stratasys

FDM and PolyJet 3D Printing

DETERMINING WHICH TECHNOLOGY IS RIGHT FOR YOUR APPLICATION

This white paper is probably not the first step in your 3D printing learning journey. By now, you may have realized 3D printing is the solution for your design, prototyping and/or production needs, since the advantages of 3D printing technology are widely known.

Driven by Computer-Aided Design (CAD), files that communicate directly with a 3D printerand build a layered design from the bottom up, 3D printing technology provides limitlesspossibilities. It enables nimble design iteration, rapid prototyping and the ability to print production parts. With 3D printing's capacity to revolutionize

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industries, disrupt supply chains and lead medical innovation, it's no surprise the additive technology has been described as the Third Industrial Revolution.

The right 3D technology depends on the materials, aesthetics, mechanical properties and overall performance your product requires. You may have already ruled out 3D printing technologies, such as Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS) and other processes, to arrive at plastics as a material solution. Of course, that still leaves the choice of Fused Deposition Modeling® (FDM), or PolyJet™ technology, two of the most advanced and versatile additive manufacturing (AM) or 3D printing technologies available. This white paper provides a detailed comparison of Fused Deposition Modeling (FDM) and PolyJet technologies and their applications within different industries.

There is some crossover in FDM and PolyJet 3D printer applications, but for the most part these two technology platforms remain distinct and offer different benefits to the user. Understanding the two technologies and their application potential for your product needs is the key to their successful application within your business. Additionally, the range of available printers goes from budget-friendly, desktop models to large-format, factory-floor equipment and produce precise, finely detailed models to durable production goods. Being fully informed about printer capabilities and output, and matching a printer process and material to your needs is the foundation to the successful application of 3D printing within your business.

"The adoption of 3D printing as an engine for growth and innovation is reaching levels where the potential disruption is becoming very real."
—Dr. Phil Reeves, VP, Stratasys Expert Services

THE TECHNOLOGIES

Fused Deposition Modeling (FDM)

3D printers that run on FDM technology build parts layer-by-layer from the bottom up by heating and extruding thermoplastic filament. During pre-processing, build-preparation software slices and positions a 3D CAD file and calculates a path to extrude thermoplastic and any necessary support material. In production, thermoplastic filament feeds through a heated head and exits, under high pressure, as a fine thread of semi-molten plastic. In a heated chamber, this extrusion process lays down a continuous bead of plastic to form a layer. Where support or buffering is needed, the 3D printer deposits a removable material that acts as scaffolding. This layering process repeats to manufacture thermoplastic parts. Post-processing involves the removal of support material, either by manually breaking it away or dissolving it in detergent and water. At this point, the part is ready to use (Figure 1).

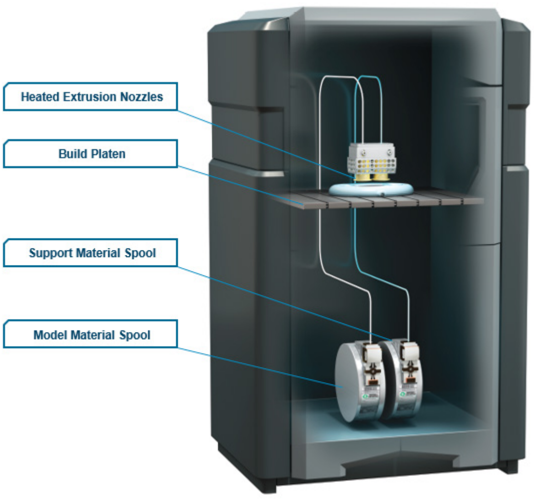

Figure 1: Fused Deposition Modeling (FDM) process.

PolyJet Technology

PolyJet is a powerful 3D printing technology that produces smooth, accurate parts, prototypes and tooling. With microscopic layer resolution and accuracy down to 0.1 mm, it can produce thin walls and complex geometries. During pre-processing, build preparation software automatically calculates the placement of photopolymers and support material from a 3D CAD file. During production, a carriage with four or more print heads and ultraviolet (UV) lamps traverses the work space, depositing tiny droplets of photopolymers, materials that solidify when exposed to UV light. Fine layers accumulate on the build tray to create one, or several, precise models or parts. Where overhangs or complex shapes require support, the 3D printer jets a removable support material. After printing a thin layer of material, the process repeats until a complete 3D object is formed. Support material is easily removed by hand, with water or in a solution bath. Models and parts are ready to handle and use right out of the 3D printer, with no post-curing needed (Figure 2). Certainly, employing both FDM and PolyJet printers is an option. But in most cases, one technology is better suited to your product needs than the other. A comparison and contrast of existing systems, operations, part characteristics and material options is a good place to start to determine how to best serve your business needs.

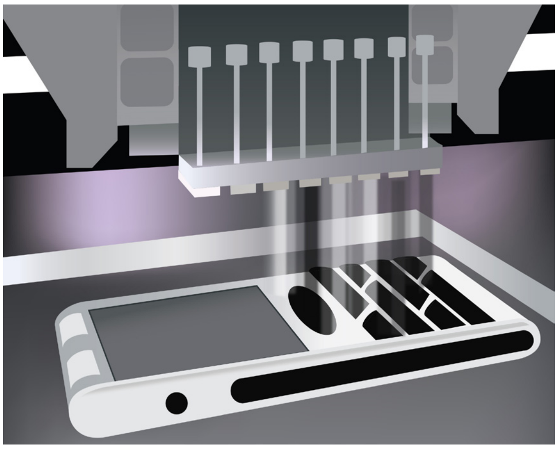

Figure 2: PolyJet technology process.

OPERATIONS

Speed

Build speed is an area of great interest to users; however, there is no clear-cut answer as to which technology is faster. Knowing your operations, your parts and your requirements before measuring speed is essential. Estimating one process, FDM or PolyJet to be capable of quicker build times can be very misleading. Some of the variable elements of build time come from the build styles you will use. High resolution, smooth surfaces and solid parts with the best mechanical properties will take more time. Build time is a function of many variables, some you select and others which are fixed. On average, FDM and PolyJet have similar (and very competitive) total elapsed times.

The detail of the parts and the height (since the additive technology builds in layers from the bottom up), contribute to overall build time. Printer and file preparation adds time to the front end while post-build idle (while waiting for the binder to harden) and post-processing in the form of cleaning, post-curing, de-powdering, support removal, infiltration sanding or other steps add time to the back end of production. In general, 3D printer users typically fall into one of three build patterns: four-hour cycles (half a workday), eight-hour cycles (full workday) and overnight cycles.

Material volume, surface area and part footprint and configuration can all add hours to the build time. Also, to measure speed, one must clock the entire process, starting with the moment an STL file is received and stopped when a part is ready for use. Along that path, a slower build time still may outpace a process with a faster build time which requires more post-processing. So, a four-hour build plus the additional required steps can result in a 12-hour process. Conversely, an eight-hour build time plus other required steps can result in only a 10-hour process. So, the process with a slower build stage could be the overall faster process (Figure 3).

Print speed alone should not drive your decision to use FDM or PolyJet technology; the bigger picture

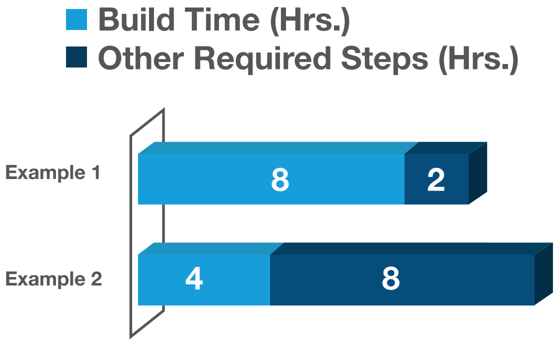

Figure 3: Build time steps from STL file to completion of part.

involves taking into account the geometry of parts, and any support material needed in terms of post-processing. Only after taking all these factors into account can 3D printing build times be compared.

Time-to-Part Shortened

Piper Aircraft, a single and twin-engine jet manufacturer wanted to reduce the time-to-part for its hydroforming form tools, a process that involves pressing sheet metal against the form tool to force it to take its final shape. Piper uses hydroforming to produce hundreds of aluminum structural components of these aircraft such as the inner frame, gussets, brackets and skins. In the past, the company machined aluminum form tools for use in hydroforming machines, but found machining geometrically complex form tools was expensive due to the amount of time required for programming every part. As is often the case, the material properties necessary for their hydroforming process led engineers to FDM technology. FDM printers offers unparalleled versatility in durable parts. These parts are tough enough to be used as advanced conceptual models, functional prototypes, manufacturing tools and production parts. In Piper's case, the material best suited to their needs was Polycarbonate (PC), which can withstand hydroforming pressures ranging from 3,000 to 6,000 psi, suitable for forming all the structural parts produced by Piper (Figure 4).

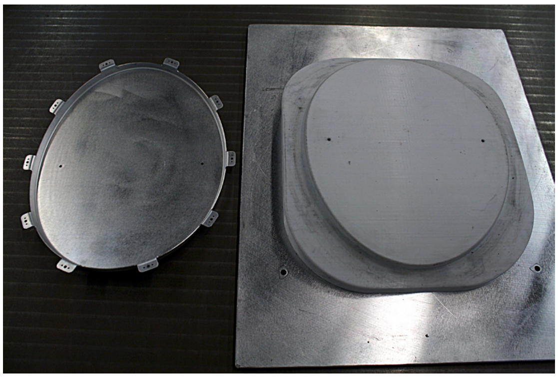

Figure 4: Hydroformed parts at Piper Aircraft using FDM technology.

Once the necessary material properties dictated the best print technology, the jet manufacturer was able to turn to other considerations, namely the value of 3D printing to their operation, in general. "I can program an FDM part in 10 minutes while a typical CNC program takes four hours to write," said Jacob Allenbaugh, manufacturing engineer for Piper. "The FDM printer is much faster than a CNC machine and does not require an operator be in attendance."

In addition to faster time-to-part, the company looked to FDM technology to satisfy its need for a large build envelope and a high level of accuracy. After forming, the route and drill fixtures are used as a guide for routing and drilling operations that finish the part. An added benefit of FDM to Piper is the ability for future design improvements in structural parts. With no limit to geometries of finished parts, Allenbaugh believes it may be possible to build a more efficient aircraft by moving to more complex and organically shaped parts, built with FDM form tooling.

Volvo Construction Equipment (VCE), tasked its engineering team with cutting development costs and reducing the lead time on large engine projects from 36 to 24 months. VCE looked to 3D printing, but wondered if 3D printed water pump housings could withstand functional testing.

FDM technology was not the answer, but PolyJet was thanks to its wide array of materials, even transparent ones. Water pump housing prototypes need to survive the high pressure of the engine compartment. Engineers printed the housing in FullCure®720, a transparent material, mounted nine threaded inserts into the part and sealed the housing with epoxy resin and hardener to prevent leakage. Then they fastened the housing to a water pump so engineers could take water flow and pressure measurements (Figure 5).

Figure 5: Water pump prototype at Volvo Construction Equipment, 3D printed using PolyJet technology.

PRE-PROCESSING: WHAT'S INVOLVED

FDM

In GrabCAD or Catalyst software, a CAD file is opened in STL format. Next, material, color and slice thickness is selected. Then, a build and support style is chosen to match your application's requirements. Finally, an orientation is selected, and the software takes over from here. The software sections the design into layers and creates toolpaths for both the part and its disposable support structures. It then outputs a build file that defines precise motion control paths. Clicking "print" sends the build file to the 3D printer.

Both technologies offer very simple, front-end file processing that can make ready-to-print files in less than five minutes. One difference is that FDM's production 3D printers add sophisticated user controls that adjust the part-building process to match the demands for the application. All build parameters are open to the user. Both FDM and PolyJet can print parts within 10 minutes of a file upload.

PolyJet

PolyJet 3D printing works similarly to inkjet printing but instead of jetting drops of ink onto paper, PolyJet 3D printers jet layers of curable liquid photopolymer onto a build tray. During pre-processing, build-preparation software automatically calculates the placement of photopolymers and support material from a 3D CAD file.

POST-PROCESS

When it comes to support removal and part cleaning, there are some similarities between FDM and PolyJet. With FDM, you have either a fully automated soak in a tank to remove soluble supports or a manual step that removes rigid, breakaway supports with simple hand tools.

PolyJet gives you a quick, manual step to remove the gel-like support material SUP705 by spraying with a WaterJet. In addition, SUP706, a soluble support material for PolyJet technology, runs on all triple-jetting 3D printers and requires a simple two-step soak-and-rinse process like FDM. When speed is paramount, SUP706 can also be removed semi-manually or manually and washed away easily with a WaterJet.

SUP706 enables increased geometric freedom, giving users the ability to print complex, delicate features and small cavities with PolyJet.

PolyJet parts require no post-printing curing and little effort for support removal.

The Jacobs Institute (JI), a medical device and leading vascular center in Buffalo, New York, uses PolyJet 3D printing technology for patient-specific models based on CT and MRI scans. These models represent a patient's unique vascular anatomy, enabling surgeons to not only plan and practice a surgery before getting into the operating room, but also to serve as patient reference points before complex procedures (Figure 6).

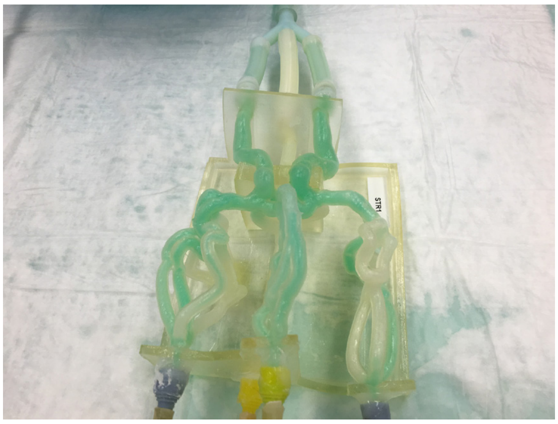

Figure 6: The Jacobs Institute 3D prints vascular models using Agilus30 material and PolyJet technology.

Post-processing of these thin-walled vasculatures can be tricky and time-consuming. Support material needs to be extinguished from the narrow arterial openings of these delicate models. PolyJet technology, with its option for clear, rubber-like materials that can withstand 30-50 device tests prior to degrading has been the answer for the JI.

Initially using TangoPlus, a clear, rubber-like Digital Material, the JI sought a material whose strength would eliminate post-processing tearing. In partnership with Stratasys, the JI is now working with Agilus30, a clear Digital material, to be used as an adjunct material.

The JI is pioneering the development of 3D printed neurovascular models using PolyJet to accelerate the development of new devices and improve physicians' ability to treat cerebrovascular diseases such as strokes and aneurysms. These 3D printed models provide anatomically and physiologically accurate models of the vasculature within a patient's brain, using PolyJet technology.

Office Environment

Both FDM and PolyJet require very little in the way of special requirements, no sealed-off labs and OSHA respiratory protection requirements. All systems need only minimal plumbing and electrical work and there is no airborne powder produced by either process. Power and access to water and drain tiles (for post-processing work) is all that is required.

Additionally, both FDM and PolyJet come in office-friendly sizes. The only exception is the Fortus® 900mc™ and Objet®1000™, which have large footprints and require a large work area.

Ease of Use

Both processes, FDM and PolyJet are relatively user-friendly, beginning with the simplicity of file setup. Other benefits are:

- Material changeovers: simply remove one material and slide a new material cartridge into the 3D printer.
- Setup for a build: insert a build sheet (FDM only), bring the system up to operating temperature, push start and walk away.
- When complete: open the door/hood and remove parts just seconds after a job completes.

Operating Expense

Again, both processes have their own budgetary perks and limitations. Overall, however, operating expenses are a bit higher for PolyJet. Consumables, or materials, are the largest operating expense with additive manufacturing, both in hardware and materials, and PolyJet materials are more costly than FDM.

PolyJet: PolyJet print heads require replacement after 2,000 hours (or more) of PolyJet 3D printing.

The total material cost per cubic inch of part is less with FDM. In the cartridge, the technologies have comparable material costs by weight. Yet, FDM has a lower cost per part because it needs only minimal support material. PolyJet systems need more support material to restrain the tiny liquid droplets.

FDM: Build trays or sheets need routine replacement as do extrusion nozzles. The material cost per cubic inch of part is less with FDM, and FDM has a total lower cost per part because it needs only minimal support material.

Utah Trikes, a custom-producer of trikes, quads and custom wheelchairs located in Payson, Utah, quickly realized their customization had its obstacles, namely time and cost. The trike manufacturer "had some CNC machines we ran pretty much nonstop," said Ashley Guy, president and CEO. "But this was always a hassle without committing to jigs and fixtures, which meant a lot of man hours to prototype."

Utah Trikes needed not only a process that could be quick and cost-effective, but also one with materials strong enough to go from prototype to production parts. With 3D printing and FDM technology, Guy said, "I no longer have to constrain my designs because of prototyping limitations." Their ability to custom print, on-site cut production time from two months to two weeks, reducing the company's costs 8-10 times.

The trike manufacturer started using FDM Nylon 12™ on its Stratasys Fortus 3D Printer, "and it got us about 75% of the way there," said Guy. As the manufacturer moved to production grade parts needing excellent strength they looked to FDM Nylon 12CF™ to provide "parts that can be printed faster, with superior stiffness-to-weight performance and with better repeatability than any other 3D printing technology we've seen," said Guy. Again, in the case of Utah Trikes, material properties dictated print technology (Figure 7).

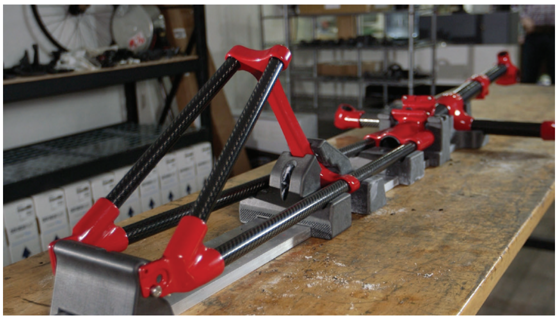

Figure 7: Utah Trikes uses FDM Nylon 12CF material in its advanced prototyping.

PART CHARACTERISTICS

Surface Finish

If a near-paint-ready surface, or flexibility is your goal, then PolyJet is your process. With a little wet-sanding and polishing it can deliver a smooth, glossy surface ready for any product that requires no surface imperfections. PolyJet technology enables parts and prototypes with the best surface quality, finest details and widest range of material properties available.

FDM is produced with an extrusion process that leaves visible layer lines on side walls and "tool paths" on the top and bottom surfaces. These can be eliminated but this requires additional post-processing, such as an automated finishing station or manual finishing. Still, FDM technology uses production-grade thermoplastic and builds strong, long-lasting and dimensionally stable parts with the best accuracy and repeatability of any 3D printing technology.

Mikkelsen Electronics, in Denmark, develops customized cable and molding industry solutions. The company invested in 3D printing to reduce production time and cost, and to offer affordable prototypes. "We have long been focused on the customer's value chain with regard to low-pressure molding," said Kim Christiansen, CEO of Mikkelsen.

FDM is the company's technology of choice due to its ability to 3D print precise parts that endure high temperatures. Mikkelsen depends on FDM thermoplastics that withstand high heat for long periods of time. "The finished parts are fully operational from the outset, giving us far greater credibility with our customers," said Christiansen. Purchasing a Fortus 3D Printer from Stratasys, Mikkelsen prints in both ABS thermoplastic and ULTEM™ resin, depending on usage (Figure 8). "Dialogue with customers has taken a completely different, and very positive turn," said Christensen. "We now offer new features and we are monitoring developments and focusing on developing our products. Additionally, we are considered a more serious player in the market."

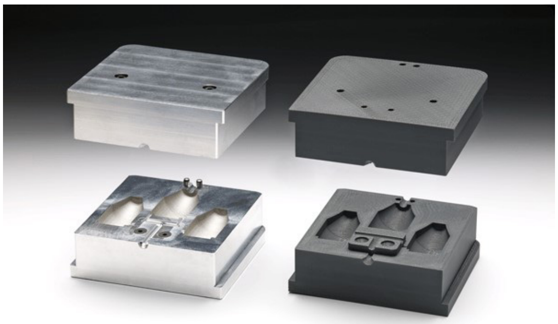

Figure 8: FDM's low pressure molding capabilities made it the right 3D printing process for Mikkelsen Electronics.

Brooks Running, in Seattle, Washington, just may be the happiest place on earth, according to Kenny Krotzer, associate footwear developer at the company. "And this is due, in no small part, to our Connex3™ 3D Printer," Krotzer said. The company "aims to build the best performance product on the market and now we have a new tool to help us get there."

The large print bed on the PolyJet 3D Printer enables Brooks to print four to five outsole, midsole combination prototypes at a time, something that greatly speeds their designs to market. "There's such freedom with having it, the ability to set up a redesign to print overnight and it's ready in the morning."

Frequent design iteration and designers and shoe developers in China and the U.S. "used to make for a bit of a nightmare," said Krotzer. "Our 3D printer has revolutionized our entire design validation process." In addition to saving time during the design iteration process, the company also saves $500 to $800 per shoe design (Figure 9).

Figure 9: Brooks Running uses PolyJet technology to 3D print midsole and outsole prototypes to expedite its design process.

Design validation is a huge component of the business, according to Krotzer. Product fit and functionality come first, but design is a close second. "There's a lot of give and take in shoe design and the ability to quickly change a concept is key." Also, Brooks' PolyJet technology enables them to print dozens of colors "and while we only need black, white and gray right now, that could change someday," said Krotzer.

Accuracy

For dimensional accuracy, the published specifications show that comparable FDM and PolyJet platforms have similar results for parts when they are removed from the systems. However, over time and under a load, FDM materials are more dimensionally stable, which is critical when used for production parts.

Size

Note: The following specifications have been rounded for simplicity. For exact specifications, refer to the product spec sheets.

PolyJet and FDM machines offer build volumes ranging from 5 x 5 x 5 inches (127 x 127 x 127 mm) to 39 x 31 x 20 inches (1000 x 800 x 500 mm), and they have comparable mid and large-size options. The difference is only in the small volume category. With FDM, there is an entry-level 5 x 5 x

5-inch option with a footprint small enough to sit on a desktop.

PolyJet's smallest is 9 x 8 x 6-inch (240 x 200 x 150 mm), and that 3D printer is best placed on a stand near the work area.

For maximum part size, consider the orientation in the 3D printer. For example, the two largest machines, the FDM 900mc and the Objet1000, have similarly sized build envelopes, but the tallest part in the Fortus 900mc is 36 inches. The tallest for the Objet1000 is 20 inches. The opposite is true for width, the Fortus 900mc offers 24 inches and the Objet1000 offers 31 inches.

Materials

Materials may be the greatest differentiator between FDM and PolyJet processes for many. Combined, there are thousands of options, ranging from real thermoplastics to thermoplastic-like resin, rigid to flexible, and opaque to transparent.

PolyJet offers product realism across a wide range of materials and colors. With over 1,200 color options available and a wide range of Digital Materials (two or three materials blended at the printhead), there are literally thousands of available colors, in a range of hues, transparency, strength, rigidity and flexibility. For example, flexible, rubberlike parts can be printed with Shore A hardness ratings of 27 to 95. Another factor that contributes to product realism is multi-material printing. Parts can have up to 82 distinct material properties, so applications like flexible overmolding of rigid structures can be reproduced in one print job. Certainly, if a range of material properties serves your needs, then PolyJet may be your preferred platform.

Conversely, if your applications require real thermoplastics with both functionality and durability, FDM may be the correct platform for you. Thirteen material options range from commonly used plastics like ABS and ASA, to the highly advanced, like ULTEM™ 9085 resin. Material options include: anti-static, FST rating (flame, smoke and toxicity), chemical resistance and very high temperature resistance. FDM can also make soluble patterns for challenging manufacturing jobs.

Both FDM and PolyJet offer bio-compatible materials with USP Plastic Class VI to ISO 10993 ratings. They can be used for hearing aids, dental procedures, surgical guides and fixtures, and food and pharmaceutical processing.

FDM and PolyJet 3D Printing

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Additive manufacturing, in both FDM and PolyJet processes, spans the concept, design and production components of product development in industries that range from medical appliances to industrial goods. It is these application-specific demands that ultimately answer the question of which technology is best suited for a particular need.

The State University of New York (SUNY), New Paltz and its Stratasys-MakerBot Additive Research & Teaching (SMART) Lab, has more than 40 3D printers, including both FDM and PolyJet. The SMART Lab is part of the Hudson Valley Additive manufacturing center (HVAMC), partnering with SUNY to provide 3D printing learning and opportunities for students and the community.

Perhaps the most interesting aspect of the SMART Lab is students' ability to not only gain valuable experience using 3D printing, but also the opportunity for students to be paired with local businesses to problem-solve 3D printed solutions. "It's great for students to get an understanding of what's needed in the workforce and then get the skill set they need in order to succeed," said Kat Wilson, assistant director of HVAMC. The university has even designed a new minor around the capabilities of their SMART Lab, Digital Design and Fabrication, designed to teach students how to use computer software and integrate that knowledge into 3D printing.

Although not necessarily a typical student-business partnership opportunity, the owner of Lagusta's Luscious, a local chocolate shop, partnered with the lab to design a mold in the shape of a human skull. Students scanned a skull procured from the anthropology department, then produced a digital file that could be used to 3D print the mold, which was used to create realistic, chocolate skulls for a party celebrating a popular television show.

Students at SUNY learn to take their 3D printing knowledge and partner with the local business community. "When businesses have a need, we're able to say we have a student that's great at this," Wilson said (Figure 10). In this case, 3D printing in PolyJet technology, using VeroClear material, ended up providing students and a local business owner with a 3D printed solution that was both efficient and cost-effective.

Figure 10: 3D printed skulls, a product of business partnering with SUNY New Paltz's 3D printing SMART Lab.

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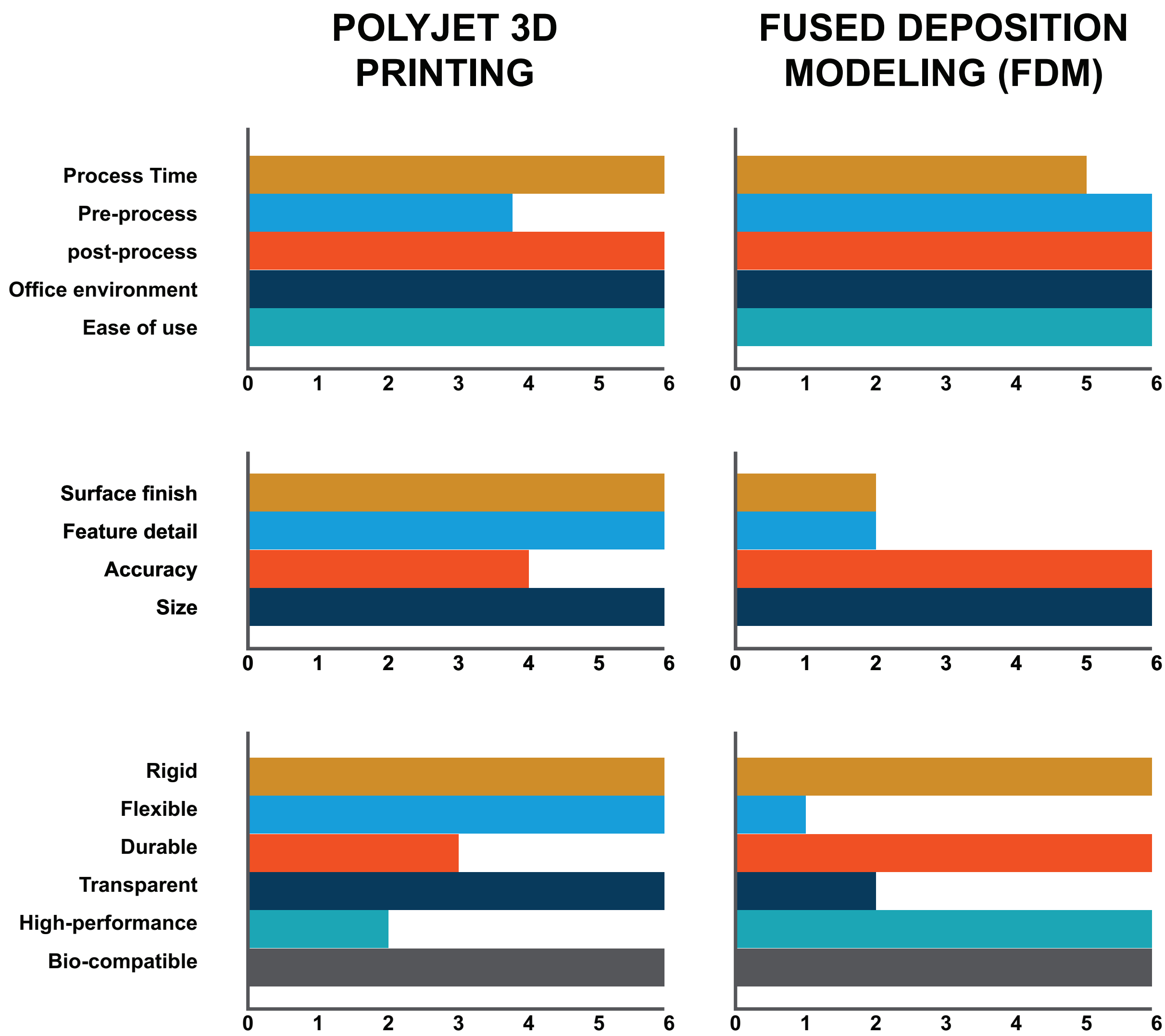

Summary

Benefits of PolyJet 3D Printing

PolyJet technology offers exceptional detail, surface smoothness and precision. The process creates smooth, detailed prototypes that convey final-product aesthetics. This allows for accurate molds, jigs, fixtures and other manufacturing tools. Also, complex shapes and intricate details and delicate features can be achieved. PolyJet also incorporates the widest variety of colors and materials into a single model for unbeatable efficiency.

Benefits of FDM 3D Printing

FDM technology is clean, simple-to-use and office-friendly due to supporting production-grade thermoplastics that are mechanically and environmentally stable. Complex geometries and cavities that would otherwise be problematic become practical with FDM technology. Also, FDM technology uses the same tried-and-tested thermoplastics found in traditional manufacturing processes. For applications that demand tight tolerances, toughness and environmental stability, or properties like electrostatic dissipation, translucence, biocompatibility, VO flammability or FST ratings, FDM thermoplastics deliver.

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