. Using polishing compounds or creams is also recommended to help bring out the object's luster.

There is hope for those who don't feel like post-processing. Kickstarter company Sinterhard is developing metal 3D printing filament that can be hardened and metalized using a sintering process. These filaments allow users to 3D print items that are furnace ready so they can be debinded and sintered into solid metal objects. Using 316 Stainless Steel or Aluminum Powder combined with PLA or ABS, Sinterhard filament replaces the need for Metal Injection Molding (MIM) or investment casting. Known as the MPF process (Metal Printed Filament), an object 3D printed with Sinterhard is first debinded with solvent and then placed in a furnace to achieve the sintered metal process. Sinterhard is also working on replicating this for ceramic filament.

In either ABA or PLA Thermoplastic Filaments [pellets as a Stretch goal]

PET+ filament

MadeSolid has released its PET+ filament, combining easier printability with the strength characteristics of ABS. The filament is tough yet extremely flexible and perfect for engineering grade components in robotics, mechanical assemblies, and wearable devices. In flexibility strength tests, PET+ is able to handle over twice the pressure when compared to ABS. It's more flame resistant than either PLA or ABS and offers good adhesion capabilities during prints; eliminating the need for a heated platform.

Amphora Polymer filament

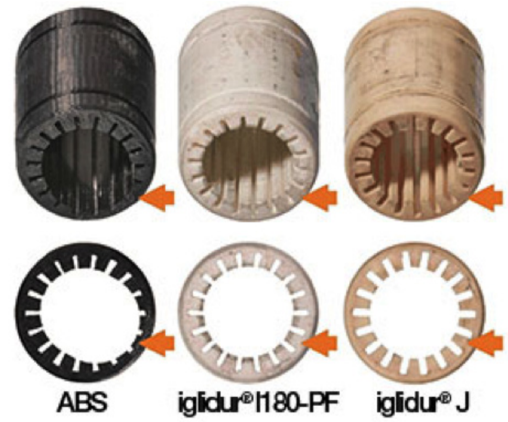
Leading manufacturers ColorFabb, Taulman3D, TripTech Plastics have partnered with Eastman to offer Amphora 3D polymer filament. The material is approved by the FDA for food contact applications and is also BPA-free. This low-odor, styrene-free material allows users to create parts that are not only attractive in finish, but also functional, tough, and durable. They combine superior melt strength with dimensional stability, allowing for stronger parts that exhibit great detail.

Advanced Composite Filament

Avante FilaOne composite filament allows you to create engineering grade prototypes and parts that are easier to print with than Nylon. Strong and impact resistant, it requires a heated print bed but doesn't emit toxic fumes. It's also not affected by humidity or contact with water. FilaOne requires a special adhesion surface to print with which can be purchased separately. Perfect for engineering prototypes or parts, this filament features high stiffness and tensile strength.

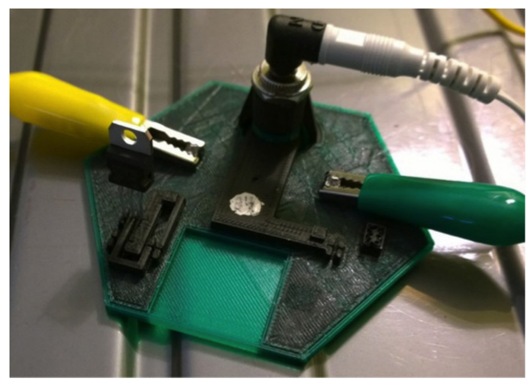
Low Friction Filaments

IGUS iglidur I180-PF is the first filament developed with 50x more abrasion resistance than traditional 3D printer filaments. Perfect for self-lubricating bearings or other low-friction prototypes, this material prints similar to ABS; requiring a heated build plate and hot end ranges between 220 – 250 °C. I180-PF is commonly used for designs that require repetitive movement or where surface contact between parts plays an important role.



Conductive Filament

For the world of electronics, several companies have already released conductive ABS and PLA filament. Conductive ABS and PLA is great for small LED or low current draw circuits. It provides anti-static or electromagnetic interference shielding for objects. Conductive filament is semi-flexible, offers good strength, but requires more attention to proper layer adhesion than standard PLA.



Wood Filaments

The original wood 3D printing filament was developed by Kai Parthy and is also known as "Laywoo-D3". Combining recycled wood fiber with binding polymers, Laywood was an instant hit. Wood filament offers a key advantage for unique objects: by lowering or raising the extrusion temperature throughout the print, one can achieve varying wood finishes along

the surface of an object for "tree ring" effects. Subsequently, varying the print temperature will also achieve smoother or rougher surface characteristics. Wood filament is fairly easy to print with, requiring no heated bed and slight changes in print settings to achieve the desired look. It barely warps and can be post processed using sanding, grinding, staining, or painting. Make sure to work within the extrusion temperature ranges – wood filament burns and tars if overheated, leading to excessive clogging.

In 2015, companies began to develop an array of new wood and plastic combinations. There's cheery wood, light wood, flexible wood, and a wood-PLA hybrid. ColorFabb took it a step further, recently releasing BambooFill and CorkFill to their lineup of specialty filaments. It's become a standard material offered by suppliers including Zen Toolworks, Gizmo Dorks, HatchBox, Alchement, Sainsmart, and eSun.

Microporous Filaments

These filaments are still somewhat in the experimental stage but are available for sale. Developed by Kai Parthy, the PORO-LAY line is ideal for printing rubber polymer parts that have micro-porous features. It includes GEL-LAY, a jelly like material for fabricating artificial body parts, floating objects, or flexible products. LAY-FOMM is ideal for soft rubber applications such as sponges, micro-foam, elastics, or ink-absorbing material. These materials are made with a combination of PVA and rubber-elastomeric polymers. Once submersed in water, the PVA disappears from the model. As a result, the object will lose its rigidity and strength but increase in flexibility and elasticity.

Nylon

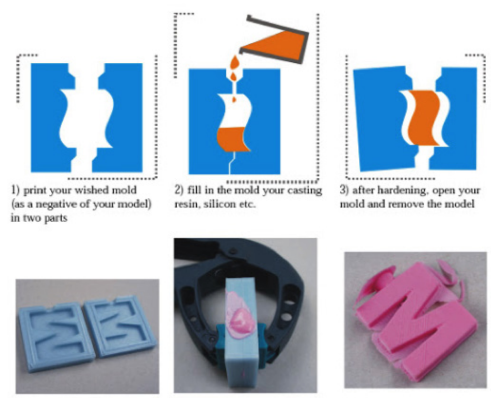
In the early days of desktop 3D printing, nylon line from weed whackers and lawn trimmers were used as filament. While it generally worked, the added ingredients at that time would ruin extruder assemblies and nozzles. The recipe soon evolved, with additives removed that ultimately harmed the printer. Nylon has been around for some time for 3D printers. Particularly, the Taulman Nylons.

Biodegradable Linen Filament

BioFila is developed by twoBEars and is 100% biodegradable, allowing it to breakdown in landfills or soils. Made from Lignin, this material is found in the cellular walls of plants. Combined with polymers, it forms a unique filament that's harder and more durable than PLA. Made in Germany, BioFila produces prints with a unique satin appearance. Surface sheens can be adjusted depending on the print temperature. BioFila is also made with Silk as an option, providing the same features as linen but known for its smooth, shiny, liquid-like qualities.

Mold Fabrication Filament

For the casting crowd, MoldLay allows you to 3D print plastic molds with wax-like properties for mold casting, lost wax casting, and in some cases, investment casting. It extrudes in the 170 – 180° C range, is almost warp-free, and can be printed without a heated bed. Printed molds can be sanded and smoothed beforehand for use with simple resins, concrete, or even silica and plaster. Prior to beginning the cast process, the molds should be pre-treated using an old baking oven; heated to 270° C.



Cleaning Filament

Performing intense surgery on your nozzle or heating assembly to remove clogs is never a dull moment. While there are various ways to go about cleaning your nozzle, eSun's cleaning filament makes the process simple. Just feed several inches of cleaning filament through your printer between 235 and 250 ° C. As it passes through the nozzle it will help dislodge or remove old filament matter. Cleaning filament is great for instances where you only have one nozzle but have to switch through colors or materials. It's also a wonderful way to clean out your nozzle after using wood or metal filaments; helping to remove burnt fiber or metallic particulate.

Specialty filaments expand desktop 3D printing capabilities

In terms of specialty filaments, the material itself now has the power to make the part; offering new options for the look, feel, and performance of your objects. Your prototype piston assembly that you want to show to clients is no longer bound by your ROYGBIV taste in materials. Rather, it's produced in a realistic metallic

3D Printing
Multi-Color Madness

While you may not be able to afford a $300,000 multi-color, multi-material 3D printer for your garage just yet, there are still plenty of technologies, tricks, and hacks within our grasp; helping us maintain some level of sanity from the horrors monochrome 3D printing.

Eventually, everyone hits a point in their 3D printing travels, quickly realizing that multicolor and multi-material capabilities will become geek-kind's ultimate destiny. Desktop 3D printing still has some catching up to do ... a lot of catching up, actually. Regardless, that hasn't stopped innovation to flourish thanks to the diligent work of prosumers and entrepreneurs across the globe. From the mind-boggling do-it-yourself hacking tricks to pre-installed capabilities on upcoming units, we look at ways to approach multi-color and multi-material 3D printing.

Where we are today

Last year's release of the Object500 Connex3 3D printer by Stratasys was considered a groundbreaking achievement for additive manufacturing. It marks a pinnacle – streamlining both prototyping and small scale manufacturing into a single, omnipotent monolith we can all bow to. But what really sets the Connex3 apart is that it's the first unit designed to fuse an array of colors and material options together, creating a game changing box that revolutionizes the product development process.

The Connex3's triple-jetting technology allows users to create models with an endless amount of surface options, color schemes, and mechanical properties in one pass, bringing both concepts to reality and products to market faster.

> **Leveraging 10 color palettes and 3 base resins into a single print run is no easy task, but it certainly represents where we're heading at home or in small offices.**

While we're tempted to call the nearest Stratasys reseller, mortgage the house, and purchase one for ourselves, we have to make due for what's on hand today - especially in the realm of Fused Deposition Modeling (FDM).

Dual, triple, and quadruple extrusion hardware

In parallel to single extruder 3D printers hitting the market, dual and triple extrusion systems soon made headway. Most are familiar with how these work: dual or triple nozzles with separate feeds entering the heating assembly, one for each color of filament. Most FDM machines will have separate filament spool holders in the back, rotating upon command to push melted filament through each nozzle. Like a maestro coordinating the orchestra, G-code commands decide which nozzle spits out filament during the build process while layer upon layer of different colors are designated by the user in coordination with the printer's OEM or open source software. These printers are widely available by manufacturers for purchase or as upgrade options. Several prominent multi-nozzle 3D printers include Ord Solutions, Flashforge, Airwolf 3D, and Makerbot.

There are caveats. Watching multiple nozzles move around a model is nail biting at best and "punt-the entire-contraption-over-the-roof" at worst. Improper leveling, unequal nozzle height, or bad first-layer adhesion causes your model to go airborne, separated from the build platform and swinging around like Tarzan (of course, the printer doesn't realize, continuously spitting filament in every direction).

The other problem is that there's no color transition – resulting in stark dividing lines between colors layered on top of each other. For multiple material operations, using one nozzle for build filament and the other for support filament is refreshing. Just pay attention to nozzle temperatures. With nozzles this close together, heating variances can occur, causing one filament to be too hot or too cool when leaving the nozzle.

Multiple filament feeds, one hot end

Other machines have developed filament mixing systems directly into their hardware. Different manufacturers have created various approaches to this process, typically achieving the same desired results for color transitions through a single nozzle.

Dutch company Builder offers dual feed color mixing through a single nozzle. In conjunction with their software, users can choose the color designations and percentage of color transition along the models layers. The information is converted to G-code and sent to the printer. With dual feed extrusion, both colors are mixed and converted to the designated color hue before leaving the nozzle.

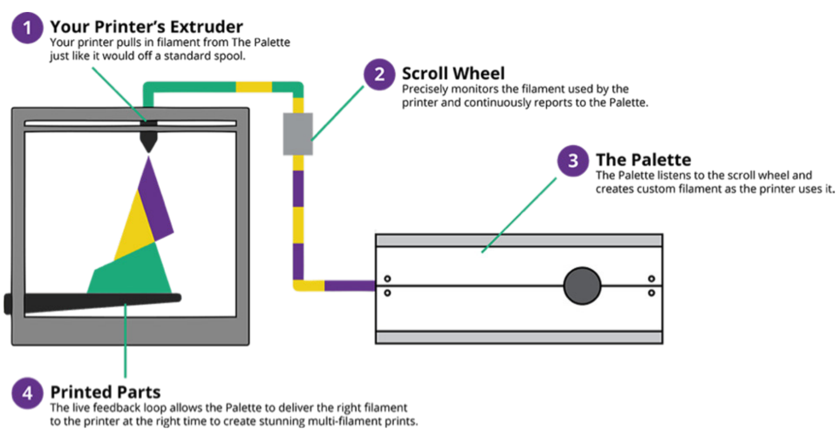
Bot Objects, recently acquired by 3D Systems, uses a proprietary PLA cartridge system; mixing 5 primary colors together to create the color scheme you want along your model's surface. There's also a dual extruder head version so you can print color transitions through one nozzle and PVA support material through the other.

Pausing like its 1999

Many 3D printers on the market now have firmware with built-in pause and switch features, allowing users to change filament during mid-print. While you can't achieve a smooth color transition or gradient, it's a foolproof way to get the job done. Pause as little or as many times you as you like, switching out different filaments to achieve quick color differences throughout certain areas of your model.

Filament splicing

If you have a single extruder 3D printer, filament splicing is one way to achieve multi-color or multi-material capabilities. Splicing together two filament colors by heating both ends and merging them together by hand is the poor-man's way, although feasible. Be aware that you're increasing the chances of extrusion jams, separation, or retraction issues due to the fragile nature of the joined pieces.



Companies like Artesa GmbH may have a semi-affordable, open source, answer. They've created a filament splicing unit that evenly joins two pieces together using a copper heating and cooling block assembly. The result is a consistent and stable

connection with appropriate tensile strength to stay connected.
https://www.youtube.com/watch?v=fX4XdSVbEr8

For industrial strength filament splicing on steroids, a more expensive option is the Palette by Mosaic Manufacturing.

The unit takes in four different filaments and combines them together for custom color or material transitions. With their included slicer software, users can designate the length, order of color, and transition before it passes through your single extruder.

For multi-material operations, you can use a filament like PLA to print your electronics enclosure then quickly switch to conductive filament for the circuits without any modifications or downtime.

Dubbed as SEEM (Series Enabled Extrusion of Materials) Technology, the company boasts the Palette as the first closed loop system that synchronously mixes and calibrates filament before it passes through the extruder's heating assembly.

G-Code based color swapping

For those savvy enough, there are several techniques that employ G-Code editing, scripting, or cutting your object into several pieces for separated color printing. Essentially, you're going to tell the printer when to pause for a filament change using the universal language of G-Code.

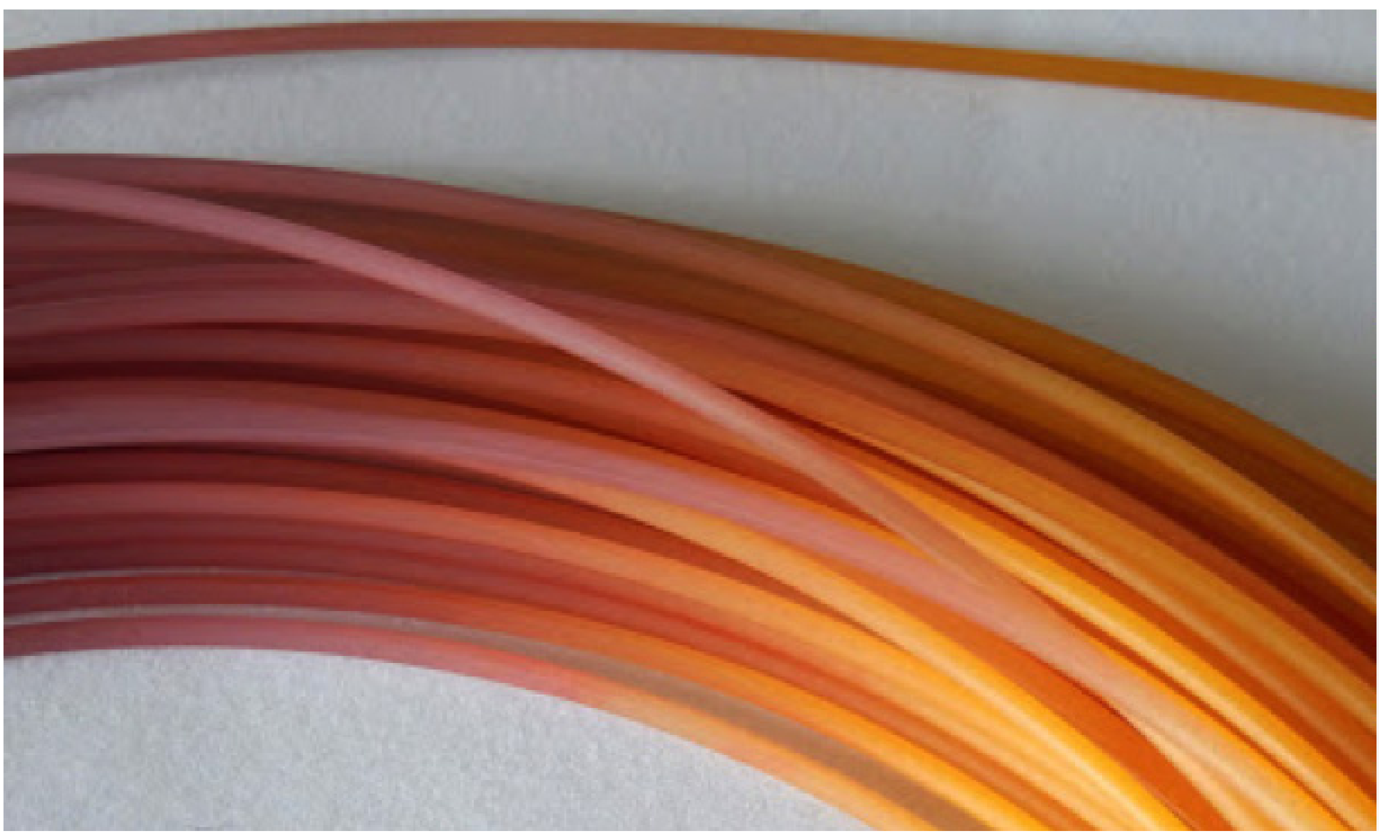
Instructables user Jan Henrik has developed a simple OpenScad script that splits up a 3D file into separate layers for different colors or materials. You specify the print height for each color, export the file to STL, and then convert it to G-Code. Run the print with a specific color or material until it reaches the chosen height. The printer pauses, allowing you to load a new filament color in before continuing. The process is repeated until you have a completed, multi-color model. Visit here and here to learn more.

Using slicing packages such as Slic3r, Simplify3D, and other open source or paid versions, you can simply take the direct route. Import your .STL and use the G-Code search tool to find the specific layer height/number you want to pause at for your printer's color changeover. Keep the nozzle hot during the pause and use this time to purge any trace of your previous material before installing a new filament. There are plenty of techniques for switching colors and materials mid-print while also discussing the basics of G-Code editing in your preferred slicing package. Here's a quick video tutorial using Slic3r.

Tie-dye your Nylon filament hippy style

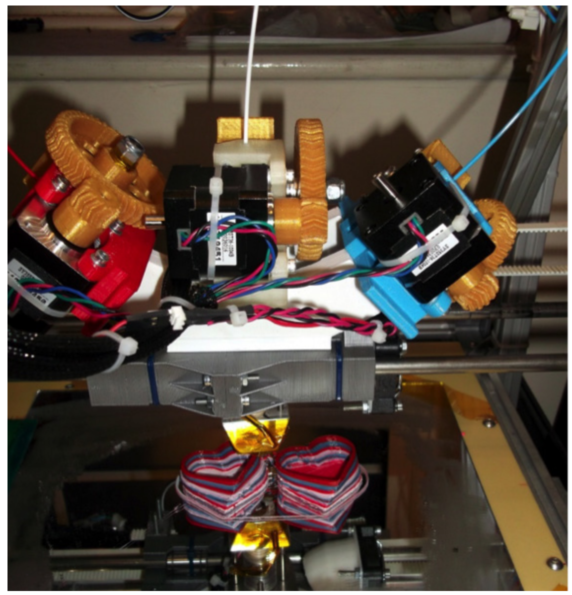
Popular blogger RichRap offers great advice and techniques for multi-color 3D printing. One particular area he pioneered is the use of tie-dye to colorize various Taulman Nylon filaments. Using powder-based Rit dye, simply submerge coiled portions of the filament into a Ziploc bag or container.

Repeat along different ends of the coiled filament using different color dyes. In less than 30 minutes soaking for each color, you'll have filament that offers vibrant transition; ready to be loaded for 3D printing.



Build your own, if you dare

Of course, you can always build your own color blending system from scratch. RichRap also developed a DIY 3-color blending system using a single nozzle - should you have the guts to do it yourself, you'll be one of the elite. It combines sourcing parts, 3D printing components, and machining some metal. If you're ready to get crazy innovative, here's an extensive list to get you started.



DIY color today, full blown spectra-vision tomorrow

There are numerous techniques evolving for multi-color and multi-material desktop 3D printing. Various hacks, tricks, and tips will help you keep your single extruder 3D printer challenged, while pushing the envelope for innovative new models or products. While some of these processes may be “rough around the edges”, don't worry. In due time, that $300,000 printer you always wanted may one day be reduced to $300 on Amazon.

What if 3D printing were easy?

There is a new solution coming your way in the summer — 2016.

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